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Petunia (*Petunia ×hybrida*) Cultivars Vary in Silicon Accumulation and Distribution

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Abstract. **Silicon (Si) is a plant-beneficial element that can alleviate the effects of abiotic and biotic stress. Plants are typically classified as Si accumulators based on foliar Si concentrations (≥1% Si on a dry weight basis for accumulators). By this definition, most greenhouse-grown ornamentals are low Si accumulators. However, plants that accumulate low foliar Si concentrations may still accumulate high Si concentrations elsewhere in the plant. Additionally, screening cultivars for variability in Si uptake has not been investigated for low Si accumulator species. Therefore, the objective of this study was to assess cultivar variability in Si accumulation and distribution in petunia (*Petunia ×hybrida*). Eight cultivars (Supertunia Black Cherry, Supertunia Limoncello, Supertunia Priscilla, Supertunia Raspberry Blast, Supertunia Royal Velvet, Supertunia Sangria Charm, Supertunia Vista Silverberry, and Supertunia White Improved) were grown in a commercial peat-based soilless substrate under typical greenhouse conditions. They were supplemented with either 2 mM potassium silicate (+Si) or potassium sulfate (-Si) at every irrigation. Silicon supplementation increased leaf dry mass (4.5%) but did not affect total dry mass. In plants not receiving Si supplementation, leaf Si ranged from 243 to 1295 mg·kg^{-1}, stem Si ranged from 48 to 380 mg·kg^{-1}, flower Si ranged from 97 to 437 mg·kg^{-1}, and root Si ranged from 103 to 653 mg·kg^{-1}. Silicon supplementation increased Si throughout the plant, but most predominantly in the roots. Leaf Si in the 2 mM Si treatment ranged from 1248 to 3541 mg·kg^{-1} (173% to 534% increase), stem Si ranged from 195 to 654 mg·kg^{-1} (72% to 376% increase), flower Si ranged from 253 to 1383 mg·kg^{-1} (74% to 1082% increase), and root Si ranged from 4018 to 10,457 mg·kg^{-1} (593% to 9161% increase). The large increase in root Si following supplementation shifted Si distribution within plants. In nonsupplemented plants, it ranged from 51.2% to 76.8% in leaves, 8.2% to 40.2% in stems, 2.8% to 23.8% in flowers, and 1.2% to 13.8% in roots. In Si-supplemented plants, it ranged from 63.5% to 67.7% in leaves, 10.5% to 22.6% in roots, 9.4% to 17.7% in stems, and 1.6% to 9.6% in flowers. This study indicates that petunia, a low foliar Si accumulator, can accumulate appreciable quantities of Si in roots when provided supplemental Si.**

Silicon (Si) is associated with many positive physiological responses in plants (Kamenidou et al., 2008, 2010; Liang et al., 1996; Ma, 2004; Ma and Yamaji, 2006; Romero-Aranda et al., 2006; Savant et al., 1999). It is classified as a beneficial element and has been shown to mitigate the impacts of many biotic and abiotic stresses, including fungal pathogens (Chain et al., 2009; Datnoff et al., 1997; Guével et al., 2007; Menzies et al., 1992), herbivory (Massey et al., 2006; Reynolds et al., 2009), drought (Hattori et al., 2005; Zhu and Gong, 2014), salt stress (Liang et al., 1996; Romero-Aranda et al., 2006), heat stress (Agarie et al., 1998), chilling injury (He et al., 2010; Liang et al., 2008), nutrient deficiencies (Ma, 2004), and heavy metal toxicity (Frantz et al., 2011). The use of soilless substrates or hydroponic systems in greenhouse production has resulted in low Si availability for many plants. Silicon fertilization in greenhouse production is becoming more widespread as its role in plant health is better understood (Voogt and Sonneveld, 2001; personal observation).

Foliar Si concentration can range from 0.1% to 10% on a dry mass basis (Epstein, 1999). Silicon accumulators are classified as plants that attain ≥1% Si on a dry mass basis (i.e., 10,000 mg·kg^{-1}) (Epstein, 1999; Ma et al., 2001). Many species within Poaceae are Si accumulators, including important agronomic crops such as barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), oats (*Avena sativa* L.), rice (*Oryza sativa* L.), sugarcane (*Saccharum officinarum* L.), and wheat (*Triticum aestivum* L.) (Deren et al., 1992, 1993; Handreck and Jones, 1968; Hodson et al., 2005; Jones and Handreck, 1967; Lanning et al., 1980; Ma et al., 2007; Murozuka et al., 2015; Savant et al., 1999). Some species within the horticulturally important Cucurbitaceae [cucumber (*Cucumis sativus* L.), squash and pumpkin (*Cucurbita* spp.)] and Asteraceae [sunflower (*Helianthus annuus* L.) and zinnia (*Zinnia elegans* L.)] are also Si accumulators (Frantz et al., 2010). However, most greenhouse-grown ornamentals are low Si accumulators. Frantz et al. (2010) quantified the foliar Si concentration of 48 horticultural crops, grown hydroponically in a modified Hoagland's solution amended with 1 mM Si, and they found it to range between 102 mg·kg^{-1} [ornamental tobacco (*Nicotiana sylvestris* Speg. & Comes.)] and 12,682 mg·kg^{-1} Si (zinnia).

Plant Si concentration can vary with environmental conditions, substrate (soil, soilless, or hydroponic), nutrients supplied, plant tissue, species, and genotype. Genotypic variation in Si concentration has been reported for barley grain (Ma et al., 2003), rice (Deren et al., 1992; Ma et al., 2007; Wu et al., 2006), sugarcane (Deren et al., 1993), wheat straw (Murozuka et al., 2015), bamboo (Collin et al., 2012), finger millet [*Eleusine coracana* (L.) Gaertn.] (Sandhya et al., 2011), and calibrachoa (*Calibrachoa ×hybrida* Cerv.) (Mattson and Leatherwood, 2010). However, there is little published research on the distribution of Si in ornamental plants, let alone cultivar variation in Si distribution. In species where Si distribution has been documented, it was not uniform within the plant. Rice grown in nutrient solution with 150 ppm SiO_2 averaged 9800 mg·kg^{-1} Si in roots, 57,000 mg·kg^{-1} in leaf sheaths, and 63,000 mg·kg^{-1} in leaf blades, as calculated from values reported as %SiO_2 on a dry matter basis (Yoshida et al., 1962). In oat, Si ranged from 280 mg·kg^{-1} in caryopses to 36,000 mg·kg^{-1} in inflorescences, with over 40% of total aboveground SiO_2 localized in inflorescences (Jones and Handreck, 1967). Kamenidou et al. (2008) compared the effects of different sources of Si supplementation on tissue Si concentration of sunflower 'Ring of Fire' grown in a peat-based soilless substrate, and while tissue concentrations were not compared within a treatment, reported leaf Si concentrations (4900 to 15,300 mg·kg^{-1}) were greater than flowers (3800 to 5100 mg·kg^{-1}) or stems (2900 to 4200 mg·kg^{-1}).

The use of Si fertilization historically has been limited in greenhouse production, partially because its many benefits were not known and because most greenhouse-grown crops are low Si accumulators. There has been debate as to whether Si supplementation is beneficial to low Si accumulators, because

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they do not accumulate high foliar concentrations of Si (Ma et al., 2001; Mitani and Ma, 2005). However, Si can provide benefit in both a structural capacity and as a signaling compound (Fauteux et al., 2006), and therefore, low Si accumulators may still benefit from Si supplementation, especially following imposition of a stress. For example, adding Si to the hydroponic nutrient solution delayed *Tobacco ringspot virus* (TSRV) symptom formation and reduced symptomatic leaf area in tobacco (*Nicotiana tabacum* L.), a low Si accumulator (Zellner et al., 2011). Silicon ameliorated copper (Cu) toxicity in arabidopsis [*Arabidopsis thaliana* L. (Heynh.)] (Li et al., 2008) and snapdragon (*Antirrhinum majus* L.) (Frantz et al., 2011), also low Si accumulators. Knowledge of Si distribution in plants, as well as variability amongst cultivars, may be critical if using Si to mitigate plant stresses that are tissue-specific. For example, botrytis (*Botrytis cinerea*) typically attacks flowers and leaves, whereas pythium (*Pythium ultimum*) causes root rot. If, for instance, flowers of one or more genotypes were found to contain appreciable quantities of Si, studies could investigate whether the accumulation provides protection and offers growers a nonpesticide alternative to include in their pest management rotation.

Petunia (*Petunia ×hybrida* Hort. Vilm.-Andr.) is a popular bedding plant. In 2014, it accounted for 12% of the annuals sold in the United States, with a value of almost $263 million (U.S. Department of Agriculture, National Agricultural Statistics Service, 2015). Despite its popularity, it presents some production and shipping challenges to growers, including flower sensitivity to botrytis infection. Petunia is a low Si accumulator, and its foliar response to Si supplementation has been evaluated previously. Frantz et al. (2008) observed 193 $mg \cdot kg^{-1}$ Si in petunia 'White Madness' grown hydroponically in a nutrient solution amended with 2 mM potassium silicate. Mattson and Leatherwood (2010) observed 506 $mg \cdot kg^{-1}$ Si in petunia 'Cascadias Cherry Spark' grown in a peat-based soilless substrate and supplemented with weekly drenches of 3.57 mM potassium silicate. Boldt et al. (data not published) detected, on average, 1045 $mg \cdot kg^{-1}$ Si in petunia 'Dreams Pink' grown in a peat-based substrate and supplemented with 2 mM potassium silicate. In another study, 'Dreams Pink' accumulated 2036 $mg \cdot kg^{-1}$ when grown in a peat-based substrate amended with 20% (by volume) parboiled rice hulls (Boldt et al., 2018). In all these studies, petunias supplemented with Si had greater foliar Si accumulation than plants not receiving supplemental Si. This suggests that even though petunia is a low Si accumulator, 1) it has the capacity to accumulate Si in leaves following Si supplementation, and 2) cultivars vary in foliar Si concentration. Therefore, the objective of this study was to quantify Si accumulation and distribution in the leaves, stems, flowers, and roots of eight petunia cultivars to better understand genotypic variation in how this crop accumulates and distributes Si.

Materials and Methods

Rooted liners of eight petunia cultivars ['Supertunia Black Cherry' (Black Cherry), 'Supertunia Limoncello' (Limoncello), 'Supertunia Priscilla' (Priscilla), 'Supertunia Raspberry Blast' (Raspberry Blast), 'Supertunia Royal Velvet' (Royal Velvet), 'Supertunia Sangria Charm' (Sangria Charm), 'Supertunia Vista Silverberry' (Silverberry), and 'Supertunia White Improved' (White)] in 72-count cell trays were received from a commercial greenhouse (Pleasant View Gardens, Louden, NH) on 12 Nov. 2015. They were transplanted on 16 Nov. 2015 into 11.5-cm diameter pots filled with a peat-based soilless substrate (LB-2; SunGro Horticulture, Agawam, MA). Plants were grown in a glass-glazed greenhouse (Toledo, OH). Air temperature set points were 22 °C day/18 °C night. Supplemental irradiance was provided by 1000-W high pressure sodium lamps between 0700–1900 HR when benchtop ambient irradiance was less than 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux density (*PPFD*). Air temperature and *PPFD* were measured with aspirated thermocouples and quantum sensors (MQ-200; Apogee Instruments, Logan, UT), respectively, and recorded every 15 min using a Campbell Scientific datalogger (CR10X; Campbell Scientific, Logan, UT). Mean air temperatures were 21.4 ± 0.2 °C day/18.1 ± 0.3 °C night, and mean daily light integral (DLI) was 6.4 ± 0.8 $mol \cdot m^{-2} \cdot d^{-1}$.

The base fertilizer solution was 20N–4.4P–16.6K (Jacks 20–10–20; JR Peters, Inc., Allentown, PA) at a concentration of 150 $mg \cdot L^{-1}$ N. It was amended with either 2 mM potassium silicate (+Si) or 2 mM potassium sulfate (–Si) as an offset to balance potassium application. Silicic acid and potassium hydroxide (KOH) (Fisher Scientific, Fair Lawn, NJ) were dissolved to formulate the potassium silicate solution. The pH of the two nutrient solutions was adjusted to 5.5 ± 0.1 using KOH or hydrochloric acid (HCl). Ultra-purified water (18 MΩ) was used to minimize Si contamination.

Plants were irrigated as needed with nutrient solution. The volume applied at each irrigation increased from 50 to 200 mL as plant size increased. Not all cultivars were irrigated at the same frequency due to differences in plant size. An equal volume of nutrient solution was applied to all plants, across both Si treatments, within a cultivar when irrigated. Containers were irrigated to near-container capacity, and a saucer was placed beneath each pot to catch any runoff (which infrequently occurred) and to allow it to be reabsorbed by the substrate. The volume of nutrient solution applied at each irrigation was recorded for each cultivar so that total Si applied could later be calculated. Plants were harvested ≈10 weeks after transplant, once a sufficient number of flowers had opened to provide enough dry mass for an analysis of Si concentration. This was ≈30 flowers for all cultivars except Priscilla (a double-flowered cultivar), based on a preharvest assessment of mean flower dry mass of flowers collected from additional (nonexperimental) plants of these cultivars.

The pour-through technique (LeBude and Bilderback, 2009) was conducted, and a 50 mL sample of leachate was collected from each pot. Leachate samples were immediately refrigerated at 4 °C until the following day, and pH and electrical conductivity (EC) was measured (HANNA HI9814 GroPro; Hanna Instruments, Woonsocket, RI) once samples had returned to room temperature. Samples were then frozen until nutrient analyses could be conducted. After thawing, the leachates were filtered (Whatman #2 filter paper; Whatman Ltd., Kent, UK). To determine Si concentration, 9.5 mL of 2.1% KOH was added to a 0.5 mL aliquot of leachate, and the solution was analyzed using inductively coupled plasma–optical emission spectroscopy (ICP-OES; iCAP 6300 Duo, Thermo Electron Corp., Waltham, MA).

Aboveground tissue was separated into leaves, stems (including stems, petioles, sepals, and immature flower buds), and flowers (senesced flowers, open flowers, and buds with visible petal coloration). Roots were washed in 18 MΩ water and gently separated from the soilless substrate. Each tissue type was separately dipped into acidified water (0.1 M HCl), rinsed in 18 MΩ water, placed in a paper bag, dried in a forced-air oven at 60 °C for a minimum of 3 d, and weighed for dry mass. They were ground into a fine powder using a mortar and pestle (roots, leaves, and flowers) or coffee grinder (stems).

To analyze for Si concentration, ≈0.15 g of dry tissue was weighed and placed in a Teflon vessel. Three milliliters of 7.5 M KOH was added, and the samples were heated in a programmable microwave (MARS6; CEM Corp., Matthews, NC). The temperature was ramped up to 200 °C over 15 min., maintained at 200 °C for 15 min., then cooled to room temperature. After cooling, 2 mL of hydrogen peroxide was added. Solutions were reheated to 200 °C and maintained for an additional 5 min. After cooling, 10 mL of 18 MΩ water was added, and the solutions were filtered (Whatman #2). Finally, a 1 mL aliquot of solution was diluted with 9 mL of 18 MΩ water and analyzed using ICP-OES.

Foliar nitrogen (N) was determined by measuring ≈2.5 mg of dry tissue into tin capsules (Costech Analytical, Valencia, CA) and then analyzing with a CHN analyzer (vario MICRO cube; Elementar, Hanau, Germany). For all other elements (except N and Si), ≈0.25 g of dry tissue was placed in a Teflon vessel, and 5 mL of nitric acid was added. Samples were heated in a programmable microwave as described above for Si quantification with the following exceptions: 1.5 mL of hydrogen peroxide was added after the first heating stage, and 12 mL of 18 MΩ water was added after the second heating stage. After cooling, solutions were filtered.

A 1.3 mL aliquot of solution was diluted with 8.7 mL 18 MΩ water and analyzed using ICP-OES.

To compare the total amount of Si taken up and stored within the plants, Si content (mg per plant) for leaves, flowers, stems, and roots of each plant was calculated by multiplying tissue dry mass (converted to kg per plant) by tissue Si concentration ($mg \cdot kg^{-1}$). Using the calculated values for Si content, Si distribution was determined individually for each plant as the percent of total plant Si content present in each tissue.

The percent of applied Si incorporated by each cultivar was calculated. As described above, the volume of nutrient solution supplied to each cultivar was recorded; multiplying the total volume applied (3.2 to 4.6 L) by the Si concentration of the nutrient solution (2 mM Si = 56 $mg \cdot L^{-1}$) yielded the total Si (in mg) supplied to each cultivar. Next, mean plant Si content (in mg per plant) of the 2 mM treatment for each cultivar was divided by the total Si supplied (mg) to that cultivar, to calculate the fraction of total Si supplied that had been incorporated into the plants (expressed on a percent basis). This, however, did not account for background Si present (e.g., in the substrate, base fertilizer, or starting plant material). Therefore, a second calculation was made that subtracted the mean Si content of the 0 mM treatment of each cultivar from the mean Si content of the 2 mM treatment before dividing by the total Si supplied. Means rather than individual values were used because the 0 and 2 mM experimental replicates were arranged in a randomized (unpaired) arrangement.

The treatment design was a 2 × 8 factorial arrangement with two Si concentrations and eight cultivars. The experimental design was completely randomized with 10 single plant replicates per treatment. Data were subjected to analysis of variance using SAS 9.3 (PROC GLM; SAS Institute Inc., Cary, NC). Means were separated with Tukey's honest significant difference test ($\alpha = 0.05$).

Results

Leachate pH, EC, and Si. Leachate pH averaged 5.61 ± 0.05 to 6.02 ± 0.06 for plants receiving 0 mM Si, and 5.81 ± 0.08 to 6.17 ± 0.07 for plants receiving 2 mM Si (mean ± SE; Table 1). Despite a cultivar × Si interaction ($P = 0.0005$), pH between the 0 and 2 mM Si treatments did not differ for any of the eight cultivars evaluated. Leachate EC concentrations ranged between 2.92 ± 0.16 and 3.81 ± 0.14 $mS \cdot cm^{-1}$ when provided 0 mM Si and between 1.50 ± 0.09 and 3.81 ± 0.21 $mS \cdot cm^{-1}$ when provided 2 mM Si (Table 1). All cultivars, except Black Cherry, had higher EC concentrations when fertilized with 0 mM Si compared with 2 mM Si.

Leachate Si averaged 0.73 ± 0.09 to 2.90 ± 0.23 $mg \cdot L^{-1}$ for plants grown without supplemental Si (Table 1). Low background levels of Si likely released from the sphagnum peatmoss (Frantz et al., 2010). Leachate Si averaged 25.68 ± 1.20 to 37.28 ± 1.83 $mg \cdot L^{-1}$ for plants supplied 2 mM Si (Table 1). As expected, all cultivars had higher leachate Si when supplemented with 2 mM Si, compared with nonsupplemented plants.

Si concentration. All cultivars had higher leaf, stem, flower, and root Si concentrations when supplemented with 2 mM Si, and thus the interactions observed (Table 1) resulted from differences in the magnitude of enhancement resulting from Si supplementation. Leaf Si concentration ranged between 243 ± 27 and 1295 ± 396 $mg \cdot kg^{-1}$ in plants fertilized with 0 mM Si, and between 1248 ± 64 and 3541 ± 339 $mg \cdot kg^{-1}$ in plants fertilized with 2 mM Si. The percent increase in leaf Si concentration with supplemental Si ranged from 173% in Limoncello to 534% in Raspberry Blast.

Stem Si concentration ranged between 48 ± 8 and 380 ± 76 $mg \cdot kg^{-1}$ in the 0 mM Si treatment, and between 195 ± 20 and 654 ± 54 $mg \cdot kg^{-1}$ in the 2 mM treatment (Table 1). Stem Si concentration increased 72% to 376% with Si supplementation. Five cultivars had enhanced stem Si concentration when fertilized with 2 mM Si (Black Cherry, Limoncello, Priscilla, Royal Velvet, and White), while the other three cultivars (Raspberry Blast, Sangria Charm, and Silverberry) had similar stem Si concentrations in both treatments. The lack of a statistically significant increase in those three cultivars was due to plant-to-plant variability and the choice of a conservative post-hoc test for multiple comparisons.

Floral (petal, pistil, and stamen) Si concentration ranged between 97 ± 31 and 437 ± 96 $mg \cdot kg^{-1}$ in nonsupplemented plants, and between 253 ± 22 and 1383 ± 543 $mg \cdot kg^{-1}$ in Si-supplemented plants (Table 1). Silicon concentration increased 74% to 1082% in flowers of plants supplied 2 mM Si. However, Black Cherry was the only cultivar to have a significant increase in floral Si concentration. This was likely due, in part, to large plant-to-plant variability within treatments.

Root Si concentration ranged between 103 ± 14 and 653 ± 169 $mg \cdot kg^{-1}$ in nonsupplemented plants, and between 4018 ± 983 and 10,457 ± 1270 $mg \cdot kg^{-1}$ in Si-treated plants (Table 1). All cultivars had a higher Si concentration in the 2 mM Si treatment, compared with the 0 mM Si treatment, and the percent increase was 593% to 9161% in Si-treated plants.

Dry mass. While plant growth was not visually impacted by Si supplementation,

Table 1. Solution pH, electrical conductivity (EC), and silicon (Si) concentration of leachate samples (mean ± SE) collected following the pour-through procedure, and Si concentration in leaves, stems, flowers, and roots of eight petunia (*Petunia ×hybrida*) cultivars grown in soilless substrate and fertilized with (2 mM) or without (0 mM) supplemental Si, provided as potassium silicate, at every irrigation.

Si	Cultivar[z]	pH	EC ($mS \cdot cm^{-1}$)	Pour-through Si ($mg \cdot L^{-1}$)	Leaf Si ($mg \cdot kg^{-1}$)	Stem Si ($mg \cdot kg^{-1}$)	Flower Si ($mg \cdot kg^{-1}$)	Root Si ($mg \cdot kg^{-1}$)
0 mM	Black Cherry	6.02 ± 0.06	3.76 ± 0.17	2.90 ± 0.23	452 ± 43	380 ± 76	117 ± 33	354 ± 35
	Limoncello	5.87 ± 0.05	3.30 ± 0.21	1.75 ± 0.21	1295 ± 396	155 ± 23	97 ± 31	103 ± 14
	Priscilla	5.83 ± 0.05	3.69 ± 0.18	2.51 ± 0.18	866 ± 116	84 ± 14	169 ± 67	237 ± 48
	Raspberry Blast	5.93 ± 0.07	3.12 ± 0.15	1.10 ± 0.14	262 ± 26	48 ± 8	158 ± 23	631 ± 96
	Royal Velvet	5.79 ± 0.02	3.27 ± 0.13	0.98 ± 0.13	643 ± 194	173 ± 49	437 ± 96	653 ± 169
	Sangria Charm	5.71 ± 0.03	3.72 ± 0.19	1.97 ± 0.20	349 ± 69	49 ± 8	253 ± 81	589 ± 130
	Silverberry	5.61 ± 0.05	3.81 ± 0.14	1.70 ± 0.14	243 ± 27	99 ± 37	209 ± 62	240 ± 52
	White	5.76 ± 0.03	2.92 ± 0.16	0.73 ± 0.09	382 ± 34	67 ± 12	145 ± 14	154 ± 22
2 mM	Black Cherry	5.81 ± 0.08	3.81 ± 0.21	37.28 ± 1.83	2049 ± 96	654 ± 54	1383 ± 543	4018 ± 983
	Limoncello	6.03 ± 0.04	1.83 ± 0.13	28.14 ± 1.46	3541 ± 339	602 ± 93	425 ± 96	9539 ± 925
	Priscilla	6.02 ± 0.05	2.10 ± 0.14	28.79 ± 1.07	2732 ± 240	361 ± 23	311 ± 42	10,457 ± 1270
	Raspberry Blast	6.17 ± 0.07	1.50 ± 0.08	26.40 ± 1.44	1660 ± 143	195 ± 20	363 ± 65	4370 ± 838
	Royal Velvet	5.98 ± 0.03	1.50 ± 0.09	25.68 ± 1.20	2715 ± 329	444 ± 31	891 ± 218	7439 ± 604
	Sangria Charm	5.85 ± 0.06	1.87 ± 0.10	31.97 ± 0.84	1877 ± 88	233 ± 37	657 ± 133	9358 ± 640
	Silverberry	5.87 ± 0.04	2.07 ± 0.12	28.77 ± 0.77	1248 ± 64	248 ± 27	463 ± 117	4362 ± 352
	White	5.99 ± 0.04	1.66 ± 0.06	28.58 ± 1.05	1992 ± 158	289 ± 66	253 ± 22	4724 ± 461
ANOVA[y]	Cv	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0028	<0.0001
	Si	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Cv × Si	0.0005	<0.0001	<0.0001	0.0393	0.0194	0.0138	<0.0001
	HSD[x]	0.26	0.73	9.86	926	215	801	2842

[z]'Supertunia Black Cherry' (Black Cherry), 'Supertunia Limoncello' (Limoncello), 'Supertunia Priscilla' (Priscilla), 'Supertunia Raspberry Blast' (Raspberry Blast), 'Supertunia Royal Velvet' (Royal Velvet), 'Supertunia Sangria Charm' (Sangria Charm), 'Supertunia Vista Silverberry' (Silverberry), and 'Supertunia White Improved' (White)
[y]Analysis of variance (significant at $P \leq 0.05$).
[x]Tukey's honestly significant difference ($\alpha = 0.05$) for cultivar × Si interactions.

Table 2. Dry mass (mean ± SE) for eight petunia (*Petunia ×hybrida*) cultivars grown in soilless substrate and fertilized with (2 mM) or without (0 mM) supplemental silicon (Si), provided as potassium silicate, at every irrigation.

Source	Treatment	Leaf dry mass (g)	Flower dry mass (g)	Stem dry mass (g)	Root dry mass (g)	Total dry mass (g)
Cultivar	Black Cherry[z]	3.67 ± 0.10	0.63 ± 0.05	3.49 ± 0.11	0.43 ± 0.02	8.22 ± 0.21
	Limoncello	4.84 ± 0.13	1.00 ± 0.12	5.45 ± 0.18	0.52 ± 0.02	11.82 ± 0.26
	Priscilla	4.35 ± 0.13	3.59 ± 0.20	4.64 ± 0.16	0.43 ± 0.02	13.01 ± 0.29
	Raspberry Blast	6.47 ± 0.09	1.96 ± 0.08	9.03 ± 0.21	0.62 ± 0.03	18.07 ± 0.26
	Royal Velvet	4.23 ± 0.12	2.26 ± 0.17	6.17 ± 0.10	0.26 ± 0.02	12.92 ± 0.31
	Sangria Charm	5.68 ± 0.16	0.89 ± 0.06	7.69 ± 0.18	0.44 ± 0.02	14.70 ± 0.33
	Silverberry	7.00 ± 0.14	0.88 ± 0.11	7.89 ± 0.30	0.42 ± 0.02	16.19 ± 0.44
	White Imp.	5.48 ± 0.11	2.98 ± 0.12	9.56 ± 0.16	0.43 ± 0.02	18.44 ± 0.26
	HSD[y]	0.52	—	0.81	0.09	1.33
Si	0 mM	5.10 ± 0.14	1.93 ± 0.15	6.70 ± 0.25	0.46 ± 0.02	14.20 ± 0.39
	2 mM	5.33 ± 0.13	1.62 ± 0.11	6.77 ± 0.24	0.42 ± 0.01	14.14 ± 0.39
	HSD	0.17	—	—	0.03	—
ANOVA[x]	Cv	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Si	0.0089	<0.0001	0.5958	0.0064	0.7906
	Cv × Si	0.1474	<0.0001	0.5828	0.6964	0.7450

[z]'Supertunia Black Cherry' (Black Cherry), 'Supertunia Limoncello' (Limoncello), 'Supertunia Priscilla' (Priscilla), 'Supertunia Raspberry Blast' (Raspberry Blast), 'Supertunia Royal Velvet' (Royal Velvet), 'Supertunia Sangria Charm' (Sangria Charm), 'Supertunia Vista Silverberry' (Silverberry), and 'Supertunia White Improved' (White).
[y]Tukey's honestly significant difference ($\alpha = 0.05$); hyphen for HSD indicates value not reported due to either a nonsignificant main effect or a significant cultivar × Si interaction for the variable of interest.
[x]Analysis of variance (significant at $P \leq 0.05$).

Table 3. Silicon (Si) content (mg per plant) of leaves, stems, flowers, and roots (mean ± SE) of eight petunia (*Petunia ×hybrida*) cultivars grown in soilless substrate and fertilized with (2 mM) or without (0 mM) supplemental Si, provided as potassium silicate, at every irrigation.

Si	Cultivar[z]	Si_leaf	Si_stem	Si_flower	Si_root	Si_total
0 mM	Black Cherry	1.53 ± 0.13	1.42 ± 0.30	0.08 ± 0.02	0.17 ± 0.02	3.20 ± 0.35
	Limoncello	6.23 ± 1.99	0.84 ± 0.15	0.13 ± 0.07	0.06 ± 0.01	7.25 ± 1.90
	Priscilla	3.53 ± 0.51	0.38 ± 0.07	0.70 ± 0.27	0.10 ± 0.02	4.70 ± 0.63
	Raspberry Blast	1.71 ± 0.18	0.41 ± 0.06	0.32 ± 0.04	0.41 ± 0.07	2.85 ± 0.26
	Royal Velvet	2.74 ± 0.74	1.05 ± 0.30	1.22 ± 0.34	0.19 ± 0.04	5.19 ± 1.07
	Sangria Charm	2.01 ± 0.44	0.39 ± 0.06	0.26 ± 0.09	0.30 ± 0.09	2.96 ± 0.45
	Silverberry	1.66 ± 0.18	0.74 ± 0.24	0.14 ± 0.04	0.10 ± 0.02	2.63 ± 0.35
	White	2.07 ± 0.20	0.64 ± 0.12	0.86 ± 0.42	0.07 ± 0.01	3.63 ± 0.44
2 mM	Black Cherry	7.99 ± 0.45	2.25 ± 0.30	0.82 ± 0.34	1.67 ± 0.46	12.73 ± 1.00
	Limoncello	17.65 ± 1.35	3.24 ± 0.41	0.42 ± 0.34	4.83 ± 0.43	26.14 ± 1.86
	Priscilla	12.75 ± 1.08	1.78 ± 0.12	0.94 ± 0.08	4.00 ± 0.49	19.46 ± 1.25
	Raspberry Blast	10.52 ± 0.73	1.80 ± 0.20	0.70 ± 0.17	2.38 ± 0.36	15.40 ± 0.73
	Royal Velvet	10.91 ± 0.93	2.78 ± 0.21	1.62 ± 0.14	1.73 ± 0.16	17.04 ± 0.93
	Sangria Charm	10.82 ± 0.62	1.84 ± 0.34	0.52 ± 0.36	3.87 ± 0.36	17.05 ± 1.10
	Silverberry	8.85 ± 0.49	1.91 ± 0.21	0.49 ± 0.11	1.87 ± 0.16	13.11 ± 0.75
	White	10.93 ± 0.71	2.65 ± 0.52	0.75 ± 0.20	1.96 ± 0.25	16.30 ± 1.22
ANOVA[y]	Cv	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Si	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Cv × Si	0.1367	0.0877	0.7742	<0.0001	0.0004
HSD[x]	Cv	2.53	0.80	0.66	—	—
	Si	0.81	0.26	0.21	—	—
	Cv × Si	—	—	—	1.25	5.01

[z]'Supertunia Black Cherry' (Black Cherry), 'Supertunia Limoncello' (Limoncello), 'Supertunia Priscilla' (Priscilla), 'Supertunia Raspberry Blast' (Raspberry Blast), 'Supertunia Royal Velvet' (Royal Velvet), 'Supertunia Sangria Charm' (Sangria Charm), 'Supertunia Vista Silverberry' (Silverberry), and 'Supertunia White Improved' (White).
[y]Analysis of variance (significant at $P \leq 0.05$).
[x]Tukey's honestly significant difference ($\alpha = 0.05$); hyphen for HSD indicates value not reported, based on which ANOVA effects were significant for the variable of interest.

some small differences did occur (Table 2). Leaf dry mass increased 4.5% with supplemental Si (5.10 ± 0.14 vs. 5.33 ± 0.13 g for 0 and 2 mM Si, respectively, pooled across cultivars; $P = 0.0089$). Stem dry mass was unaffected by Si ($P > 0.05$). Flower dry mass was affected by the interaction of cultivar and Si ($P < 0.0001$), and it ranged between 0.55 ± 0.08 g (Black Cherry, 2 mM Si) and 4.25 ± 0.16 g (Priscilla, 0 mM). Six cultivars exhibited no difference in flower dry mass when supplied 0 or 2 mM Si; but two cultivars, Priscilla and Royal Velvet, had a 31% lower flower dry mass when supplied 2 mM Si. Root dry mass decreased 9.5% with supplemental Si (0.46 ± 0.02 vs. 0.42 ± 0.01 g, respectively, pooled across cultivars; $P = 0.0064$).

Si content. Silicon content (calculated from Si concentration and tissue dry mass) was affected by the main effects of cultivar and Si in the leaves, stems, and flowers ($P < 0.0001$ for all; Table 3). Leaves, stems, and flowers averaged 2.68 ± 0.32, 0.73 ± 0.07, and 0.46 ± 0.09 mg Si per plant, respectively, for plants grown without supplemental Si; and 11.30 ± 0.42, 2.28 ± 0.12, and 0.78 ± 0.08 mg Si per plant, respectively, in plants grown with supplemental Si. Root Si content ($P < 0.0001$ for cultivar × Si interaction) ranged between 0.06 ± 0.01 mg Si per plant (Limoncello, 0 mM Si) and 4.83 ± 0.43 mg Si per plant (Limoncello, 2 mM Si; Table 2). Total Si content ($P = 0.0004$ for cultivar × Si interaction) ranged from 2.63 ± 0.35 mg Si per plant (Silverberry, 0 mM Si) to 26.14 ± 1.86 mg Si per plant (Limoncello, 2 mM Si; Table 3). Supplemental Si increased root and total plant Si content in all eight cultivars, and the interactions resulted from differences in the magnitude of increase in individual cultivars in response to supplemental Si.

Si distribution. The percent of total plant Si localized in leaves ranged between 51.2% ± 5.1% and 76.8% ± 6.5% in the 0 mM Si treatment, and between 63.5% ± 2.7% and 67.7% ± 1.2% in the 2 mM Si treatment

Table 4. Silicon (Si) distribution (mean ± SE) in eight petunia (*Petunia ×hybrida*) cultivars grown in soilless substrate and fertilized with (2 mM) or without (0 mM) supplemental Si, provided as potassium silicate, at every irrigation.

Si	Cultivar[z]	Leaf (%)	Stem (%)	Flower (%)	Root (%)
0 mM	Black Cherry	51.2 ± 5.1	40.2 ± 5.9	2.8 ± 0.9	5.8 ± 1.0
	Limoncello	76.8 ± 6.5	18.9 ± 5.2	3.1 ± 1.8	1.2 ± 0.3
	Priscilla	74.5 ± 3.6	8.2 ± 1.1	14.8 ± 4.0	2.5 ± 0.5
	Raspberry Blast	59.5 ± 1.6	14.8 ± 1.9	11.9 ± 1.8	13.8 ± 1.5
	Royal Velvet	52.0 ± 5.6	19.9 ± 4.7	23.8 ± 3.5	4.3 ± 1.1
	Sangria Charm	63.8 ± 4.7	15.4 ± 2.8	8.6 ± 1.8	12.2 ± 3.5
	Silverberry	65.2 ± 3.7	24.9 ± 3.9	5.8 ± 1.7	4.1 ± 0.8
	White	60.3 ± 5.4	18.7 ± 3.8	19.0 ± 5.2	2.1 ± 0.4
2 mM	Black Cherry	64.8 ± 3.7	17.7 ± 1.7	5.7 ± 2.0	11.9 ± 2.5
	Limoncello	67.5 ± 1.5	12.4 ± 1.2	1.6 ± 0.3	18.6 ± 1.3
	Priscilla	65.0 ± 1.8	9.4 ± 0.7	4.8 ± 0.7	20.9 ± 2.3
	Raspberry Blast	68.2 ± 2.9	11.8 ± 1.3	4.6 ± 1.0	15.4 ± 2.5
	Royal Velvet	63.5 ± 2.7	16.4 ± 1.1	9.6 ± 2.2	10.5 ± 1.2
	Sangria Charm	64.0 ± 1.6	10.4 ± 1.5	3.0 ± 0.6	22.6 ± 1.5
	Silverberry	67.7 ± 1.2	14.5 ± 1.3	3.4 ± 1.2	14.4 ± 1.1
	White	67.5 ± 1.6	15.7 ± 1.8	4.7 ± 0.5	12.1 ± 1.3
ANOVA[y]	Cv	0.0011	<0.0001	<0.0001	<0.0001
	Si	0.0975	<0.0001	<0.0001	<0.0001
	Cv × Si	0.0081	0.0059	0.0011	<0.0001
	HSD[x]	18.4	14.6	11.1	8.1

[z]'Supertunia Black Cherry' (Black Cherry), 'Supertunia Limoncello' (Limoncello), 'Supertunia Priscilla' (Priscilla), 'Supertunia Raspberry Blast' (Raspberry Blast), 'Supertunia Royal Velvet' (Royal Velvet), 'Supertunia Sangria Charm' (Sangria Charm), 'Supertunia Vista Silverberry' (Silverberry), and 'Supertunia White Improved' (White).
[y]Analysis of variance (significant at $P \leq 0.05$).
[x]Tukey's honestly significant difference ($\alpha = 0.05$) for cultivar × Si interactions.

Table 5. Percent of applied silicon (Si) taken up by eight petunia (*Petunia ×hybrida*) cultivars grown in soilless substrate and fertilized with 2 mM supplemental Si, provided as potassium silicate, at every irrigation (mean ± SE). Control plants that received no supplemental Si were maintained, to account for background Si levels in substrates, other applied fertilizers, or irrigation water.

Cultivar[z]	Cumulative volume of nutrient solution applied (mL)	Percent incorporation (based on total Si applied during fertigation)	Percent incorporation (after subtracting Si uptake by 0 mM trt)
Limoncello	3500	11.97%	8.75%
Raspberry Blast	4400	8.59%	7.20%
Priscilla	3900	9.39%	7.05%
Sangria Charm	3700	6.62%	5.49%
White	4400	6.62%	5.37%
Royal Velvet	4600	6.84%	5.09%
Black Cherry	3200	6.49%	4.75%
Silverberry	4450	5.32%	4.18%

[z]'Supertunia Black Cherry' (Black Cherry), 'Supertunia Limoncello' (Limoncello), 'Supertunia Priscilla' (Priscilla), 'Supertunia Raspberry Blast' (Raspberry Blast), 'Supertunia Royal Velvet' (Royal Velvet), 'Supertunia Sangria Charm' (Sangria Charm), 'Supertunia Vista Silverberry' (Silverberry), and 'Supertunia White Improved' (White).

(Table 4). The cultivar × Si interaction (P = 0.0081) occurred due to variation in leaf allocation across cultivars in the 0 mM Si treatment. Leaf Si allocation was similar between Si treatments for all cultivars. Percent of total plant Si localized in stems ranged between 8.2% ± 1.1% and 40.2% ± 5.9% in the 0 mM Si treatment, and between 9.4% ± 0.7% and 17.7% ± 1.7% in the 2 mM Si treatment (P = 0.0059 for cultivar × Si interaction; Table 4). Only Black Cherry differed between Si treatments, and it had a greater percent Si accumulation in stems when supplied 0 mM Si compared with 2 mM Si. Percent of total plant Si localized in flowers ranged between 2.8% ± 0.9% and 23.8% ± 3.5% with 0 mM Si, and between 1.6% ± 0.3% and 9.6% ± 2.2% with 2 mM Si (P = 0.0011 for cultivar × Si interaction; Table 4). Royal Velvet and White differed between Si treatments, and both had higher percent accumulation of Si in flowers at 0 mM Si compared with 2 mM Si. Percent of total plant Si localized in roots ranged between 1.2% ± 0.3% and 13.8% ± 1.5% in the 0 mM Si treatment, and between 10.5% ± 1.2% and 22.6% ± 1.5% in the 2 mM Si treatment (P < 0.0001 for cultivar × Si interaction; Table 4). Root allocation was higher in the 2 mM Si treatment, compared with the 0 mM Si treatment, in five of the eight cultivars evaluated (Limoncello, Priscilla, Sangria Charm, Silverberry, and White).

Percent of applied Si incorporated into plants. Knowing the volume of nutrient solution applied to each cultivar, the Si concentration (2 mM Si = 56 mg·L^{-1}), and plant Si content, we calculated the percent of applied Si from potassium silicate incorporated by each cultivar. It ranged from 4.18% to 8.75% (Table 5).

Discussion

In the eight genotypes evaluated, maximum Si concentrations attained without supplemental Si were 380 mg·kg^{-1} in stems, 437 mg·kg^{-1} in flowers, 653 mg·kg^{-1} in roots, and 1295 mg·kg^{-1} in leaves. Leaf Si concentrations ranged from 243 to 1295 mg·kg^{-1}, with five of eight cultivars accumulating less than 500 mg·kg^{-1} (Table 1). These values are similar to leaf Si concentrations previously reported for petunia grown in soilless substrate without Si supplementation. Mattson and Leatherwood (2010) observed 211 mg·kg^{-1} Si in leaves of 'Cascadias Cherry Spark', and we have observed between 263 and 946 mg·kg^{-1} in 'Dreams Pink' in our own studies (Boldt et al., 2018; J. Boldt, unpublished data). However, petunia 'White Madness' grown hydroponically in ultra-purified water had nondetectable foliar concentrations of Si (Frantz et al., 2008). This suggests cultivar selection, growing conditions, and the presence of background Si (e.g., in soilless substrate components, irrigation water, and fertilizers) can affect foliar Si even when supplemental Si is not supplied. Although we minimized background Si from the irrigation water (below detectable limit, or <0.01 mg·L^{-1}) in our study, the substrate components did supply some Si; nonsupplemented plants had accumulated up to 7.25 mg Si by the end of the experiment. Sphagnum peatmoss has been shown to release small amounts of Si into the substrate solution (<1 mg Si per L of water per g of sphagnum peatmoss; Frantz et al. 2010). While our substrate did also contain perlite, a potassium sodium aluminum silicate that contains 73% SiO_2 (34% Si), it is chemically inert and not readily available for plant uptake (Olympios, 1992).

Silicon concentration increased, as expected, in response to Si supplementation,

often in a cultivar-specific response. Maximum Si concentrations attained in our study with 2 mM supplemental Si were 654 mg·kg^{-1} in stems, 1383 mg·kg^{-1} in flowers, 3541 mg·kg^{-1} in leaves, and 10,457 mg·kg^{-1} in roots (Table 1). Foliar Si concentrations ranged from 1248 to 3541 mg·kg^{-1}, which overlaps with concentrations observed previously for petunia 'Dreams Pink' grown in a rice hull-amended soilless substrate (2036 mg·kg^{-1}; Boldt et al., 2018) or grown in a soilless substrate and fertilized with 2 mM Si (894 to 1576 mg·kg^{-1}, J. Boldt, unpublished data). However, the foliar Si concentrations in our current and prior studies were higher than the 506 mg·kg^{-1} observed in petunia 'Cascadias Cherry Spark' drenched weekly with 250 mL of a 100 mg·L^{-1} potassium silicate solution (Mattson and Leatherwood, 2010) or the 197 mg·kg^{-1} Si observed in petunia 'White Madness' grown hydroponically with 2 mM potassium silicate (Frantz et al., 2008). As mentioned previously, these differences may be due to the growing system (soilless substrate vs. hydroponics), Si application method, environmental growth conditions, or cultivar. Other floricultural crops, including low and high Si accumulators, have also exhibited an increase in foliar Si in response to potassium silicate supplementation (hydroponic or drench application), including snapdragon 'Bedding Rocket White' (Frantz et al., 2011), rose (*Rosa hybrida* 'Meipelta') (Gillman et al., 2003), chrysanthemum (*Dendranthema grandiflorum* 'Shinro') (Jeong et al., 2012), gerbera (*Gerbera* hybrid L. 'Acapella') (Kamenidou et al., 2010), sunflower 'Ring of Fire' (Kamenidou et al., 2008, 2011), and zinnia 'Oklahoma Formula Mix' (Kamenidou et al., 2009).

Highest Si concentrations in Si-supplemented plants were localized in roots, followed by leaves, and then lower (but similar) values in flowers and stems (analysis not shown). Few studies have directly compared root and shoot Si concentrations. In low-Si accumulator species, higher root Si concentrations compared with foliar Si concentrations have been observed in tomato (*Solanum lycopersicum* Mill.) grown in 0 and 1 mM Si-amended nutrient solutions (Heine et al., 2005), in petunia 'Dreams Pink' grown in a rice hull-amended soilless substrate (Boldt et al., 2018), and in the eight cultivars evaluated in this study. However, in intermediate and high-Si accumulator species, higher shoot Si concentrations compared with root Si concentrations have been observed in bitter gourd (*Mormodica charantia*) grown in 0 and 1 mM Si-amended nutrient solutions (Heine et al., 2005), in sunflower 'Pacino Gold' grown in a rice hull-amended soilless substrate (Boldt et al., 2018), and in rice grown in 0.5, 1, and 2 mM Si-amended nutrient solutions (Guo et al., 2005).

The trend of detecting higher root Si concentrations (compared with foliar) in low Si accumulators, and lower root Si concentrations (compared with foliar) in Si accumulators following Si supplementation raises a few points for discussion.

First, this trend extends to the magnitude of increase in Si following supplementation. In our study, the largest percent increase in Si was localized in the roots. For comparison, Si concentration increased 173% to 534% in the leaves and 593% to 9161% in the roots. Similarly, other studies have reported increased shoot Si, but to a lesser extent, relative to root Si in petunia 'Dreams Pink' (115% vs. 688%, respectively) and tomato (117% vs. 173%, respectively), both low Si accumulators (Boldt et al., 2018; Heine et al., 2005). In contrast, shoot Si increased more than root Si in bitter gourd (402% vs. 247%, respectively; intermediate Si accumulator) and sunflower (766% vs. 414%, respectively; high Si accumulator) (Boldt et al., 2018; Heine et al., 2005). Plants have traditionally been classified as low, intermediate, or high Si accumulators based on foliar concentrations. Less attention has been given to root Si concentrations, the relative balance between root and shoot Si concentrations across crops, and the relative percent increase in Si when provided supplemental Si; but these factors should not be overlooked.

Second, Si translocation from roots to shoots is regulated by efflux transporters. Variation in transporter activity and density between low and high accumulators may explain why low Si accumulators have higher root Si concentrations than Si accumulators, under supplemented and nonsupplemented conditions, and why they have a greater percent accumulation following supplementation. One hypothesis is that Si efflux may be more tightly controlled in low Si accumulator species and less tightly controlled in Si accumulator species. Presently, however, regulation of Si translocation from roots to aerial portions of the plant is not well characterized in low Si accumulators. Another contributing factor may be transporter density, with fewer transporters correlating to a shift toward higher root (rather than shoot) Si accumulation. Mitani and Ma (2005) observed a decrease in Si transporter density in the plasma membrane of rice, cucumber, and tomato, respectively, which corresponded to foliar Si concentrations.

Last, numerous studies have reported the effectiveness of Si in mitigating foliar fungal pathogens, namely powdery mildews (e.g., *Blumeria graminis* f. sp. *tritici*, *Erysiphe cichoracearum*, and *Sphaerotheca fulginea*), leaf blast (e.g., *Magnaporthe grisea* in rice), and rust (*Puccinia* sp.), in Si accumulators (Bakhat et al., 2018; Chain et al., 2009; Datnoff et al., 1997; Fauteux et al., 2006; Guével et al., 2007; Menzies et al., 1992). Although many greenhouse-grown crops are low foliar Si accumulators, it is possible they, like petunia in this study, accumulate appreciable root Si following supplementation. This may, in turn, provide benefit against commonly encountered root pathogens in ornamental crop production (e.g., *Pythium*, *Phytophthora*, *Rhizoctonia*, and *Thielaviopsis*), and consideration should be given to investigating its effectiveness. For example, Si supplementation reduced fusarium wilt (*Fusarium oxysporum* f. sp. *cubense*) in banana (*Musa acuminata*) (Fortunato et al., 2012) and *P. ultimum* in cucumber (Bélanger et al., 1995), but it had limited effectiveness against *P. aphanidermatum* in bitter gourd (Heine et al., 2007).

The substantial increase in root Si content of plants grown with 2 mM Si altered the distribution of Si between nonsupplemented and supplemented plants. For example, the allocation of Si to flowers decreased from 19.0% to 4.7% in White, respectively, with a corresponding increase to roots, from 2.1% to 12.1% (Table 4). Percent of total plant Si stored in roots increased in five of the eight cultivars, while leaf Si allocation remained unchanged in all cultivars. The increased deposition of Si in Si-supplemented petunia roots (10.5% to 22.6%) was much greater than what has been seen in Si accumulators, where root Si was about 2% of total plant Si accumulation in oat (Jones and Handreck, 1967).

Assuming Si released from the soilless substrate was similar in both the 0 and 2 mM Si treatments, the percent of Si applied as liquid potassium silicate that was taken up and incorporated ranged from 4.18% in Silverberry to 8.75% in Limoncello (Table 5). These were relatively low values, considering the cost of applying potassium silicate. To increase uptake efficiency, a lower concentration could be supplied to low Si accumulators, or Si supplementation could be provided at regular intervals but not at every irrigation.

Plant growth was not visually impacted by Si supplementation, although leaf dry mass increased 4.5%, flower dry mass decreased 31% in two cultivars (Priscilla and Royal Velvet), and root dry mass decreased 9.5% (Table 2). While not a primary objective of this study, we did also analyze foliar macro- and micronutrient concentrations. Leaf nutrient status varied in response to Si supplementation (Supplemental Table 1), but not substantially enough to impact growth and development. Although statistically significant differences between Si treatments were observed for many foliar macro- and micronutrients (all except copper and zinc), values remained within recommended tissue nutrient ranges. Silicon supplementation also influenced leachate pH and EC. Except for Black Cherry, leachate pH was ≈0.2 units greater and EC was 1.3 to 1.8 mS·cm^{-1} lower in Si-supplemented plants, despite adjusting starting pH and EC to similar values in both nutrient solutions. Across cultivars, EC was inversely related to dry mass (r = –0.52 and –0.73 in the 0 and 2 mM Si treatments, respectively).

The eight cultivars in this study, while from one distributor, originated from five different breeding programs (J. Tatro, personal communication). This genetic diversity, and the corresponding variability in Si concentrations observed, suggests there is potential to select plants with enhanced Si uptake or preferred Si distribution. However, it should first be established that enhanced Si

uptake in petunia will correspond with abiotic or biotic stress tolerance. While the addition of Si did not substantially impact plant growth in this study, previous studies have shown that growth differences and benefits of Si supplementation are generally more pronounced when plants are grown in the presence of biotic or abiotic stresses (Chérif et al., 1994; Epstein, 1999; Flora et al., 2019; Frantz et al., 2011).

In summary, a key finding of this study was the appreciable accumulation of Si in roots of a low Si accumulator following Si supplementation, both in terms of Si concentration and the magnitude of increase observed. Leaves contained the highest concentrations of Si in nonsupplemented plants, but this shifted to roots in Si-supplemented plants. This trend was consistent across all eight cultivars evaluated.

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Supplemental Table 1. Foliar macronutrient (% dry mass) and micronutrient (mg·kg^{-1}) concentrations of eight petunia (*Petunia ×hybrida*) cultivars grown in soilless substrate and fertilized with (2 mM) or without (0 mM) supplemental Si, provided as potassium silicate, at every irrigation.

Si	Cultivar[z]	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
0 mM	Black Cherry	5.42 ± 0.07	0.82 ± 0.02	6.55 ± 0.07	1.64 ± 0.03	1.08 ± 0.02	1.02 ± 0.03	34.3 ± 1.8	4.8 ± 1.0	107.6 ± 4.1	76.9 ± 2.7	36.3 ± 1.1
	Limoncello	4.55 ± 0.09	0.52 ± 0.02	7.64 ± 0.27	1.58 ± 0.07	1.09 ± 0.04	1.45 ± 0.10	30.7 ± 1.1	3.0 ± 0.2	108.1 ± 4.4	90.2 ± 4.4	42.4 ± 2.4
	Priscilla	4.59 ± 0.10	0.60 ± 0.02	6.39 ± 0.15	1.34 ± 0.05	0.98 ± 0.02	0.89 ± 0.05	50.0 ± 1.5	2.1 ± 0.1	111.1 ± 4.1	52.2 ± 4.3	30.1 ± 1.8
	Raspberry Blast	3.98 ± 0.08	0.56 ± 0.01	6.77 ± 0.12	0.97 ± 0.03	0.63 ± 0.01	1.36 ± 0.04	35.7 ± 0.6	1.9 ± 0.2	95.6 ± 3.5	50.3 ± 1.6	33.9 ± 1.1
	Royal Velvet	5.14 ± 0.11	0.92 ± 0.03	7.52 ± 0.22	1.35 ± 0.04	0.81 ± 0.02	1.09 ± 0.05	38.8 ± 1.2	3.7 ± 0.2	119.6 ± 4.7	73.8 ± 2.1	31.9 ± 1.2
	Sangria Charm	4.35 ± 0.05	0.78 ± 0.02	6.45 ± 0.11	1.48 ± 0.03	0.90 ± 0.02	1.08 ± 0.03	40.6 ± 1.0	3.0 ± 0.2	104.4 ± 1.3	56.5 ± 1.5	28.9 ± 1.3
	Silverberry	4.32 ± 0.08	0.63 ± 0.02	6.59 ± 0.07	1.10 ± 0.02	0.74 ± 0.01	0.87 ± 0.02	29.2 ± 1.0	6.2 ± 1.3	94.7 ± 1.6	68.6 ± 1.4	32.7 ± 2.0
	White Imp.	4.02 ± 0.07	0.76 ± 0.02	7.91 ± 0.13	1.38 ± 0.03	0.75 ± 0.02	1.53 ± 0.05	46.7 ± 1.0	2.3 ± 0.2	94.8 ± 2.0	97.0 ± 2.5	33.4 ± 1.1
2 mM	Black Cherry	5.35 ± 0.07	0.77 ± 0.02	6.42 ± 0.21	1.76 ± 0.05	1.13 ± 0.02	0.53 ± 0.01	30.3 ± 1.0	5.0 ± 0.5	100.3 ± 3.6	75.8 ± 3.0	40.4 ± 2.2
	Limoncello	4.65 ± 0.08	0.48 ± 0.01	6.39 ± 0.08	1.85 ± 0.05	1.28 ± 0.03	0.44 ± 0.02	27.6 ± 0.9	2.7 ± 0.1	90.3 ± 2.2	80.8 ± 2.5	41.1 ± 2.2
	Priscilla	4.91 ± 0.06	0.69 ± 0.02	6.16 ± 0.10	1.74 ± 0.03	1.29 ± 0.01	0.37 ± 0.01	30.3 ± 3.2	2.4 ± 0.1	107.0 ± 2.9	61.0 ± 2.3	34.2 ± 1.2
	Raspberry Blast	4.03 ± 0.05	0.56 ± 0.01	6.12 ± 0.10	1.26 ± 0.02	0.81 ± 0.01	0.44 ± 0.01	32.9 ± 0.6	3.2 ± 1.0	80.7 ± 3.2	47.8 ± 1.6	31.5 ± 1.6
	Royal Velvet	5.18 ± 0.06	0.86 ± 0.01	6.61 ± 0.12	1.64 ± 0.04	0.94 ± 0.02	0.44 ± 0.01	35.7 ± 0.9	3.0 ± 0.2	112.2 ± 4.2	71.6 ± 2.8	33.4 ± 1.1
	Sangria Charm	4.51 ± 0.10	0.73 ± 0.02	5.61 ± 0.14	1.70 ± 0.05	1.01 ± 0.04	0.39 ± 0.01	33.6 ± 1.7	4.3 ± 1.0	94.0 ± 4.0	55.1 ± 1.9	33.3 ± 2.2
	Silverberry	4.49 ± 0.11	0.60 ± 0.01	6.28 ± 0.10	1.33 ± 0.03	0.90 ± 0.01	0.42 ± 0.02	28.3 ± 1.1	6.0 ± 0.5	88.2 ± 2.1	64.8 ± 2.4	34.7 ± 1.7
	White Imp.	4.08 ± 0.05	0.77 ± 0.01	6.74 ± 0.07	1.59 ± 0.04	0.94 ± 0.02	0.38 ± 0.01	40.0 ± 0.8	1.9 ± 0.1	85.4 ± 3.8	79.5 ± 3.5	30.3 ± 1.1
ANOVA[y]	Cv	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Si	0.0103	0.0491	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.4796	<0.0001	0.0078	0.1707
	Cv × Si	0.3812	0.0003	0.0001	0.0576	<0.0001	<0.0001	<0.0001	0.5422	0.5036	0.0006	0.1297
HSD[x]	Cv	0.24	—	—	0.12	—	—	—	1.8	10.4	—	5.1
	Si	0.08	—	—	0.04	—	—	—	—	3.4	—	—
	Cv × Si	—	0.09	0.70	—	0.11	0.18	6.6	—	—	13.3	—

[z]'Supertunia Black Cherry' (Black Cherry), 'Supertunia Limoncello' (Limoncello), 'Supertunia Priscilla' (Priscilla), 'Supertunia Raspberry Blast' (Raspberry Blast), 'Supertunia Royal Velvet' (Royal Velvet), 'Supertunia Sangria Charm' (Sangria Charm), 'Supertunia Vista Silverberry' (Silverberry), and 'Supertunia White Improved' (White).

[y]Analysis of variance (significant at $P \leq 0.05$).

[x]Tukey's honestly significant difference ($\alpha = 0.05$); hyphen for HSD indicates value not reported, based on which ANOVA effects were significant for the variable of interest.