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Evaluating Silicon Foliar Sprays as a Strategy to Improve Postproduction Performance of Potted Basil (Ocimum basilicum L.)

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Abstract

The objective of the study was to evaluate foliar silicon (Si) applications for effects on the growth and performance of container-grown basil during production and resistance to postproduction wilt in retail. Basil (*Ocimum basilicum* 'Genovese' L.) seedling plugs were transplanted into 10-cm diameter plastic containers with peat-based substrate and grown for 42 d in a polycarbonate greenhouse. Plants were irrigated with fertilizer solution consisting of a 17.0 nitrogen (N)-1.3 phosphorus-14.1 potassium water-soluble fertilizer dissolved in tap water at 150 $mg \cdot L^{-1}$ N. Foliar sprays containing sodium silicate at 0, 50, 100, 200, and 400 $mg \cdot L^{-1}$ Si mixed with deionized water were applied every 7 d. Spray solutions also contained a non-ionic surfactant at 0. 3 $mL \cdot L^{-1}$, and a 100% deionized water spray treatment was included as a no-surfactant control. Data collection consisted of leaf SPAD chlorophyll content, shoot height, shoot fresh and dry mass, and Si concentration in dried shoot tissue for four replicates per treatment. Four remaining replicates per treatment continued for a simulated retail phase, during which all replicate containers were irrigated to saturation with clear (no fertilizer) water and placed an indoor environment. Plants were checked twice daily for visible wilt, and number of days until wilting was recorded. To minimize the variability in daily evapotranspiration caused by fluctuations in the retail environment and temperature, days to wilt was standardized by dividing the total water loss per replicate determined using gravimetric methods by the average daily water loss from evaporation pans. The 0 $mg \cdot L^{-1}$ Si and no-surfactant control treatments were combined for greater statistical power as there were no differences in their effects. Single degree-of-freedom contrasts were used to compare the effects of each Si treatment to the non-silicon control. Leaf SPAD chlorophyll content was greater for each Si treatment compared to the control. Shoot dry mass was also greater when Si was applied at 400 $mg \cdot L^{-1}$, but there was no effect on shoot fresh mass or height. Shoot Si content increased with spray concentration, ranging from 466 to 882 $\mu g \cdot g^{-1}$ of dry tissue for 0 and 400 $mg \cdot L^{-1}$ Si treatments, respectively. Foliar sprays of 200 and 400 $mg \cdot L^{-1}$ Si increased the number of days until wilting by 2.2 and 2.5 d, respectively. Based on these results, foliar Si sprays applied during production may be a practical and effective strategy for growers to increase resistance to wilting during retail for basil, with minimal effects on plant growth and quality.

CHAPTER 1: BACKGROUND AND LITERATURE REVIEW

Sweet basil (*Ocimum basilicum* L.) is among one of the most popular items in the market of potted culinary herbs. High-quality fresh potted herbs are often grown in greenhouses, since growers have the luxury of controlling fertilizer and irrigation practices, temperature, light levels, and other cultural factors to maximize quality and yield. However, growers have little control over environmental conditions at the end of production, and plant quality tends to decline rapidly during postproduction shipping and retail (Samarakoon et al, 2017). High plant performance in postproduction is emphasized by growers as in some scenarios, growers operate under a pay-by-scan system where they are only paid for plants that are purchased by customers.

Basil is particularly sensitive to low-temperature chilling injury during shipping and postproduction conditions. In addition, basil is often stored and shipped in coolers with other crops that require lower temperatures, such as other leafy greens and herbs. Lange and Cameron (1994) reported cool temperatures lasting only 1 to 3 d, a common duration for shipping, was enough to provide acute chilling stress and damage. Basil is sometimes shipped and stored separately at warmer temperatures, but this has an added consequence of speeding up the rate of decay and shortening shelf-life.

Postproduction handling and packaging can impose physical stresses on plant tissues. For example, basil has large, cupped leaves that are highly susceptible to mechanical or physical damage, including leaf puncturing, smashing, tearing, and bruising. Physical damage not only reduces quality but can also lead to entry of disease, commonly *Botrytis cinerea* (Samarakoon et al, 2017).

Potted herbs sold in retail supermarkets often receive their last irrigation in the greenhouse at the end of production and before being shipped. Container-grown edibles are typically not irrigated during shipping and in retail and can wilt within a week of leaving the greenhouse production environment. Even slight wilting in potted herbs can deter consumers, and plants reaching the permanent wilting point cause growers to lose profit.

Silicon (Si) is a beneficial element that has been shown to positively impact plant growth and performance for certain species when taken up into plant tissues. Silicon is abundant in field mineral soils but is not typically supplied during the production of container-grown greenhouse crops. Beneficial effects of supplying supplemental Si in the fertilizer program has been reported for both floriculture crops and horticulture crops, with major benefits including increased suppression of foliar diseases and greater resistance to plant wilting and water stress, and other physiological disorders (Franz, et al. 2010) For some crops, such as melon (*Cucumis melon L*.), increased Si concentrations in leaf tissues were correlated with increased leaf chlorophyll concentrations (i.e., darker green foliage) (Kamenidou et al, 2008). Kamenidou et al (2008) found that these beneficial changes were present when supplemental Si was applied to plants as rice husk ash incorporated into the growing substrate, potassium silicate substrate drenches, hydrous potassium silicate incorporated in the rootzone of the substrate, and sodium silicate foliar sprays (2008).

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CHAPTER 2: EVALUATING SILICON FOLIAR SPRAYS FOR EFFECTS ON PLANT GROWTH AND POSTPRODUCTION PERFORMANCE WITH CONTAINER-GROWN BASIL

Introduction

Sweet basil (*Ocimum basilicum* L.) is a culinary herb being increasingly grown as a greenhouse container crop for sale in retail supermarkets. However, greenhouse-grown culinary herbs are produced in relatively small containers and rarely irrigated after production and the point-of-sale (POS), leading to rapid wilting for the consumer. In addition, basil is sensitive to chilling injury when postproduction and shipping temperatures drop below 55°F (Lopez, 2018), which is common. Wilting and chilling injury are common postproduction issues negatively impacting the quality and sales of container-grown basil.

Silicon (Si) is a major constituent of many mineral field soils and often accumulates in the tissues of field-grown crop species (Marschner, 1995). Many floricultural and edible crops are benefited by Si. For example, Marschner (1995) reported the supply and accumulation of Si in plant tissues of agronomic crop species has a role in alleviating a range of abiotic stresses caused by drought and extreme temperature and light conditions. In addition, the role of Si in reducing plant susceptibility to foliar and root rot diseases is well-document for field and greenhouse-grown crops (Datnoff e al., 2008).

Supplemental Si applied as either a foliar spray or substrate drench during greenhouse production has been shown to increase plant resistance to wilting during postproduction and in retail for container-grown floriculture crops (Kamenidou et al, 2008; Mattson and Leatherwood, 2010). Effects of Si can vary with crop species and application rates. Kamenidou (2008) found that high rates of supplemental Si caused distortion of leaves and flowers for sunflower. Given the potential benefits with floriculture crops, the authors believe there is potential for Si applications during production to improve resistance to wilting and chilling injury during postproduction for container-grown basil.

The objective of this research was to evaluate foliar applications of silicon (Si) for effects on the growth and performance of container-grown basil during production as well as basil sensitivity to wilt and chilling injury in simulated consumer retail conditions. Basil seedlings were transplanted into plastic containers and grown in a controlled-environment greenhouse for 28 d, where plants received foliar spray applications with silicon every 7 d at 0, 50, 100, 200, and 400 $mg{\cdot}L^{-1}$ Si using reagent-grade Si mixed with de-ionized water. Leaf SPAD chlorophyll index, canopy height and width, shoot fresh and dry weight were measured on one group of plants per treatment at 28 d. Additional plants were then moved to a postproduction testing facility, where the number of days until visible plant wilt and the percentage of leaves per plant showing chilling injury when stored at 4 °C for 7 d were measured. It is hypothesized that foliar applications of Si would increase the number of days until plant wilting and decrease the percentage of leaves with chilling injury during the consumer retail phase, with minimal effects on plant growth during production.

Methods and materials

A single-factor experiment was conducted to evaluate foliar silicon spray applications during for effects on plant growth, sensitivity to chilling injury, and resistance to wilting for container-grown basil. The experiment took place in a polycarbonate and controlled-environment greenhouse located at the University of Arkansas in Fayetteville, AR (36.0822 °N, 94.1719 °W).

Average daily temperature and daily light integral during the project was (mean ± standard deviation) 22.7 ± 1.1 °C and 19.3 ± 7.2 $mol \cdot m^{-2} \cdot d^{-1}$, respectively.

Pelleted seed of ‘Compact Genovese’ basil were sown into 128-cell plug tray at one pellet per cell and germinated in soilless peat-based substrate (ProMix BX; PremierTech, Deslon, Quebec, Canada) on a greenhouse bench. At the 2-true leaf stage, seedlings were thinned to one plant per plug and transplanted into 10-cm standard pots (Poppelmann Plastics, Claremont, North Carolina) containing ProMix BX at two plugs per pot. For the duration of the experiment, plants were fertigated as needed with a commercial 17-3-17 Peters Peat-Lite Special® (Everiss, Geldermalsen, The Netherlands) water-soluble fertilizer complete with all plant essential elements mixed at 150 $mg \cdot L^{-1}$ nitrogen (N) in tap water with an electrical conductivity of <0.3 $mS \cdot cm^{-1}$ and <60 $mg \cdot L^{-1}$ bicarbonate alkalinity.

The experiment started on 1 May 2020 with the first Si foliar spray treatment, made 3 d after transplant. Foliar spray treatments were then made every 7 d, and the project lasted a total of 45 d. Treatments consisted of spraying solution containing 0, 50, 100, 200, and 400 $mg \cdot L^{-1}$ Si mixed with reagent-grade sodium silicate in de-ionized water. Solutions also contained a nonionic surfactant (Aquatrols, Paulsboro, NJ) at 0.3 $mL \cdot L^{-1}$ to reduce water tension on leaf surfaces. A 0 $mg \cdot L^{-1}$ Si and no surfactant spray (100% de-ionized water) was also applied as an additional control treatment. Each spray application occurred between 1800 and 2000 HR, and plants were sprayed to runoff.

The experiment was a single-factor experiment with six treatment levels (five Si spray concentrations plus a 100% de-ionized water control) arranged using a randomized complete block design with four blocks. Each containerized basil plant was one replicate, with three replicates per treatment per block. At the end of greenhouse production on 12 June 2020, four replicates per treatment were destructively sampled for measuring plant growth and quality. The remaining replicates continued for postproduction evaluations, where four replicates per treatment were evaluated for chilling injury and four separate replicates per treatment were evaluated for resistance to wilting.

Plant growth and quality. At the end of production, leaf SPAD chlorophyll content was measured using a Minolta leaf SPAD chlorophyll index meter(), where each replicate measurement was the average of six measurements taken on randomly selected leaves per plant. Canopy height was measured from the substrate surface to the tallest shoot tip, and canopy width from the widest diameter of the plant. Shoots were cut at the substrate surface, weighed for fresh mass determination, and then placed in a drying oven for 3 d. After the 3 d, the plants were reweighed for dry mass determination. Dry shoot samples per replicate were analyzed for Si concentration (University of Florida Soils Testing Laboratory, Gainesville, FL).

Sensitivity to chilling injury. Four replicates per treatment were irrigated tocontainer-capacity and placed in a walk-in cooler at 4°C for 7 d. A large pan of water was placed in the cooler to keep relative humidity high. Chilling damage for this experiment was defined as the presence of any necrosis, chlorosis or discoloration, or water-soaked appearance on the surface of the basil leaf. At the end of the 7 d, the number of damaged leaves/plant and the total number of leaves/plants were counted.

Days to wilting. Days to wilting was determined for four replicates per treatment using a modified postproduction method described by Million et al. (2002). All replicates were irrigated to container-capacity, weighed, and moved to a postproduction facility with a 12-hour photoperiod and temperature ranging from 20-25° C. Plants were checked daily for wilting between 1000 and 1100 hr. Date and replicate pot weight were recorded at visible wilt for each replicate. Total water loss was calculated by subtracting replicate weight at wilt from weight at container capacity for each replicate. Daily evaporation was also measured using evaporation pans placed in the crop. To minimize the variability in daily evapotranspiration caused by fluctuations in the retail environment and temperature, days to wilt was standardized by dividing the total water loss per replicate determined using gravimetric methods by the average daily water loss from evaporation pans. After wilting, each replicate was rehydrated for fresh mass and dry mass determination at the end of the postproduction period using methods previously described.

Data and statistical analysis. The effects of foliar silicon spray applications during production on plant growth, sensitivity to chilling injury, and days to wilting for sweet basil was evaluated using analysis of variance (ANOVA) with PROC GLIMMIX in SAS 9.4 (SAS Institute, Cary, NC). The 0 mg·L^{-1} Si and no-surfactant control treatments were combined for greater statistical power as there were no differences in their effects. To evaluate treatment effects, single degree-of-freedom contrasts were used to compare the effects of each Si treatment to the non-silicon control at α=0.05.

Results and Discussion

Plant Growth and Quality. Weekly Si foliar spray treatments ranging from 50 mg·L^{-1} Si to 400 mg·L^{-1} Si increased leaf SPAD chlorophyll content at harvest compared to the control treatment (Fig. 1A, Table 1). However, all basil plants had dark green foliage and appeared healthy at harvest regardless of Si spray treatment, indicated by leaf SPAD values >30. Previous authors have shown that increased supply and uptake of Si promotes the distribution of micronutrients in leaf tissues, particularly iron and manganese, which are known elements involved in structure and functioning of chlorophyll (Marschner, 1995).

Foliar Si applications at 400 $mg{\cdot}L^{-1}$ Si significantly increased shoot dry mass at harvest compared to the control (Fig. 1B, Table 1). Previous studies have shown that increasing supplied Si to plants can increase plant growth for certain species (Kamiendou et al., 2010; Voogt and Sonneveld, 2001), particularly crop species classified as “accumulators” of Si. It was beyond the scope of this study to determine whether basil is an “accumulator” of Si, and because increased dry mass occurred only at the highest Si treatment and was slightly below the significance level (P=0.0488, Table 1), further experimentation is needed to validate these results.

Increasing Si concentration in the applied foliar spray treatment increased Si concentrations measured in basil leaf tissue at harvest (Figure 1C and Table 1). Compared to the non-silicon control (466.3 $\mu g{\cdot}g^{-1}$ Si in dry leaf tissue), leaf Si concentrations were greater for basil sprayed with 100, 200, and 400 $mg{\cdot}L^{-1}$ Si with final leaf concentrations of 593.2, 772.3, and 882.7 $\mu g{\cdot}g^{-1}$ of dry tissue, respectively. These results are similar to observations by Kamenidou et al. (2002), who found applying sodium silicate foliar sprays every 7 d at 150 $mg{\cdot}L^{-1}$ Si increased leaf Si concentrations in container-grown zinnia (*Zinnia elegans* Jacq.) and sunflower (*Helianthus annus* L.). Supplementing Si in the fertilizer solution can also increase leaf Si concentrations via increased Si uptake by roots for a range of edible and floriculture crop species including cucumber (*Cucumis sativus* L.), strawberry (*Fragaria ananassa* L.), and rose (*Rosa sp.* L.) as shown by Voogt and Sonneveld (2001).

Sensitivity to Chilling. Silicon treatment had no effects on chilling injury, and all plants experienced high amounts of injury (>50% of leaves showing injury) rapidly and within several days of being stored at 4 °C (data not shown). Basil is susceptible to postproduction chilling injury at temperatures below 12 ºC (Lopez, 2018), and these results suggest that supplemental Si foliar sprays during production and an increase of tissue Si concentrations would not reduce chilling damage at 4 °C.

Days to Wilting. The 200 mg·L^{-1} Si and 400 mg·L^{-1} Si treatments significantly increased days to wilt during postproduction by 2.2 and 2.5 d, respectively (Fig. 2, Table 1). Basil sprayed with 200 mg·L^{-1} Si and 400 mg·L^{-1} Si wilted after 13.8 and 14.1 d, respectively, compared to 11.6 d for the non-silicon controls. Changes in plant fresh and dry mass during this period were insignificant (*data not shown*). Past research with floriculture container crop species has also shown that supplemental Si applications can increase plant resistance to wilting during postproduction and in retail (Kamenidou et al. 2009), where Si was reported to increase leaf cuticle thickness and decrease transpiration rates.

Conclusions

The results of the experiment show that while foliar Si sprays did not prevent chilling injury in potted basil, they are an effective way to increase leaf tissue Si concentration and also increase the days to wilt for potted basil during postproduction. Although foliar Si applications were evaluated in this study, there are other documented methods of increasing tissue Si concentrations including the incorporation of rice hulls and rice hull ash into the growing substrate, substrate incorporation of hydrous potassium silicate, and applying potassium silicate substrate drenches (Kamiendou et al. 2008). In commercial production, container-grown basil is irrigated at the end of production but typically not in the retail environment, and therefore wilting during retail is a common plant quality issue negatively impacting consumer sales. If container crops are not sold within the first week in retail, plant quality and the likelihood of sales after that point rapidly declines (personal communication Ryan Dickson). The increase in the days to wilt for basil treated with supplemental Si may be the most compelling argument for growers to implement supplemental Si into their production periods. The greater resistance to wilting from Si applications can increase the quality and shelf-life of container-grown basil in retail, increasing the potential for consumer sales.

Table 1. Effects of weekly silicon (Si) foliar sprays during production (50, 100, 200, 400 $mg \cdot L^{-1}$ Si) on the number of days until wilting during postproduction, leaf SPAD chlorophyll index, shoot dry mass at harvest, and shoot Si concentration at harvest for potted basil. Statistical parameters represent single degree-of-freedom (df) contrasts between each weekly Si spray treatment and the non-Si control.

Foliar Si treatment ($mg \cdot L^{-1}$ Si)	df	F-value	P-value
		Number of days until wilting	
50	1	2.22	0.1569
100	1	4.19	0.0586
200	1	4.60	0.0488
400	1	5.81	0.0292
		Leaf SPAD chlorophyll index	
50	1	26.68	0.0001
100	1	17.05	0.0009
200	1	19.52	0.0005
400	1	15.14	0.0014
		Shoot dry mass (g)	
50	1	1.66	0.2177
100	1	0.68	0.4239
200	1	2.36	0.1451
400	1	4.60	0.0488
		Shoot Si concentration ($mg \cdot L^{-1}$)	
50	1	0.60	0.4514
100	1	13.59	0.0022
200	1	78.93	<0.0001
400	1	146.16	<0.0001

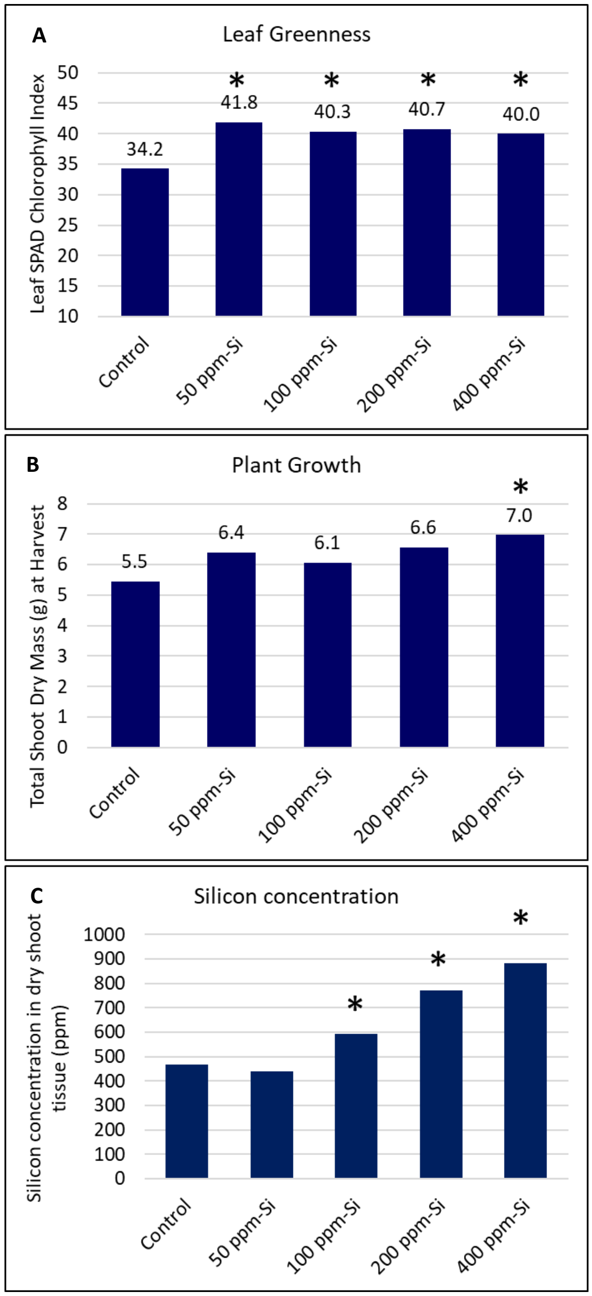

Figure 1. Silicon (Si) spray effects on leaf SPAD chlorophyll content (A), shoot dry mass (B), and Silicon concentration in leaf tissue (C) at the end of production. Asterisks indicate a significant difference compared to the non-Si control (alpha = 0.05).

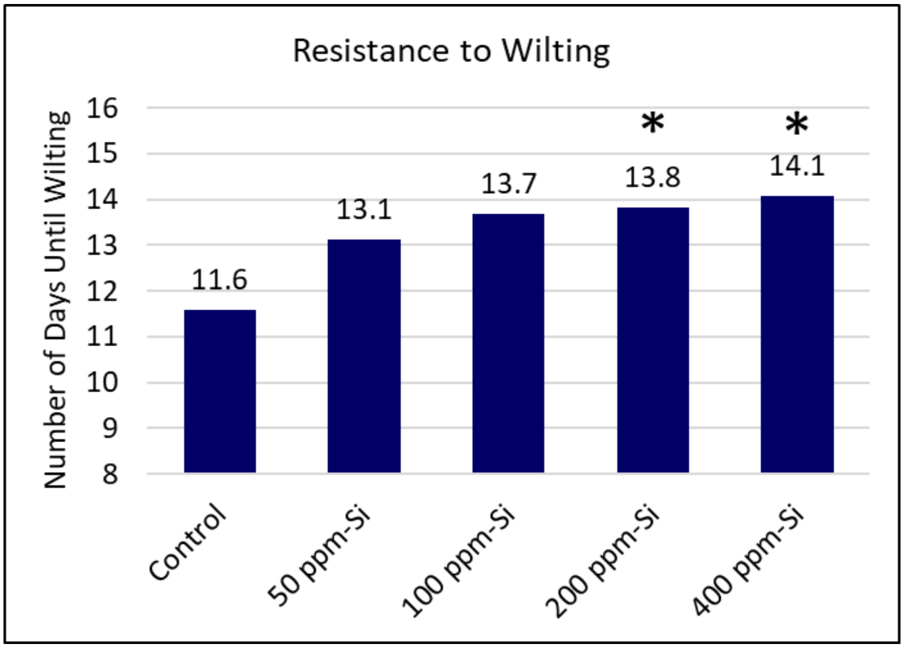

Figure 2. Silicon (Si) spray effects on days until wilt for container-grown basil. Asterisks indicate a significant difference compared to the non-Si control (alpha = 0.05).

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CHAPTER 3: CONCLUSION

Basil and other potted herbs are becoming increasingly popular in retail settings. Basil is susceptible to chilling injury and mechanical damage during postproduction storage and shipping and wilting of potted herbs is also a common issue in retail settings. Poor plant performance as a result of these issues results in decreased sales which has a negative impact on profitability for growers. In addition, in some scenarios, growers are only paid for plants that are purchased by consumers—otherwise known as “pay-by-scan”—emphasizing the need to maximize postproduction quality.

All Supplemental Si foliar sprays treatments in this study increased leaf SPAD for basil and the 100, 200, and 400 $mg{\cdot}L^{-1}$ treatments also increased the Si concentration in basil leaf tissue, but none of Si spray treatments increased the resistance to chilling injury. Additionally, there was some evidence that 400 $mg{\cdot}L^{-1}$ increased dry mass, but the authors believe there would need to be further testing to confirm this finding as the physiological mechanisms behind dry mass gains is unclear. The most impactful result from this experiment was that the 200 and 400 $mg{\cdot}L^{-1}$ Si treatment sprays increased the days to wilt for basil by 2 d compared to the control.

Based on the results of this study, foliar Si applications were effective at increasing SPAD and increasing resistance to wilting in a simulated retail environment. Weekly foliar sprays of Si during production would be a practical and effective grower strategy to increase the performance of potted herbs during postproduction, increasing the likelihood of customer sales and satisfaction.