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# Gaseous, Physicochemical and Microbial Performances of Silicon Foliar Spraying Techniques on Cherry Tomatoes

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**ABSTRACT**

Silicon (Si) foliar spraying techniques (17 mM Si leaf and whole plant) were applied to determine the effect of gaseous, physicochemical and microbial activities on cherry tomatoes. Whole treated tomato plant showed significantly ($p \le 0.05$) the lowest respiration and ethylene production occurred during harvest time and after storage. The lowest fresh weight loss, fungal incidence and microbial activity were observed in whole plant treated tomatoes. In addition, the longest shelf life 24 days and the highest firmness were maintained by whole plant Si treated tomatoes. A higher vitamin C content was found in the whole Si treated tomato plants compared to Si leaf or no treated tomatoes. In addition, in the whole Si treated tomato plant showed the lowest soluble solid content by suppressing the color development. Based on the above results, whole plant Si treatment may be a useful technique to maintain respiration, ethylene production, firmness, shelf life and microbial activity of cherry tomatoes.

## INTRODUCTION

Silicon (Si) is not only a micronutrient for plants, but it also has other beneficial effects on plant's cell-wall growth and development, quality and storability of postharvest fruit, as well as disease prevention. Specific information is needed on nutrient solution to extend the Si application in hydroponic cultivated cucumbers and roses (Savvas, Giotis, Chatzieustratiou, Bakea, & Patakioutas, 2009).

The Si treatment increased the yield and reduced the cracked/damaged tomato fruits (Marodin et al., 2014). Five applications of potassium silicate over 12 days significantly reduced the severity of the tomatoes' powdery mildew (Yanar, Yanar, & Gebologlu, 2011) and increased the plants' resistance to disease, which is associated with active and/or passive mechanisms (Ouellette et al., 2017). Si treated tomato fruits increased the source of Si, thus improved the post-harvest and physicochemical properties (Marodin et al., 2016). Si treatment increased ascorbic acid content and this indicates that Si may be related to the trigger of antioxidant defense system in musk melon fruit (Li et al., 2012). Si elicited polyphenol induced genes and enzymes in the metabolic pathways, thus avocado fruit's increased the ability against stress, and reduced lipid peroxidation, lessened electrolyte leakage and increased catalase activity (Tesfay, Bertling, & Bower, 2011).

Root treatment with Si did not affect soluble solids, titratable acidity, nor fresh and dry fruits' weight of cucumis (Buttaro, Bonasia, Minuto, Serio, & Santamaria, 2009) and it may happen due to non-mobility character of Si nutrient. In addition, no previous study has directly compared cherry tomato fruits' gaseous, physicochemical and microbial activity of Si foliar spraying technique. The low-temperature storage condition (Islam, Mele, Baek, & Kang, 2016) and the Si foliar spraying technique may maintain the tomato fruits gaseous, physicochemical and microbial activities. This research was conducted in cherry tomatoes to demonstrate the performance of Si foliar application techniques on gaseous, physicochemical and microbial activities.

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## MATERIALS AND METHODS

### Tomatoes and Treatments

Cherry tomatoes (*Solanum lycopersicum* cv. 'Unicorn') were grown by deep flow technique (DFT) during summer in 2016 at plastic house of Gangwon Province in Korea. Supplied nutrient contained EC 2.3 dS $m^{-1}$ and pH 5.8-6.2 (Islam, Mele, Baek, & Kang, 2016). The 17 mM silicon (Si) from silicon dioxide (Lee & Yiem, 2000) a 50 mL each was sprayed on only leaf and whole plant once a week for 5 weeks when tomato bearded 3 trusses.

### Storage Condition

The harvest time of gaseous performance, quality parameters and microbial activity was measured from light red color cherry tomatoes in room temperature (20 °C). The harvested cherry tomatoes were stored at 5 °C, by carton box (34 cm × 24 cm × 13 cm), for 25 days with 85 % relative humidity to measure the gaseous performance, quality parameters and microbial activity.

### Gaseous Parameters

Respiration was measured by a portable hand-held Dan-sensor (Check Mate 9900, Denmark) and a Gas Chromatography Shimadzu 2010 (Shimadzu Corporation, Japan) used to measure the ethylene production (Islam, Mele, Baek, & Kang, 2016).

### Physicochemical Parameters

The weight loss of fresh tomatoes was assayed by deducting sample on weights from their previous recorded weights; results are mentioned as percentage of fresh fruit weight loss (Mele, Islam, Baek, & Kang, 2017). Tomato fruit's visual quality was analyzed on the scale of 1 to 5 which denoted as 1 = waste, 2 = bad, 3 = good, marketable, 4 = very good, and 5 = excellent. The five trained panel members were employed to assess the visual quality of the tomatoes (Islam, Mele, Baek, & Kang, 2016). A Rheo meter (Sun Scientific Co. Ltd., Japan) was accustomed to study the fruit firmness. A Chroma Meter CR 400 Model (Konica Minolta Sensing, Inc., Japan) was accustomed to study the tomatoes' skin color and redness of tomatoes were noted as a*/b* values.

For lycopene content a 0.5 g of the homogenized tomato sample (puree) was weighed into 50 mL centrifuge tube. A 5 mL butylated hydroxytoluene (BHT) in acetone solution (0.5 g $L^{-1}$, w/v), a 10 mL hexane and a 5 mL of 95 % ethanol added into 50 mL centrifuge tube. Samples were centrifuged for 15 minutes with 3,528 g at 4 ˚C by Mega17R (Hanil Science Ind. Co. Ltd, Korea). After adding 3 mL deionized water, samples were centrifuged another 5 minutes. Afterwards, for 5 minutes the samples were placed at a room temperature to get hexane (upper) layer. One cm quartz cuvette was used to study the hexane (upper) layer absorbance. The absorbance was 503 nm blanked with hexane solvent using a UV-Spectrophotometer (Shimadzu Corporation, Tokyo, Japan).

Lycopene content$^{*)}$ = Absorbance 503 × 31.2/g tissue

$^{*)}$ Lycopene content (mg $kg^{-1}$ fresh wt.)

A DL 22 Food & Beverage Analyzer (Metter Toledo Ltd., Korea) was used to measure titratable acidity. Vitamin C was measured according to Mele, Islam, Baek, & Kang (2017) with a HPLC system (Waters Associates, Milford, MA, USA), the ZORBAX Eclipse XDB-C18 was used as an analytical column (4.6 cm × 250 mm, 5 µm, agilent, USA), at 265nm. The soluble solids were studied by a Refractometer (Atago U.S.A. Inc., U.S.A.).

### Silicon Content

Si content was analyzed according to the Islam, Mele, Baek, & Kang (2016) method. Inductively coupled plasma (ICP) - atomic emission spectroscopy (AES) (Integra XL Dual, GBC, and Melbourne, Victoria) was used to measure minerals content.

### Bacterial and Fungal Evaluation

Tomatoes were chilled at 4 °C. A 3 $cm^2$ each segmented samples were collected, and sterilized with 10 ml of 0.1 % peptone and shaken. The nutrient agar (NA) was used for bacterial colony culture and the potato dextrose agar (PDA) was applied to grow the fungal spores. Cultured plates were incubated for 48 h at 35 °C (Bacteria) or for 5 days at 25 °C (Fungi). Bacteria and fungi were identified based on colony characterization and microscopic methods.

### Statistical Analysis

The SPSS V. 16 (SPSS Inc., Chicago, USA) operated to analyze the data. Moreover, the data significant differences were scrutinized by Duncan's multiple range test (DMRT) of the one-way analysis of variance (ANOVA).

## RESULTS AND DISCUSSION

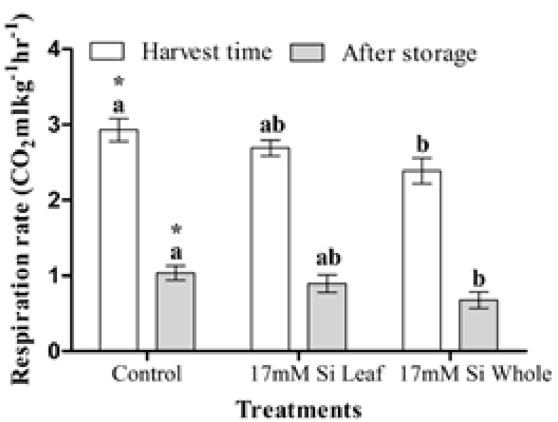
### Gaseous Performance

The Si foliar spray reduced the respiration rate at harvest time, showing a greater effect on 17 mM whole tomato plants than on 17 mM leaves (Fig. 1). The respiration rate decreased due to the tomatoes' improved membrane integrity (Islam, Mele, Baek, & Kang, 2016). Si covered fruits stomata, and thus reduced respiration in banana (Asmar et al., 2015). The respiration rate also decreased during the storage period, which may have happened due to the low storage temperature and the fruits may have maintained their Si deposits in epidermal cells, thus, inhibited fruit softening. Postharvest application of Si suppressed the respiration in avocadoes (Kaluwa, Bertling, Bower, & Tesfay, 2010) and in apple (Tarabih, El-Metwally, & El-Eryan, 2014). The increasing respiration rate after storage of the control fruit could be related to fungal infection, or tissue damage. As respiration is a physiological process associated with postharvest tomato fruit deterioration, a lower respiration rate is beneficial to achieve long storage time.

This experiment was conducted on harvested light red maturity-stage tomatoes. Whole tomato plants treated with Si foliar spray had a low level of ethylene production at harvest time (Fig. 1). Improved cell-wall thickness of tomatoes decreased ethylene production (Islam, Mele, Baek, & Kang, 2016). In addition, using the Si foliar spray on whole tomato plants suppressed most of ethylene production and it may happen due to anti-senescence activity; therefore, the fruits got more ripening time. Postharvest Si-treated avocadoes showed decreased ethylene production at different storage temperatures (Kaluwa, Bertling, Bower, & Tesfay, 2010). Storage period of ethylene production was lower compared to harvest time due to reduced respiration. Si-treated tomatoes that have lower ethylene production; the fruits can be stored for a longer period.

### Physicochemical Performance

Reducing fresh weight loss in tomato fruits helps to maintain fruit quality during storage. As the storage periods onward, the tomatoes fresh weight loss elevated and the quality decreased, despite the controlled humidity. Tomatoes fresh weight loss mainly happened because of water/moisture loss in the fruit caused by respiration and transpiration (Islam, Mele, Baek, & Kang, 2016). Si treatment increased Si layer in fruit stomata thus weight loss was reduced in banana (Asmar et al., 2015) and Si treatment reduced weight loss by maintaining avocado's moisturation (Tesfay, Bertling, & Bower, 2011). Whole plants treated with Si foliar spray had the lowest fresh weight loss (Fig. 2). We agree with Ayvaz, Santos, & Rodriguez-Saona (2016) that the Si developed cuticle to make a barrier to protect moisture loss. In addition, Epstein (2009) also reported that Si reduced the weight loss by modifying cell membranes.



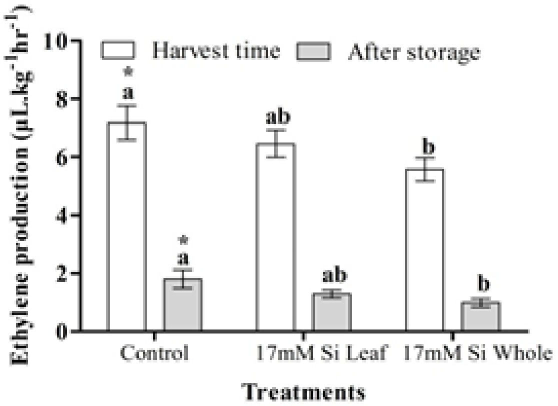




**Fig. 1.** Cherry tomato fruits respiration and ethylene production rate at harvest time (0 day at 20 ˚C) and after storage time (25$^{th}$ day at 5 ˚C); * = significant at $p \leq 0.05$ of DMRT (n = 5 ± standard error)

The control, leaf, and whole plant foliar sprays had marketable visual quality (≥ 3) for 19, 21, and 24 days, respectively. The whole plants treated with Si foliar spray had better visual quality and storability than the plants with only Si-treated leaves (Fig. 2). This is in agreement with Islam, Mele, Baek, & Kang (2016) that suppressed respiration and ethylene production maintains the tomatoes' marketable visual quality and prolongs the shelf life. Therefore, this indicates that Si foliar spray has a beneficial effect on visual quality of tomatoes by reducing the physiological metabolism during storage. Si improved the shelf life of Valerianella locusta leaves by delaying senescence and slowing down chlorophyll degradation (Gottardi et al., 2012). Si treatment inhibits decay which was associated with improved resistance in oxidative stress in musk melon (Li et al., 2012). Tomato fruit softening starts with the increase in respiration during the storage period. Si foliar spray on whole tomato plants can help maintain tomato's quality and shelf life. Fungal incidence was the lowest in whole plants treated tomato (data did not show).

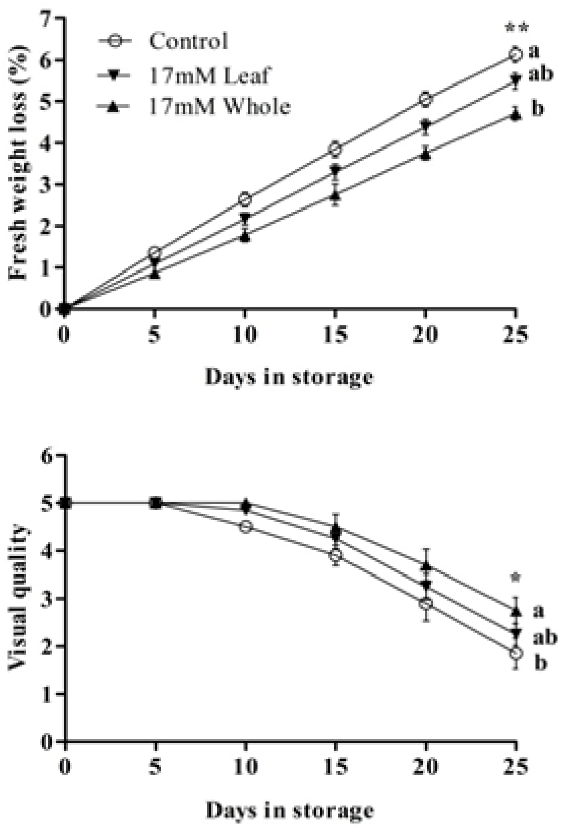



**Fig. 2.** Changes of fresh weight loss (%) and visual quality of tomatoes at 5 ˚C storage temperature until 25th day. Fruit visual quality was analyzed on the scale of 1 to 5 which denoted as 1 = waste, 2 = bad, 3 = good, marketable, 4 = very good, and 5 = excellent at 5 ˚C storage; *,** = significant at $p \leq 0.05, 0.01$ of DMRT (n=10 ± standard error)

Extended firmness is desirable for a long-time storage of tomato fruits. Whole plant treatment had increased firmness at harvest time (Table 1). Similarly, Si enhanced the firmness of apple (Tarabih, El-Metwally, & El-Eryan, 2014) and tomato fruits (Marodin et al., 2016) at harvest time and retained them during storage. Fruit softening mainly occurs due to the cell wall degradation of the middle lamella of cortical parenchyma cells (Yahia & Woolf, 2011), and Si foliar spray on whole plant treatment retain tomatoes firmness which may happen due to the slowing down of the cell-wall degradation. Si may crosslink in cell wall of pectin molecules, and the cell wall structure is stabilized by metal bindings in the pectin network. Cell wall compactness/thickness and shelf life increase, as result tomatoes retain their firmness longer (Islam, Mele, Baek, & Kang, 2016). Si improves membrane integrity in avocado (Tesfay, Bertling, & Bower, 2011). As firmness and ripeness are closely associated, therefore after storage the firmness decreases because of over ripeness and more color development.

Color is an important consideration when buyers, sellers, and consumers choose tomatoes. At harvest time, there was no significant difference in color of the different treatments, even as we picked up the similar color (maturity) stage (light red) for this research; however, there were color differences that appeared during the storage period. The whole tomato plants treated with the Si foliar spray had reduced color development, followed by the leaf treatment and control group (Table 1), because the respiration and ethylene production rates affect the ripening changes during storage. As color development indicates ripeness, Si foliar spray as a whole plant treatment may reduce the rapid color development in fruits during storage, which can prolong the shelf life. Si delayed ripening and maintained quality in apple fruits (Tarabih, El-Metwally, & El-Eryan, 2014).

The lycopene content is affected by the tomato fruit ripeness (maturity stages). Si foliar spray as a whole plant treatment significantly affected the lycopene content after storage. The lycopene content has a difference among the maturity stages of gac fruits (Bhumsaidon & Chamchong, 2016). The control of tomato fruits showed the most ripeness and most lycopene content after storage (Table 1). Si foliar spray as a whole plant treatment resulted in the lowest lycopene content due to suppressive color development by reducing ethylene production.

**Table 1.** Cherry tomato fruits' firmness, color, and lycopene content at harvest time (0 day at 20 ˚C) and after storage (25th day at 5 ˚C)

| Treatments | Firmness (N) | | Color (a*/b*) | | Lycopene (mg kg$^{-1}$ FW) | |
|---|---|---|---|---|---|---|
| | Harvest | 5 ˚C | Harvest | 5 ˚C | Harvest | 5 ˚C |
| Control | 14.76b$^{z}$ | 9.20b | 0.40a | 0.59a | 93.71a | 156.01a |
| 17mM leaf | 16.31ab | 11.64ab | 0.39a | 0.55ab | 92.21a | 153.57ab |
| 17mM whole | 17.34a | 12.26a | 0.39a | 0.52b | 91.32a | 134.61b |
| P value | * | * | NS | * | NS | * |

Remarks: $^{Z}$ = Mean separation of columns by DMRT (n = 10 ± standard error); NS, * = not significant, significant at p ≤ 0.05; FW = fresh weight

**Table 2.** Cherry tomato fruits' titratable acidity, vitamin C, and soluble solids at harvest time (0 day at 20 ˚C) and after storage (25th day at 5 ˚C)

| Treatments | Titratable acidity (% citric acid) | | Vitamin C (mg.100 g$^{-1}$ FW) | | Soluble solids (˚Brix) | |
|---|---|---|---|---|---|---|
| | Harvest | 5 ˚C | Harvest | 5 ˚C | Harvest | 5 ˚C |
| Control | 0.54a$^{z}$ | 0.42b | 14.35b | 8.63b | 7.29a | 8.18a |
| 17mM leaf | 0.55a | 0.47ab | 15.60ab | 10.68ab | 7.16ab | 7.68ab |
| 17mM whole | 0.56a | 0.50a | 17.43a | 12.05a | 6.73b | 7.10b |
| P value | NS | * | *** | *** | * | * |

Remarks: $^{Z}$ = Mean separation of columns by DMRT (n=10 ± standard error); NS, *, *** = not significant, significant at p ≤ 0.05 and 0.001, accordingly; FW = fresh weight

The whole plants treated with Si foliar spraying yielded tomatoes with the highest titratable acidity after storage, which might happen due to improved membrane integrity. Si-treated apples had shown higher acidity due to less metabolic activity (Tarabih, El-Metwally, & El-Eryan, 2014). The tomato fruit from the whole plants treated with Si foliar spray had a higher titratable acidity after storage compared to the control (Table 2), which could be attributed to low respiration rate and low ethylene production.

At harvest time and after storage, the control had the lowest vitamin C content, whereas the whole plants treated with Si foliar spray had the highest vitamin C content (Table 2). At harvest time, Si helped to enhance the vitamin C content (Marodin et al., 2016) and it might happen due to deposition of Si in the cell walls of fruits. Increased vitamin C content in fruits from whole plants treated with Si foliar spray might depend on less ethylene production during storage. All groups of tomatoes lost vitamin C after storage but the whole plants treated with Si foliar spray lost the least amount.

The whole plants treated with Si foliar spray had the lowest soluble solids, and the control had the highest soluble solids at harvest time and after storage (Table 2). The silicon-treated plants had less-soluble solid content in apple (Tarabih, El-Metwally, & El-Eryan, 2014) at harvest time. Si-treated tomatoes had increasing soluble solids during the storage period because the tomatoes turned to red due to physicochemical changes of disaccharides to monosaccharide. The whole plants treated with Si foliar spray yielded tomatoes with the lowest soluble solids after storage due to lower ethylene production rates.

### Silicon Content

As Si is strongly associated with the assimilation and/or physiological functions of plants, it improves the quality and shelf life of cherry tomatoes by reducing physicochemical changes. The fruits and leaves from the whole plants treated with Si foliar spray had the highest Si content due to a greater assimilation of Si in the fruits and leaves (Table 3). However, Si foliar spray on leaves did not significantly increase the Si content in the fruit because it could not easily move from the leaves to the fruits. As Si has low mobility in plants (Pilon, Soratto, & Moreno, 2013), treating whole plants with Si would be better to improve quality and shelf life of tomatoes. Si-treated strawberry had proper transporters to uptake Si content (Ouellette et al., 2017). As the tomato plants accumulated more Si, the fruit firmness and shelf life increased.

**Table 3.** Silicon (Si) content in fruit and leaf of cherry tomato that sprayed to 17 mM Si solutions as a leaf and whole plant

| Treatments | Si (mg kg-1 DW) | |
|---|---|---|
| | Fruit | Leaf |
| Control | 272.20b[z] | 300.71b |
| 17mM leaf | 278.17b | 313.91a |
| 17mM whole | 293.10a | 316.25a |
| P value | * | * |

Remarks: [Z] = Mean separation of columns by DMRT (n = 5 ± standard error); * = significant at p ≤ 0.05; DW = dry weight

**Table 4.** Count of the microbial activity associated with cherry tomato fruits at harvest time (0 day at 20 °C) and after storage (25th day at 5˚C)

| Treatments | Bacteria (x 10 colony $ml^{-1}$) | | Fungi (x 10 spores $ml^{-1}$) | |
|---|---|---|---|---|
| | Harvest | 5 ˚C | Harvest | 5 ˚C |
| Control | 213.00a[z] | 224.33a | 6.33a | 8.33a |
| 17mM leaf | 206.67ab | 220.33ab | 5.33ab | 7.33ab |
| 17mM whole | 197.33b | 209.33b | 4.67b | 5.67b |
| P value | * | ** | * | * |

Remarks: [Z] = Mean separation of columns by DMRT (n = 10 ± standard error); NS, * = not significant, significant at p ≤ 0.05; FW = fresh weight

**Bacterial and Fungal Evaluation**

The lowest bacterial colony and fungal spores count were showed in the whole plant treated tomatoes both harvest time and after storage (Table 4). The fungal density was lower than bacteria in either harvest time or after storage. Si suppressed zucchinis' powdery mildew (Savvas, Giotis, Chatzieustratiou, Bakea, & Patakioutas, 2009), *Cucumis melo* powdery mildew (Buttaro, Bonasia, Minuto, Serio, & Santamaria, 2009), tomatoes' powdery mildew (Yanar, Yanar, & Gebologlu, 2011), jujubes' postharvest *Alternaria* rot (Yan et al., 2011). So, whole plant treatment is effective to suppress the bacterial and fungal activities.

## CONCLUSION AND SUGGESTION

Silicon (Si) foliar spraying method (17 mM Si leaf and whole plant) was used to find out the effects on gaseous, physicochemical and microbial activities of cherry tomatoes. Si foliar spraying as a whole plant treatment reduced the respiration and ethylene production rates. Whole plant treatment increased firmness at harvest time and (the firmness) retained after storage. Lower fresh weight loss was observed in whole plant treatment compared to the control or untreated plant. The highest vitamin C, longest shelf life and the lowest microbial activity were found in whole plant treated tomatoes. Moreover, Si-foliar spraying as a whole plant treatment increased the Si content in fruits and leaves. Therefore, this treatment had more effects on cherry tomato's respiration, ethylene production, firmness, shelf life, bacterial and fungal activity that were beneficial compared to the control.

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