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Potassium Silicate Drenches Increase Leaf Silicon Content and Affect Morphological Traits of Several Floriculture Crops Grown in a Peat-based Substrate

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***Abstract*. Silicon (Si) is a beneficial nutrient that improves biotic and abiotic stress tolerance of several crop species. Previous Si research with container-grown floriculture crops has either focused on a limited number of species or has been conducted in hydroponics using purified water, but little research has been conducted with plants grown in soilless substrates. The objective of this experiment was to examine whether weekly potassium silicate drenches would alter leaf Si concentration or affect morphological traits of several floriculture species grown in soilless substrate. Rooted liners of 21 cultivars were transplanted into a peat-based substrate. Control plants received no Si supplementation, whereas treated plants were given weekly drenches of 100 mg·L^{-1} Si from potassium silicate for 10 weeks. Leaf Si concentration of control plants ranged from 211 mg·L^{-1} for petunia (*Petunia ×hybrida* Vilm. 'Cascadias Cherry Spark') to 2606 mg·L^{-1} for argyranthemum [*Argyranthemum frutescens* (L.) Sch. Bip. 'Sunlight']. Si supplementation increased leaf Si concentration of 11 cultivars; leaf Si concentrations for these supplemented plants were 13% to 145% greater than control plants. Among the taxa studied, Si supplementation response was variable; Si either increased or decreased height, diameter, fresh weight, dry weight, flower diameter, and leaf thickness. For three cultivars, these morphological traits were apparently unaffected by Si supplementation despite accumulating Si. Similarly, significant morphological differences were observed in four cultivars that did not accumulate Si. Eight cultivars both accumulated Si and showed significant morphological differences. Our results demonstrate that many common floriculture species grown in a peat-based substrate do take up Si and that SI may have an effect on plant development. Consequently, more work is needed to determine the appropriate rate of Si supplementation and to examine additional species.**

Silicon (Si) is not considered an essential plant nutrient; however, several plant species demonstrate improved disease resistance, abiotic stress tolerance, and altered morphological traits when Si is present (Epstein, 1999). Soil contains, on average, 31% Si from silica (SiO_2) (Epstein, 1999). Plants absorb Si in the form of soluble silicic acid, which is found in soils at concentrations ranging from 0.1 to 0.6 mM (2.8 to 16.9 ppm Si) (Epstein, 1994). Soilless substrates (Chen et al., 2000) and standard commercial fertilizers (Epstein, 1994) contain little soluble Si. Depending on the water source, irrigation water may contain trace amounts of Si (Voogt and Sonneveld, 2001).

Horticultural crops grown in Si-amended substrates exhibit a variety of responses related to abiotic and biotic stresses and morphology. For example, Si supplementation has been reported to reduce incidence of powdery mildew of miniature potted roses (*Rosa hybrid* L.) (Datnoff et al., 2006; Larsen, 2008). 'Meipelta' shrub rose irrigated with Si-supplemented water had decreased black spot disease occurrence (Gillman et al., 2003). Botrytis infection was significantly decreased in calcium silicate-amended sunflowers (*Helianthus annuus* L. 'Ring of Fire') and Si-supplemented plants had an extended postharvest life compared with control plants (Kamenidou et al., 2002). *Pythium* colonization was reduced on roots of a greenhouse-grown bitter gourd (*Mormodica charantia* L.) that received continuous Si supply in the irrigation water (Heine et al., 2007). However, powdery mildew [*Podosphaera fusca* (Fr.) U. Braun & Shishkoff (2000)] severity of gerbera (*Gerbera jamesonii* Bolus ex. Hook f. 'Snow White') was unaffected by Si treatment (Moyer et al., 2008). Si foliar sprays were effective in ameliorating bract edge burn in poinsettia (*Euphorbia pulcherrima* Willd. 'Supjibi Red') (McAvoy and Bible, 1996).

Si supplementation was reported to increase stem diameters of chrysanthemum (*Chrysanthemum ×morifolium* Ramat. 'Backwang') (Moon et al., 2008), spray rose 'Pinocchio' (Hwang et al., 2005), and gerbera (Savvas et al., 2002). Si additions increased both stem and flower diameter of greenhouse-grown sunflower (Kamenidou et al., 2008) and zinnia (*Zinnia elegans* Jacq. 'Oklahoma Formula Mix') (Kamenidou et al., 2009). Vegetative growth of NaCl-stressed hydroponic cucumber (*Cucumis sativus* L. 'Jinlu4' and 'Jinyan4') (Zhu et al., 2004) and cut-flower roses (Savvas et al., 2007) was improved by Si supplementation. Si also reportedly improves the net photosynthic rate of NaCl-stressed zucchini (Savvas et al., 2009).

Si is accumulated by a broad range of bedding and potted plant species (Frantz et al., 2008). Of the 14 species examined by Frantz et al. (2008), all 14 accumulated additional amounts of Si in their leaves when supplemented with potassium silicate. Leaf tissue concentration varied from 237 mg·kg^{-1} Si for petunia (*Petunia ×hybrida* Vilm. 'White madness') to 11,700 mg·kg^{-1} for zinnia 'Oklahoma white'. Although Frantz et al. (2008) demonstrated that these ornamental species accumulate Si under hydroponic cultivation, it is not clear how these results would translate to substrate-based growing conditions. It has been suggested (Ma and Yamaji, 2006), and many researchers operate under the assumption, that high rates of Si absorption and tissue concentration are a prerequisite for Si benefits; hence, it is desirable to determine which floriculture species accumulate this element.

Previous researchers who have examined the effects of Si supplementation on greenhouse crops have either focused on a limited number of species or have grown plants using hydroponic methods. It is unproven in the literature whether the majority of bedding or potted crops grown using substrates and tap water would respond positively to Si supplementation. Therefore, the objectives of this experiment were to examine whether weekly potassium silicate drenches would increase leaf Si concentration and affect morphological traits of several floriculture species.

Materials and Methods

Plant culture. Rooted cuttings of several floriculture species (Table 1) were received from a commercial supplier on 8 Feb. 2008. The plants had several unfolded leaves and were considered to be at the commercial transplant stage. The rooted cuttings were transplanted into 15-cm round pots (1780 mL) containing a commercial peat-based substrate (Metro-Mix 360; Sun Gro Horticulture Ltd., Vancouver, Canada). Plants were grown in a glasshouse under ambient light (lat. 42° N) and temperature set points of 22 °C during the daytime (0600 to 1700 HR) and 18 °C during the nighttime (1700 to 06:00 HR).

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Table 1. List of species tested, number of replicates per treatment, and date of harvest [days after transplanting (DAT)].

Genus/species	Cultivar	Common name	Replicates (n)	Harvest date (DAT)
Argyranthemum frutescens (L.) Sch. Bip.	Sunlight	Argyranthemum	7	105
Begonia ×tuberhybrida Voss	Nonstop Rose Petticoat	Tuberous begonia	7	90
Bracteantha bracteata (Vent.) Anderb. & Heagi	Golden Beauty	Bracteantha	7	83
Calibrachoa ×hybrida Cerv.	Celebration Blue	Calibrachoa	7	74
Calibrachoa ×hybrida Cerv.	Celebration Rose	Calibrachoa	7	75
Fuchsia hybrida hort. ex Siebold & Voss	Marinka	Fuchsia	8	90
Impatiens hawkeri Bull.	Pure Beauty White	New Guinea impatiens	7	87
Impatiens wallerana Hook. f	Cameo Scarlet Surprise Improved	Impatiens	5	73
Lobelia erinus L.	Hot Waterblue Improved	Lobelia	10	83
Lysimachia nummularia L.	Goldii	Lysimachia	10	89
Pelargonium peltatum L. L'Hér. ex Aiton	Global Ruby Red	Ivy geranium	4	83
Pelargonium peltatum L. L'Hér. ex Aiton	Global Soft Pink	Ivy geranium	3	83
Pelargonium ×hortorum L.H. Bailey	Patriot Bright Red	Geranium	5	109
Petunia ×hybrida Vilm.	Cascadias Cherry Spark	Petunia	9	67
Portulaca grandiflora Hook.	Yubi Summer Joy Wine Red	Portulaca	7	105
Scaevola aemula R. Br.	Brilliant	Scaevola	7	76
Sutera grandiflora (Galpin) Hilliard	Gulliver White	Bacopa	8	69
Torenia fournieri Linden ex E. Fourn.	Blue Moon	Torenia	7	73
Verbena ×hybrida Groenl. & Rümpler	Tropical Breeze Deep Purple	Verbena	7	110
Vinca major L.	Variegata	Vinca	10	109
Vinca major L.	Wojo's Jem	Vinca	8	90

Mean temperature during the experimental period was 19.7 ± 3.1 °C (mean ± SD). Plants were spaced at 750 cm^2 per container and were irrigated as needed with municipal tap water injected with 150 $mg \cdot L^{-1}$ nitrogen from 20N–2.2P–16.6 K (Jack's Professional LX™ Water Soluble Fertilizer 21-5-20 All-Purpose; J. R. Peter's Inc., Allentown, PA) with 30 $mg \cdot L^{-1}$ magnesium added from $MgSO_4 \cdot 7H_2O$. Tap water Si concentration was measured using the colorimetric method described below and was 0.7 $mg \cdot L^{-1}$. Substrate Si concentration was determined by saturated media extract at a commercial laboratory (MMI Laboratories, Athens, GA) and was determined to be 2.1 $mg \cdot L^{-1}$.

Plants were divided into two groups. Control plants did not receive supplemental Si and +Si plants received weekly substrate drenches. Si drenches started 7 d after transplanting (DAT) 15 Feb. 2008 and continued for 10 weeks until 63 DAT (18 Apr. 2008). Drenches were 250 mL per pot at a concentration of 100 $mg \cdot L^{-1}$ Si from potassium silicate (Pro-TeKt; Dyna-Gro Nutrition Solutions, Richmond, CA). Thus, each +Si container received a total of 250 mg of supplemental Si. From the potassium silicate, each +Si pot also received an additional 8 mg of potassium (K) per week. Because this represented a small fraction of the K received in 1 week through the irrigation water, the control plants were not amended to provide additional K. Pourthrough root-zone pH and electrical conductiviyy (EC) measurements of several plants were taken weekly following the methods of Cavins et al. (2000). During the experimental period, pH was 6.3 ± 0.3 (SD) and 6.5 ± 0.3 for control and +Si plants, respectively. The EC values averaged 2.3 ± 0.7 $dS \cdot m^{-1}$ and 1.8 ± 0.7 $dS \cdot m^{-1}$ for control and +Si plants, respectively. During the experimental period, irrigation and silicon drench water were not pH-adjusted.

Data collection and analysis. Beginning at 67 DAT (Table 1), measurements were recorded on: plant height to the growing point on the main stem; diameter of the main stem 1 cm above the soil line measured with a caliper (basal diameter); diameter of the main stem 1 cm below the primary growing point measured with a caliper (apical diameter); leaf thickness of five most recently expanded (MRE) leaves per plant, measured with a caliper at the middle of the leaf but not including the midrib; diameter of five flowers per plant, at the stage of anthesis (flower diameter); aboveground fresh weight (FW); and aboveground dry weight (DW).

After measurements were completed, ≈20 MRE leaves per plant were collected for tissue Si analysis. The leaves were washed with deionized water then placed in an oven for 3 d at 70 °C. Leaves were then ground to pass through a 40-mesh screen. Leaf tissue Si concentration was determined following the autoclave digestion and silicomolybdous acid colorimetric method of Elliott and Snyder (1991).

The experiment was set up as a completely randomized design with three to 10 replicated experimental units per treatment depending on cultivar availability (Table 1). Plants were randomly placed among four greenhouse benches. All statistical analyses were conducted with Statistical Analysis System (SAS Version 9.1; SAS Institute, Cary, NC). One-way analysis of variance tests (SAS Proc GLM) were conducted to identify differences in the measured parameters in response to Si treatment. When significant differences were found, Tukey's honestly significant difference method was used to conduct pairwise comparisons.

Results

Leaf silicon concentration. Leaf Si concentrations of control plants ranged from 211 $mg \cdot kg^{-1}$ for petunia 'Cascadias Cherry Spark' to 2606 $mg \cdot kg^{-1}$ for argyranthemum [*Argyranthemum frutescens* (L.) Sch. Bip. 'Sunlight'] (Fig. 1). Seven cultivars in the control treatment had leaf Si concentrations greater than 1000 $mg \cdot kg^{-1}$ (i.e., 0.1% of DW); these were argyranthemum, lobelia (*Lobelia erinus* L. 'Hot Waterblue Improved'), New Guinea impatiens (*Impatiens hawkeri* Bull. 'Pure Beauty White'), torenia (*Torenia fournieri* Linden ex E. Fourn. 'Blue Moon'), verbena (*Verbena ×hybrida* Groenl. & Rümpler 'Tropica Breeze Deep Purple'), vinca (*Vinca major* L. 'Variegata'), and 'Wojo's Jem' vinca. Si drenches significantly increased leaf Si concentration in 11 of the 21 cultivars examined in this study (Fig. 1). Among Si-treated plants, torenia contained the highest Si concentration (4267 $mg \cdot kg^{-1}$) followed by argyranthemum (3507 $mg \cdot kg^{-1}$), verbena (3365 $mg \cdot kg^{-1}$), calibrachoa (*Calibrachoa ×hybrida* Cerv. 'Celebration Rose') (2308 $mg \cdot kg^{-1}$), and New Guinea impatiens (1976 $mg \cdot kg^{-1}$). The 11 affected cultivars showed an increase in leaf Si concentration of 13% to 145% compared with control plants. In terms of differential Si accumulation (Fig. 2), most affected were 'Celebration Rose' calibrachoa (145% increase in leaf Si), petunia (+140%), and verbena (+135%).

Plant growth characteristics. The effect of Si addition on the measured growth traits varied depending on species and parameter measured. Seven cultivars showed no Si response in any of the measured growth parameters; these include: begonia (*Begonia ×tuberhybrida* Voss 'Nonstop Rose Petticoat'), 'Celebration rose' calibrachoa, impatiens (*Impatiens wallerana* Hook. F 'Cameo Scarlet Surprise Improved'), ivy geranium (*Pelargonium peltatum* L. L'Hér. ex Aiton 'Global ruby red'), 'Global Soft Pink' ivy geranium, geranium (*Pelargonium ×hortorum* L.H. Bailey 'Patriot Bright Red'), and 'Variegata' vinca (Table 2).

Four species demonstrated a significant plant height response with added Si (Table 2). Three species had increased height under Si supplementation: New Guinea impatiens (+10%), lobelia (+13%), and portulaca (*Portulaca grandiflora* Hook. 'Yubi Summer Joy Wine Red') (+9%), whereas bracteantha

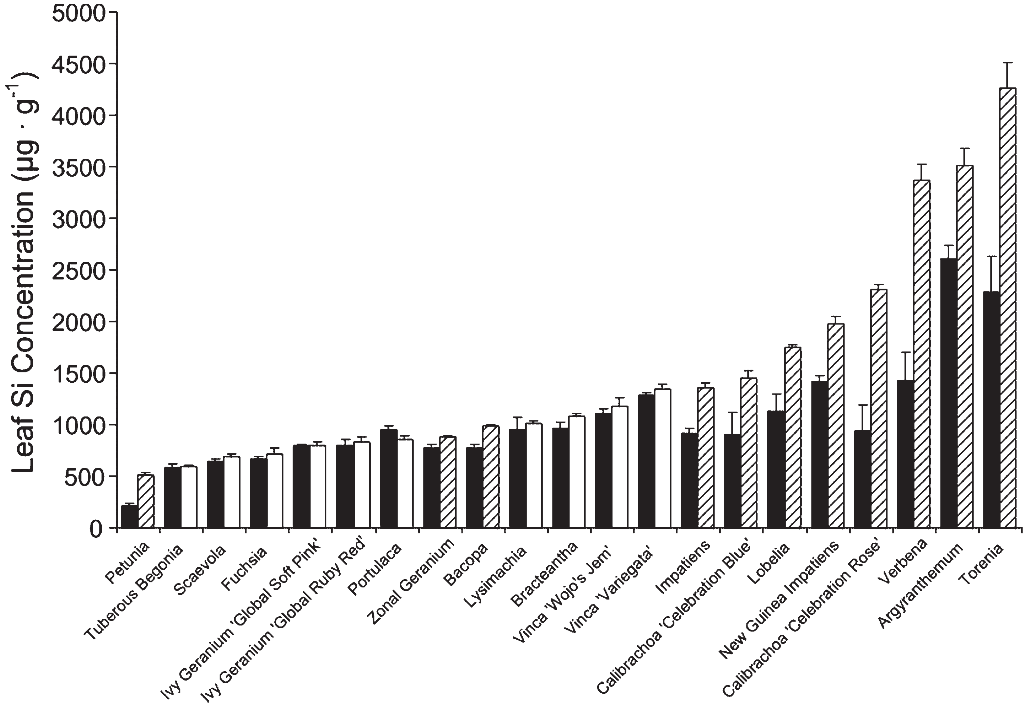

Fig. 1. Leaf silicon (Si) concentration of Si-unsupplemented plants (Control, black bars) or Si-supplemented plants (+Si, white bars). Supplemented plants received 10 weekly drenches of 100 mg·L^{-1} Si from potassium silicate. Each bar represents the mean ± se; n varied by cultivar as reported in Table 1. Striped bars denote that +Si plants had significantly greater leaf Si concentration than untreated controls as determined by Tukey's honestly significant difference test at $\alpha = 0.05$.

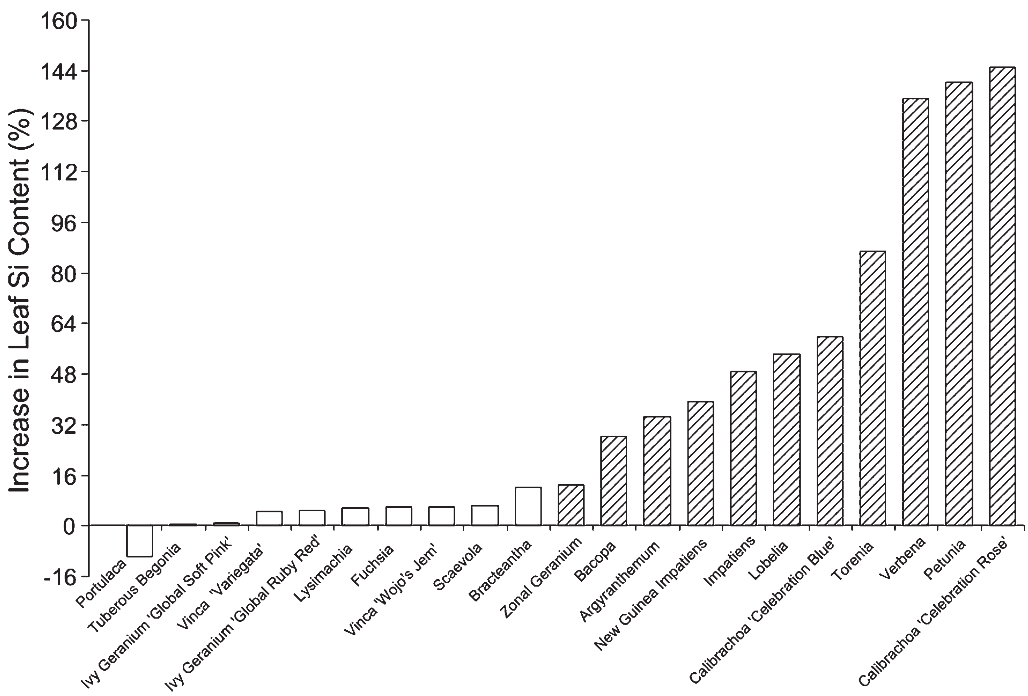

Fig. 2. Percentage increase in leaf silicon (Si) concentration of Si-supplemented plants (+Si) relative to unsupplemented (control) plants. Striped bars denote that +Si plants had a significantly greater leaf Si concentration than untreated controls as determined by Tukey's honestly significant difference test at $\alpha = 0.05$. Data are calculated from means of each treatment; n varied by cultivar as reported in Table 1.

[*Bracteantha bracteata* (Vent.) Anderb. & Heagi 'Golden Beauty'] had a reduced height (–9%).

Reduced apical stem diameters were measured for four species that had added Si: bracteantha, lobelia, lysimachia (*Lysimachia nummularia* L. 'Goldii'), and torenia (Table 2). No species demonstrated a positive Si effect on apical diameter. Only 'Wojo's Jem' vinca demonstrated basal diameter response; Si-treated plants had a 23% wider diameter than control plants.

Ten species had altered flower diameters in response to Si supplementation (Table 2). Six species had increased flower diameters, whereas four species demonstrated reduced flower diameters. Flower diameter differences between treatments were relatively

Table 2. Plant height, apical diameter, basal diameter, flower diameter, leaf thickness, fresh weight, and dry weight of plants grown in a soilless substrate unamended with silicon (Si) (control) or receiving 10 weekly 250-mL potassium silicate drenches at 100 $mg\cdot L^{-1}$ Si (+Si).

	Plant ht (cm)		Apical diam (mm)		Basal diam (mm)		Flower diam (mm)		Leaf thickness (mm)		Fresh wt (g)		Dry wt (g)	
Plant	Control	+Si	Control	+Si	Control	+Si	Control	+Si	Control	+Si	Control	+Si	Control	+Si
Argyranthemum	28.7	31.1	2.22	2.53	13.12	12.90	**66.4**	**65.6*** **	0.421	0.428	283.6	297.4	36.9	39.9
Tuberous begonia	10.1	10.4	7.10	6.77	9.17	9.56	64.6	[z]	0.661	0.707	67.6	62.9	3.0	3.0
Bracteantha	**13.9**	**12.6***	**3.92**	**3.47***	9.91	10.97	48.2	49.7	0.303	0.250	**249.3**	**290.9***	**30.6**	**35.6****
Calibrachoa Celebration Blue	5.4	5.6	1.46	1.37	3.94	3.84	**30.2**	**30.7****	0.319	0.285	115.6	91.9	18.5	13.1
Calibrachoa Celebration Rose	5.8	6.0	1.61	1.63	5.26	5.45	34.4	34.1	0.306	0.304	151.3	136.8	23.8	21.1
Fuchsia	8.2	7.3	2.13	1.95	8.61	8.51	**48.8**	**55.4*****	**0.309**	**0.306****	339.3	334.2	50.4	49.0
New Guinea impatiens	**15.5**	**17.1***	4.29	4.29	15.32	16.35	70.1	70.6	**0.364**	**0.339****	220.9	266.9	19.2	22.8
Impatiens	16.6	17.1	3.79	3.57	14.59	14.85	37.8	39.7	0.362	0.359	228.5	248.1	15.6	15.7
Lobelia	**18.9**	**21.4***	**1.32**	**1.14***	6.10	6.66	**23.3**	**22.9***	**0.191**	**0.163*****	**121.2**	**151.2*****	**15.0**	**17.9****
Lysimachia	5.7	5.9	**1.67**	**1.44****	1.75	1.71	[z]	[z]	0.149	0.146	131.1	126.4	13.5	13.1
Ivy geranium Global Ruby Red	18.3	15.9	3.74	3.62	5.39	6.04	54.7	54.2	0.904	0.838	254.9	256.5	22.7	22.7
Ivy geranium Global Soft Pink	19.4	17.2	3.75	3.67	5.73	5.18	52.3	55.2	0.860	0.848	209.4	233.8	18.3	19.5
Geranium	15.3	17.3	6.49	6.27	10.89	11.33	48.5	47.8	0.386	0.437	307.5	303.4	39.2	39.8
Petunia	5.7	6.0	2.15	2.22	7.39	6.60	**58.2**	**59.5***	**0.453**	**0.471*****	147.4	156.9	15.3	15.2
Portulaca	**5.3**	**5.8***	2.35	2.20	6.66	6.37	**49.1**	**51.0***	**1.132**	**1.098****	383.6	348.2	24.9	21.7
Scaevola	5.0	4.5	2.96	3.32	7.70	7.75	**31.5**	**32.2**	**0.487**	**0.505**	248.3	233.1	28.3	25.9
Bacopa	6.2	6.7	1.57	1.46	2.90	2.99	**24.1**	**22.8****	**0.279**	**0.289***	77.5	73.8	9.6	8.9
Torenia	6.1	5.4	**2.83**	**2.51***	3.64	3.90	**34.0**	**35.6***	0.291	0.301	109.1	121.1	10.5	10.6
Verbena	4.0	4.5	2.17	2.27	3.42	3.88	**19.5**	**19.1***	**0.254**	**0.264***	118.7	134.4	**23.4**	**27.9***
Vinca Variegata	5.4	5.1	2.40	2.29	2.70	2.83	[z]	[z]	0.227	0.223	107.7	119.5	16.8	18.6
Vinca Wojo's Jem	10.7	11.6	1.55	1.71	**2.30**	**2.79***	[z]	[z]	0.283	0.277	43.4	57.5	5.0	6.6

[z]Plants in these treatments had not flowered by the harvest date.

*, **, ***Significantly different from control at $P \leq 0.05$, 0.01, or 0.001, respectively.

Bold numbers highlight cases where +Si differed significantly from control.

modest (±1% to 5%) with the exception of fuchsia (*Fuchsia hybrida* hort. ex Siebold & Voss 'Marinka'), which exhibited a 12% increase in flower diameter with added Si.

Four species had reduced leaf thickness with added Si (Table 2): fuchsia, New Guinea Impatiens, lobelia, and portulaca, whereas four species had thicker leaves with Si: bacopa [*Sutera grandiflora* (Galpin) Hilliard 'Gulliver White'], petunia, scaevola (*Scaevola aemula* R. Br. 'Brilliant'), and verbena (Table 2). However, most differences were quite small (±1% to 4%), with the exception of New Guinea impatiens and lobelia, which had leaf thickness reductions of 7% and 15%, respectively, with Si supplementation.

Bracteantha and lobelia showed a positive FW response to Si treatments; no species exhibited a negative FW response to Si. These two species as well as verbena had a positive DW response to Si of 16% to 19% greater DW than their control counterparts. No species had a negative DW response to Si.

Discussion

Leaf silicon concentration. Leaf Si concentration of plants in this experiment was determined colorimetrically. Leaf Si concentration of several of the same species was independently determined by inductively coupled plasma–optical emission spectroscopy and colorimetrically by Frantz et al. (2008). They found that the two analytical methods gave similar results in relative terms of tissue Si quantification. Comparing our experimental results with the results of Frantz et al. (2008), differences were observed in absolute Si concentration, most likely as a result of differing plant growth conditions and variations in experimental protocol. The plants in our study were grown in soilless media, whereas Frantz et al. (2008) grew plants in an aspirated modified Hoagland solution. Although we did not find the same absolute Si concentrations as Frantz et al. (2008), we did find similar patterns for these species: petunia accumulated the least Si of any species examined; there was much greater accumulation by *Calibrachoa* than the related genus *Petunia*; verbena had among the highest Si concentrations; and New Guinea impatiens (*Impatiens hawkeri*) accumulated more Si than the related species, *Impatiens walleriana*.

Differential silicon accumulation. In our experiment, the eight cultivars with the greatest absolute leaf Si concentrations accumulated significantly more Si when they received weekly Si drenches. Yet, not all of these species exhibited the same type or scale of morphological response. Interestingly, other cultivars we examined did not accumulate Si differentially yet did exhibit morphological responses, indicating that Si accumulation may not be a requisite step for morphological responses to Si supplementation.

Petunia had the lowest Si concentration of any plant in this study, yet when supplemented with Si, it was able to accumulate 140% more Si than control plants, suggesting that baseline leaf Si concentration is not indicative of potential Si uptake. In addition, we observed a cultivar-specific response to Si supplementation. 'Celebration Rose' Calibrachoa accumulated 145% more Si than controls, yet 'Celebration Blue' calibrachoa accumulated only 60% more. Similar to the cultivar difference described previously, within the genus *Pelargonium*, *P.* ×*hortorum* exhibited increased leaf Si concentration with drenches, whereas the two *P. peltatum* cultivars did not. Although genotypic differences in Si accumulation have been reported in rice (Deren et al., 1992), this may be the first such report for floricultural crops.

Differential uptake suggests that these cultivars may have functional homologs to *Lsi1*, the gene encoding a Si carrier in rice (Ma and Yamaji, 2006) and thus may have the underlying molecular mechanisms to accumulate significant amounts of Si. A study conducted with rice (*Oryza sativa* L. 'Oochikara'), cucumber (*Cucumis sativus* L. 'Suyo'), and tomato (*Solanum esculentum* Mill. 'Oogatahukujyu'), which accumulate high, medium, and low levels of Si, respectively, suggests that Si uptake into the root cortex of cucumber and tomato may be mediated by a similar Si transporter as rice (*Lsi1*) but that the density of the carrier differs by plant species (Mitani and Ma, 2005). Similarly, patterns of *Lsi1* expression observed in rice roots (Ma et al., 2007) may suggest another possible explanation for the variable results observed between species and cultivars in this study.

Growth measurements. Our finding of both positive and negative morphological affects attributed to Si is comparable to results reported by other researchers. Kamenidou et al. (2008, 2009) reported that the form and concentration of applied Si significantly impacts morphology. Although substrate-incorporated potassium silicate powder at 140 $g\cdot m^{-3}$ Si resulted in increased stem height of zinnia, weekly potassium silicate drenches (100 to 200 $mg\cdot L^{-1}$) delayed anthesis and reduced stem height in zinnia and sunflower and was associated with deformed flowers for sunflower.

In this study, the most frequent response to Si supplementation was an increase in flower diameter, yet some species exhibited decreased flower diameter. The most common growth response was an increase in height in three species. Si supplementation decreased apical diameter in four species and had no affect on other species. Surprisingly, two of the species with reduced apical diameter did not accumulate additional Si in their leaves. It is a generally accepted hypothesis that plants that accumulate supplemental Si benefit from improved biotic or abiotic stress resistance or altered morphology (Ma and Yamaji, 2006). For half the species in this study, Si supplementation did not alter leaf tissue Si concentrations. Thus, trace Si amounts in irrigation water and substrate were apparently sufficient for these species. Yet, these same species exhibited morphological changes when provided with supplemental Si. We suggest that some species that do not differentially accumulate Si in leaves might still benefit from Si supplementation. This result lends support to the hypothesized active role for Si in plant physiology (Fauteux et al., 2006; Rodrigues et al., 2004) and invites further investigation.

Conclusions

All species examined accumulated measurable Si concentrations even when plants did not receive supplemental Si. Trace Si in the substrate and irrigation water may be enough for maximum leaf Si concentration for many cultivars in this study. The increased DW effects on bracteantha, lobelia, and verbena with Si supplementation are noteworthy and suggest further experimentation. Also of interest was that increased Si accumulation (versus control) was not necessary for there to be a measurable effect on morphological parameters. Our study followed only horticultural traits, yet there may be other unobserved abiotic and biotic stress tolerance benefits from Si supplementation, which deserve further inquiry. For example, it is possible that an imposed stress would have had more dramatic effects on the growth characteristics of Si-supplemented plants. Our results demonstrate that a range of floriculture species do absorb Si and that responses may be variable among species and cultivars.

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