EFFECTS OF SILICON FERTILIZATION IN *PHALAENOPSIS*

By

CHARLES WAJSBROT

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2011

To my family, my greatest treasure

ACKNOWLEDGMENTS

I would like to thank Dulce and Gladys from Kerry's Nursery, Inc., for taking care of the plants during the first 28 weeks; also to Kerry's and Dr. McMillan for providing the plants. My appreciation to Luci Fisher and Michelle Tomes as well as Joanne Korvick. I would also like to thank my graduate committee members: Dr. Timothy Broschat, Dr. Wagner Vendrame, and Dr. Kimberly A. Moore for their support and guidance. Thanks for my wife, Dalia, for the help with the statistical analyses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DW	dry weight
EC	electro conductivity
FW	fresh weight
K_m	Michaelis Constant
mg	milligrams
pH	concentration of H ions
rdw	root dry weight
sdw	shoot dry weight
Si	silicon
SME	saturated media extraction
V_{max}	maximal transport rate
VWC	volumetric water concentration

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

EFFECTS OF SILICON FERTILIZATION IN *PHALAENOPSIS*

By

Charles Wajsbrot

August 2011

Chair: Kimberly Moore
Major: Horticultural Science

The effect of Silicon (Si) fertilization applied from week 24 to 34 on *Phalaenopsis* orchids was studied (24 to 28 week was considered the liner stage while weeks 29 to 34 were post liner stage). Three experiments were conducted. In the first experiment, Si was applied from week 29 to 34. In experiment 2, Si was applied from week 24 to 28. In experiment 3, Si was applied from week 24 to 34. In all three experiments Si was applied as 10ml of solution per plant once a week with potassium silicate ($KSiO_3$) as a drench at three different concentrations (0.25, 0.5, 1 mg of Si per plant per application). In experiment 1, *Phalaenopsis* root and shoot dry weight (DW) increased as Si application rate of Si increased from 0 to 0.5 mg, but then decreased. In experiment 2, at week 34 plants that received 1 mg of Si had higher shoot DW than other treatments while root DW was greatest at 0.25 mg of Si. In experiment 3, shoot and root DW increased as Si concentration increased from 0 to 0.5 mg and then decreased from 0.5 mg to 1 mg. In all three experiments, Si concentrations in shoot and root tissues was higher in Si treated plants than control plants. This study indicates that *Phalaenopsis* plants appear to be Si accumulators but further work needs to be conducted as to the long term benefits of Si applications to *Phalaenopsis.*

CHAPTER 1
INTRODUCTION

Silicon (Si) is the second most abundant element after oxygen in soil. Silicon dioxide comprises 50–70% of the soil mass. As a consequence, all plants rooting in soil contain some Si in their tissues. However, the role of Si in plant growth and development was overlooked until the beginning of the 20th century (Richmond and Sussman, 2003). Silicon is not considered an essential element, but Si can reach levels in plants similar to those of macronutrients (Epstein, 1994). Its importance as a nutrient has been demonstrated in numerous studies reporting the beneficial effects of Si supplementation to agronomic crops, such as rice and sugar cane (Datnoff and Snyder, 1991; Ma and Takahashi, 2002; Gao et al., 2004), the dry weight increased from 6% to 80% depending on species (Chen et al., 2000, 2001).

Orchid production has increased for the past 15 years due to their popularity, the rapid expansion of the market, and the interest of growers and customers for new and improved hybrids. Orchid production reached 8% of the global floriculture trade by 2006 (Martin and Madassery, 2006).

Vendrame at al. (2010) reported that *Phalaenopsis* orchids liners accumulate Si. They reported increased liner shoot and root dry weights when Si was applied at 1% concentration as compared to controls. The effects of Si application in *Phalaenopsis* orchids past the liner stage have not been evaluated.

Hypothesis: Silicon applications in *Phalaenopsis* commercial production settings past the liner stage can improve overall plant growth.

Objective: The objective of this experiment was to evaluate the effects of different concentrations of Si in *Phalaenopsis* growth when applied during the 24^{th} to 34^{th} weeks of production in a commercial greenhouse.

CHAPTER 2
LITERATURE REVIEW

Silicon

Silicon is a non-essential element with beneficial effects reported for several crops (Epstein, 1994). It has been characterized as ‘agronomically essential’ for rice (*Oryza sativa* L.). In Japan Si is a requirement for obtaining high yields of rice (Ma and Takahashi, 2002). ‘Quasi-essential’ is another term used to describe Si for its prophylactic role against several stresses observed in a variety of plant species (Epstein and Bloom, 2005).

Silicon is the second most prevalent element within the soil. Although deemed a non-essential nutrient for the majority of plants, Si uptake by plants provides many benefits such as improved pest and pathogen resistance (Ishiguro, 2001; Meyer and Keepeing, 2001), drought tolerance (Lux et al. ,2002), heavy-metal tolerance (Neuman and Nieden, 2001),and improved agricultural crop quality and yield (Korndofer and Lepsch, 2001). As the effects and benefits of Si absorption vary from species to species, and are usually only noted under conditions of biotic and abiotic stress, a comprehensive view of Si plant biology and its role in plant health has not been formed (Richmond & Sussman, 2003).

The current knowledge of Si metabolism in higher plants lags behind that in other organisms, such as diatoms (Zurzolo and Bowler,2001; Falciatore and Bowler,2002), making plant research with Si important. Although abundant, Si is never found in a ‘free’ form and is always combined with other elements, usually forming oxides or silicates (Richmond and Sussman, 2003). Silicon is absorbed by plants in the form of uncharged silicic acid, $Si(OH)_4$, and is ultimately irreversibly precipitated throughout the plant as amorphous silica (SiO_2–nH_2O; also referred to as ‘opal’, silica gel, or phytoliths in higher plants). Although Si is plentiful, most sources of Si are insoluble and not in a plant-available form (Richmond & Sussman, 2003).

Silicon Uptake Mechanism

Plant species differ greatly in Si accumulation, ranging from 0.1% to 10% in shoot dry weight (Epstein, 1994; Ma & Takahashi, 2002).This difference was attributed to the difference in the ability of roots to take up Si (Takahashi et al., 1990). Rice can accumulate Si to the level of up to 10% of shoot dry weight, which is several times higher than that of essential macronutrients such as nitrogen (N), phosphorus (P) and potassium (K) (Savant et al., 1997).

In Ma et al.’s (2001) study of more than 500 plant species, divisions were formed to group the high-, intermediate-, and non Si accumulators. The groupings were based upon measurements (on a dry weight basis) of Si and the Si-to-calcium (Ca) ratio in plant tissue, and illustrate how Si accumulation varies widely between species. After analyzing more than 147 species for Si content, different modes of Si uptake (active, passive and rejective) were suggested to account for accumulator, intermediate and excluder groups, respectively (Takahashi et al.1990). Silicon contents of more than 0.5% suggested that the plants were using an active-uptake or sequestration mechanism to acquire Si (Sangstter and Hodson,1992; Mayland et al,1993). Ma and Takahashi, (2002) showed that there was a characteristic distribution of Si accumulation in the plant kingdom. In higher plants, plants in Gramineae and Cyperaceae show high Si accumulation. Plants in Cucurbitaceae, Urticaceae, and Commelinaceae show intermediate Si accumulation, whereas most other plants species show low Si accumulation. Plants with an active mode of uptake take up Si faster than water, resulting in a depletion of Si in the uptake solution. Plants with a passive mode of uptake take up Si at a rate that is similar to the uptake rate of water; thus, no significant changes in the concentration of Si in the uptake solution are observed. By contrast, plants with a rejective mode of uptake tend to exclude Si, which is demonstrated by the increasing concentration of Si in the uptake solution.

In a study using rice, cucumber and tomato, species that accumulate high, medium and low levels of Si, respectively, it was found that transportation of Si from the external solution to the cortical cells was mediated by a similar transporter with a Km (Michaelis constant-substrate concentration on which the reaction rate is at half maximum)) value of 0.15 mM in all three species (Mitani and Ma, 2005). However, the Vmax (maximum rate achieved at maximum substrate concentration) differed with plant species (i.e. rice > cucumber > tomato), suggesting that the density of the transporter differs among plant species. It seems that this transport process is energy dependent because metabolic inhibitors and low temperature inhibit transport (Mitani and Ma, 2005). Furthermore, the Si concentration in the xylem sap was much higher in rice than it was in cucumber and tomato. Unlike in rice, where xylem loading of Si was mediated by a kind of transporter, xylem loading was mediated by diffusion in cucumber and tomato. These results indicate that xylem loading was the most important determinant for a high level of Si to accumulate in rice shoots. The much lower accumulation of Si in cucumber and tomato might be explained by a lower density of the transporter to transport Si from the external solution to the cortical cells, and a defective or absence of transporter to transport Si from cortical cells to the xylem (Ma and Yamaji, 2006).

Depositions of opal occur throughout the plant in cell walls, cell lumens, trichomes, intracellular spaces, roots, leaves and reproductive organs. It has been thought that these depositions primarily occur through evapotranspiration (Motomura et al., 1996), a hypothesis that is partially based on the fact that the common locations of opal coincide with major evapotranspiration sites. However, there is some evidence that plant macromolecules participate in forming an organic matrix for silica deposition (Harrison,1996;Inanaga and Okasaka,1995;Inanaga et al.,1995). Such molecules have already been identified in other organisms that deposit silica (Kroger et al, 2000; Kroger et al., 2001; Kroger et al., 2002).

Benefits of Silicon

Several studies have indicated a relationship between Si and disease suppression of horticultural crops like cucumber (*Cucumis sativus* L.), miniature roses (*Rosa* sp.), and zinnia (*Zinnia elegans* Jacq.) (Cherif et al., 1992; Datnoff et al., 2006; Dik et al., 1998; Locke et al., 2006; Menzies et al.,1991). Silicon-supplemented melon (*Cucumis melo* L.) contained higher chlorophyll levels and reduced transpiration rates compared with untreated plants (Lu and Cao, 2001). Silicon sprays significantly reduced the occurrence and severity of bract necrosis of poinsettia (*Euphorbia pulcherrima* Willd. ex. Klotzsch), a physiological disorder caused by calcium deficiency. This effect was attributed to reduced evapotranspiration (McAvoy and Bernard, 1996). Silicon is a predominant element in mineral soils. However, in greenhouse floriculture production, most plants are cultivated using soilless substrates in which Si availability is limited (Voogt and Sonneveld, 2001).

Some beneficial effects of Si may occur even if Si is not taken up in appreciable amounts (Voogt and Sonnenfeld 2001). Silicon can also alleviate imbalances between zinc and phosphorus supply (Marschner et al. 1990).

Silicon plays an important role in increasing the resistance of plants to pathogens such as blast on rice (*Oryza sativa* L.) (Datnoff et al.,1997). Silicon is effective in preventing lodging in rice by increasing the thickness of the culm wall and the size of the vascular bundles (Shimoyama, 1958), thereby enhancing the strength of the stems. Silicon also alleviates the effects of other abiotic stresses including salt stress, metal toxicity, drought stress, radiation damage, nutrient imbalance, high temperature, and freezing (Epstein, 1999; Ma and Tahakashi, 2002; Ma, 2004). Savvas et al. (2002) reported that gerbera (*Gerbera jamesonii*) plants amended with Si in the nutrient solution had significantly thicker flower stems and a higher proportion of flowers graded Class I. Moreover, Richter (2001) revealed that vase life of different gerbera cultivars could be extended and the number of flowers with bent neck could be reduced by supplying plants with Si. Foliar and root applications of Si reduced the number of colonies of powdery mildew developing in cucurbits such as cucumber (*Cucumis sativus* L.), muskmelon (*Cucumis melo* L.) and zucchini squash (*Cucurbita maxima* Duch.) (Menzies et al., 1992). Powdery mildew colony number in grape (*Vitis vinifera* L.) leaves was reduced to 11% of the control leaves when foliar Si sprays were used (Bowen et al., 1992). Powdery mildew development in *Arabidopsis thaliana* was observed rarely when plants were watered with a nutrient solution containing soluble Si (Ghanmi et al., 2004). Application of Si to soil or in hydroponic cultivation resulted in suppression of powdery mildew in the highly susceptible 'Toyonoka' strawberry (*Fragraria fresco*) cultivar (Kanto et al., 2004; 2006). Belanger et al. (2003) found that Si amendments to the soil mix or added to the nutrient solution protected wheat (*Triticum aestivum*) from powdery mildew. The protective role of Si has been attributed to the accumulation of Si in the leaves, which creates a physical barrier to pathogens (Adatia and Besford, 1986; Samuels et al., 1991).

Alternatively, Si may have a more active role by inducing the plant's own defense mechanisms (Fauteux et al., 2006; Remus-Borel et al., 2005; Rodrigues et al., 2004; 2005). For instance, Fawe et al. (1998) demonstrated that the addition of Si to cucumber (*Cucumis sativa L.*) plants enhanced resistance to powdery mildew by increasing antifungal activity in the plant. Similarly, Liang et al. (2005) and Rodrigues et al. (2005) found that root-applied Si enhanced the activity of pathogenesis-related (PR) proteins and thus increased resistance to pathogen attack on cucumber and rice (*Oryza sativa*) plants, respectively.

In the Netherlands, Si supplementation of the hydroponic solution was recommended for the production of crops like cucumber (*Cucumis sativus* L.) and roses (*Rosa sp*.) to avoid negative effects of Si deprived plants (De Kreij et al., 1999). Addition of Si to recirculated nutrient solution in a closed hydroponic system, ameliorated most of the negative effects of recirculation on cut rose production, resulting in better stem quality (Ehret et al., 2005). Silicon supplementation in the form of external foliar treatments has proven to increase pathogen resistance of plant species that do not take up Si efficiently (Bowen et al,1992; Menzies et al,1992). Silicon is an element that does not cause severe injury to plants when present in excess and can provide multiple benefits (Ma et al,2001).

Orchids

In many orchid plants, silica bodies have been observed as longitudinal rows along the veins of the leaves. They were spherical or conical in shape depending on the species (Zhou,1995). After it is taken up, Si is translocated to the shoot in the form of monomeric silicic acid (Casey et al.,2003; Mitani et al.,2005) and is finally deposited on cell wall material as a polymer of hydrated, amorphous silica, Vendrame et al.(2010) reported that *Phalaenopsis* are Si accumulators.

According to the AOS (American Orchid Society) in the US, there are over 130 reported plant diseases affecting one or more orchid genera, caused by pathogens such as nematodes, fungi, bacteria, and viruses. Several studies have reported relationship between Si and disease suppression. However, limited studies report on the use of supplemental Si applications as it relates to disease suppression in *Phalaenopsis.* A previous study by Vendrame et al. (2010) indicates that Si has a potential for improving *Phalaenopsis* growth and development.

CHAPTER 3
MATERIAL AND METHODS

Phase I (Weeks 24 to 28)

Eight hundred *Phalaenopsis* plugs from germination bottles were randomly planted as 25 plugs per 12 in X12 in (25 cm X 25 cm) tray filled with a 60% ½ in pine bark and 40% coconut coir medium (by volume). Plants were grown for 28 weeks at Kerry's Bromeliads and Orchids Inc. (Homestead, FL). When the media reached 1% VWC plants were irrigated with 20N-8.7P-16.6K (Peters 20-20-20; J.R. Peters, Allentown, PA).

After 28 weeks, the 800 plants were divided into four groups of 200 plants. Silicon was randomly applied at rates of 0, 0.5, 1 or 2 times the dilution suggested by the supplier to each group of 200 plants, respectively 0, 0.25, 0.5, 1 (mg) of Si (Table 3-1). Each plant received 10 ml of solution once a week for 4 weeks, from week 24 to 28. Silicon was applied as AgSil 25 PQ Corp. (Valley Forge PA) starting on January12, 2011 (week 24). This product supplied Si as $KSiO_3$ consisting of 6.9% of K and 9.7% of Si, 70.9% water, pH 11.3. The average light intensity in the greenhouse during phase I under the 55% shade was 150 $\mu mol.m^{-2}$ with an average temperature of 17.68^{o}C (63.83^{o} F) and an average RH of 83%.

At the end of phase I (week 28), 25 plants per group were harvested to record the length and width of the longest leaf, length of the longest root, root and shoot fresh weight (FW) and dry weight (DW). Shoots and roots were oven-dried at 75^{o}C for 48 H and DW was determined. Root and shoot Si was determined by Florida Spectrum Environmental Inc (Ft Lauderdale, FL) to determine the amount of total Si in these tissues. Media samples were also collected at this time and sent to Florida Spectrum

Environmental Services Inc.(Ft Lauderdale, FL) to determine extractable Si concentrations according to their method EPA 6010B. One substrate sample was collected per group to determine pH and electrical conductivity (EC). Substrates were extracted with distilled water using the saturated media extraction method (SME). The pH was measured using a pH meter Milwaukee (Rocky Mount) SM 100 and EC using a Milwaukee (Rocky Mount, NC) EC meter T 75.

Phase II (Weeks 29 to 34)

At week 29 (February 14, 2011) plants were transferred from Kerry's Nursery Inc. to the University of Florida's Ft Lauderdale Research and Education Center (FLREC) teaching greenhouse. The remaining 700 (100 were harvested for analysis) plants from phase I were divided into three experiments (Table 3-2). For experiment 1, plants that did not receive Si during phase I randomly received 0, 0.5, 1, or 2 x the recommended rate, respectively 0, 0.25, 0.5, 1 (mg) of Si for weeks 29 to 34. Experiment 2 consisted on plants that received 0.5, 1, or 2x the Si during phase I did not receive any additional Si during weeks 29 to 34. Experiment 3 consisted of plants that received 0.5, 1, and 2x Si in phase I and continued to receive the same rates for weeks 29 to 34. Average light intensity in the greenhouse at FLREC was 240 $\mu mol.m^{-2}$ with an average temperature of was 22.1^{o}C (71.8^{o} F) and average RH% of 73%.

Plants received fertigation once a week with 11N-35P-15K ("orchid bloom booster"; Sun Bulb Company Inc., Arcadia, FL). Starting on February 17, 2011(week 29) AgSil25 was applied once a week, as shown in table 3-2. At week 34, 10 plants were harvested per treatment to determine DW, and Si % in root and shoots. Tissue samples were sent to Florida Spectrum Environmental Inc for analysis.

Statistical Methods

Phase I

The following nine variables were measured at the end of Phase I(week 28): Root fresh weight (FW) and dry weight (DW), shoots FW and DW, length and width of longest leaves, length of roots and total number of roots and shoots. For each variable, one ANOVA analysis was performed to evaluate the effect of treatment group (Si solution concentrations). Mean separations were performed using the Tukey method. The dose-response relationship between treatment group and each variable, if any, was evaluated using a quadratic equation, and the R^2 coefficient was used to measure the quality of this adjustment.

Phase II

Root and shoot DW and FW were measured at week 34. Plants from phase I were divided into three experiments (Table 3-2). Data was analyzed separately for each experiment using ANOVA, Tukey mean separation and quadratic regression equations.

Table 3-1. Concentrations of Silicon (Si) applied to 200 *Phalaenopsis* orchid liners from week 24 to 28 at Kerry's Nursery Inc (Homestead FL), and from week 29 to 34 at University of Florida, Ft Lauderdale. Silicon was applied at 0, 0.25, 0.5, 1 (mg) . Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA)

	0 no Si	0.5X 1/2 commercial recommendation	1X commercial recommendation	2X twice commercial recommendation
mg of Si per 10 ml of the solution	0	0.25	0.5	1.0
ml of solution per plant per application	0	10	10	10
ml of AgSil25 per liter to mix	0	20	40	80
mg of Si per application that the plant is receiving	0	0.25	0.5	1.0

Table 3- 2. Treatment combinations for applications of Silicon (Si) during weeks 29 to 34 of *Phalaenopsis* growth at the University of Florida Fort Lauderdale greenhouse. Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA) at 0 mg, 0.25 mg, 0.5 mg, and 1mg per application. These treatments were randomly applied to 175 plants per experiment based on the application of Si applied from 24 to 28 weeks and then Si application from 29 to 34 weeks.

Treatment	Phase I (24-28 weeks)	Phase II (29 to 34 weeks)
	Experiment 1 Si(g)	
1	0	0
2	0	0.25
3	0	0.5
4	0	1
	Experiment 2 Si(g)	
5	0.25	0
6	0.5	0
7	1	0
	Experiment 3 Si(g)	
8	0.25	0.25
9	0.5	0.5
10	1	1

CHAPTER 4
RESULTS AND DISCUSSION

Phase I (Weeks 24-28)

According to Kamenidou et al. (2008), the effect of Si supplements on sunflower height and flower diameter varied depending on Si source and concentration. During phase I, as Si increased from 0 to 0.5 mg, *Phalaenopsis* root and shoot FW, root and shoot DW, width of longest leaf and root length increased and then decreased. (Figs. 4-1, 4-2, and 4-3). Vendrame et al. (2010) reported similar results during liner production.

Earlier reports provided a wide range of acceptable EC for *Phalaenopsis* ranging from 0.63 and 3.8 $dS \cdot m^{-1}$(Wang 1996; Wang and Gregg, 1994). In general, plant growth is reduced as EC levels increase in the substrate (Wootton et al.,1981).

The EC in the substrate increased as the levels of Si applied increased (Table 4-1). It is possible that high EC when using 1mg of Si per application contributed to poor growth in *Phalaenopsis* plants. However, the substrate's pH appeared to be within the acceptable range (Table 4-1).

Silicon concentrations in the root and shoot tissue increased as Si application increased from 0 to 1mg (Table 4-2). The concentration of Si was higher in roots than it was in shoots (Table 4-2). This confirms that *Phalaenopsis* is indeed a Si accumulator species. Vendrame et al. (2010) also reported that Si concentration in roots and shoots increased as Si application rate increased.

Phase II (Weeks 29 -34)

Experiment 1: Plants did not receive any Si during 24 to 28 weeks but received Si during 29 to 34 weeks. As Si concentration increased from 0 to 1 mg, *Phalaenopsis* root and shoot dry weight increased (Fig 4-4). Silicon concentrations in root and shoot tissues increased as application rate of Si increased from 0 to 0.5 mg, and then decreased (Table 4-2).

Experiment 2: Plants received Si weeks 24 to 28 but did not receive any additional Si from weeks 29 to 34. At week 34, plants that received 1 mg of Si during weeks 24 to 28 had greatest shoot DW, but root DW was greatest at 0.25 mg (Fig 4-5). Silicon concentration in the roots increased as application rate increased from 0 to 1 mg (Table 4-2). However, Si concentrations in the shoots increased as application rate increased from 0 to 0.25 mg and then decreased (Table 4-2).

Experiment 3: Plants received Si at 0.25 mg, 0.5 mg, and1 mg from week 24 to 34 As observed during the first 4 weeks, shoot and root DW increased as Si concentration increased from 0 to 0.5 mg and then decreased (Fig 4-6). Unlike the data collected at week 28, where Si in tissues linearly increased as application rate increased, Si concentrations in root and shoot tissues was greatest for plants treated with 0.25 mg and 0.5 mg respectively at week 34 (Table 4-2).

As reported by Vendrame et al. (2010) reduced growth parameters in *Phalaenopsis* orchid liners were possibly related to the applied concentration of Si and the elevated EC value. Although substrate EC levels appeared to be in an acceptable range for most ornamentals, we did observe symptoms of salt damage at the higher application rates of Si. It appears that the most adverse effect from Si application during liner phase was due to increased EC levels. According to Wang (1998), the most obvious adverse effect of increasing salinity was the degree of root injury. In this study roots died, suggesting that *Phalaenopsis* may be more susceptible to high salinity concentrations than previously described.

Another possible explanation for decreased *Phalaenopis* growth at high Si levels could be an induced magnesium (Mg) defeiciency). According to Kamenidou et al. (2009), apparent antagonism between K^+ supplied by potassium silicate sources lead to Mg deficiency in sunflower (*Helianthus annuus* L.) and zinnia (*Zinnia elegans*). We did not observe any symptoms of Mg deficiency in this experiment.

Because we did not run a K control, it is possible that the improved growth of *Phalaenopsis* in this study was due to K fertilization and not Si. Silicon supplementation effects on greenhouse produced sunflowers can vary from beneficial to detrimental depending on the applied source and concentration of Si (Kamenidou et al.,2008).

Table 4-1. Substrate pH, electrical conductivity (EC) and Silicon (Si) at week 28. *Phalaenopsis* liners were treated from week 24 to 28 with AgSil 25 PQ Corp. (Valley Forge PA) applied at 0, 0.25, 0.5 or 1 (mg) plant/week. Silicon concentrations in the substrate were determined by Florida Spectrum Environmental Inc while pH and EC were determined on the extracted solution from the saturated media extraction method. One sample per treatment

Si Treatment	pH	EC (dS/m)	Si (mg/Kg)
0	5.8	2.58	72.2
0.25	6.1	2.66	81.6
0.5	6.9	2.79	90.9
1	7.2	2.89	133.0

Table 4-2. Concentration of Silicon (Si) in *Phalaenopsis* root and shoot tissue at week 28 and at week 34. During weeks 24 to 28, plants received Si applied at 0, 0.25, 0.5 or 1 (mg) plant/week. During weeks 29 to 34 plants were divided into three experiments. In experiment 1 plants did not receive Silicon (Si) during liner production (weeks 24 to 28) but received Si applied at 0,0.25,0.5 or1 (mg) plant/week during weeks 29 to 34. In experiment 2 plants received Si during liner production (weeks 24 to 28) at 0, 0.25, 0.5 or 1 (mg) plant/week but did not receive any Si application during weeks 29 to 34. In experiment 3, plants received Si during liner production (weeks 24 to 28) as well as from weeks 29 to 34 at 0, 0.25, 0.5 or 1 (mg) plant/week. Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA). Concentrations of Si in the tissue were determined by Florida Spectrum Environmental Inc .10 plants per treatment were analyzed

Week 24 to 28	Week 29 to 34	Root Si (mg/Kg)	Shoot Si (mg/Kg)
0		109.0	73.3
0.25		137.0	114.0
0.5		135.0	106.0
1		198.0	145.0
Exp 1-0	0	110.0	77.7
0	0.25	229.0	127.0
0	0.5	199.0	102.0
0	1	187.0	98.8
Exp 2-0	0	110.0	77.7
0.25	0	168.0	120.0
0.5	0	156.0	90.1
1	0	194.0	89.2
Exp 3-0	0	110.0	77.7
0.25	0.25	190.0	124.0
0.5	0.5	181.0	126.0
1	1	167.0	81.0

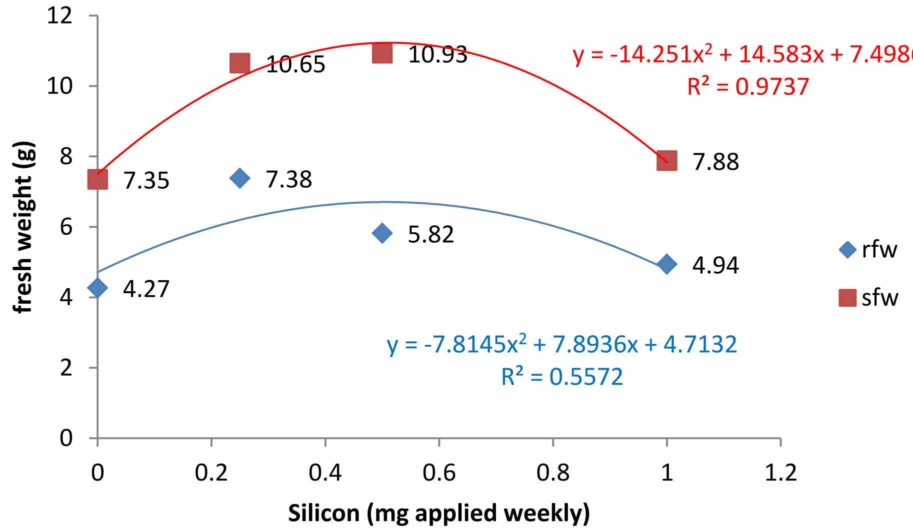

Figure 4-1. Root (rfw) and shoot (sfw) FW at week 28 after *Phalaenopsis* liners had received Silicon (Si) applied at 0 ,0.25, 0.5 or 1 (mg) per plant/week from week 24 to 28 (phase I). Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA). Data are means of 25 plants.

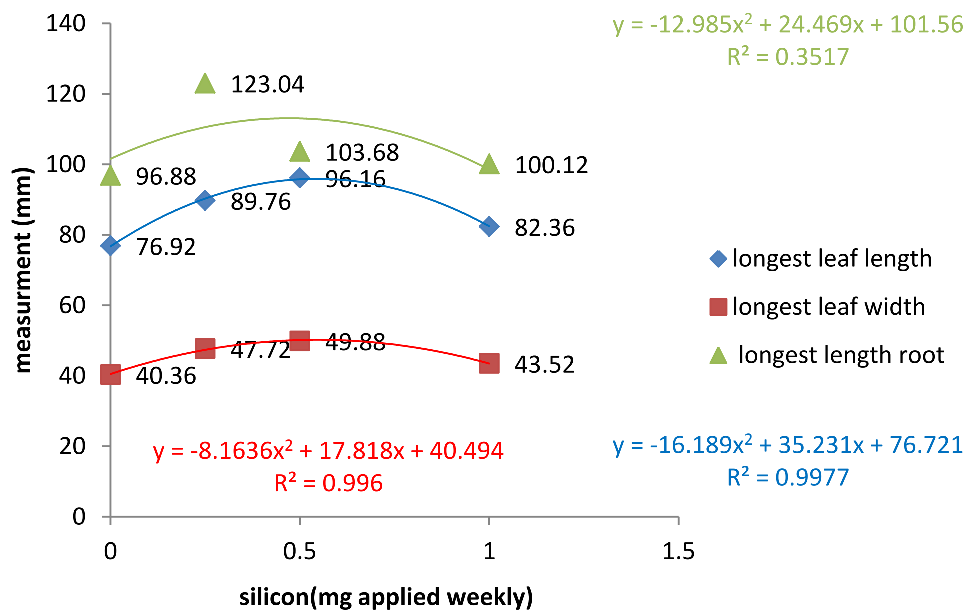

Figure 4-2. Length and width of largest leaf and length of longest root of *Phalaenopsis* liners that had received Silicon (Si) applied at 0, 0.25 ,0.5 or1 (mg) per plant/week from week 24 to 28 (phase I). Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA). Data are means of 25 plants.

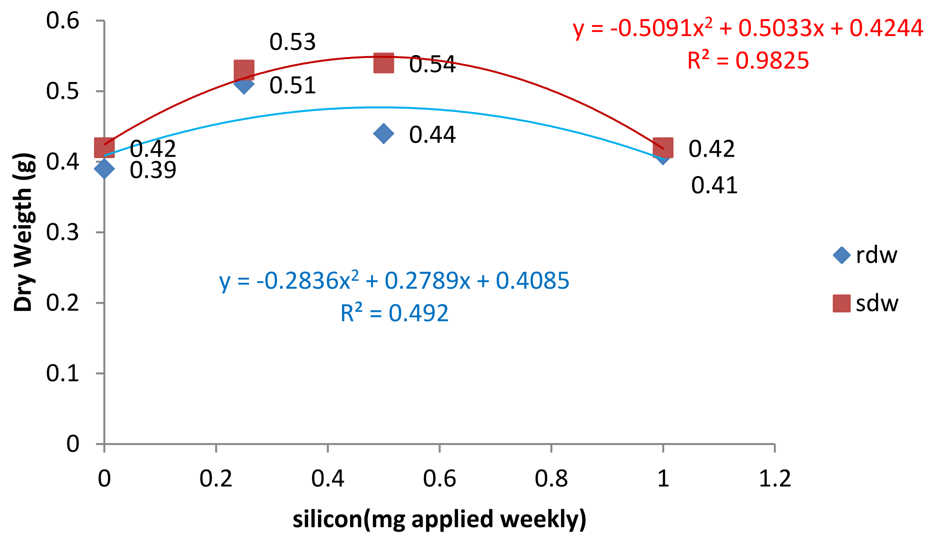

Figure 4-3. Root (rdw) and shoot (sdw) DW at week 28 after *Phalaenopsis* liners had received Silicon (Si) applied at 0, 0.25, 0.5 or 1 (mg) per plant/week from week 24 to 28 (phase I). Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA). Data are means of 25 plants.

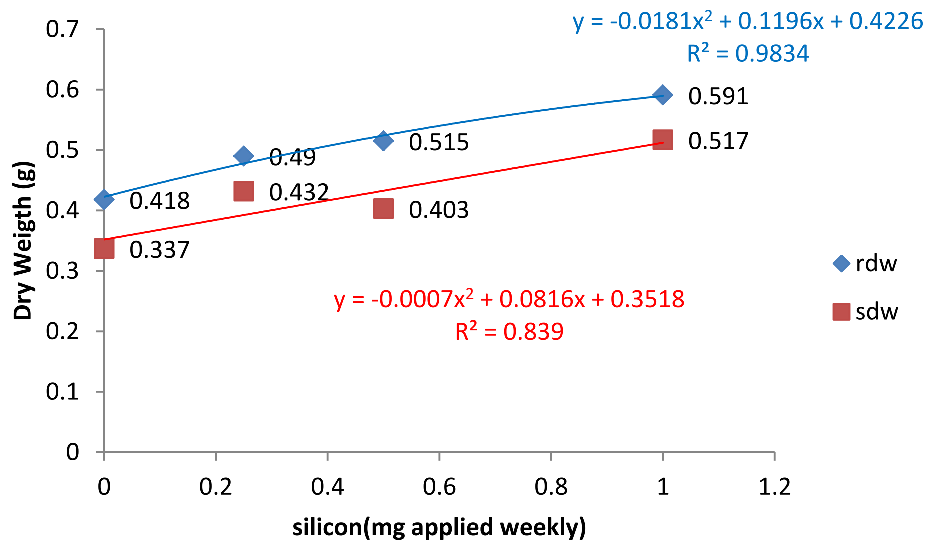

Figure 4-4. Root (rdw) and shoot dry weight (sdw) at week 34 of *Phalaenopsis* plants that did not receive Silicon (Si) during liner production (weeks 24 to 28) but received Si applied at 0, 0.25, 0.5 or 1 (mg) per plant/week during weeks 29 to 34 (Experiment 1). Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA). Data are means of 10 plants.

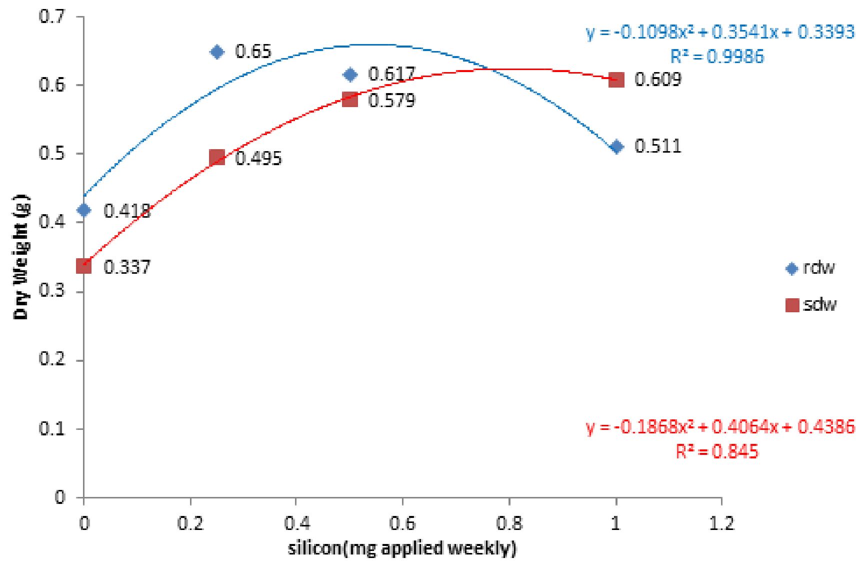

Figure 4-5. Root (rdw) and shoot dry weight (sdw) at week 34 of *Phalaenopsis* plants that received Silicon (Si) during liner production (weeks 24 to 28) at 0,0.25,0.5 or1 (mg) per plant/week but did not receive any Si application during weeks 29 to 34(Experiment 2). Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA). Data are means of 10 plants.

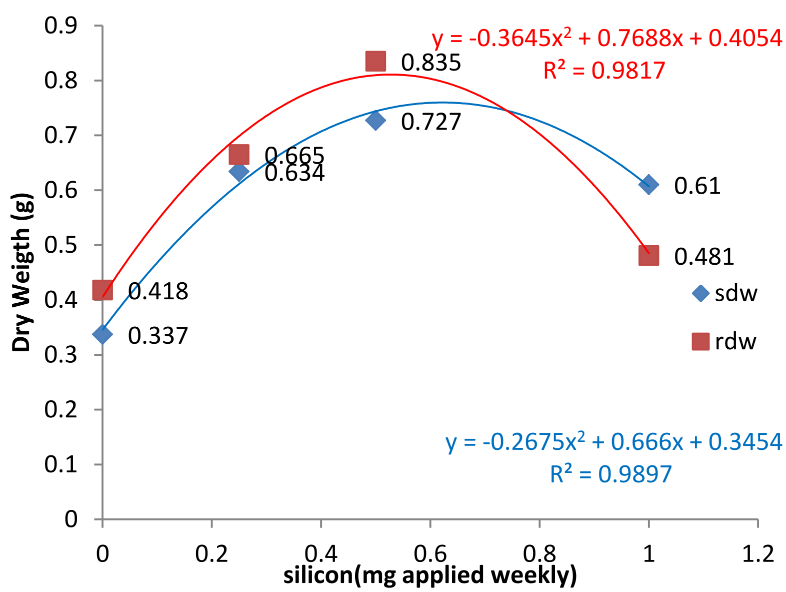

Figure 4-6. Root (rdw) and shoot dry weight (sdw) at week 34 of *Phalaenopsis* plants that received Silicon (Si) during liner production (weeks 24 to 28) as well as from weeks 29 to 34 (Experiment 3) at 0, 0.25, 0.5 or1 (mg) per plant/week. Silicon was supplied as AgSil 25 PQ Corp. (Valley Forge PA). Data are means of 10 plants.

CHAPTER 5
CONCLUSION

Based on the results of this study, the addition of Si to *Phalaenopsis* indicates that *Phalaenopsis* appear to accumulate Si and support the work reported by Vendrame et al (2010). Silicon appears to have a positive impact on overall growth. The liner stage appears to be very sensitive to over application of Si due to increased salinity concentrations in the growing substrate. Past the liner stage plants seem to be less sensitive to salinity. However, as salinity increases more roots die (Wang, 1998). At week 34 plants, from experiment two showed no negative effects of salinity, while still showing Si accumulation in the root. This suggests a higher tolerance to salinity for *Phalaenopsis* plants at a more advanced stage of vegetative growth. According to Tamai and Ma 2003, the uptake of Si involves at least two processes; the transport of Si from external solution to cortical cells, and from cortical cells to the xylem. Roots died possibly compromising Si uptake and consequently the final DW of tissue. The higher concentration of Si in the roots as compared to the shoots could indicate a higher concentration of Si transporters from the external solution to the cortical cell than that of transporters to xylem cells. It seems that at the liner stage Si has to be applied in a lower concentration to avoid salinity damage. Further studies need to be performed to determine recommended levels of Si that prevent salinity damage, but also promote positive growth results. Additional studies on the benefits of Si in flower development and quality are also warranted.

LIST OF REFERENCES

Adatia, M. H., and R. T. Besford. 1986. The effects of Si on cucumber plants grown in recirculating nutrient solution. Annals of Botany 58: 343–351.

Belanger, R. R., N. Benhamou, and J. G. Menzies. 2003. Cytological evidence of an active role of Si in wheat resistance to powderymildew (*Blumeria graminis* f. sp. *tritici*). Phytopathology 93: 402–412.

Bowen, P., J, Menzies, D. Ehret, L. Samuels, and A. D. M. Glass. 1992. Soluble Silicon sprays inhibit powdery mildew development on grape leaves. J. Amer. Soc. Hort. Sci.117: 906–912

Casey, W. H., S.D. Kinrade, C.T.G. Knight, D.W. Rains, and E. Epstein. 2003. Aqueous silicate complexes in wheat (*Triticum aestivum* L.). Plant Cell Environ. 27: 51-–54.

Cherif, M., N. Benhamou, J.G. Menzies, and R.R. Belanger. 1992. Silicon induced resistance in cucumber plants against *Pythium ultimum*. Phys. Mol. Plant Path. 41:411–425.

Chen, J., R.D. Caldwell, C.A. Robinson, and R. Steinkamp. 2000. Let’s put Silicon back into soil-Part I. Greenhouse Production News 10:48-51.

Chen, J., R.D. Caldwell, C.A. Robinson, and R. Steinkamp. 2001. Let’s put Silicon back into soil-Part II. Greenhouse Production News 11:44-47.

Datnoff, L.E., and G.H. Snyder. 1991. Effect of calcium silicate on blast and brown spot intensities and yields of rice. Plant Dis. 75 (7): 729–732.

Datnoff, L.E., C.W. Deren, and G.H. Snyder. 1997. Silicon fertilization for disease management of rice in Florida. Crop Prot. 16(6):525-531.

Datnoff, L.E., T.A. Nell, R.T. Leonard, and B.A. Rutherford. 2006. Effect of Silicon on powdery mildew development on miniature potted rose. Phytopathology 96:S28. (abstr.).

De Kreij, C., W.Voogt, and R. Baas. 1999. Nutrient Solutions and Water Quality for Soilless Cultures. Research Station for Floriculture and Glasshouse Vegetables (PBG) Brochure, Naaldwijk, The Netherlands, p. 196.

Dik, A.J., M.A. Verhaar, and R.R. Belanger. 1998. Comparison of three biological control agents against cucumber powdery mildew (*Sphaerotheca fuliginea*) in semi-commercial scale glasshouse trials. Eur. J. Plant Path. 104:413–423

Ehret, D.L., J. G. Menzies, and T. Helmer. 2005. Production and quality of greenhouse roses in recirculating nutrient systems. Sci. Hort. 106, 103–113.

Epstein, E. 1994. The anomaly of Silicon in plant biology. Proc. Nat. Acad. Sci. USA 91, 11–-17.

Epstein, E. 1999. Silicon. Annu. Rev. Plant Phys. Plant Mol. Biol. 50:641-664.

Epstein, E., and A. Bloom. 2005. Mineral Nutrition of Plants: Principles and Perspectives, 2nd ed. Sinauer Associates, Sunderland, MA.

Falciatore, A. and C. Bowler. 2002. Revealing the molecular secrets of marine diatoms. Ann. Rev. Plant Bio. 53: 109-130.

Fauteux, F., F. Chain, F. Belzile, J. G. Menzies, and R. R. Belanger. 2006. The protective role of Si in the *Arabidopsis*—powdery mildew pathosystem. Proc. Nat. Acad. of Sci. 103: 17554–17559.

Fawe, A., M. Abou-Zaid, J. G. Menzies, and R. R. Belanger. 1998. Simediated accumulation of flavonoid phytoalexins in cucumber. Phytopathology 88: 396–401.

Gao, X., C. Zou, L. Wang, and F. Zhang. 2004. Silicon improves water use efficiency in maize plants. J. Plant Nutr. 27 (8), 1457–1470.

Ghanmi, D., D. J. McNally, N. Benhamou, J. G. Menzies, and R. R. Belanger. 2004. Powdery mildew of *Arabidopsis thaliana*: A pathosystem for exploring the role of Silicon in plant-microbe interactions. Phys. Mol. Plant Path. 64(4): 189–199.

Harrison, C.C. 1996. Evidence for intramineral macromolecules containing protein from plant silicas. Phytochem. 41:37-42.

Inanaga S, A. Okasaka, and S.Tanaka. 1995. Does Silicon exist in association with organic compounds in rice plants? Soil Sci. Plant Nutr. 41:111-117.

Inanaga S, A. Okasaka. 1995. Calcium and Silicon binding compounds in cell walls of rice shoots. Soil Sci. Plant Nutr. 41:103-110.

Ishiguro, K. 2001. Review of research in Japan on the roles of Silicon in conferring resistance against rice blast. In: Datonoff L, Korndorfer G, Synder G (eds). Silicon in Agriculture. Elsevier Science. New York.

Kamenidou,S.,T.J. Cavins, and S. Marek. 2008. Silicon supplement affect horticultural traits of greenhouse-produced ornamental sunflowers. HortScience 43(1):236-239.

Kamenidou, S., T.J. Cavins, and S. Marek.2009. Evaluation of Si as a supplement for greenhouse zinnia production. Sci. Hort. 119:297-301.

Kanto, T., A. Miyoshi, T. Ogawa, K.Maekawa, and M. Aino. 2006. Suppressive effect of liquid potassium silicate on powdery mildew of strawberry in soil. J. Gen. Plant Path. 72: 137–142.

Kanto, T., A. Miyoshi, T. Ogawa, K. Maekawa, and M. Aino. 2004. Suppressive effect of potassium silicate on powdery mildew of strawberry in hydroponics. J. Gen. Plant Path. 70: 207–211.

Korndorfer, G.H., and I. Lepsch.2001. Effect of Silicon on plant growth and crop yield. In: Datonoff L, Korndorfer G, Synder G (eds). Silicon in Agriculture. Elsevier Science. New York.

New York, Kroger, N., R.Deutzmann, C. Bergsdorf, and M. Sumper. 2000. Species specific polyamines from diatoms control silica morphology. Proc Nat.l Acad Sci 97:14133-14138.

Kroger, N., R. Deutzmann, and M. Sumper. 2001. Silica-precipitating peptides from diatoms. The chemical structure of silaffin-A from Cylindrotheca fusiformis. J. Biol Chem 276:26066-26070.

Kroger, N., S. Lorenz, E. Brunner, and M. Sumper. 2002. Self-assembly of highly phosphorylated silaffins and their function in biosilica morphogenesis. Science 298:584-586.

Liang, Y. C., W. C. Sun, J. Si, and V. R¨omheld. 2005. Effects of foliar- and root-applied Silicon on the enhancement of induced resistance to powdery mildew in *Cucumis sativus*. Plant Path. 54: 678–685.

Locke, C., M. Omer, A.K. Widrig, and C.R. Krause. 2006. Delay of expression of powdery mildew on zinnia grown hydroponically in Hoagland's solution fortified with Si. Phytopathology 96:S70. (abstr).

Lu, G., and J. Cao. 2001. Effects of silicon on earliness and photosynthetic characteristics of melon. Acta Hort. Sci. 28:421-424.

Lux, A., M. Luxova, T. Hattori, S. Inanaga, and Y. Sugimoto. 2002. Silicification in sorghum (*Sorghum bicolor*) cultivars with different drought tolerance. Phys. Plant 115:87-92.

Ma, J.F., Y. Miyake, E. Takahashi. 2001. Silicon as a beneficial element for crop plants. In: Datonoff L, Korndorfer G, Synder G (eds). Silicon in Agriculture. Elsevier Science. New York.

Ma, J. F., and E. Takahashi. 2002. Soil, Fertilizer, and Plant Si Research in Japan Elsevier, Amsterdam.

Ma, J.F. 2004. Role of Silicon in enhancing the resistence of plants to biotic and abiotic stresses. Soil Sci. Plant Nutr. 50:11-18

Ma, J.F., and N. Yamaji. 2006. Silicon uptake and accumulation in higher plants. Trends Plant Sci. 11 (8): 392-397.

McAvoy, R.J., and B.B. Bernard. 1996. Silica spray reduce the incidence and severity of bract necrosis in poinsettia. HortScience 31:1146-1149.

Marschner, H., H. Oberle, I. Cakmak, and V. Romheld. 1990. Growth enhancement by Silcon in cucumber (*Cucumis sativus*) plants depends on imbalance in phosphorus and zinc supply. Plant and Soil 124:211–219

Martin, K.P. and J. Madassery. 2006. Rapid *in vitro* propagation of *Dendrobium* Hybrids through direct shoot formation from explants, and protocorm-like bodies. Sci. Hort. 108:95-99.

Mayland, H.F., D.A. Johnson, K.H. Asay, and J.J. Read. 1993. Ash, carbon isotope discrimination, and Silcon as estimators of transpiration efficiency in crested wheatgrass. Aust J Plant Phys. 20:361-369.

Menzies, J., P. Bowen, D. Ehret, and D. M. Glass. 1992. Foliar application of potassium silicate reduce severity of powdery mildew on cucumber, muskmelon, and zucchini squash. J. Amer. Soc. Hort. Sci. 117: 902–905.

Menzies, J.G., D.L. Ehret, A.D.M. Glass, T. Helmer, C. Koch, and F. Seywerd. 1991. Effects of soluble Silcon on the parasitic fitness of *Sphaerotheca fuliginea* on *Cucumis sativus*. Phytopathology 81:84–88.

Meyer, J.H., and M.G. Keeping MG. 2001. Past, present and future research of the role of Si for sugarcane in southern Africa. In: Datonoff L, Korndorfer G, Synder G (eds). Silicon in Agriculture. Elsevier Science. New York.

Mitani, N., and J.F. Ma. 2005. Uptake system of Silcon in different plant species. J. Exp. Bot. 56:1255–1261.

Mitani, N., J.F. Ma, and T. Iwashita. 2005. Identification of Silicon form in the xylem of rice (*Oryza sativa* L.). Plant Cell Phys.. 46: 279-283.

Motomura, H., N. Mita, and M. Suzuki. 1996. Silica accumulation in long-lived leaves of *Sasa veitchii* (Carriere) Rehder (*Poaceae- Bambusoideae*). Ann Bot 90:149-152.

Neumann, D., and U. zur Nieden. 2001. Silicon and heavy metal tolerance of higher plants. Phytochem. 56:685-692.

Remus-Borel, W., J. G. Menzies, and R. R. Belanger. 2005. Silicon induced antifungal compounds in powdery mildew-infected wheat. Phys. Mol. Plant Path. 66(3):108–115.

Richmond, K.E. and M. Sussman. 2003. Got Silicon? The non-essential beneficial plant nutrient Curr. Opin. Plant Bio. 6, 268–272

Ritcher,M.. 2001. Silicium verbessert haltbarkeit bei Gerbera [Si fertilization and vase life of gerbera]. Das Magazin fur Zierpflanzenbau 22:42–44.

Rodrigues, F. A., D. J. McNally, L. E. Datnoff, J. B. Jones, C. Labbe, N. Benhamou, J. G. Menzies, and R. R. Belanger. 2004. Silicon enhances the accumulation of diterpenoid phytoalexins in rice: A potential mechanism for blast resistance. Phytopathology 94: 177–183.

Rodrigues, F. A., W. M. Jurick, L. E. Datnoff, J. B. Jones, and J.A. Rollins. 2005. Cytological and molecular aspects of Si-mediated resistance in rice against *Magnaporthe grisea*. Phys. Mol. Plant Path. 66: 144–159.

Samuels, A.L., A.D.M. Glass, D.L. Ehret, and J.G. Menzies.1991. Mobility and deposition of silicon in cucumber plants. Plant, Cell and Environ. 14 (5): 485-492.

Sangstter, A.G., and M.J. Hodson. 1992. Silica in higher plants. In: Evered D,,O'Connor M. (eds). Silicon Biochemistry. Wiley, New York.

Savant, N. K., G.H. Snyder, and L. E. Datnoff. 1997. Silicon management and sustainable rice production. Adv. Agron. 58:151–-199.

Savvas D., G. Manos, A. Kotsiras, and S. Souvaliotis. 2002. Effects of Silicon and nutrient-induced salinity on yield, flower quality and nutrient uptake of gerbera grown in a closed hydroponic system. J. Appl. Bot. 76: 153–158.

Shimoyama, S. 1958. Effect of calcium silicate application to rice plants on the alleviation of lodging and damage from strong gales. Studies in the improvement of ultimate ields of crops by the application of silicate materials. Japanese Assoc. Adv. Sci. 57-99.

Takahashi, E., J. F. Ma, and Y. Miyake.1990. The possibility of Silicon as an essential element for higher plants. Comments Agric. Food Chem. 2:99-122

Tamai, K., and J.F. Ma. 2003. Characterization of Silicon uptake by rice roots. New Phytol. 158, 431–-436.

Vendrame, W., A.J. Palmater, A. Pinares, K. A. Moore, and L.E. Datnoff. 2010. Si fertilization affects growth of hybrid *Phalaenopsis* orchids linears. HortTechnology 20(3): 603-607.

Voogt, W., and C. Sonnenfeld. 2001. Silicon in horticultural crops grown in soilless culture. In: Datonoff L, Korndorfer G, Synder G (eds). Silicon in Agriculture. Elsevier Science. New York.

Wang,Y.T. 1996. Effects of six fertilizers on vegetative growth and flowering of *Phalaeopsis* orchids. Sci. Hort. 65:191-197.

Wang, Y. T. 1998. Impact of salinity and media on growth, flowering, and leaf mineral concentration of a hybrid *Phalaenopis* orchid. HortScience 33:247-250.

Wang,Y.T. and L.L. Gregg.1994. Medium and fertilizer affect the performance of *Phalaenopsis* during two flowering cycles. HortScience 29:269-27.

Wootton,R.D., F.R. Gouin, and F.C. Stark. 1981. Composed digested sludge as a medium for growing flowering annuals. J. Amer. Soc. Hort. Sci. 106: 46-49.

Zhou,T. 1995. The detection of the Accumulation of Silcon in *Phalaenopsis*(Orchidaceae), Annals of Bot. 75:605-607.

Zurzolo, C., and C. Bowler. 2001. Exploring bioinorganic pattern formation in diatoms. A story of polarized trafficking. Plant Phys. 127(4):1339-1345.

BIOGRAPHICAL SKETCH

Charles Wajsbrot was born in Sao Paulo, Brazil. The younger of two children, he grew up in Sao Paulo, Brazil, graduating from Renascenca High School in 1984. He earned a bachelor's degree in biology in 2001from Uninove in Sao Paulo, Brazil.

Charles started as an entrepreneur after graduating from high school. He worked on a family business until 1997 when he started his own recycling factory. In 1999, he started to manufacture pipes from recycled plastic produced by his company, and later his company specialized in pipes for telecommunication. The company also produced plastic bags for garbage with the recycled material.

In 2004, he moved to New Jersey, and in 2008, he sold his company and decided to go back to school to pursue a Master's of Science degree. He received his master's degree and started a PhD program in fall 2011 to continue his work with orchids. Charles has been married to Dalia Ballas Wajsbrot for 15 years and they have two children, Victoria, age 14 and Daniel age 9.