Silicon Fertilization Affects Growth of Hybrid Phalaenopsis Orchid Liners

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SUMMARY. Experiments were conducted during two different time periods to determine if hybrid phalaenopsis orchid (*Phalaenopsis* spp.) liners accumulate silicon (Si) and if this element can affect liner growth. A total of 800 liners were evaluated and Si fertilization was performed by applying potassium silicate (KSiO₃) as a drench with three treatments (0.5%, 1.0%, and 2.0% v/v) and a control (water, no Si fertilization). The application of KSiO₃ affected overall growth of phalaenopsis orchid liners, where Si content of the plant ranged from 0.5% to 1.7%. Overall, Si applied at 0.5% and 1.0% increased fresh weight and dry weight (DW) and at 1.0% Si significantly increased DW of root, shoot, and whole plant over the control. Increases in DW ranged from 27% up to 118%. Results from the second experiment were similar. Other plant parameters evaluated such as leaf number and size, root number, and length were unaffected by Si application. Although leaves of phalaenopsis orchid liners treated with Si appeared darker green when compared with the control, no significant differences were observed in chlorophyll content of leaves. Reduced growth was observed when 2.0% Si was applied affecting Si tissue concentrations and substrate electric conductivity. The data obtained from this study indicate that hybrid phalaenopsis orchid liners are Si accumulators and that this element influences their growth. Further studies are warranted to address the long-term effects of Si fertilization on the complete life cycle of hybrid phalaenopsis orchids.

Silicon (Si) is the second most abundant element in soil (Epstein, 1999) and its function in plants still represents a subject for continued research (Raven, 2003). A recent study demonstrated that Si plays a role in enhancing the growth and appearance of flowering ornamentals. Silicon fertilization enhanced shoot number, flower number, and dry weight by 25%, 62%, and 66%, respectively, over controls for paper daisies (*Helichrysum adenophorum*) (Muir et al., 1999). Thicker flower stems and a higher proportion of flowers graded Class I were observed in gerbera (*Gerbera jamesonii*) when using 35.1 mg·L⁻¹ Si (Savvas et al., 2002). Similarly, Kamenidou

et al. (2010) reported taller flowers and larger flower diameters in gerbera when sodium silicate foliar sprays were applied at 50 to 100 mg·L⁻¹ and peduncles with increased basal and apical diameters when potassium silicate (KSiO₃) drenches were applied at 200 mg·L⁻¹. Dry weight increases of 6% to 80% were also observed in several ornamental plants when Si was applied as KSiO₃ at 47 mg·L⁻¹ (Chen et al., 2000b, 2000c, 2001). Greater leaf thickness was also observed compared with the control. Thick, straight stems, increased flower and stem diameters, and increased height have been reported in ornamental sunflower (*Helianthus annuus* 'Ring of Fire'), improving quality (Kamenidou et al., 2008). Similarly, variable responses were reported for

several floriculture crops, whereby Si supplementation affected plant height, diameter, fresh weight, dry weight, flower diameter, and leaf thickness (Mattson and Leatherwood, 2010).

Other benefits of Si for crops reported in the literature include disease and insect control, decrease in mineral toxicity concentrations, freeze alleviation, water-use efficiency, improved crop quality and yield (Datnoff et al., 2001; Richmond and Sussman, 2003); and salinity (Epstein, 1999), heavy metal (Neumann and zur Nieden, 2001), and drought (Lux et al., 2002) tolerance.

Among ornamental plants, orchid production has increased over the past 10 years as a result of their popularity, the rapid expansion of the market, and the interest of growers and customers for new and improved hybrids. By 2004, orchids ranked second among potted floriculture crops in the United States with wholesale revenues estimated at \$128 million [U.S. Department of Agriculture (USDA), 2005]. Orchid production reached 8% of the global floriculture trade by 2006 (Martin and Madassery, 2006). In 2005, wholesale numbers added to 18 million potted orchids sold in the United States (USDA, 2006). Phalaenopsis orchids are the most popular potted orchids sold (USDA, 2006) as a result of their short cycle and large hybrid numbers with variety of flower colors and patterns as well as number of flowers and long duration of flowering period. In Holland, potted phalaenopsis orchids are highly valuable and in 2006, wholesale revenues of 173.7 million Euros were reported (Vereniging van Bloemenveilingen in Nederland, 2007).

A previous study used light and electron microscopy to detect Si accumulation in phalaenopsis orchids (Zhou, 1995). Results indicated that the growth of the silica bodies increased by increasing the concentration

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Units

To convert U.S. to Si, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274 × 10 ⁻⁵
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

of calcium silicate (CaSiO_3). The objective of this study was to evaluate the use of three rates of supplemental Si fertilizer on the growth of phalaenopsis orchid liners in a large-scale orchid production nursery. Silicon concentrations were measured to verify that phalaenopsis orchid liners are Si accumulators and if Si accumulation can be detrimental to liners.

Material and methods

PLANT MATERIAL. Phalaenopsis orchid liners (7.5 to 10.0 cm in size) growing in 50-cell plug trays (50 liners per tray) containing sphagnum moss as the substrate were selected as plant material. Two experiments were conducted. The first was performed between Apr. and June 2007 with a second replicated experiment between Jan. and Mar. 2008. A total of 16 trays (800 liners) from a commercial nursery was randomly selected for each experiment. Liners were maintained at an average relative humidity of 62.5% day/85.4% night and an average light intensity of $150 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetic photon flux under 55% shade and natural day length for each experiment period. The average temperature for the first experiment was 29.2/21.7 °C day/night, whereas for the second experiment, the average temperature was 26.4/13.8 °C day/night. Liner trays were irrigated once per week for 12 weeks at a rate of $2.95 \text{ L}\cdot\text{min}^{-1}$ for ≈ 20 min per irrigation cycle using the nursery's reverse osmosis water system as the irrigation water source. Irrigation and fertilization were performed at the same time by drenching trays. All trays were fertilized with $150 \text{ mg}\cdot\text{L}^{-1}$ of nitrogen (N) per irrigation event as 20N-8.7P-16.6K (Peters 20-20-20; J.R. Peters, Allentown, PA).

SILICON TREATMENTS. Silicon was applied as KSiO_3 from PQ Corp. (Valley Forge, PA) consisting of 8.3% potassium oxide (K_2O), 20.8% silicon dioxide (SiO_2), 70.9% water, pH 11.3, in which SiO_2 is the a.i. On the days when fertigation was applied to the plants in the morning, KSiO_3 drenches (v/v) were applied in the afternoon for 4 weeks. Treatments performed in both experiments included: 1) no Si fertilization (water control); 2) 0.5% Si; 3) 1.0% Si (general commercial recommended dose); and 4) 2.0% Si. For the control, only

water was applied using reverse osmosis water at the same rate as described previously. Trays containing 50 phalaenopsis orchid liners were labeled for each treatment and monitored weekly for overall appearance, health, and growth. Treatments were arranged in a completely randomized design with four trays (200 liners) per treatment.

SUBSTRATE AND PLANT TISSUE ANALYSES. Analyses of the sphagnum substrate and liners were performed for Si content before the initiation of the experiment. Analysis of sphagnum for Si was performed at the University of Florida Everglades Research and Education Center Soils Laboratory, Belle Glade. Tissue Si analysis was performed at the University of Florida, Department of Plant Pathology, Gainesville. Sphagnum samples were collected before liners were planted. Sphagnum Si concentrations were determined by the method described by Snyder (1991). Briefly, Si was extracted from medium with 0.5 M acetic acid from a 10:25 medium:extractant (v/v) mix and determined by a Technicon Auto Analyzer (Seal Analytical, Mequon, WI). Determination of Si content in plant tissue (percent by dry weight) followed procedures by Elliott and Snyder (1991). Briefly, 100 mg of plant tissue (leaf blades dried at 75 °C for 48 h) was mixed with 2 mL of 50% hydrogen peroxide (H_2O_2) and 4.5 g of 50% sodium hydroxide (NaOH) in a polyethylene tube. The tubes were covered with loose fitting plastic caps and autoclaved at 138 kPa for 1 h. The contents were then brought to 50 mL with demineralized water. Silicon was extracted by mixing with 35 mL of 20% acetic acid, 10 mL of ammonium molybdate, 5 mL of 20% tartaric acid, and 1 mL of reducing solution (prepared with sodium sulfite, 1-amino-2-naphthol-4-sulfonic acid, and sodium bisulfite). The mixture was allowed to stand for 30 min. Automated colorimetric analysis was then used for determination of tissue Si content. Substrate pH and electric conductivity (EC) were measured using the pour-through method. Briefly, after fertigation, the substrate was drained for 30 min. A saucer was placed under the container and ≈ 100 mL of distilled water was added to the substrate to allow the collection of ≈ 50 mL of extract solution. The pH and EC of

extract samples of substrate solution were measured using a pH meter (Accumet AB 15+; Fisher Scientific, Pittsburgh, PA) and a portable EC meter (Extech EC400; Extech Instruments, Waltham, MA), respectively.

GROWTH PARAMETER EVALUATIONS AND SILICON ANALYSES. Leaf number and size (length $\times$ width) were evaluated weekly using 25 randomly selected liners per tray per treatment (100 total per treatment). Chlorophyll content was estimated weekly using 10 randomly selected liners per tray per treatment (40 total per treatment). Chlorophyll content was estimated using a chlorophyll meter (Minolta SPAD-502; Konica Minolta Sensing, Osaka, Japan). Root number and length and whole fresh weight (FW) and dry weight (DW) were evaluated at the end of each experiment using 25 randomly selected liners per tray per treatment (100 total per treatment). Root and shoot FW were measured separately. Roots and shoots were oven-dried at 75 °C for 48 h and DW was determined. Concentration (percent) Si in liner leaf tissue was assessed at the end of the experiment using two randomly selected liners per tray per treatment (eight total per treatment). Silicon analyses of plant tissue were performed at the University of Florida, Department of Plant Pathology, Gainesville, using the procedures described previously for plant tissue analysis.

STATISTICAL ANALYSIS. Analysis of variance and regression analyses were performed and treatment means were compared using Fisher's protected least significant difference multiple comparison procedure ($P \leq 0.05$) using SAS (Version 9.1; SAS Institute, Cary, NC).

Results and discussion

Initial analyses of sphagnum substrate used for growing phalaenopsis orchid liners in trays indicated Si concentrations of $2 \text{ mg}\cdot\text{L}^{-1}$, whereas the Si concentrations in liner tissues varied from 0.1% to 0.2%. Large variations in Si content have been long reported among species growing in the same soil (Ma and Takahashi, 2002). In general, the Si content in plant tissues may vary from 0.1% to 10% (Epstein, 1999). In this study, the concentrations of Si found in phalaenopsis orchid tissues before receiving supplemental Si fertilizer were

found to be extremely low. The average Si content in liner tissues was 0.18% for Expt. 1 and 0.14% for Expt. 2. However, as Si application increased from 0% to 2%, the Si content in leaf tissue linearly increased in both experiments [Table 1; Fig. 1A ($r^2 = 0.97$ and $r^2 = 0.99$, respectively)].

The initial pH of the substrate was 5.8 and the EC 0.78 dS·m⁻¹. As Si applications increased from 1% to 2%, the pH increased to 6.0, whereas the EC increased to 1.7 dS·m⁻¹. Similar EC increases have been reported in foliage plants fertilized with Si by Chen et al. (2000a).

Silicon can dramatically affect plant growth and development in a number of plant species (Epstein, 1999). The beneficial effects of Si are usually visible in leaves and stems (Ma et al., 2001). Adatia and Besford (1986) reported darker green and thicker leaves in plants of cucumber (*Cucumis sativus*) amended with Si, whereas Chen et al. (2001) observed greater leaf thickness in Si-responsive ornamental plants. Kamenidou et al. (2008) also reported increased thickness and mechanical strength in stems of ornamental sunflowers. In this study, increasing rates of Si did not significantly change leaf number and size or root number and length. In both experiments, we observed that liners under 0.5% and 1.0% Si fertilization had darker green leaves, but no significant differences were observed in chlorophyll content (data not shown).

However, we did observe an increase in DW or FW for whole plant, shoot, and root as Si increased from 0% to 1% and then decreased at the highest Si treatment rate (2%) (Fig. 1). Similar results were observed by Mattson and Leatherwood (2010) in bracteantha (*Bracteantha bracteata*),

lobelia (*Lobelia erinus*), and verbena (*Verbena xhybrida*). Likewise, Chen et al. (2001) reported an increase in DW in 32 ornamental species fertilized with Si, including dendrobium orchid (*Dendrobium nobile*) with an increase in DW of 18% or higher compared with the control. For the phalaenopsis orchids in our study, increases in DW ranged from 27% up to 118% (Table 1).

Growth parameters were reduced when Si fertilization increased to 2.0% Si. Kamenidou et al. (2008) reported that Si treatments resulting in leaf Si concentrations above 1.2% caused flower deformations and stunted growth in sunflower. The conclusion was that the effects of Si fertilization on container-grown sunflowers can be either positive or negative depending on the Si source and applied concentration. In both experiments, one source of Si (KSiO₃) was used and treatments supplemented with 2.0% Si resulted in leaf tissue Si concentrations of 1.34% and 1.67% for Expts. 1 and 2, respectively. Although pH and EC levels measured at the end of each experiment were within normal ranges, the EC of the substrate increased to 1.7 dS·m⁻¹ when 2.0% Si was applied. Therefore, reduced growth parameters in phalaenopsis orchid liners observed in both experiments were possibly related to the applied concentration of Si and the elevated EC value. This indicates that Si rates of 2.0% were detrimental to phalaenopsis orchid liners and fertilization rates ranging from 0.5% to 1.0% provide the best results in growth parameters. In general, plant growth is reduced as EC levels increase in the substrate (Wootton et al., 1981). Judd and Cox (1992) reported that high substrate EC inhibited growth and re-

duced dry weight in new guinea impatiens (*Impatiens hawkeri*). In phalaenopsis, Wang (1998) indicated that high EC promoted larger total leaf area and increased flower number. However, smaller flowers and root injury were observed. Furthermore, shoot FW was reduced at the highest EC, thus agreeing with the results in this study.

The data obtained from both experiments show that phalaenopsis orchid liners are accumulators of Si. The Si concentrations in phalaenopsis orchid leaf tissues increased three- to 10-fold as Si application rates increased as compared with control, thus confirming that phalaenopsis orchid liners are Si accumulators and responsive to Si fertilization. The increase in Si content in phalaenopsis orchid tissues may be the result of an active transport mechanism for Si uptake. We raise this hypothesis based on previous studies as reported by Chen et al. (2001) who demonstrated that foliage plant roots absorb Si from the substrate and translocate a greater fraction of Si to shoots, resulting in Si accumulation. Furthermore, associated with Si accumulation, Si uptake has been reported to be faster than water in some grasses (Gramineae), and an active transport mechanism for Si uptake has been identified, characterized, and described (Ma et al., 2006). Such active uptake mechanism has resulted in a threefold Si content increase in tissues of grasses, therefore providing support to our hypothesis.

To our knowledge, this is the first study using Si fertilization in a commercial orchid nursery demonstrating phalaenopsis orchid liners are Si accumulators with a potential active uptake system. Follow-up studies should examine how Si affects phalaenopsis orchids throughout its

Table 1. Effect of silicon (Si) applied as potassium silicate on percent silicon (Si) leaf tissue content and plant growth parameters of phalaenopsis orchid liners.^z

	Leaf Si (%)		Plant FW (g) ^y		Plant DW (g)		Shoot FW (g)		Shoot DW (g)		Root FW (g)		Root DW (g)	
	Expt. 1 ^x	Expt. 2 ^x	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2
Control	0.18 c ^w	0.14 c	3.7 a	3.2 b	0.30 b	0.07 b	2.4 b	2.6 a	0.19 b	0.04 b	1.3 a	0.6 b	0.10 b	0.03 b
0.5% Si	0.50 b	0.50 b	4.0 a	4.2 a	0.38 b	0.13 a	2.8 a	2.7 a	0.23 b	0.07 a	1.2 a	1.5 a	0.14 b	0.06 a
1.0% Si	0.60 b	0.90 b	4.0 a	4.7 a	0.60 a	0.16 a	2.8 a	2.9 a	0.35 a	0.09 a	1.1 a	1.8 a	0.26 a	0.07 a
2.0% Si	1.30 a	1.70 a	2.3 b	2.0 c	0.25 c	0.14 a	1.6 c	1.4 b	0.15 b	0.08 a	0.7 b	0.6 b	0.10 b	0.06 a

^zFresh weight (FW) and dry weight (DW) of the plants, shoots, and roots were evaluated. Values represent means of eight liners for percent Si in leaf tissue and 25 liners for all other parameters evaluated.

^y1 g = 0.0353 oz.

^xExpt. 1 conducted between Apr. and June 2007. Expt. 2 conducted between Jan. and Mar. 2008.

^wMean separation within columns by Fisher's protected least significant difference multiple comparison procedure at $P \leq 0.05$.

Fig. 1. Effects of silicon (Si) fertilization on phalaenopsis orchid liners supplemented with 0.5%, 1.0%, and 2.0% Si. (A) Si content in leaves. The line represents the relationship between Si concentration in leaves of phalaenopsis orchid liners (y) and concentration of Si (x) applied. (B) Plant dry weight (DW), (C) shoot DW, and (D) root DW. The curves represent the relationship between plant DW, shoot DW, and root DW of phalaenopsis orchid liners (y) and concentration of Si (x) applied, respectively. Each measurement represents means of eight liners for Si content in leaves and 25 liners for plant, shoot, and root DW; 1 g = 0.0353 oz.

complete life cycle, especially because important horticultural traits such as plant growth rate, size, flower initiation, development, and quality might

be enhanced by the uptake of Si. Phalaenopsis orchid liners amended with Si also showed thicker leaves, possibly as a result of cell wall

reinforcement by Si, which could confer plant protection, as discussed by Epstein (1999). Therefore, additional studies on the effects of Si fertilization on reducing abiotic (i.e., temperature, light, and edema) and biotic (i.e., plant disease) stresses are warranted because of the potential positive impact for the orchid industry.

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