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RESEARCH ARTICLE

Evaluation of Silica Uptake from Foliar-Applied Silicon Nanoparticles in Melon (*Cucumis melo* L.) under Soilless Culture

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Abstract

Melon (*Cucumis melo* L.) is a fruit commodity that gets a great interest to be developed in Indonesia and has a high nutritional value. However, the fungal infection and pathogens in melon cultivation are considered significant problems that are difficult to manage. Therefore, efforts are needed to improve the productivity and quality of melon and prevent pest and disease attacks. One mineral nutrient that is assumed to enhance plant resistance and increase the quality and production of melon is silica. The purpose of the research was to evaluate silica absorption from foliar-applied silicon nanoparticles in melon under soilless culture and improve melon fruit's growth and quality by applying silica fertilizer. The experimental design used was a split-plot randomized complete block design 3 x 2 factorial pattern with four replicates. The main plot factor is silica fertilizer (Novelgro, water-soluble), consisting of three silica concentrations of 0.67; 1.33 ppm, and control. The spray volume of each treatment was 160 ml per plant with seven days' intervals and a frequency of three times. The subplot factor is melon varieties consisting of "Alisha" and "Glamour". The findings showed that silica fertilizer significantly increased the plant height, stem diameter, internode length, total number of hermaphrodite flowers, number of hermaphrodite flowers that are swelling, while decreased the fruit moisture content and gave the best average fruit position. Instead, The "Glamour" variety gave the best response to plant growth and fruit quality. Moreover, the melon plant could absorb silica in the low category (<1% Si). The highest silica contents were found in the "Alisha" cultivar leaves and the "Glamour" cultivar's rinds treated with the silica concentration of 1.33 ppm as much as 0.34% and 0.30%, respectively.

Keywords: drip irrigation system, fertigation, moisture content, silica absorption efficiency

Introduction

Melon (*Cucumis melo* L.) is an important horticultural crop grown throughout the world, mainly in Asia, America, and Europe, with an overall production of 27.5 million tons and about 1.03 million hectares planted (FAOSTAT, 2019). Therefore, melon is considered a fruit commodity that gets a great interest to be developed in Indonesia (Bangun, 2004). As a result, melon production in Indonesia reached 85.161 tons in 2010, increasing year after year and became 150.347 tons in 2014 (Kementerian Pertanian, 2016). In comparison with many other fruits, melon has a high nutritional value. The nutrient content in 236 g edible part of melon fruit is 78 calories, 593 mg potassium, 28 mg sodium, 90 mg vitamin C, 4 mg calcium, 10 mg of iron, 25 g of carbohydrate, 21 g sugar, 2 g fiber. One crucial feature of melon fruit is that it contains adenosine to avoid clumping blood cells, leading to stroke or heart disease. Also, the high carotenoid content in melon fruit can prevent cancer and minimize the risk of lung cancer (Lester, 1997). Pre-clinical observations have shown that some carotenoids have anti-tumor abilities in both in-vitro and in-vivo conditions, indicating the potential of carotenoids as an anti-cancer agent (Tanaka et al., 2012). Melon was also reported as a rich natural source of vitamin A, mainly because of its content of b-carotene, having high antioxidant potentials. It has been proven to guard against cancers of the lung and oral cavity (Key et al., 2004).

The hydroponic system, also known as soilless culture, is one of the innovations applied in melon plant cultivation techniques. Soilless culture is the modern farming method of plants that use either inert organic or inorganic substrate by nutrient solution nourishment. Horticultural crops' quality increases significantly via soilless culture compared to traditional soil culture. In addition, this protected farming method can control the growing environment by controlling the weather conditions, volume and composition of nutrient solution, and the growing medium. As a result, many studies also proposed soilless cultivation in the greenhouse as an alternative to traditional field production for high-value vegetable crops. This system is also the most intensive cultivation system that uses all the resources efficiently to maximize crop yield and, therefore, the most intense style of agricultural enterprises for commercial production of greenhouse vegetables (Asaduzzaman et al., 2015).

Horticultural crops are usually considered high-value, so a water system (irrigation) is essential for open-field vegetable crops to get high quality and yield. Protected vegetable crops also need this irrigation system (Pardossi and Incrocci, 2011). Drip irrigation is the foremost effective methodology to apply water. It produces a restricted root system that requires a regular supply of nutrients. And this is fulfilled by providing fertilizers with irrigation water (fertigation). Fertigation can be defined as a management technique of agricultural water that can apply fertilizer and water simultaneously in a drip irrigation system, feed the crop by injecting dissolvable fertilizers into the water, and transports them to the root area (Hagin and Lowengart, 1996). According to Howell (2001), fertigation is considered a modern form of fertilization in precision agriculture, increasing fertilizer and irrigation water efficiency. Fertigation typically permits a substantial improvement in the efficiency of nutrient usage in the recovery of plant nutrients, with much higher outcomes (up to 90%) than in other fertilizer application systems (40–45%) (Lichtfouse, 2010). The significant benefits of fertigation are represented in optimizing fertilizer distribution in the root area, the potential of maintaining a low level of the nutrient in the soil solution (but constant), and improving the flexibility to divide the dosage of fertilizer depending on the crop's uptake rate. As a result, fertilization usage was found to minimize the run-off of mobile nutrients like N by up to 70% compared to traditional fertilizer applications (Solaimalai et al., 2005).

The fungal infection and pathogens in the cultivation of melon are considered significant problems that are difficult to manage. Among these diseases are fruit rot, stem rust, and powdery mildew. According to Fatmawati and Daryono (2016), the powdery mildew infection resulted in a lack of fruit quality and productivity of melon, causing a shortage of fruit sale value and crop failure. Therefore, efforts are needed to improve the productivity and quality of melon and prevent pest and disease attacks. One of those efforts is by using the Nano-silica application.

Fertilizers have a promising role in improving food quality and production, particularly with introducing high-yielding and fertilizer responsive varieties. Several studies have been conducted to optimize plant production; however, just a few can be seen in the literature involving nanomaterials (NMs) (Huang et al., 2015; Rose et al., 2015). Nanoparticles (NPs) are classified as materials with a single unit sized from 1 to 100 nm in a minimum of one dimension. Nano fertilizers having smaller sizes than the sizes of cell wall pores (5-20 nm) can be absorbed and enter the plant cells directly using the sieve-like cell wall structures, but absorption of these NPs through soil or water is still not yet known (Rose et al., 2015); Liu and Lal, 2015). According to El-Shetehy et al. (2021), NPs seem to have the ability to serve as a low-cost, safe, high-efficiency, and sustainable alternative for plant disease prevention. In a dose-dependent way, NPs can promote systemic acquired resistance, including the defense hormone salicylic acid. Silicon (Si) is known as a beneficial element for plant growth. It can allow plants to surmount various stresses, namely biotic and abiotic stresses. The beneficial effects of Si were observed in a large variety of plant species, although silicon (Si) was not identified as an essential element for plant growth (Ma, 2004). The critical function of silicon is represented as an inducer of plant resistance, making plants more resistant to pest attacks, pathogens, and climatic stress. The reason for that is because when Si accumulates and polymerizes in plant cells beneath the cuticle and in the cell wall, it can confer plant protection which creates a mechanical barrier inhibiting pest attack. The role of Si accumulation is reported as it is due to biotic stress, but further biochemical studies are required to evaluate the exact pathways using proteomics and metabolomics studies (Song et al., 2021; Andreacute et al. 2016). Furthermore, according to Marschner (1995), A vital role that can be played by Si in enhancing the ability of photosynthetic of plant, greater plant size, larger stem diameter, and increases the number of leaves. However, no information has been revealed on applying silica fertilizers to improve the growth and quality of melons. The purpose of this study was to investigate the influence of silica fertilizer concentrations on the plant growth and fruit quality of two melon varieties, especially fruit moisture content, and to assess silica absorption from foliar-applied silicon nanoparticles in melon grown under soilless culture. The application of silica to melon cultivars used in this research is expected to improve plant resistance and increase the growth and quality of the melon.

Material and Methods

Experimental Site and Planting Material

The study was conducted from January to June 2021 at a greenhouse of the IPB experimental station in Leuwikopo, Bogor, located at latitude -6.5507 and longitude 106.7286 and an altitude of 218.79 m above sea level. Post-harvest analysis, including fruit quality, was held at the Post Harvest Laboratory in the Department of Agronomy and Horticulture of Bogor Agricultural University. In addition, analysis of silica absorption was carried out at the Analyses laboratory in the Institute of Indonesian Soil Research.

Materials used in this experiment included melon seeds ("Alisha" variety and "Glamour" variety), husk charcoal, Rockwool media, AB mix nutrition, germination trays, polybag, silica solution (Novelgro, water-soluble), NaOH (50%), ammonium molybdate (20%), ascorbic acid (20%), acetic acid (20%), 2 g of Na_2SO_3, 0.4 g of 1-Amino-2-naphthol-4-sulfonic acid, and 25 g of $NaHSO_3$ in 1 L of distilled water. Tools used include water tanks, PVC pipe, water jet pump machines, dripper sticks, PE hoses 16 mm, PE hoses 5mm, timer, cameras, stationery, sprayers, calipers, penetrometer, meters, scales, vortex, mortar and pestle, Petri dishes, Erlenmeyer flasks, pipettes, and UV-vis spectrophotometer.

Agronomic Management Practices

The "Alisha" and "Glamour" melon seeds used as a plant material were soaked in warm water for 15 minutes to break dormancy. Afterwards, the seeds were sown in germination trays using planting media of Rockwool using one seed per hole. After 28 days or soon after forming two perfect leaves, the seedlings were ready and moved into the polybags packed with husk charcoal media. Transplanting was carried out in the afternoon to avoid plant stagnation. The planting space used was 25 cm x 25 cm.

The nutrient solution was provided in an AB mix solution consisting of formula A (KNO_3, $Ca(NO_3)_2$ and Fe-EDTA) and formula B (KNO_3, K_2SO_4, KH_2PO_4, $MgSO_4$, $MnSO_4$, $CuSO_4$, (NH_4) SO_4, Na_2HBO_3, $ZnSO_4$ and $NaMoO_4$). The nutrient compositions used were: Ca^{++} 177 ppm, Mg^{++} 24 ppm, K^+ 210 ppm, NH_4^+ 25 ppm, NO_3^- 233 ppm, SO_4^- 113 ppm, PO_4^- 60 ppm, Fe 2.14 ppm, B 1.2 ppm, Zn 0.26 ppm, Cu 0.048 ppm, Mn 0.18 ppm and Mo 0.046 ppm. Fertigation was applied with an EC ranging from 1.2 to 1.5 μS.cm^{-1} depending on plant growth. Plants were given during the vegetative phase an EC of 1.2 - 1.3 μS.cm^{-1}, which equated to 5 litres of solution A and 5 litres of solution B per 1000 litres of water. When the plants entered the generative phase, the EC was increased to 1.5 - 1.6 μS.cm^{-1} or 7 litres of solution A and 7 litres of solution B per 1000 litres of water. Nutrients were provided with automatically controlled pumps by Encomotion or manually turned on four times a day, at 8.00, 10.00, 12.00, and 14.00 for 5 - 10 minutes. Every 2 hours, the nutrient solution was distributed to each polybag as much as 200 - 350 ml depending on the phase of plant growth.

Pruning of melon plants was carried out on any lateral bud that appears on the 1st node up to the 8th node. In contrast, the buds that appear on the 9th node and above were maintained for fruition. Fruit thinning occurs after the flowers have been successfully pollinated. Fruit pruning was when the plant had fruit as large as a ping pong ball. Fruit thinning was carried out by leaving the best fruit from each tree to be preserved until harvesting. The fruit selected was the fruit that emerges on the 9th node and above. The topping was done when the height of the plant was as high as +2.25 meters. Once the plant was fruiting, the leaves on 1st node until the 8th were pruned to improve air circulation and prevent diseases.

Foliar fertilization of Nano-silica (Novelgro Silica, water-soluble) was carried out on melon plants using a sprayer. Each treatment was sprayed according to the guideline (1.5 L for 8 plant replications) at the adaxial and abaxial surfaces of the leaves. Spraying was applied in the afternoon to reduce evaporation, starting two weeks after planting (WAP) with a frequency of 3 times and a spray interval of seven days. A spray volume of 160 ml per plant from 2 WAP until the end of the vegetative phase.

Melon harvesting was carried out when the fruit underwent the physiological maturity phase, which occurred approximately 79 days after the transplanting (DAT) and was characterized by an abscission layer on the fruit stalk. The flag leaf was withered; when pressed, the bottom part of the fruit was relatively mushy and gave off a distinctive aroma of melon.

Experimental Design

The experimental design was carried out with two factors using a split-plot randomized complete block design. The main plot factor consisted of three treatments of silica fertilizer concentration. Silica fertilizer used (silica dissolved in water, Novelgro) contains 13.56 mg of silica /160 mL of solvents with a recommended concentration of 10 ppm. The concentrations applied were control C0 (without silica), C1 (silica concentration of 0.67 ppm), and C2 (silica concentration of 1.33 ppm), the spray volume of each treatment was 160 ml per plant with seven days' intervals and a frequency of three times. In contrast, the subplot factor was the varieties, consisting of "Alisha" and "Glamour". These treatments were then replicated four times for a total of 24 experimental units. There were 96 plant samples in the experiment since each experimental unit had four observed plants.

Data Collection

The vegetative phase variables observed were: a) Plant height was measured from the stem's base to the main stem's growing point node; b) Number of leaves per plant; c) Stem diameter using digital caliper; and d) Average internode length was calculated from the plant height divided by the number of internodes. These variables were collected weekly from the 2nd to the 5th week after transplanting. In contrast, generative phase variables measured were: a) The total number of hermaphrodite flowers per plant; b) Number of swollen hermaphrodite flowers was determined by counting the number of hermaphrodite flowers that have bud swelling, which would develop into a fruit; and c) Fruit position was determined by recording the node number that bore fruit. These parameters were collected on the 5th week after transplanting. In addition, melon plants of both cultivars were ready for harvesting at 75-80 DAT, with the following quality variables observed: a) Total soluble solids using hand refractometer; b) Fruit weight during the harvesting; c) Firmness of fruit rind by using penetrometer; and d) Fruit moisture content. Scoring of fruit quality was carried out on 72 sample fruits randomly selected from each experimental plot.

Determination of Fruit Moisture Content

Determination of the moisture content of the fruit was carried out according to Sudarmadji (1997). First, 72 fruit samples of 5 g each were weighed and placed in the evaporating dishes. The samples were dried in the oven at 70°C for two days until a constant dry weight was achieved. Moisture content was obtained by using the following formula:

Moisture content (%) = [(initial weight – final weight)/ initial weight] x 100

Content and Efficiency of Silica Uptake in Melon Plant Organs

Analysis of silica content was determined by using Alkali Fusion Method (Liang et al., 2007). The leaves, fruit rind, root, and stem of melon were oven-dried at 60 °C for 3×24 hours; each one as much as 500 mg was ground in a mortar. The samples were being given 3 mL of NaOH (50%) and homogenized with a vortex. Subsequently, distilled water was being added up to 50 ml. A sample of 1 mL was entered into an Erlenmeyer flask using a pipette, then added 30 mL of acetic acid (20%), 10 mL of ammonium molybdate (20%) shaken until dissolved. The solution was stored for 5 minutes and added 5 mL of ascorbic acid (20%) and 1 mL of reducing solution. Reducing solution consists of a mixture of solution A (2 g of Na_2SO_3 and 0.4 g of 1-Amino-2-naphthol-4-sulfonic acid in 25 mL of distilled water) and solution B (25 g of $NaHSO_3$ in 200 mL of distilled water), which were added into 250 mL of distilled water and stored in a dark bottle. The solution mixture was kept for 20 minutes afterward, and absorbance was measured with a UV-vis spectrophotometer at a wavelength of 650 nm. Extraction was carried out three times for each treatment. The silica content was determined using a standard silica curve drawn according to the Lambert-Beer Law (Yuan et al., 2019).

The efficiency of silica uptake is the ratio between silica absorbed by plants and silica applied. The efficiency of silica uptake was calculated using the formula of Bustami et al. (2012):

SAE = mg Si (plant)/mg of Si (applied)

Statistical Analysis

Data were analyzed by analysis of variance (ANOVA) using SPSS statistical software (version 26) and Microsoft Excel 2016. Whenever the results obtained were significant, then Duncan's multiple range test (DMRT) at a range of 5% was used to test their differences.

Result and Discussion

Plant Height and Number of Leaves

The plants' height showed no significant difference among silica fertilizer concentrations (0.00, 0.67, and 1.33 ppm) during the 2nd and 3rd weeks after planting. Noticeable differences were observed during the 4th and 5th weeks after planting, in which plants that were treated with 0.67 and 1.33 ppm showed the maximum height compared to the control (Table 1). In contrast, silica application did not significantly affect the number of leaves of melon throughout the observation period. A significant increase in melon plant height due to silica addition during the 4th and 5th weeks after planting was similar to the one reported by Triadiati et al. (2019), which indicated an increase in melon plant height after using silica fertilizer. The increase in plant height is assumed to result from increased cell formation due to increased assimilation (Harjanti et al., 2014). According to Meena et al. (2014), silica plays a role in improving plant erection, including leaves, which leads to an increase in the interception of solar energy used during the photosynthetic process. Therefore, it is hypothesized that the application of silica with a concentration of 1.33 ppm also stimulated plant height growth compared to the control.

"Glamour" plant's height was significantly different from the "Alisha" plant's height during the 3rd week until the 5th week. Genetic factors may be the main cause as these cultivars belong to different variety groups. The environment and the genotype also influence some agronomic traits of plants by environment interaction (Asnawi and Dwiwarni, 2000). As for the number of leaves, varieties significantly affected the number of leaves from the 4th week until the 5th week after planting (Table 1). The "Alisha" variety showed the highest leaves number compared to the "Glamour" variety. The addition of silica fertilizer and varieties showed good plant growth. This implies the plants can grow despite the high-temperature conditions in the greenhouse.

Stem Diameter and Internode Length

An increase in the internode length and stem diameter occurred during the 4th and 5th weeks. The highest length was recorded in 0.67 and 1.33 ppm compared to control (Table 2). Moreover, plants treated with 0.67 and 1.33 ppm silica fertilizer resulted in the highest stem diameter with a 12.01% and 15.66% increase in diameter relative to control, respectively (Table 2). On

Table 1. Effect of silica concentrations and varieties on melon height and number of leaf.

Treatment	Plant height (cm)			
	2 WAP	3 WAP	4 WAP	5 WAP
Si concentrations (ppm)				
0	42.31 ± 3.94	83.41 ± 9.31	135.13 ± 12.57 b	228.55 ± 23.25 b
0.67	43.77 ± 5.23	86.23 ± 9.34	144.83 ± 7.13 a	243.08 ± 7.71 a
1.33	42.73 ± 6.38	85.34 ± 11.90	146.91 ± 11.91 a	247.43 ± 22.01 a
Varieties				
"Alisha"	41.52 ± 4.28	79.21 ± 7.72 b	135.37 ± 11.83 b	228.49 ± 19.19 b
"Glamour"	44.36 ± 5.59	90.77 ± 8.44 a	149.22 ± 6.02 a	250.88 ± 13.80 a
Si concentrations	ns	ns	*	*
Varieties	ns	*	*	*
Si concentrations x Varieties	ns	ns	ns	ns
	Number of leaf			
Si concentrations (ppm)				
0	8.07 ± 0.67	13.13 ± 0.40	21.38 ± 1.09	35.13 ± 0.96
0.67	8.27 ± 0.41	13.82 ± 0.57	21.83 ± 1.05	36.04 ± 1.98
1.33	8.03 ± 0.54	13.53 ± 1.31	21.79 ± 1.07	35.33 ± 1.10
Varieties				
"Alisha"	8.34 ± 0.46	13.65 ± 0.76	22.42 ± 0.89 a	36.08 ± 1.74 a
"Glamour"	7.91 ± 0.54	13.34 ± 0.97	20.92 ± 0.51 b	34.92 ± 0.65 b
Si concentrations	ns	ns	ns	ns
Varieties	ns	ns	*	*
Si concentrations x Varieties	ns	ns	ns	ns

Note: Means followed by different letters in the same column are significantly different according to Duncan's multiple range test (DMRT) at α = 5%; ns = not significantly different; * = significantly different; WAP = Week after planting; values are means followed by standard error the other hand, plants of "Glamour" cultivar showed higher stem diameter and internode length than plants of "Alisha" cultivar throughout all observation weeks. These results were also similar to those obtained by Djajadi et al. (2017), who concluded that the addition of liquid silica fertilizer could increase the diameter and length of the stem. The increase in stem diameter and internode length is associated with the role of silica in enhancing photosynthesis and leaf chlorophyll content, resulting in more carbohydrates being produced for the growth and development of plant cells. Mulyadi and Toharisman (2003) stated that the application of silica fertilizer increased the height of the sugarcane plant, which means the internode length of the sugarcane also increased.

Generative Parameters

Table 3 shows the significant difference among the silica concentrations regarding the total number of hermaphrodite flowers and the number of hermaphrodite flowers that swelling during the 5 WAP. The concentration of 1.33 ppm was significantly different from the control but wasn't significantly different from 0.67 ppm. Meanwhile, treatments 0.67 ppm and control were not significantly different. At the same time, the addition of silica influenced fruit position. The silica concentration of 1.33 ppm was not significantly different from 0.67 ppm, but they were significantly different from the control (Table 3). The addition of silica at concentrations of 0.67 ppm and 1.33 ppm produces the best average fruit position compared to control with an average fruit position on the 13th node (Table 3). Furthermore, the "Alisha" variety differed significantly from the "Glamour" variety regarding the number of hermaphrodite flowers and hermaphrodite flowers that swelling, with 58.30 % and 58.87 %, respectively (Table 3).

The best fruit position and an increased number of the hermaphrodite flowers could have been caused since liquid silicate fertilizer includes all essential nutrients,

Table 2. Influence of silica concentrations and melon varieties on the stem diameter and internode length of the melon plant

Treatment	Stem diameter (mm)			
	2 WAP	3 WAP	4 WAP	5 WAP
Si concentrations (ppm)				
0	3.98 ± 0.62	4.48 ± 0.56	5.62 ± 0.55 b	7.12 ± 0.56 b
0.67	4.19 ± 0.46	4.74 ± 0.52	6.30 ± 0.51 a	7.89 ± 0.82 a
1.33	4.08 ± 0.37	4.61 ± 0.44	6.50 ± 0.55 a	8.00 ± 0.60 a
Varieties				
"Alisha"	3.69 ± 0.28 b	4.21 ± 0.33 b	5.70 ± 0.51 b	7.10 ± 0.43 b
"Glamour"	4.47 ± 0.26 a	5.01 ± 0.25 a	6.58 ± 0.42 a	8.24 ± 0.55 a
Si concentrations	ns	ns	*	*
Varieties	*	*	*	*
Si concentrations x Varieties	ns	ns	ns	ns
	Internode length (cm)			
Si concentrations (ppm)				
0	6.12 ± 0.57	6.57 ± 0.81	6.73 ± 0.75 b	7.23 ± 0.64 b
0.67	6.06 ± 0.61	6.50 ± 0.61	7.01 ± 0.62 a	7.72 ± 0.47 a
1.33	6.12 ± 0.62	6.52 ± 0.57	7.08 ± 0.63 a	7.89 ± 0.86 a
Varieties				
"Alisha"	5.72 ± 0.44 b	5.99 ± 0.28 b	6.37 ± 0.38 b	7.07 ± 0.41 b
"Glamour"	6.48 ± 0.42 a	7.07 ± 0.38 a	7.51 ± 0.22 a	8.15 ± 0.50 a
Si concentrations	ns	ns	*	*
Varieties	*	*	*	*
Si concentrations x Varieties	ns	ns	ns	ns

Note: Means followed by different letters in the same column are significantly different according to Duncan's multiple range test (DMRT) at α = 5%; ns = not significantly different; * = significantly different; WAP = week after planting; values are means followed by standard error

Table 3. Effect of silica concentrations and melon varieties on the total number of hermaphrodite flowers, number of swollen hermaphrodite flowers, and fruit position

Treatment	Total number of hermaphrodite flowers	Number of swollen hermaphrodite flowers	Fruit position (node)
Si concentrations (ppm)			
0	6.13 ± 2.32 b	2.50 ± 0.94 b	15.94 ± 3.12 a
0.67	7.10 ± 2.54 ab	3.30 ± 1.27 ab	12.79 ± 1.95 b
1.33	7.77 ± 2.64 a	3.82 ± 1.69 a	12.10 ± 1.40 b
Varieties			
"Alisha"	8.58 ± 1.95 a	3.94 ± 1.20 a	12.88 ± 2.66
"Glamour"	5.42 ± 1.93 b	2.48 ± 1.21 b	14.35 ± 2.77
Si concentrations	*	*	*
Varieties	*	*	ns
Si concentrations x Varieties	ns	ns	ns

Note: Means followed by different letters in the same column are significantly different according to Duncan's multiple range test (DMRT) at α = 5%, ns = not significantly different; * = significantly different; values are means followed by standard error (se)

both macro (N, P, and K) and micro. The availability of nutrients N, P, and K is critical in the flower and fruit formation process. N nutrient is required for protein formation; P nutrient is essential in forming new proteins and cells, accelerating the growth of flowers, fruits, and seeds. In contrast, K nutrient can facilitate carbohydrate transport and plays an essential role in cell division, affecting the formation and growth of fruit until the fruit ripens (Darjanto and Satifah, 1982).

Fruit Quality

Application of silica fertilizer showed no significant effects on the fruit weight and total soluble solids of melon fruit (Table 4). The melon varieties significantly differ in the fruit weight and sugar content. "Glamour" varieties produced considerably higher fruit weight and total soluble solids than "Alisha" varieties; the average fruit weight and total soluble solids of "Alisha" varieties were 840 g and12.22 ^{0}Brix, respectively were 1230 g and13.26 ^{0}Brix in "Glamour" varieties (Table 4). In this study, it is assumed that silica did not play a role in the structure of the tissue cells that form the fruit during the fruit enlargement process. Furthermore, it is suspected that the silica accumulated on the cell wall does not affect the fruit to become a strong sink. Fruit weight is primarily determined by the phases of cell division and enlargement during fruit growth and development, although cell growth and enlargement require silica (Falk et al., 2007). Silica in primary cell walls will bind to pectin and polyphenols, increasing cell elasticity during organ enlargement (Marschner, 2012). In our study, both cultivars did not reach their yield potential; the fruit weight was far from the maximum. The low yield could be explained by the microclimate in the greenhouse, where temperatures could reach above 40°C during the day and the lack of light received by plants.

Table 4 also indicated a slight difference in the rind firmness of melon fruit between silica treatments. However, Table 4 shows that the addition of silica affected the fruit moisture content. Whereby, silica concentration of 1.33 ppm was not significantly different from silica concentration of 0.67 ppm, but substantially different from the control. Meanwhile, concentrations 0.67 ppm and control were not significantly different. The addition of silica at a concentration of 1.33 ppm tended to produce the best average fruit moisture content among other concentrations with an average of 90.03%. The moisture content of the fruit is closely associated with its firmness. If the moisture content is high, the fruit will be tender or have a lower firmness; if the moisture content is low, the fruit will be firmer. According to Ryall and Lipton (1972), one of the criteria of good quality fruit favoured by consumers is high firmness with moderate moisture content. If the fruit has a more than 95% moisture level, it will quickly rot when kept, break easily, and feel soft when consumed.

Content and Efficiency of Silica Uptake in Melon Plant Organs

Figure 1 illustrates silica content in the melon plant organs with various silica concentrations applied. Silica concentration used on both cultivars could increase the silica content in leaf, rind, and stem, excluding the root. Whereby, plants treated with the silica concentrations of 1.33 ppm (C2) and 0.67

Table 4. Influence of silica concentrations and melon varieties on the fruit weight, total soluble solids, rind firmness, and fruit moisture content

Treatment	Fruit weight (kg)	Total soluble solids (^{0}Brix)	Rind firmness (mm.kg^{-1}.5s^{-1})	Moisture content (%)
Si concentrations (ppm)				
0	1.04 ± 0.32	12.26 ± 1.68	15.19 ± 1.56	94.08 ± 1.80 a
0.67	1.03 ± 0.16	12.87 ± 1.18	14.71 ± 3.10	91.73 ± 3.05 ab
1.33	1.04 ± 0.26	13.10 ± 1.45	14.30 ± 1.48	90.03 ± 2.15 b
Varieties				
"Alisha"	0.84 ± 0.09 b	12.22 ± 1.54 b	14.77 ± 1.64	91.84 ± 2.80
"Glamour"	1.23 ± 0.17 a	13.26 ± 1.15 a	14.70 ± 2.57	92.05 ± 3.01
Si concentrations	ns	ns	ns	*
Varieties	*	*	ns	ns
Si concentrations x Varieties	ns	ns	ns	ns

Note: Means followed by different letters in the same column are significantly different according to Duncan's multiple range test (DMRT) at α = 5%; ns = not significantly different; * = significantly different; values are means followed by standard error (se)

ppm (C1) tend to result in a higher silicon content compared to the control (C0) (Figure 1A and B). Generally, the silica concentrations of 0.67ppm and 1.33 ppm represent a higher silica content in the "Alisha" leaf with an average of 0.34% compared to the control (Figure 1A), and the silica concentration of 1.33 ppm showed higher silica content in the Glamor rind with an average of 0.30% compared to other concentrations (Figure 1B).

The levels of silica in the leaves of "Alisha" was higher than that of "Glamour", with a 37% difference in the content (Table 5). While the silica content of the two cultivars' rinds did not differ considerably, the similar values were found for the roots and stems (Figure 1A and B). Based on Table 5, which represents the efficiency of silica uptake in melon plant organs, the highest silica uptake efficiency was found in "Alisha" leaves treated with a silica concentration of 0.67 ppm with an average efficiency of 0.51.

The silica is absorbed by plants and distributed to all plant parts, although the accumulation is different in each part of the plant (Richmond and Sussman, 2003). In this study, silica was added in the form of a solution that was sprayed over all parts of the melon plant's leaves. Si may be absorbed by plants through the pores of the plant cell wall, through leaf stomata, and young shoots. This fact may be related to Si uptake through a passive mechanism through nodes, namely mass flow (Cornellis et al., 2011). According to Luz et al. (2006), silica is an abundant element in nature that may be found everywhere, including in water, which explains the existence of silica in melon plant organs treated with control (without silica).

This study indicates that silica accumulates more in "Alisha" cultivar leaf given silica fertilizer with

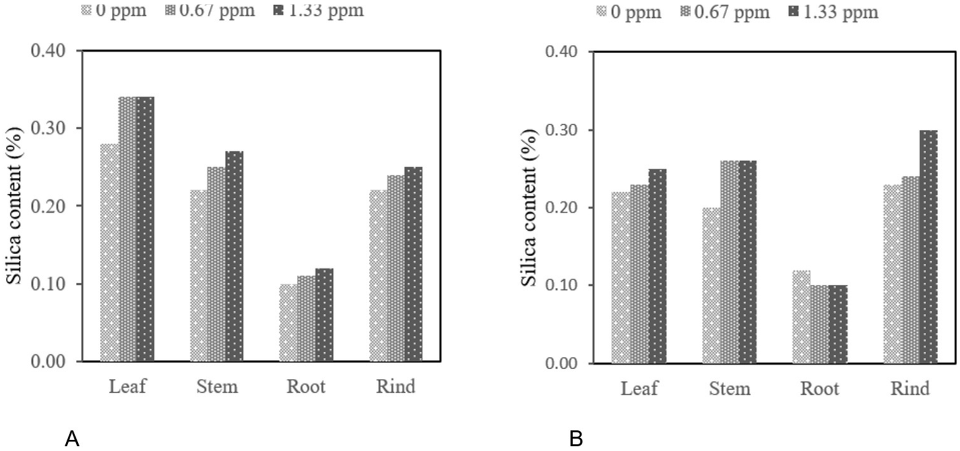

Figure 1. The contents of silica in melon plants' organs of "Alisha" (A) and "Glamour" (B) varieties

Table 5. Efficiency of silica uptake in melon plant organs with silica application at the 8th week after planting

Varieties	Si concentration (ppm)	Silica absorption efficiency (%)			
		Root	Stem	Leaf	Rind
“Alisha”	0	0.00	0.00	0.00	0.00
	0.67	0.16	0.37	0.51	0.36
	1.33	0.09	0.20	0.26	0.19
“Glamour”	0	0.00	0.00	0.00	0.00
	0.67	0.15	0.39	0.34	0.36
	1.33	0.08	0.20	0.19	0.23

concentrations of 0.67 ppm 1.33 ppm, which is 0.34%. Silica content in melon plant organs in each treatment increased along with the increase in the concentration of silica fertilizer given. This is in line with Djajadi’s (2013) findings, which found that increasing silica concentration can increase the Si content in plant tissues, resulting in increased sugarcane production. According to Asmar et al. (2013), adding silica in the form of calcium silicate to banana leaves increased the thickness of the epidermis and mesophyll of the leaves while also accumulating silica in these tissues.

A lower amount of silica found in the plant roots could have been caused by the fact that this element accumulates in the leaf of both cultivars. These results are similar to the one obtained by Oliveira and Castro (2002), who stated that the leaves and stem’s average silica content is higher than the Si content in the roots. However, the stem and rind of the “Glamour” cultivar contained a higher level of Si than in the leaf, which has yet to be confirmed in other trials involving the addition of silica to melon fruit.

This study showed that melon (Cucurbitaceae family) accumulated silica in the leaves of “Alisha” cultivar and the rinds of “Glamour” cultivar treated with silica concentration of 1.33 ppm much as 0.34% and 0.30%, respectively. The results of this study are similar to those obtained from Hodson et al. (2005), in which Cucurbitaceae, Urticaceae, and Commelinaceae were able to accumulate Si with moderate criteria (0.2-2% Si), while families Poaceae, Equisetaceae, and Cyperaceae were able to accumulate high Si (>2% Si). Therefore, the melon fruit was not an accumulator of silica in the roots, stems, leaves, and rinds. Whereby, Ma et al. (2001) classified plants into three groups in terms of accumulating silica, Si accumulators when Si content in plants is more than 1 % of Si; intermediate when the plants contain between 0.5 and 1 % of Si; and non-accumulators when Si content in plants less than 1% of Si. This study also recorded that silica was an active pest and diseases controller, and the silica-treated plants grew better than the control plants.

Conclusion

The foliar application of silica fertilizer significantly increased the plant height, stem diameter, internode length, total number of hermaphrodite flowers, number of hermaphrodite flowers that swelling, while decreased the fruit moisture content and gave the best average fruit position. Instead, The “Glamour” variety gave the best response to plant growth and fruit quality regarding plant height, stem diameter, internode length, total soluble solids and fruit weight. In contrast, the “Alisha” variety gave the best response regarding the number of leaves, the total number of hermaphrodite flowers, and the number of hermaphrodite flowers that are swelling. However, the results of this study did not show any interaction between treatments on the experimental parameters. Moreover, our study indicated that the highest silica contents were found in the “Alisha” cultivar leaves and the “Glamour” cultivar’s rinds treated with the silica concentration of 1.33 ppm, i.e. 0.34% 0.30%, respectively. It is concluded that the “Alisha” and “Glamour” cultivars could absorb silica in the low category (<1% Si). In addition, silica was highly effective for the growth of both “Alisha” and “Glamour” varieties and could be tested as a potential pest and diseases inhibitor for future studies. “Glamour” had higher plant growth and fruit quality, especially in terms of total soluble solids and fruit weight than “Alisha”.

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References

Andreacute, L. A., Antonio, C. T. da C., Jos eacute, B. D. J. uacute nior, Vanda, P., and Marcos, C. M. (2016). Agronomic performance of common bean (*Phaseolus vulgaris* L.) according to foliar application of potassium silicate in two sowing times. *African Journal of Agricultural Research* **11**, 2528–2535.

Asaduzzaman, M., Saifullah, M., Mollick, A. K. M. S. R., Hossain, M. M., Halim, G. M. A., and Asao, T. (2015). “Influence of Soilless Culture Substrate on Improvement of Yield and Produce Quality of Horticultural Crops”. https://doi.org/10.5772/59708

Asmar, S. A., Castro, E. M., Pasqual, M., Pereira, F. J., and Soares, J. D. R. (2013). Changes in leaf anatomy and photosynthesis of micropropagated banana plantlets under different silicon sources. *Scientia Horticulturae* **161**, 328–332.

Asnawi, R dan I. Dwiwarni. (2000). Pengaruh mulsa terhadap pertumbuhan dan produksi enam varietas cabai (*Capsicum annum* Linn.). *Jurnal Tanah Tropika* **5**, 5-8.

Bangun, A.P. (2004). ‘‘Menangkal Penyakit dengan Jus Buah dan Sayuran’’. AgroMedia. Jakarta.

Bustami, Sufardi, and Bakhtiar. (2012). Serapan hara dan efisiensi pemupukan phosphat serta pertumbuhan padi varietas lokal. *Jurnal Manajemen Sumberdaya lahan* **1**, 159-170.

Cornelis, J. T., B. Delvaux, R. B. Georg, Y. Lucas, J. Ranger, and S. Opfergelt. (2011). Tracing the origin of dissolved silicon transferred from various soil-plant systems towards Rivers: A Review. *Biogeosciences* **8**, 89–112.

Darjanto dan Satifah, S. (1982). ‘‘Pengetahuan Dasar Biologi Bunga dan Teknik Penyerbukan Silang Buatan’’ p. 142. PT Gramedia, Jakarta.

Djajadi. (2013). Silicon (Si): Beneficial element for sugarcane (*Saccharum officinarum* L.). *Perspektif* **12**, 47-55.

Djajadi, D., Hidayati, S. N., Syaputra, R., and Supriyadi, S. (2017). Effect of liquid Si fertilizer on yield and commercial cane content of sugarcane. *Jurnal Penelitian Tanaman Industri.* **22**, 176-181.

El-Shetehy, M., Moradi, A., Maceroni, M., Reinhardt, D., Petri-Fink, A., Rothen-Rutishauser, B., Mauch, F., and Schwab, F. (2021). Silica nanoparticles enhance disease resistance in Arabidopsis plants. *Nature Nanotechnology* **16**, 344–353.

Falk, K.L., Tokuhisa, J.G., and Gershenzon, J. (2007). The effect of sulfur nutrition on plant glucosinolate content: physiology and molecular mechanisms. *Plant Biology* **9**, 573-581.

FAOSTAT. (2019). “Food and Agriculture Organization of the United Nations”. http://www.faostat.fao.org. [December 22, 2020].

Fatmawati, A., and Daryono, B.S. (2016). Detection of powdery mildew (*Podosphaera xanthii* (Castagne) U. Braun & N. Shishkoff) resistance gene in melon (*Cucumis melo* L.) cultivar Tacapa Green Black. *Bioengineering and Bioscience* **4**, 51-55.

Hagin, J., and Lowengart, A. (1996). Fertigation for minimizing environmental pollution by fertilizers. *Fertilizer Research* **43**, 5–7.

Harjanti, R.A., Tohari, and Utami, S.N.H. (2014). Pengaruh takaran pupuk nitrogen dan silika terhadap pertumbuhan awal (*Saccharum officinarum* L.) pada inceptisol. *Vegetalika* **3**, 35-44.

Hodson, M.J., White, P.J., Mead, A., and Broadley, M.R. (2005). Phylogenetic variation in the silicon composition of plants. *Annals of Botany* **96**, 1027-1046.

Howell, T.A. (2001). Enhancing water use efficiency in irrigated agriculture. *Agronomy Journal* **93**, 281–289.

Huang, S., Wang, L., Liu, L., Hou, Y., and Li, L., (2015). Nanotechnology in agriculture, livestock, and aquaculture in China, a review. *Agronomy for Sustainable Development* **35**, 369-400 https://doi.org/10.1007/s13593-014-0274-x

Kementerian Pertanian. (2016). “Basis Data Statistik Pertanian”. https://aplikasi.pertanian.go.id/bdsp/hasil_ind.asp. [July 1, 2019].

Lester, G. (1997). Melon (*Cucumis melo* L.) fruit nutritional quality and health functionality. *Hortechnology* **7**, 222-227.

Liang, Y., Sun, W., Zhu, Y.G., and Chrisrie, P. (2007). Mechanisms of silicone mediated alleviation of abiotic stresses in higher plants. *Environment Pollution* **147**, 422-428.

Lichtfouse, E. (2010). "Genetic Engineering, Biofertilization, Soil Quality and Organic Farming". https://doi: 10.1007/978-90-481-8741-6.

Liu, R., and Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Science of the Total Environment* **514**, 131–39.

Luz, J.M.Q., Guimarães, S.T.M.R., and Korndörfer, G.H. (2006). Produção hidropônica de alface em solução nutritiva com e sem silício. *Horticultura Brasileira* **24**, 295–300.

Ma, J. F., Miyake, Y., and Takahashi, E. (2001). Silicon as a beneficial element for crop plants. *Studies in Plant Science* **8**, 17–39.

Ma, J.F. (2004). Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. *Soil Science and Plant Nutrition* **50**, 11–18.

Marschner, H. (1995). ''Mineral Nutrition of Higher Plants''. 2nd ed. p. 889. London Academic Press.

Marschner, P. (2012). ''Marschner's Mineral Nutrition of Higher Plants''. London Academic Press.

Meena, V.D., Dotaniya, M.L., Coumar, V., Rajendiran, S., Ajay, Kundu, S., and Subba Rao, A. (2014). A case for silicon fertilization to improve crop yields in tropical soils. *Proceeding National Academy of Science India– Biological Science* **84**, 505–518.

Mulyadi, M., and Toharisman, A. (2003). Silikat: hara fungsional yang berperan dalam meningkatkan produktivitas tebu. *Pusat Penelitian Perkebunan Gula Indonesia*, pp.1-14.

Oliveira, L.A., and Castro, N.M. (2002). Ocorrência de silica nas folhas de Curatella americana L. e de *Davilla elliptica* St. Hil. *Revista Horizonte Cientifico* **38**, 159-170.

Pardossi, A., and Incrocci, L. (2011). Traditional and new approaches to irrigation scheduling in vegetable crops. *HortTechnology* **21**, 309–313.

Richmond, K.E., and Sussman, M. (2003). Got silicon? The non-essential beneficial plant nutrient. *Current Opinion in Plant Biology* **6**, 268–272.

Rose, H., Benzon, L., Rosnah, M., Rubenecia, U., Ultra, V.U., and Lee, S.C. (2015). Nano-fertilizer affects the growth, development, and chemical properties of rice. *International Journal of Agronomy and Agricultural Research* **7**, 2223–7054.

Ryall, A.L., and Lipton, W.J. (1972). ''Handling, Transportation and Storage of Fruits and Vegetables''. West Point Connecticut. The AVI Publication.

Solaimalai, A., Baskar, M., Sadasakthi, A., and Subburamu, K. (2005). Fertigation in high value crops-A review. *Agricultural Reviews* **1**, 1-13.

Song, X.P., Verma, K.K., Tian, D.D., Zhang, X.Q., Liang, Y.J., Huang, X., Li, C.N., and Li, Y.R. (2021). Exploration of silicon functions to integrate with biotic stress tolerance and crop improvement. *Biological Research* **54**, 1–12.

Sudarmadji. (1997). ''Analisa Kadar Air Pada Bahan Makanan''. Liberty Press, Yogyakarta.

Tanaka, T., Shnimizu, M., and Moriwaki, H. (2012). Cancer chemoprevention by carotenoids. *Molecules* **17**, 3202–3242. https://doi.org/10.3390/molecules17033202

Triadiati, T., Muttaqin, M., and Saidah Amalia, N. (2019). Growth, yield, and fruit of melon quality using silica fertilizer. *Agritrop Jurnal Ilmu-Ilmu Pertanian* **24**, 366–374.

Yuan, N., Cai, H., Liu, T., Huang, Q., and Zhang, X. (2019). Adsorptive removal of methylene blue from aqueous solution using coal fly ash-derived mesoporous silica material. *Adsorption Science and Technology* **37**, 333-348.