SILICON SUPPLEMENTATION AFFECTS GREENHOUSE PRODUCED CUT FLOWERS

By

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SILICON SUPPLEMENTATION AFFECTS GREENHOUSE PRODUCED CUT FLOWERS

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The purpose of this work was to determine potential beneficial effects of the non-essential element silicon to greenhouse produced cut flowers.

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CHAPTER I

INTRODUCTION

Silicon (Si) is the second most abundant element in soils and its concentration in plant dry matter ranges from 1% to 10% or higher. However, it is not considered an “essential” nutrient for most plants, with the exception of some Equisitaceae members, and generally is not incorporated in commercially available fertilizers (Epstein, 1993). By 18th century, experiments around the world had shown the benefits of silicon fertilization, especially in the Graminaceae family. Nowadays, Si is considered an agronomically essential element in Japan (Ma and Takahashi, 2002).

The results of initial Si experiments indicate that silicon affects plant growth and crop quality, stimulates photosynthesis, reduces transpiration rate, and enhances plant resistance to a series of both abiotic and biotic stresses such as water and chemical stresses, nutrient imbalances, metal toxicities, diseases and pests problems (Ma and Takahashi, 2002; Zhou et al., 2002; Hodson and Sangster, 2002; Liang et al., 2001; Seebold et al., 2001; Cherif et al., 1992; Lu and Cao, 2001; McAvoy and Bible, 1996; Savvas et al., 2002).

Although Si is important for plant growth, its abundance in soils undervalues its role compared to other elements (Ma and Takahashi, 2002). Recently, there has been an increased interest for sustainable crop production, and Si can contribute to that direction with its prophylactic properties and promotion of plant health.

Ornamental horticulture is a field of study in which Si application could have major benefits. In floriculture, most plants are grown in containers using soilless substrates as growing media (Chen et al., 2000). Consequently, Si concentration in those media is limited and often the only source of Si provided to the plants arrives from the water supply. The application of Si to plants growing in soilless substrates may improve growth, quality and postharvest life.

The objective of this research was the evaluation of silicon (Si) supplements to enhance cut flower production quality. This was achieved by:

a. Determining the optimum application methods, sources, and rates of Si for improving crop quality (e.g. stem strength enhancement, flower diameter)
b. Evaluate Si supplement rates and evaluate suitable sources for use in cut flower production based on crop quality, Si uptake, and cost effectiveness.
c. Investigate Si effects on transpiration of greenhouse grown flowers.
d. Management of diseases in cut flowers greenhouse production by Si supplementation

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CHAPTER II

REVIEW OF LITERATURE

Sources of Silicon

Silicon sources are available as natural resources or industry by-products. Plant residues such as rice (*Oryza sativa* L.) hulls and sugarcane (*Saccharum* spp.) bagasse have a sufficient Si concentration to be used as Si supplement (Ma and Takahashi, 2002). According to the same authors, the supplementation of Si by plant residues enhances plant growth and yield production, but the plant demands are higher. Therefore, most commercial applications are from industry by-products with high Si concentrations. The most common commercially used Si sources and their main components are: calcium silicate slag ($CaSiO_3$), wollastonite (calcium meta-silicate, $CaSiO_3$), sodium silicate ($NaSiO_3$), magnesium silicate ($MgSiO_3$), potassium silicate ($KSiO_3$), silica gel (soluble SiO_2), and Portland cement.

Characteristics of Silicon uptake and Silicification Process in Plants

According to Ma et al., (2001) there are two factors responsible for the chemical form of Si form: silicic acid concentration and pH. In soil solution, Si is present as silicic acid, an uncharged monomeric molecule, when the pH is below 9.0. Higher pH promotes silicate ion speciation instead of silicic acid. Silicic acid concentrations higher than 2mM result in polymerization of silicic acid to silica gel.

Silicic acid is the form of Si that is absorbed by plant roots. After Si uptake, Si is transported by the evapotranspiration stream to the shoots and leaves. Due to water loss, Si is polymerized into silica gel and creates a cuticle-Si double layer on the surface of leaves and stems.

There are two types of silicified cells, silica cells (<5% SiO_2) and silica bodies (>5% SiO_2). These results indicate that in silicification process the initial form of silica cells results in formation of silica bodies with increasing Si content (Ma, 1990).

The Si content of plants varies among different plant species and is influenced by growth conditions. The two criteria used to classify plants as Si-accumulating plants or non-accumulators are the Si content (%) and the Si/Ca ratio.

Silicon in Agriculture

Agricultural crop production has a tendancy to eliminate Si deposits from soil (Savant et al., 1999). Researchers in many countries have noted the benefits of Si supplementation in crop production (Ma and Takahashi, 2002; Zhou et al., 2002; Hodson and Sangster, 2002; Liand et al., 2001; Seebold et al., 2001; Cherif et al., 1992; Lu and Cao, 2001; McAvoy and Bible, 1996; Savvas et al., 2002). According to Epstein (1999), there is substantial evidence to support Si as a “quasi-essential” element because it promotes growth and development in many plants. The last few years many reviews and symposiums were held in order to determine or to underline the importance of Si in agriculture, which demonstrates an increasing interest about Si in plant growth (Ma and Takahashi, 2002).

Okuda and Takahashi (1961) suggested that a large amount of Si was important to promote the growth of rice (*Oryza sativa*) and improve the grain yield. They tested different concentrations of SiO_2 (0, 5, 20, 60, and 100 ppm). The application of SiO_2 at 60 and 100 ppm increased the top length, stem number, dry weight and grain yield of the rice. The same researchers also found that when silicic acid was applied to barley (*Hordeum vulgare* L.) the percentage of ripening panicles and the grain yield of increased.

Maize (*Zea mays* L.) also responds positively to Si supplements. Leaf growth, aerial root occurence, ear development, leaf system constitution, stem development, lodging resistance, nutrient absorbing ability, grain number, and dry matter accumulation after silking were improved by Si fertilizer application (Zhou et al., 2002). According to these researchers Si fertilizer should be applied as a base-fertilizer to maize. Ren et al. (2002) found that the Si application increased yield of maize by 8.6%, increased utilization rate and absorbing ability of nutrients.

Sugarcane (*Saccharum* spp. L.) growth was promoted by Si fertilization. Anderson noted (1991) sugarcane yield increase the first year after calcium silicate application. Similarly, Raid et al. (1992) reported a concentration of 6.7t/ha increased yield of 17.2 and 21.8 % across five cultivars in two consecutive years. Boylston et al. (1990), suggested that silicon has at least one function during a specific phase of cotton (*Gossypium spp.* L.*)* fiber development. Other plants that reacted to silicon application with increased yields were soybean and bamboo (Miyake and Takahashi, 1985; Ueda et al., 1961).

Silicon accumulation in rice leaf blades maintains erect leaves resulting in better light interception; thus, increased photosynthetic rates (Epstein, 1993; Ma and Takahashi, 2002). Reported by Matoh et al. (1991) and cited by Ma and Takahashi (2002), the stimulation of photosynthesis was more intense under water-stress conditions, and was attributed to the decreased transpiration rate caused by Si foliar accumulation. Kaufman et al. (1979) attempted to explain silicon-enhanced photosynthesis and hypothesized that silica bodies acted as 'windows' that helped the light transmission to mesophyll area. This hypothesis was contested by Agarie et al. (1996), who reported lower light energy use efficiency and quantum yield of leaves from Si supplemented plants compared to untreated controls.

Silica has a role "analogous to lignin in that it is a compression-resistant structural component of cell walls" (Epstein, 1993). Epstein also reported that Si content in the plant tissue decreases the transpiration rate and increases stem thickness and strength. Plants supplied with silicon are more resistant to water stresses, and less prone to lodging caused by wind (Hodson and Sangster, 2002). Silicon has also been reported to have increased resistance to stresses caused by deficiencies and toxicities of nutrients and metals, pH and pesticides (Ma and Takahashi, 2002).

Silicon can play an important role on plant growth and crop production by preventing nutrient imbalances. Large amounts of nitrogen rich fertilizers are used in rice production. Ma and Takahashi (2002) suggested Si to equilibrate the negative results of excessive nitrogen fertilization such as disease sensitivity and lodging. A common problem in the production of agricultural crops such as rice and barley (*Hordeum vulgare* L.) is the P deficiency. Si improves the availability of P by blocking excessive Mn uptake, which can antagonize P uptake (Ma and Takahashi, 1991). When oilseed rape plants were grown under B deficiency, Si improved the B uptake. In contrast, Si reduced the B availability when the plants were grown at normal or excessive B environment (Yongchao and Zhenguo, 1994).

Silicon ameliorates aluminum toxicity in rice, wheat (*Triticum aestivum* L.) and barley, however the mechanism is not clearly understood (Gu et al., 1999; Cocker et al., 1998; Liang et al., 2001; Morikawa and Saigusa, 2002). Silicon increased Mn tolerance in several agricultural crops including cowpea (*Vigna unguiculata* L.) (Ma and Takahashi, 2002). Neumann and Nieden (2001) grew the heavy metal tolerant *Cardaminopsis halleri* in soil with high levels of Zn, and noted Si ameliorated Zn toxicity, likely due to Zn-silicate formation.

Current demands for sustainable crop production have increased interest for alternative solutions against diseases and pest problems. Silicon prophylactic effects have been reported against several plant diseases. Studies have been published on the powdery mildews caused by *Sphaerotheca fuliginea*, *Podosphaera xanthii,* and *Blumeria graminis* f. sp. tritici in cucumber (*Cucumis* *sativus* L.), pumpkin (*Cucurbita pepo* L.), wheat (*Triticum aestivum* L.), respectively. Other pathogens like *Pythium* spp., *Botrytis cinerea*, and *Didymella bryonia* have also been shown to be inhibited with Si supplementation.

Depending on the crop and the pathogen, results range from no effect to total control (Belanger et al., 1995). However, best results were observed under low to moderate pathogen pressure (Belanger and Benyagoup, 1997), or by combination of Si fertilization with lower fungicides rates and number of applications (Datnoff et al., 2001).

Silica accumulation in cell walls was believed to be physically responsible for plant disease resistance. Recent work reported Si as a potential signal that activates defense mechanisms (Cherif et al., 1994, Datnoff et al., 1997, Datnoff et al., 2001), without rejecting the previous statement that silicified cells may inhibit penetration of epidermis. Wei et al. (2004) reported that soluble silicon application stimulated the activity of the enzymes PAL, PPO and POD in hydroponically grown Chinese white-flowered gourd and increased silicon content by 1.43 times compared to Si (-) plants. These enzymes increased resistance against *Sphaerotheca fuliginea*. Also, the production of low molecular weight phenolic compounds was stimulated by silicon and enhanced resistance of cucumber plants against powdery mildew (Fawe et al., 1998).

Si supplementation provided protection against pests such as stem borer, several hoppers, leaf spiders and mites (Ma and Takahashi, 2002).

Silicon in Horticulture

Most horticultural crops are non-Si accumulators. However, positive Si effects on agricultural crops increased interest in Si fertilization of horticultural crops. The production of greenhouse crops requires different methods of Si applications since these crops are grown in soilless substrates and Si is limited (Chen et al.,2000). Both vegetable and ornamental crops have been tested and the results were similar to those noticed in agricultural crops. Most benefits were attributed to silica gel accumulation in the epidermal cells caused by Si application. As previously described, horticultural crops were more resistant to pest and diseases, had greater growth, development and better crop quality (Datnoff et. al, 2001).

Cucumber (*Cucumis sativus* L.) exhibits disease resistance when Si supplemented. Cherif et al. (1992) suggested a relationship between Si and cucumber resistance against *Pythium ultimum*. Other researchers have noted that Si promotes resistance reactions against several fungal infections of cucumber and peas (Cherif et al., 1994; Dann and Muir, 2002).

Menzies et al. (1991) reported that Si accumulation on cucumber leaves was responsible for the increased defense mechanisms against powdery mildew caused by *Sphaerotheca fulginea*. Silicon application in the ‘semi-commercial scale’ greenhouse production of cucumber resulted in a 10-16% reduction of powdery mildew (Dik et al., 1998). A more recent report indicates that there was a synergistic effect between Si and high temperatures against powdery mildew

(Schuerger and Hammer, 2003). Another study that the surface of Si-treated cucumber fruits appeared more dull and coarse compared to untreated fruits.

Silicon improves plant nutrition of cucumbers by increasing tolerance against Mn toxicity (Rogalla and Romheld, 2002). Miyake et al.(1976, 1978) cited by Ma and Takahashi (2002) reported that tomato plants grown under Si deficient conditions expressed symptoms such as depressed meristematic growth, chlorosis and necrosis of upper leaves, decreased pollen fertility, but not before the flowering stage.

In other research, the lower leaves of Si-treated tomato plants had greater Si content than untreated plants and upper leaves respectively, and SiO_2 content was higher in the stems and roots of tomato plants and compared to the leaves (Kim et al., 2002).

Melon (*Cucumis melo* L.) was another crop that showed benefits of Si supplementation with higher chlorophyll levels and reduced transpiration rates compare to untreated plants (Lu and Cao, 2001). Si applications resulted in better visual scores for quality, color, and density of seashore paspalum (*Paspatum vaginata*) (Trenholm et al., 2001), and porous hydrate calcium silicate proved to be an efficient Si supplement for turf grass (Saigusa et al.,1999). Al toxicity is a major problem especially when trees are grown in acidic soils and Si was reported to alleviate Al toxicity in conifers (Hodson and Sangster, 1999).

Rose cuttings benefited from sodium silicate mist application (Gillman and Zlesak, 1999) displaying improved rooting percentage and leaflet retention. The beneficial effects of Si such as reduced transpiration, resistance to diseases, or acceleration of root system initiation, likely contributed to these improvements.

Bract necrosis is a calcium deficiency physiological disorder occurs in poinsettia (*Euphorbia pullcherima*). Silica sprays did not cure this disorder. However, Si significantly reduced occurence and severity, which was attributed to reduced evapotranspiration (McAvoy and Bible, 1996).

Chen et al. (2000) tested the response of several ornamental foliage plants to Si applications. Not all the species tested responded to Si treatment. Seventeen species accumulated Si in their tissues and increased their dry weight. Fifteen others accumulated Si without differences in their dry weight and seven showed no response. The Si responsive plants had thicker leaves and consequently they were stronger plants. Stronger plants are beneficial for growers as the will ship better, be more resistant to rough handling and provide a better product for the consumer.

Si application in gerbera (*Gerbera jamesonii*) cultured in hydroponic system had effects on the crop quality and the nutrient uptake. Savvas et al. (2002) reported that Si application significantly improved the crop quality. A higher percentage of flowers graded Class I, the highest grade possible, and the flower stems were significantly thicker. Thicker stems are desirable for cut flowers as it allows floral designers to create more challenging floral designs that last longer.

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CHAPTER III

SILICON SUPPLEMENTATION PRACTICES ON CUT FLOWER PRODUCTION

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Abstract. The goal of this study was to determine Si supplementation effects on production of selected cut flowers. *Zinnia elegans* ‘Oklahoma Formula Mix’, *Helianthus annuus* ‘Ring of Fire’, and *Gerbera* hybrid ‘Acapella’ were used for this study. Potassium silicate media incorporation or weekly drench, sodium silicate weekly foliar spray and ashed rice hull media incorporation, a natural by-product with high Si content (20 % SiO_2), were used as Si supplements. Silicon content of Si-treated plants increased compared to untreated controls for all species. The content of Si and the deposition in plant tissue varied among the species. Depending on source and rate, several horticultural traits were improved

due to Si supplementation. Thick straight stems, increased flower diameter, and early flowering in Si optimum treatments upgraded cut flower quality compared to untreated controls.

Introduction

Silicon is a non-essential element for most plants. However, studies suggest that silicon affects plant growth, crop quality, stimulation of photosynthesis, reduction of transpiration, and enhancement of plant resistance to abiotic and biotic stresses (Ma and Takahashi, 2002; Zhou et al., 2002; Hodson and Sangster, 2002; Liang et al., 2001; Seebold et al., 2001; Cherif et al., 1992; Lu and Cao, 2001; McAvoy and Bible, 1996). Silicon is the second most abundant element in mineral soils and this is likely the reason Si has been undervalued as an important nutrient for so many years. In floriculture greenhouse production, most of plants are cultivated using soilless substrates (Chen et al., 2000). Consequently, Si concentration in those media is limited and Si supplementation may benefit greenhouse production.

However, little research has been performed and there is limited availability of commercial Si supplements or concentration recommendations for floriculture crops. The objective of this work was to determine the most suitable Si sources, rates, and method of application for floriculture greenhouse production based on Si plant tissue concentrations and visual quality characteristics such as height, stem and flower diameter.

Materials and Methods

Zinnia elegans L. ‘Oklahoma Formula Mix’ and *Helianthus annuus* ‘Ring of Fire’ were sown into 0606 (2.7 L/36 plants) bedding plant flats using a soilless commercial media (BM2, Berger Germinating Mix) and transplanted to 20.3 (1.8 L) cm pots when 4-6 true leaves were present. *Gerbera* hybrid L. ‘Acapella’ plugs were also transplanted in 20.3 (1.8 L) pots.

The media was prepared using peat:perlite 4:1 (v/v), with 875 g/m^3 micronutrients and 3.5 kg/m^3 or 5 kg/m^3 limestone. The sources, the rates and method of application of Si that were used are:

- Rice hull ash media incorporation (33, 66, 100 g/ m^3 Si)
- $NaSiO_3$ weekly foliar spray (50, 100, 150 mg/L Si)
- $KSiO_3$ -300ml weekly drenches (50, 100 and 200 mg/L Si)
- $KSiO_3$ flakes media incorporation (70, 140, 280 g/m^3 Si)

Upon transplanting into final containers, plants received supplemental Si via substrate incorporated potassium silicate flakes, rice hulls ash, or received weekly potassium silicate solution drenches, or sodium silicate foliar sprays with three rates per treatment, plus untreated control (13 treatments per species, 20 replicates per treatment).

Plants were grown in polycarbonate covered greenhouses with night/day set temperatures of 15/18^0C and fertilized with 150 mg/L N (20N-4.4P-16.6K), (The Scotts Co., Marysville, OH) that also contained a wetting agent (Wetfoot L.) (33ml/L H_2O). All plants were grown without net support.

Data collection included weekly pH and EC values, days to anthesis (first flower) from transplant into final containers, height, flower diameter and dry weights for the main stem and the first fully expanded flower for each replicate. Two stem diameters were recorded, one at the base of the main stem (basal stem diameter) and the second one below the top flower (apical stem diameter). Sample collection for tissue analysis included leaf, stem and flower samples from each treatment plus untreated controls, except the treatments of $NaSiO_4$ foliar application. In these treatments plant tissues were not washed properly and a potential polymerization of Si on exterior surfaces made the samples unusable for analysis. Tissues sampled were recently mature leaves, stem and the first fully expanded flower. For the Si plant tissue analysis each treatment was analyzed in triplicates. One-way ANOVA analysis was used to compare Si treatments to untreated controls with mean separation LSD ($P = 0.05$).

Silicon extraction

A modified Si extraction procedure (Novozamsky et al., 1998) was used. Leaf, flower and stem samples were dried at 100 ^{o}C and ground using a Wiley mill to pass an 850 µm (20-mesh) screen. Then 100 mg tissue samples, 10 mL of 1M HCl and 20 mL of 2.3M HF were placed in 50 mL polycarbonate tubes. Final steps included an overnight shaking of the samples using an orbitary shaker at 280 RPM and then filtering (Whatman #41 ashless course filter paper).

Silicon analysis

A modified blue silicomolybdous procedure (Taber et al.,1990) was used. A 1.0 mL aliquot was added to a polycarbonate test tube plus 3.0 mL boric acid

2.5% and mixed by inversion. Then, 1.0 mL ammonium molybdate (5.4g L^{-1}, pH=7) was also added, mixed again and let stand for 5 minutes. Next, 0.5 mL tartaric acid 20% was added and mixed, and finally 0.5 mL of the reducing solution was added (1-amino-2-sulfonic acid solution for silica, Fisher reagent). The mixture was mixed one more time and left to stand for 30 minutes. A 1.5mL aliquot from each sample was transferred with a plastic disposable pipette into plastic disposable cuvettes (Fig. 1) and the readings were performed at 650 nm using a Shimadzu (UV-265) UV-Visible Recording Spectrophotometer. A standard curve was prepared with 0, 3, 6, 9, 12, 24 mg Si L^{-1} (r^2>0.99).

Results and Discussion

1. *Zinnia elegans* ‘Oklahoma formula Mix’

Potassium silicate drench treatments (100 and 200 mg/L Si) suppressed plant height (Table I). In those treatments plants had the same or similar number of nodes but shorter internodes (data not presented) and flowering was delayed compared to the control (Table II). The control had either elongated thin stems or curved stems. The potassium silicate drenches resulted in shorter plants, more compact plants with straight stems (Fig. 1). Similar results were observed in rice and wheat plants where Si applications increased stem strength and plants were more resistance to lodging probably due to Si deposition as a double layer underneath the cuticle (Ma and Takahashi, 2002).

Potassium silicate applied as weekly drench at 200 mg/L as well as incorporated in the media at 280 g/m^3 increased basal stem diameter (Table I). Potassium silicate drench (200 mg/L) also increased the stem diameter below the top flower and the same effect obtained with ashed rice hull media incorporation at 100 g/m^3. Sodium silicate foliar sprays did not affect the stem thickness, but the flower diameter was increased when applied weekly at 100 or 150 mg/L (Table I).

Si concentration was highest in the leaf followed by the flower, then stem tissue (Table III). This can be attributed to the way Si deposition occurs in passive Si accumulators. Plants absorb Si as silicic acid and then through evapotranspiration stream deposition occurs mainly in areas of strong transpiration mainly on leaf and flower. Leaf Si concentration ranged from 0.5% for Si untreated plants up to 1.7%, a three fold increase, for the plants treated with $KSiO_3$ drench at 200 mg/L. Ashed rice hulls at the rates used in this experiment resulted at less noticeable increase of the observed quality characteristics. This may due to lower uptake of Si since the ashing procedure can result in unavailable Si form for the plants. Potassium silicate as a weekly drench at 50 mg/L or media incorporation at 140 g/m^3 were the best treatments based on improvement of horticultural traits and plant tissue values for zinnias.

2. *Helianthus annuus* 'Ring of Fire'

All Si sources tested increased stem diameter (Table IV). Ashed rice hull media incorporation at 100 g/m^3, all sodium silicate foliar sprays, $KSiO_3$ drench (50 and 100 mg/L), and $KSiO_3$ media incorporation at 140 g/m^3 increased both basal and apical stem diameter (Table IV, Fig. 3). Increased apical stem diameter is important to avoid flower head bending in floral arrangements and increased basal diameter suggests stems are stronger.

Flower diameter augmentation was observed with 100 g/m^3 media incorporated ashed rice hulls, 100 mg/L of sodium silicate foliar spray and 140 g/m^3 $KSiO_3$ media incorporation (Table IV). $KSiO_3$ media incorporation (140 g/m^3) resulted in taller plants compare to untreated controls.

A decrease in plant height, flower diameter and delayed anthesis was observed when the media was drenched with 200 mg/L $KSiO_3$. In this treatment stem and flower dry weights had low values (Table V) and the flower heads were deformed (Fig.4) at rates higher that 100 mg/L. Flower dry weight was suppressed compared to the control when a 100 or 200 mg/L $KSiO_3$ drench was applied to the media.

Silicon treatments increased tissue Si concentrations relative to the control in all tissues sampled, except at 33 g/m^3 rice hull in the leaves and flowers and 50 mg/L $KSiO_3$ drench in the stem (Table VI). Leaf samples had the highest Si content, following by flowers then stems, for both Si treated and untreated plants.

Sunflower is classified as intermediate silicon accumulator with Si content ranges from 0.5- 1.0% in plant tissue (Datnoff et al., 2001). The results of our work agree with the above statement. Control plants had leaf concentration 0.43% Si and Si treated plants ranged from 0.56% up to 1.54% Si depending on the Si source and rate.

Treatments with Si leaf concentration from 0.6% to 1.1% correspond to plants with thicker stems (Table VI). Silicon concentration above 1.2% in the leaf samples suggested the deformation problems described above, lowering quality characteristics crop market value. Silicon has not been reported to cause toxicity in excess levels. However, our studies suggested excessive Si may cause the problems we observed, or created a deficiency of another element through uptake competition. Based on work the Si sources and rates more suitable for sunflower greenhouse production were the 100 g/m^3 ashed rice hull media incorporation, 100 mg/L weekly sodium silicate foliar sprays, 50 mg/L potassium silicate weekly drench, and 140 g/m^3 potassium silicate flakes incorporation.

3. *Gerbera* hybrid 'Acapella'

Gerbera supplemented with sodium silicate foliar sprays, 200 mg/L potassium silicate drench, and 140 g/m^3 potassium silicate flakes incorporated into the growing media had stems with increased basal and apical diameter (Table VII). Savvas et al. (2002) reported increased flower quality and stem thickeness by including potassium silicate during hydroponic gerbera production.

Some of the Si treatments such as ashed rice hull media incorporation with 70 and 140 g/m^3, sodium silicate 50 and 100 mg/L and potassium silicate flakes incorporated in media at 70 and 140 g/m^3 promoted earlier development of the first flower (Table VIII). Earlier flowering was also reported when sodium silicate 1.0 mmol L^{-1} Si was included in hydroponic production of melon (Gang, 2001).

Leaf, stem and flower Si concentration increased for all Si-treated plants compared to untreated control (Table IX). Silicon concentration of leaf samples had similar values to the flowers, and stem values were slightly lower in most treatments. As noted above, Si moves via the transpiration stream, however the anatomical difference of gerbera compared to sunflower or zinnia may have contributed in the variation of Si distribution in plant tissue.

Even though there was a significant increase of Si concentration and stem thickening with several treatments, only the sodium silicate foliar sprays showed an increased stem height and flower diameter, and 50 mg/L was the most preferable among the treatments that were tested in our study (Fig.5)

As the rate of sodium silicate increased the benefits diminished, resulting in phytotoxicity in the highest rate used. These symptoms did not occur in all plants and were observed after several Si applications reaching the end of production (data not shown). Phytotoxic plants had very short stems and flowers were slightly deformed (Fig.6).

Conclusions

Zinnia and sunflower Si levels were highest in leaf (0.5-1.7%), followed by flower (0.3-0.5%) and stem (0.2-0.4%). Gerbera accumulated lower amounts of Si compare to zinnia and sunflower. Leaf and flower concentrations were similar ranging from 0.4-0.6% with stem values 0.4% Si.

Depending on source and rate, several horticultural traits were improved due to Si supplementation. For zinnia, benefits included increased stem thickness, increased flower diameter and stem erectness. Sunflower Si supplementation resulted in stem thickening and flower diameter increase in some of the tested Si treatments. However, in this study phytotoxicity problems occur in high Si rates (above 100 mg/L Si applied as weekly drench), since plants were significantly shorter, flowers were deformed and flowering was delayed.

For gerbera stem thickening was achieved with both $KSiO_3$ and $NaSiO_3$ applications. Sodium silicate foliar sprays can further benefit the production, because in addition to stronger stems it also increased height and flower diameter. These last two characteristics are used as criteria to determine the quality class of cut flower gerbera. However, as in sunflower, flower deformation was observed in high rates (above 100 mg/L Si) and after several applications.

Summarizing the results from all three species used indicate that rice hulls were less effective (based on the applied rates) than potassium silicate. Sodium silicate foliar application was the best treatment for gerbera but least beneficial for zinnia and sunflower. Si treatments applied as media incorporation did not cause growth abnormalities, but potassium silicate drenches and sodium silicate foliar applications at rates above 100 mg/L were problematic. General recommendation based on the plant species, Si sources and rates tested are: 50 mg/L for sodium silicate foliar or potassium silicate drench applications, and 140 g/m^3 for potassium silicate flake incorporation.

In conclusion this work suggests that Si supplementation can benefit cut flower production. Thick straight stems, increased flower diameter, and early flowering in Si treated plants increase the quality of cut flowers and their marketable value but we also have to consider that it can cause damages if Si included in excess amounts.

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TABLE I

Silicon supplementation effects on height, flower diameter, basal and apical stem diameter of *Zinnia elegans* ‘Oklahoma Formula Mix’

Silicon source	Application method	Si Rate	Si applied mg/pot	Height (cm)	Flower diameter (cm)	Basal stem diameter (mm)	Apical stem diameter (mm)
None	None	0	0	65	4.7	7.8	4.0
		g/m^3					
Rice hulls	Media	33	50	66	5.1	8.6	4.6
20% SiO_2	Incorporation	66	100	60	5.0	8.4	4.3
		100	150	65	5.5*	8.6	5.3*
$KSiO_3$	Media	70	100	61	5.3	8.1	4.3
Flakes	Incorporation	140	200	67	5.7**	8.1	4.3
		280	400	62	5.2	8.9*	4.8
		mg/L					
$NaSiO_3$	5 Weekly Foliar	50	▲	57	5.2	8.1	5.0
	Sprays	100	▲	57	5.4*	8.6	4.8
		150	▲	60	6.1**	8.6	4.3
$KSiO_3$	5 Weekly	50	75	64	5.6**	8.4	4.8
	Drenches	100	150	52**	5.7**	8.6	4.6
		200	300	50**	5.2	9.1*	5.6**

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

▲ Plants were sprayed until runoff, thus the exact amount applied per plant can not be calculated

TABLE II
Silicon supplementation effects on flowering, flower and stem dry weights and stem erectness of *Zinnia elegans* ‘Oklahoma Formula Mix’

Silicon source	Application method	Si Rate	Si applied mg/pot	Days to anthesis	Flower dry weight (g)	Stem dry weight (g)	% Straight stems
None	None	0	0	36	0.28	2.20	40
		g/m^3					
Rice hulls	Media	33	50	37	0.27	2.39	60
20% SiO_2	incorporation	66	100	37	0.37*	2.68	45
		100	150	37	0.37*	2.82*	65
$KSiO_3$	Media	70	100	36	0.32	2.45	40
Flakes	incorporation	140	200	37	0.35	2.45	75*
		280	400	37	0.32	2.43	45
		mg/L					
$NaSiO_3$	5 Weekly foliar	50	▲	35	0.31	2.42	60
	sprays	100	▲	35	0.36	2.39	65
		150	▲	37	0.37	2.41	50
$KSiO_3$	5 Weekly	50	75	40**	0.37*	2.34	80**
	drenches	100	150	39**	0.33	2.79*	85**
		200	300	41**	0.38*	2.24	95**

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

▲ Plants were sprayed until runoff, thus the exact amount applied per plant can not be calculated

TABLE III
The effect of Si source on plant tissue Si concentration of *Zinnia elegans* 'Oklahoma Formula Mix'

Silicon	Application	Rate	Si applied	Silicon concentration (µg/g)		
Source	Method	Si	mg/pot	Leaf	Stem	Flower
None	None	0	0	5182	1970	3051
		g/m^3				
Rice hulls	Media	33	50	5619*	1801	2832
20% SiO_2	Incorporation	66	100	6090**	1986	3311
		100	150	6650**	1980	3074
$KSiO_3$	Media	70	100	7102**	2099	3064
Flakes	Incorporation	140	200	13896**	1995	3352*
		280	400	14411**	2076	3418*
		mg/L				
$KSiO_3$	5 Weekly	50	75	11153**	1919	3250
	Drenches	100	150	15133**	2215*	3554**
		200	300	16960**	2406**	3849**

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

TABLE IV

Silicon supplementation effects on height, flower diameter, basal and apical stem diameter of *Helianthus annuus* 'Ring of Fire'

Silicon source	Application method	Si Rate	Si applied mg/pot	Height (cm)	Flower diameter (cm)	Basal stem diameter (mm)	Apical stem diameter (mm)
None	None	0	0	102	11.8	13.2	6.1
		g/m^3					
Rice hulls	Media	33	50	105	12.3	13.5	6.3
20% SiO_2	Incorporation	66	100	108	12.0	13.5	6.3
		100	150	106	12.6*	14.2*	6.9*
$KSiO_3$	Media	70	100	96	11.5	13.5	6.6
Flakes	Incorporation	140	200	112**	12.7*	15.0**	7.1**
		280	400	102	12.2	13.9	7.6**
		mg/L					
$NaSiO_3$	5 Weekly Foliar	50	▲	101	12.2	14.2*	6.9*
	Sprays	100	▲	101	12.6*	15.5**	7.1**
		150	▲	103	12.1	14.8**	7.1**
$KSiO_3$	5 Weekly	50	75	98	12.4	14.7**	7.1**
	Drenches	100	150	105	12.1	15.3**	7.1**
		200	300	79**	10.3**	13.9	8.4**

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

▲ Plants were sprayed until runoff, thus the exact amount applied per plant can not be calculated

TABLE V

Silicon supplementation effects on flowering, flower and stem dry weight of *Helianthus annuus* ‘Ring of Fire’

Silicon Source	Application Method	Rate Si	Si applied mg/pot	Days to Anthesis	Flower Dry weight (g)	Stem Dry weight (g)
None	None	0	0	47	2.68	9.49
		g/m^3				
Rice hulls	Media	33	50	47	2.79	9.72
20% SiO_2	Incorporation	66	100	47	2.75	10.42
		100	150	47	2.85	10.29
$KSiO_3$	Media	70	100	47	2.53	8.79
Flakes	Incorporation	140	200	48	2.99	11.24**
		280	400	47	2.51	10.12
		mg/L				
$NaSiO_3$	5 Weekly Foliar	50	▲	47	2.80	9.67
	Sprays	100	▲	48	3.01	10.5
		150	▲	46	2.94	10.35
$KSiO_3$	5 Weekly	50	75	50**	2.61	10.01
	Drenches	100	150	50**	2.12**	10.53
		200	300	52**	2.10**	7.49**

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

TABLE VI
The effect of Si source on plant tissue Si concentration
of *Helianthus annuus* 'Ring of Fire'

Silicon Source	Application Method	Rate Si	Si applied mg/pot	Silicon concentration (µg/g) Leaf	Stem	Flower
None	None	0	0	4294	2839	3156
		g/m^3				
Rice hulls	Media	33	50	4904	3050**	3773
20% SiO_2	Incorporation	66	100	5603*	3125**	3898*
		100	150	6723**	3276**	4361**
$KSiO_3$	Media	70	100	7016**	3379**	4023*
Flakes	Incorporation	140	200	6627**	3339**	4013*
		280	400	6503**	3339**	4316**
		mg/L				
$KSiO_3$	5 Weekly	50	75	11110**	2978	4300**
	Drenches	100	150	12616**	3741**	4254**
		200	300	15397**	4224**	5058**

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

TABLE VII

Silicon supplementation effects on height, flower diameter, basal and apical stem diameter of *Gerbera* hybrid 'Acapella'

Silicon source	Application method	Si Rate	Si applied mg/pot	Height (cm)	Flower diameter (cm)	Basal stem diameter (mm)	Apical stem diameter (mm)
None	None	0	0	20	9.8	6.6	4.6
		g/m^3					
Rice hulls	Media	33	50	20	10.0	6.6	4.8
20% SiO_2	Incorporation	66	100	20	9.1	7.1	5.1
		100	150	21	9.7	7.1	4.8
$KSiO_3$	Media	70	100	21	9.9	6.6	4.8
Flakes	Incorporation	140	200	19	10.2	7.6**	5.3**
		280	400	19	9.6	7.1	4.8
		mg/L					
$NaSiO_3$	5 Weekly Foliar	50	▲	22**	11.3**	7.6**	5.8**
	Sprays	100	▲	21	10.8**	7.6**	5.3**
		150	▲	18	10.0	7.6**	5.3**
$KSiO_3$	5 Weekly	50	75	18	9.7	6.6	4.8
	Drenches	100	150	20	9.6	6.6	5.1
		200	300	20	9.4	7.6**	5.3**

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

TABLE VIII

Silicon supplementation effects on flowering, flower and stem dry weight of *Gerbera* hybrid 'Acapella'

Silicon Source	Application Method	Rate Si	Si applied mg/pot	Days to Anthesis	Flower Dry weight (g)	Stem Dry weight (g)
None	None	0	0	77	1.50	1.09
		g/m^3				
Rice hulls	Media	33	50	70	1.46	1.18
20% SiO_2	Incorporation	66	100	68*	1.61	1.13
		100	150	68*	1.31	1.12
$KSiO_3$	Media	70	100	65**	1.50	1.12
Flakes	Incorporation	140	200	68*	1.32	1.13
		280	400	70	1.38	1.15
		mg/L				
$NaSiO_3$	5 Weekly Foliar	50	▲	61**	1.85*	1.56**
	Sprays	100	▲	65**	1.61	1.38*
		150	▲	73	1.48	1.29
$KSiO_3$	5 Weekly	50	75	77	1.27	1.12
	Drenches	100	150	79	1.24	1.08
		200	300	80	1.33	0.98

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

TABLE IX
The effect of Si source on plant tissue Si concentration of *Gerbera* hybrid 'Acapella'

Silicon Source	Application Method	Rate Si	Si applied mg/pot	Silicon concentration (μg/g)		
				Leaf	Stem	Flower
None	None	0	0	4056	3343	3452
		g/m^3				
Rice hulls 20% SiO_2	Media Incorporation	33	50	5388**	3901*	3504
		66	100	5775**	4164**	3648
		100	150	5723**	4722**	4201**
$KSiO_3$ Flakes	Media Incorporation	70	100	4304	4185**	5522**
		140	200	4557**	4051**	5610**
		280	400	5450**	4237**	5868**
		mg/L				
$KSiO_3$	5 Weekly Drenches	50	75	5430**	4051**	3870
		100	150	5115**	3979*	4619**
		200	300	5925**	3720	5166**

Significant from the untreated control at the 5% level (*) or 1 % level (**) by the protected LSD

Figure 1. Silicon untreated (two on the left) vs. silicon treated *Zinnia elegans* 'Oklahoma Formula Mix'. Right to left: $KSiO_3$ drench (200 mg/L Si), $KSiO_3$ drench (50 mg/L Si), $KSiO_3$ (140 g/m^3 Si) media incorporation, rice hulls (100 g/m^3 Si) media incorporation.

Figure 2. Si-untreated (left) vs. Si-treated *Zinnia elegans* 'Oklahoma Formula Mix' plants with weekly $KSiO_3$ drench (50 mg/L Si) (middle) and $KSiO_3$ media incorporation (140 g/m^3 Si).

Figure 3. Increased stem diameter of *Helianthus annuus* ‘Ring of Fire’ with Si supplementation-$KSiO_3$ media incorporation (140 g/m^3 Si) (right) vs. Si untreated plant (left).

Figure 4. Effects of $KSiO_3$ drench applications on *Helianthus annuus* 'Ring of Fire'. Si untreated (left), $KSiO_3$ (50 mg/L Si) (middle) increases stem thickness, $KSiO_3$ (200 mg/L Si) (right) phytotoxicity problems including shortening and flower head deformation.

Figure 5. Sodium silicate foliar sprays at 50 mg/L Si (right) increased flower diameter and height of Gerbera hybrid ‘ Acapella’ compare to Si-untreated plants (left)

Figure 6. Gerbera hybrid ‘ Acapella’ treated plants with sodium silicate foliar spray at 50 mg/L Si (left) and 150 mg/L (right) result in phytotoxicity symptoms of stem shortening and flower deformation

CHAPTER IV

CORRELATION BETWEEN TISSUE AND SUBSTRATE SILICON CONCENTRATION OF GREENHOUSE PRODUCED *HELIANTHUS ANNUUS* 'RING OF FIRE'

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Abstract. *Helianthus annuus* 'Ring of Fire' was used to investigate the relationship of Si tissue and substrate content, since guidelines for acceptable tissue and substrate levels are not established for floriculture greenhouse production. Rice hull ash (0, 90, 130, 170 $g{\bullet}m^{-3}$ Si), $KSiO_3$ weekly drenches (0, 25, 50 and 75 $mg{\cdot}L^{-1}$ Si), and $KSiO_3$ flake substrate incorporation (0, 140, 190 and 240 $g{\bullet}m^{-3}$ Si) were used as Si sources. Increased flower and stem diameter, as well as increased stem dry weight were obtained with Si supplementation. A positive correlation between leaf Si concentration and saturated media extract (SME) soilless substrate samples existed ($r = 0.75$). The correlation indicates the potent for using leaf samples to establish acceptable Si concentrations for floriculture soilless greenhouse production.

Introduction

Silicon (Si) is a non-essential element that has proven to be a beneficial supplement agricultural crop supplement. Silicon is not an essential element and generally not included in commercially availably fertilizers or soilless substrates used in greenhouse production. In addition, there is limited research on silicon supplementation in floriculture crops. In the previous chapter we demonstrated that certain Si sources and rates improved stem erectness, stem and flower diameter, and promoted early anthesis in some species. However, optimum Si rates for fertilization and guidelines for acceptable tissue and substrate levels are not established for floriculture greenhouse production.

Saturated media extract (SME) samples are easy to prepare and are often collected during the greenhouse production to monitor EC, pH and nutrients. Tissue preparation for Si extraction includes collection, drying and grinding of the tissue prior the extraction procedure, two steps that are not required in SME samples extraction. So the ability to determine Si levels in SME would be advantageous.

Our objective was to determine the optimum rates for Si supplementation based on previous studies and investigate the relationship of tissue Si and substrate Si concentration using *Helianthus annuus* ‘Ring of Fire’ as a model plant.

Materials and Methods

Helianthus annuus ‘Ring of Fire’ seeds were sown into 0606 (75 mL per cell) bedding flats using BM2 Germinating Mix (70% peat moss, 30% perlite) (Berger Peat Moss, StModeste, Quebec) and transplanted to 20.3 (1.8 L) cm pots when 5-6 true leaves were present. Once transplanted, plants were grown in a polycarbonate covered greenhouse with night/day set temperatures of 15/18 ^{o}C and fertilized with 150 mg/L N from 21N-2.5P-16K (The Scotts Co., Marysville, OH).

The substrate was 4:1 peat:perlite (v:v) with 875 g•m^{-3} S.T.E.M (The Scotts Co., Marysville, OH) and 3500 g•m^{-3} dolomitic limestone. The sources, the rates and method of Si application that were used were:

Rice hull ash (0, 90, 130 and 170 g•m^{-3} Si) substrate incorporation,

$KSiO_3$ (0, 25, 50 and 75 mg·L^{-1} Si) weekly drench, and

$KSiO_3$ flakes (0, 140, 190 and 240 g•m^{-3} Si) substrate incorporation.

A randomized complete block design was used with 3 Si sources at 4 rates with 12 replications per treatment combination. Data collection included weekly pH and EC values, days to anthesis, height (measured from pot rim to the tallest point), flower diameter (measured at the widest point) and dry weights for the stem and the first fully expanded flower for each replicate. Two stem diameters were recorded, one at the base of the main stem (basal stem diameter) and the second one below the top flower (apical stem diameter). Sample collection for tissue analysis included leaf, stem and flower samples from each treatment plus untreated controls. Criteria for sample collection were recently mature leaves, main stem and the first fully expanded flower of each plant. The substrate solution samples were collected with a modified SME (Warncke, 1983). Tissue and substrate Si analysis samples for each treatment were analyzed in triplicates and trend analysis was used for the collected data ($P \leq 0.05$).

Silicon extraction

A modified Si extraction procedure (Novozamsky et al., 1998) was used. Leaf, flower and stem samples were dried at 100 °C and ground using a Wiley mill to pass an 850 µm (20-mesh) screen. Then 100 mg tissue samples, 10 mL of 1M HCl and 20 mL of 2.3M HF were placed in 50 mL polycarbonate tubes. Final steps included an overnight shaking of the samples using an orbitary shaker at 280 RPM and then filtering (Whatman #41 ashless course filter paper).

Silicon analysis

A modified blue silicomolybdous procedure (Taber et al.,1990) was used. A 1.0 mL aliquot was added to a polycarbonate test tube plus 3.0 mL boric acid 2.5% and mixed by inversion. Then, 1.0 mL ammonium molybdate (5.4g L^{-1}, pH=7) was also added, mixed again and let stand for 5 minutes. Next, 0.5 mL tartaric acid 20% was added and mixed, and finally 0.5 mL of the reducing solution was added (1-amino-2-sulfonic acid solution for silica, Fisher reagent). The mixture was mixed one more time and left to stand for 30 minutes. A 1.5mL aliquot from each sample was transferred with a plastic disposable pipette into plastic disposable cuvettes (Fig. 1) and the readings were performed at 650 nm using a Shimadzu (UV-265) UV-Visible Recording Spectrophotometer. A standard curve was prepared with 0, 3, 6, 9, 12, 24 mg Si L^{-1} (r^2>0.99).

Results and Discussion

Most of horticultural crops are non active Si-accumulators. *Helianthus* was chosen as a model plant since it has been described as passive Si- accumulator (Datnoff et al., 2001) and the same can be concluded from our leaf tissue analysis values (0.4-0.6% Si).

All Si sources increased basal stem diameter (Table X). The ashed rice hull substrate incorporation and $KSiO_3$ drench were more beneficial in the highest rate used (170 g•m^{-3} Si and 75 mg•L^{-1} Si respectively), and along with the low used rate of $KSiO_3$ flakes substrate incorporation (140 g•m^{-3} Si) were the optimum rates for each Si source as they increased both basal and apical stem diameter.

Ashed rice hull incorporation improved horticultural basal and apical stem diameter and stem dry weight when applied at higher rates compared to the other Si sources. This can be attributed to an insoluble portion of Si resulting from burning. Ishibashi (1956) using rice seedlings reported that Si uptake of carbonized rice husk was better compared to common burned rice husk.

Flower diameter increased curvilinearly using $KSiO_3$ flakes, or linearly using $KSiO_3$ weekly soil drenches. Rice hulls did not affect flower diameter (Table X). Plant height was not affected by Si treatment (data not shown). In the previous chapter Si supplementation in used highest Si rates resulted in short plants. In this study we were trying to find the optimum rates based on our previous results and did not use Si rates that were problematic causing deformation problems. None of the treatments used in this study suggested phytotoxicity or shorter plants. According to Jang et al. (2003), Si supplementation enhanced endogenous gibberellins production in rice seedlings, that can lead to stem elongation. In the previous chapter gerberas height increased with sodium silicate foliar weekly applications. It seems plant height related to Si was influenced by plant species and the application rate.

Even though flower diameter increased with Si supplementation using $KSiO_3$ drench or media incorporation (Table X), flower dry weight was not affected (data not presented). However, stem dry weight of Si treated plants was increased. $KSiO_3$ weekly drench of *Helianthus* increased stem weight up to 28% compared to untreated control (Table XI). Media incorporated $KSiO_3$ increased stem dry weight about 15%, but rice hull ash did not affect Si stem dry weight.

Increased dry matter production often a result of Si supplementation due to stimulated photosynthesis, reduce transpiration rate and strengthened tissue of several plant species, especially Si accumulators (Ma and Takahashi, 2002). In rice, Si deficiency reduced the grain yield (Okuda and Takahashi, 1961). Increasing Si levels increased dry weight, grain yield and stem number of rice. Silicified tissues may also be associated with increased dry matter. Deposits can occur in epidermal, strengthening, storage and vascular tissues. The most common forms are the silica bodies and cells, silicified hairs or trichomes and the stomatal complex (Piperno, 1988). Silicification does not occur in juvenile organs during cell expansion stage (Patty and Smithson, 1964). This may explain the increase in stem dry weight of Si treated plants, opposed to flower dry weights that showed no difference to Si untreated control (Table XI).

Si accumulation was promoted with all the Si treatments in this experiment. Phytotoxicity levels were not observed in any tissue sample. Leaf samples had the highest Si content, following by flower then stem, for both Si treated and untreated plants (Table XII).

Silicic acid is the form plants uptake Si via transpiration stream and deposition takes place in areas of strong evapotranspiration, where due to water loss, silicic acid is polymerized into silica gel (Hodson and Sangster, 1989). In leaves and flowers the evapotransipiration is higher compared to shoots and roots and therefore higher values were obtained.

It seems that the three modes of Si uptake (actively, passively and rejectively) are associated with Si deposition. Rice Si uptake is activel (Yoshida et al., 1962) and according to Jones and Handreck (1969) inflorescence bracts have generally the highest silica levels for the grasses. Studies with plants utilizing a passive Si uptake like cucumber proved trichomes of leaf and fruit as the areas with higher Si content (Samuels et al., 1991 and 1992). Finally tomato plants are described to take up Si rejectively (Okuda and Takahashi, 1962) and Si was reported higher in the surface of root and stem than leaf surface (Kim et al., 2002). Most horticultural crops, including *Helianthus* are believed to uptake Si passively. The higher Si content on leaf and flower found in this study compared to stem tissue is in agreement with the above hypothesis that Si deposition is related to the mode of Si uptake.

Saturated substrate extract samples from treatments with $KSiO_3$ (75 mg/L Si) and $KSiO_3$ flake incorporation (140 and 190 g/m^3 Si) had higher Si content than the control (Table XII). Leaf and flower Si content was positively correlated with SME samples (correlation coefficients r=0.75 and 0.63 respectively), with leaf-substrate values showing the strongest correlation. Nutrient elements can have a correlation between substrate (or soil) and leaf content (Jaszczolt, 1978; Johansson, 1979; Csatho, 1998) but in many cases correlations are not well defined and the tissue content is not a satisfactory indicator of potential nutrient supply (Ulicevic et al.,1976; Parra, 1971). Experiments conducted with *Spartina anglica* a high Si accumulator halophyte showed no correlation between pore water Si concentrations and shoot Si levels (Bakker et al., 1999). Similar in our study stem Si content of *Helianthus* was not correlated with saturated substrate extract substrate samples (Table 4c). This may be attributed to the mode of Si uptake as described previously. In sunflower, a passive Si accumulator, deposition of Si is more likely to occur in areas of high transpiration and probably this is why stem is not correlated as well as leaf and flower to substrate values.

There was also a positive correlation between the applied Si concentration per pot and Si concentration of saturated substrate extract samples (Fig.7). There was lower Si content of the ashed rice hull substrate compared to potassium silicate drench and flakes incorporation. This can also support the hypothesis of Si insolubility due to the burning procedure of rice hulls that was discussed above. The potassium silicate drench application gave higher levels of Si concentration in the SME samples even though it was applied at lower rates per pot. This indicates the more soluble nature of the drench application method as opposed to Si substrate incorporation.

Conclusions

Helianthus annuus 'Ring of Fire' greenhouse production was affected by Si supplementation. Beneficial effects included increased flower and stem diameter, as well as increased stem dry weight. Silicon supplementation would benefit cut flower production since larger flowers with stronger stems are characteristics desirable for cut flowers used in floral arrangements.

Leaf samples had the highest Si concentration, following by flower then stem, for both Si treated and untreated plants. Based on the observed horticultural traits, ashed rice hull substrate incorporation (170 $g{\bullet}m^{-3}$ Si), $KSiO_3$ drench (75 $mg{\bullet}L^{-1}$ Si), and $KSiO_3$ substrate incorporation (140 $g{\bullet}m^{-3}$ Si) were the most beneficial treatments. However, ashed rice hull incorporation may not be suitable for Si supplementation because of the environmental hazard concerns concerning the burning process.

A positive correlation between leaf Si concentration and SME soilless substrate samples existed. The above correlation indicates potential use of leaf samples or SME values in establishment of acceptable Si levels for floriculture soilless greenhouse production.

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TABLE X
Silicon supplements effects on horticultural traits
of *Helianthus annuus* 'Ring of Fire'

				Crop characteristics (cm)		
Si sources	Application Method	Si Rate	Si applied mg/pot	Flower Diameter	Basal Diameter	Apical Diameter
		mg/L				
$KSiO_3$	Weekly	0	0	11.3	1.46	0.64
	Drench	25	37.5	11.5	1.56	0.71
		50	75.0	11.6	1.55	0.70
		75	112.5	12.6	1.63	0.72
	Linear			**	**	NS
	Quadratic			NS	NS	NS
		g/m^3				
$KSiO_3$	Substrate	0	0	10.6	1.48	0.67
Flakes	Incorporation	140	200	12.0	1.66	0.75
		190	270	11.8	1.67	0.72
		240	340	11.5	1.65	0.71
	Linear			NS	**	NS
	Quadratic			**	**	NS
		g/m^3				
Ashed Rice	Substrate	0	0	11.6	1.42	0.68
Hulls	Incorporation	90	135	11.6	1.59	0.72
		130	195	11.2	1.57	0.69
		170	255	12.1	1.57	0.77
	Linear			NS	**	*
	Quadratic			NS	**	NS

NS, *, **, Non significant (NS), or significant at 5% (*), or 1% (**) level

TABLE XI

Silicon supplements effects on stem dry weight of *Helianthus annuus* 'Ring of Fire'

Si sources	Application method	Si Rate	Si applied mg/pot	Stem dry weight (g)
		mg/L		
$KSiO_3$	Weekly Drench	0	0	14.9
		25	37.5	16.1
		50	75.0	16.6
		75	112.5	20.8
	Linear			**
	Quadratic			*
		g/m^3		
$KSiO_3$ Flakes	Substrate Incorporation	0	0	15.4
		140	200	18.3
		190	270	17.4
		240	340	17.7
	Linear			*
	Quadratic			NS
		g/m^3		
Ashed Rice Hulls	Substrate Incorporation	0	0	15.4
		90	135	17.9
		130	195	16.7
		170	255	17.6
	Linear			NS
	Quadratic			NS

NS, *, **, Non significant (NS), or significant at 5% (*), or 1% (**) level

TABLE XII

Correlation Between Tissue and Substrate Silicon Concentration of Greenhouse Produced *Helianthus annuus* ‘Ring of Fire’

	Application	Si Rate	Si applied		Silicon concentration (µg/g)			
Si sources	Method		mg/pot	Height	Leaf	Stem	Flower	SME
		mg/L						
$KSiO_3$	Weekly	0	0	97	4253	2350	3652	30
	Drench	25	37.5	100	4816	3198	4584	33
		50	75.0	98	5208	3000	4283	33
		75	112.5	104	5882	3247	5012	66
	Linear			NS	**	**	**	**
	Quadratic			NS	NS	**	NS	NS
		g/m^3						
$KSiO_3$	Substrate	0	0	96	4253	2350	3652	30
Flakes	Incorporation	140	200	102	5015	2411	4029	54
		190	270	103	5663	2558	4387	62
		240	340	104	5859	2238	4453	43
	Linear			NS	**	NS	**	NS
	Quadratic			NS	**	*	NS	*
		g/m^3						
Ashed Rice	Substrate	0	0	96	4253	2350	3652	30
Hulls	Incorporation	90	135	103	4638	3425	3621	33
		130	195	102	4561	3009	4580	42
		170	255	101	5829	3077	3775	43
	Linear			NS	**	**	*	NS
	Quadratic			NS	**	**	**	NS
	r				**0.75**	**-0.002**	**0.63**	

NS, *, **, Non significant (NS), or significant at 5% (*), or 1% (**) level

SME: saturated media extract soilless substrate samples

r: coefficient of correlation for leaf, flower and stem Si concentration vs. SME samples

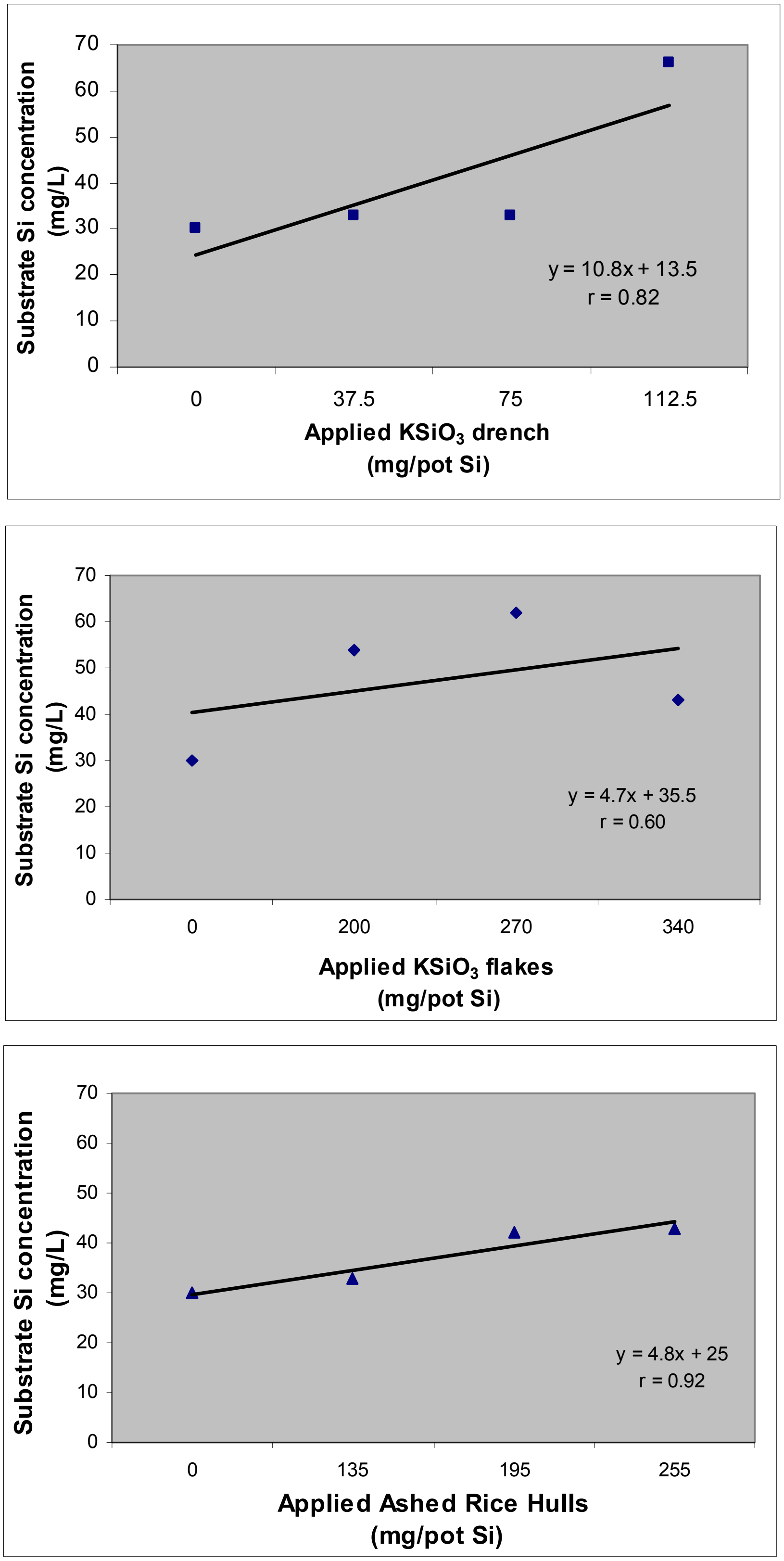

Figure 7. Correlation between substrate Si concentration and rate of Si supplementation on *Helianthus annuus* ‘Ring of Fire’

CHAPTER V

SILICON APPLICATION EFFECTS ON STOMATAL CONDUCTANCE OF ZINNIA LEAVES

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Additional index words. *Zinnia elegans* ‘Zinnita Scarlet’

Abstract. Reduction of transpiration rate and increase of leaf resistance is one of the beneficial effects attributed to the non essential element Si. Most of the conducted studies used agricultural crops and the effects were accelerated with increased environmental stresses like drought and metal toxicity. In previous chapter Si application showed to improve horticultural traits of greenhouse produced flowers. Reduction of transpiration rate can further benefit floriculture production and the goal of this study was to examine the effect of Si supplementation in stomatal conductance of zinnia leaves under normal greenhouse conditions. The results can not support an active role of Si in stomata movement but there is an indication that foliar sodium silicate spray can act as film-forming antitranspirant that increases leaf resistance.

Introduction

Silicon is not considered as an essential element, but plant content in Si reaches levels similar to those of macronutrients. Its importance is underlined by several researchers reporting beneficial effects of silicon supplementation especially in agronomical crops. One of the most controversial Si roles is its influence on transpiration and photosynthesis. Si deposition results to a Si-double layer under the cuticle. This barrier is believed to reduce water loss and provide a mechanical defense against biotic stresses (Belanger et al., 1995). According to Matoh et al. (1991) the stimulation of photosynthesis is more intense under water-stress conditions, and is attributed to the decreased transpiration rate caused by Si foliar accumulation. Different report by Hattori et al. (2005) stated increase of transpiration rate with Si application.

In greenhouse production the predominant use of soilless substrates leads to a limited amount of available Si for the cultivated crops. Application of Si can improve horticultural traits as it has already been described in the previous chapters. Potential reduced transpiration caused by Si application can add another dimension to its beneficial use in greenhouse production.

Reduction of transpiration is a desirable attribute for greenhouse floriculture crops, since it delays senescence and prolongs the shelf life performance of the commodities. The objective of this study was to determine potential effects of Si supplementation on leaf resistance by measuring the stomatal leaf conductance of greenhouse grown zinnias.

Materials and Methods

Zinnia elegans 'Zinnita Scarlet' seeds were sown in a BM2 Germinating Mix (70% peat moss, 30% perlite) (Berger Peat Moss, St.Modeste, Quebec) and transplanted to 20.3 (1.8 L) cm pots when 2-4 true leaves were present. Once transplanted, plants were grown in polycarbonate covered greenhouse with night/day set temperatures of 15/18 ^{o}C and fertilized with 150 mg/L N from 21N-2.5P-16K (The Scotts Co., Marysville, OH).

The substrate was BM1 Mix (Berger Peat Moss, St.Modeste, Quebec). The sources, the rates and method of application of Si that were used were:

$KSiO_3$ (0, 50 and 100 $mg \cdot L^{-1}$ Si) weekly drench

$NaSiO_3$ (0, 50 and 100 $mg \cdot L^{-1}$ Si) weekly foliar spray

A complete randomized design was used with 2 Si sources at two rates each plus untreated controls. Five Si weekly application occurred before the diffusive resistance (or stomatal conductance) data collection. The measurements were performed with a portable transient porometer (LI-700, LI-COR Inc., Lincoln, NE). Readings were triplicate and performed on both recently mature and older leaves. ANOVA analysis was used for the collected data with mean separation LSD ($P \leq 0.05$).

Results and Discussion

Leaf resistance was higher in older leaves than recently mature leaves for all treatments (Fig.8 and 9). A transpiration rate decrease of Si treated plants has been reported in rice, maize, soybean, and wheat (Horigushi, 1988; Gao et al., 2004; Pandey and Yadav, 1999; Kupfer and Kahnt, 1992;). The effect was associated mainly with a Si deposition in cell walls and presence of polymerized Si double layer in the cuticle (Yoshida, 1965). In most cases this beneficial effect of Si was observed under an environmental stress like water stress or metal toxicity (Trenholm et al., 2004; Horigushi, 1988). Without an environmental stress and under normal growing conditions the Si effect to reduce transpiration rate is moderate.

In our study two different Si applications were tested, $KSiO_3$ as a weekly drench and $NaSiO_3$ as a weekly foliar spray. Only the application of 100 $mg.L^{-1}$ $NaSiO_3$ increased the leaf resistance of recently mature leaves (Fig. 8). None of the treatments were significant different from the untreated control in regards of older leaf resistance (Fig. 9). These results do not support Si metiated influences on stomata resistant as it has been prior reported (Agarie et al., 1988; Gao et al., 2004).

Sodium silicate may have acted as a film-forming antitranspirant. A leaf surface burrier can explain the reported increase of leaf resistance. The fact that the effect was observed only in recently mature leaves was probably because of better foliar spray reach in the upper part of the plant instead of lower parts. Also the older leaves have naturally lower transpiration rates and the difference between the controls and Si treated plants was not significant.

Reduced transpiration was reported when plants are grown under environmental stresses. In normal cultivation conditions the results were moderate. Horigushi (1988) reported a decrease in cuticular (nonstomatal) transpiration of rice plants grown under stress from manganese toxicity. Sorghum treated with Si had greater stomatal conductance than to untreated plants under dry conditions, but no effect in wet conditions (Hattori et al., 2005). Foliar application of 1% silica to soybean increased silica accumulation in cell walls (Kupfer and Kahnt, 1992). According to the same study water loss though the cuticle was decreased when plants were grown at 60% water field capacity, but the same effect was not observed under 90% water field capacity.

There are several studies that reported an effect of Si as antitranspirant causing increase on stomatal resistance. Silica powder (6% w/v) provided moderate resistance compared to untreated *Arachis hypogaea* L. and improved pod yield (Amaregouda et al., 1994). Spray application of Si (100 ppm) on two wheat cultivars (drought torerant and susceptible) increased the grain yield and had an influence on stomatal conductance with more significant effect in the tolerant cultivar (Pandey and Yadav, 1999). The results of this study were consistent with the majority of the above investigations. Si foliar application improved moderately leaf resistance of zinnias but the mechanism is unclear.

Conclusions

The application method of Si had affected leaf resistance of zinnia plants. Increased diffusive resistance occurred only with the foliar application but the substrate drenches had no effect. Only the recently mature leaves showed a difference in stomatal conductance of Si treated and untreated plants. Most studies reporting a Si effect in transpiration and leaf resistance under an abiotic stress condition. In our study the conditions were kept at the optimum level and the effect was moderate. It seems that Si foliar spray plays the role of antitranspirant by forming a physical barrier to water vapor. In previous chapters Si application improved several horticultural traits. The increase of leaf resistance even though moderate under optimum cultural conditions, it may add a synergistic effect and further benefit the quality and shelf longevity of floriculture commodities.

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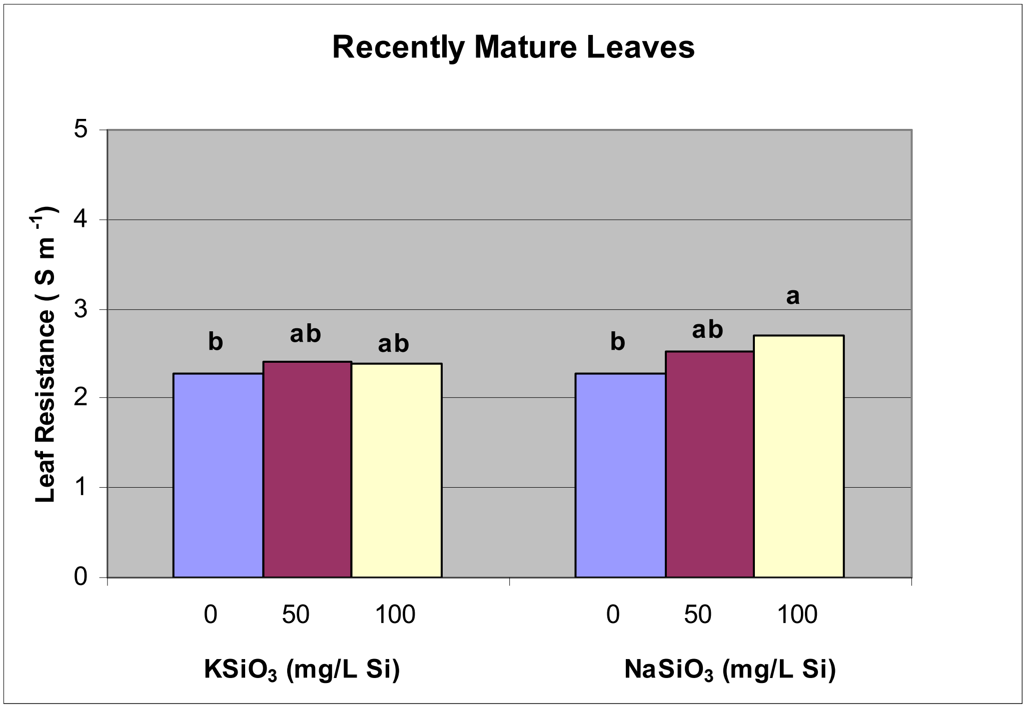

Figure 8. Effect of silicon on recently mature leaf resistance of greenhouse produced zinnias. Each bar represents a mean of three replicates.

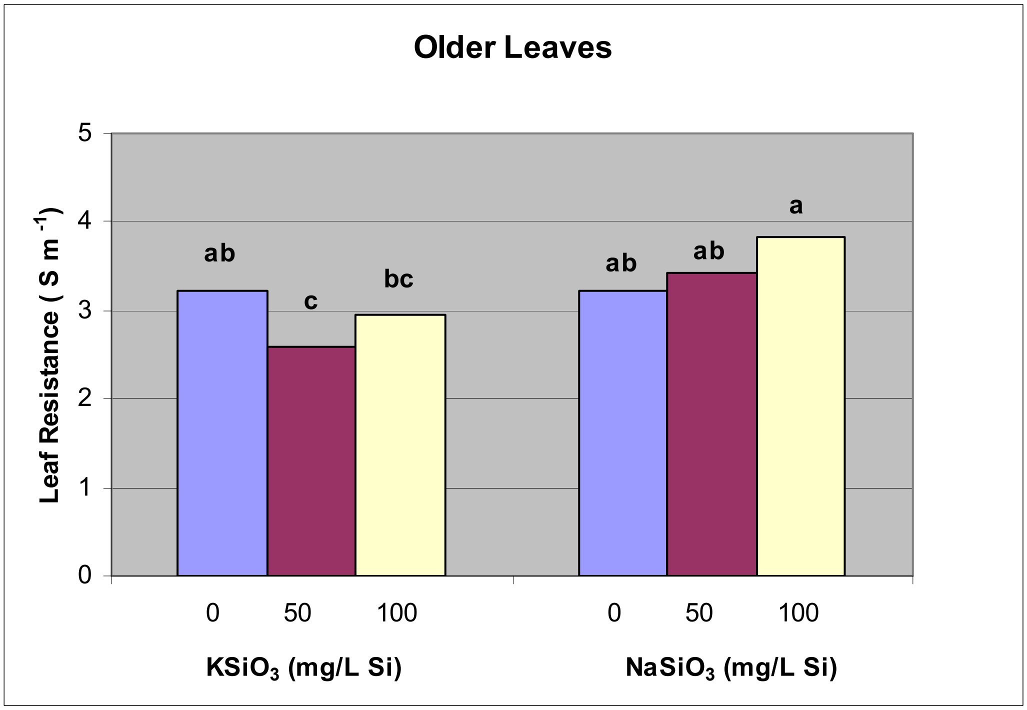

Figure 9. Effect of silicon on older leaf resistance of greenhouse produced zinnias. Each bar represents a mean of three replicates.

CHAPTER VI

GRAY MOLD MANAGEMENT IN GREENHOUSE FLOWER PRODUCTION WITH SILICON SUPPLEMENTATION

Introduction

Silicon (Si) is not considered an essential element for most of the plants, with the exception of some Equisitaceae members (Epstein, 1993). However, Si supplementation is reported to enhance plant resistance to both abiotic and biotic stresses, such as water and chemical stresses, nutrient imbalances, metal toxicities, diseases and pests problems (Ma and Takahashi, 2002; Hodson and Sangster, 2002; Cherif et al., 1992; Lu and Cao, 2001;).

Silicon's prophylactic effects have been noted against several plant diseases. Most of the studies have been performed with Si-accumulating plants, such as rice and Cucurbitaceae members, and beneficial effects were demonstrated mainly against powdery mildews and *Pythium* root rot. Depending on the crop and the pathogen, results range from no effect to total control (Belanger et al., 1995). Silica accumulation in cell walls was believed to be physically responsible for plant disease resistance. Later work reported Si as a potential signal that activates defense mechanisms such as production of phenolic compounds (Cherif et al., 1992, Datnoff et al., 2001), without rejecting the previous statement that silicified cells may inhibit penetration of epidermis. Increased phenolic production may increase lignification and promote cell wall strengthening.

The greenhouse floricultural industry predominantly uses soilless substrates with very limited amounts of silicon. So Si supplementation could be a potentially inexpensive disease management strategy for the greenhouse industry.

Botrytis diseases are the most common diseases in greenhouse production and also cause serious problems during postharvest because the pathogen remains active at low temperatures (Agrios, 1997). *Botrytis cinerea,* which causes gray mold, reduces the ornamental value and limits the shelf life of cut flowers (Meir et al., 1998). Even though it can be controlled easily by modifying the environmental conditions in the greenhouses, it is a major postharvest problem for cut flowers. Resistance development to fungicides, such as benzimidazole and dicarboximide, environmental concerns for excess chemical application and unsatisfactory degree of control (Elad, 1998) urged pursuit of alternative biological and chemical methods. The biocontrol agent *Trichoderma harzianum* provided adequate control of *B.cinerea* in greenhouse grown crops like cucumber and grape (Elad and Zimand, 1991). Phyllophane yeasts can also antagonize *B.cinerea* due to nutrient competition (Filonow, 1998) but with less consistent results compared to fungicides (Sansone, 2004). Several growth regulators such as gibberellic acid and methyl jasmonate are also reported to suppress the disease (Shaul et al., 1996; Meir et al., 1998).

The goal of this experiment was to determine the levels of disease control of *B.cinerea* achieved by different chemical forms (sodium silicate, potassium silicate and calcium silicate) and concentrations of soluble silicon compared to and in combination with reduced inputs of industry standard fungicides.

Materials and Methods

1. Plant material preparation

Helianthus annuus 'Sonora' seeds were sown into 0606 (75 mL per cell) bedding flats using BM1 Mix (Berger Peat Moss, St.Modeste, Quebec). Plants were grown in polycarbonate covered greenhouse with night/day set temperatures of 15/18 ^{o}C and fertigated with 150 ppm N from 21N-2.5P-16K (The Scotts Co., Margsville, OH). The sources, the rates and method of application of Si that were used were:

- $KSiO_3$ flakes (140 g•m^{-3} Si) substrate incorporation.
- Rice hull ash (170 g•m^{-3} Si) substrate incorporation
- $CaSiO_3$ (200 g•m^{-3} Si) substrate incorporation
- $KSiO_3$ (50 mg·L^{-1} Si) weekly drench
- $NaSiO_3$ (50 mg·L^{-1} Si) foliar spray
- $KSiO_3$ (50 mg·L^{-1} Si) foliar spray

Recommended full and half rates of conventional fungicides were included alone for comparison to standard industry practice and in combination with silicon treatments to discern any novel synergisms. The chemical fungicide foliar chlorothalonil (Daconil Ultrex®) treatments were applied a week before inoculating control plants and silicon-treated plants with spores of *Botrytis cinerea*. All treatments were replicated 3 times with 6 subsamples in a completely randomized design.

2. Fungal cultures and inoculations

Single-spore cultures of *Botrytis cinerea* isolated from commercial potted *Gerbera jamesonii* plants were maintained by serial culture on V8 agar. To promote sporulation, V8 agar cultures of *B. cinerea* were grown 1 week under fluorescent lighting at 20°C. *B. cinerea* conidia were suspended in inoculation medium with a glass rod and filtered using sterile cheese cloth to avoid remaining mycelia. The inoculation medium contained Gamborg's salts (PhytoTechnology Laboratories, L.L.C Shawnee Mission, KS) (3.1g/liter), dextrose (1.8 g/liter) and potassium phosphate (0.01 M, pH 6.0). The suspension was briefly centrifuged, suspended again to the inoculation media and the concentration quantified using a haemacytometer. Spore concentrations were adjusted to 10^5 ml^{-1}. Spore suspensions were sprayed on whole flowering plants. After which, control and *Botrytis*-inoculated plants were incubated at 100% relative humidity for 48 hours to establish infection (in separate humid chambers).

In preliminary trials wounding options were also tested as an inoculation method. Pin holes on leaf area and inoculation directly onto the holes, cuts on leaf with scissor dipped to the spore suspension and spore suspension containing a micro-abrasive (Celite) were tested in a small scale but inoculation of the whole plants followed by incubation in humid chambers proved to be the most effective inoculation method, so it was the used in the final experiment.

3. Postharvest handling

Cut flower harvesting procedure started one week after inoculation. When the top flower was fully open, stems were cut at their base, placed into vases containing tap water and transferred into cold storage (7 ^{o}C). All the cuts were performed using clean scissor. The vase water was changed weekly and no preservatives were used. The non-inoculated control flowers were harvested and treated identically to inoculated ones. The marketable vase life of the all flowers was recorded to compare postharvest performance between Si-treated and Si-untreated controls.

4. Assessment and Statistics

Disease incidence on stem, flowers, and leaves (% of symptomatic plants) and numerical ratings (stem lesion severity) were recorded one week after the inoculation, and then again one week after all flowers were in the cold storage. An index (0-4) was used to express the severity of stem lesions defined as: 0=no stem lesions; 1=1-2 lesions less than one centimeter in length; 2=more than 2 lesions less than one centimeter in length; 3=multiple lesions more than one centimeter in length; 4=girdling necrotic lesions resulting in dead plants. For disease incidence and mortality a chi-square test was used to compare Si treatments to the untreated controls. The Cochran-Armitage trend test (Cochran, 1954) was used to linear trend of disease incidence with fungicide rate. Pearson's correlation coefficients of disease incidence for fungicide rate were calculated for each Si source. For stem severity rating LSD test was used to separate differences between Si treatments and untreated controls.

Results

Symptom expression

Botrytis cinerea symptoms started to show as early as two days after inoculation. The infection was first observed on opened flowers initially as water soaking petal spots gradually resulting in blossom blight (Fig.10) and as lesions on stem at the level of decaying cotyledons and senescence leaves (Fig.11).

Recently mature leaves were also affected, especially when their surfaces were attached, with water soaked spots that later became extended brownish lesions (Fig. 11). Several of the Si treatments such as $NaSiO_3$ foliar spray, $KSiO_3$ foliar and drench application, as well as $CaSiO_3$ promoted early flowering. On the other hand, ashed rice hulls and $KSiO_3$ flakes incorporation delayed flowering compared to untreated controls (data not presented).

Non-inoculated plants had no disease incidence for all the Si treatments as well as the controls (data not presented).

Stem disease incidence

For inoculated plants one week after inoculation, without fungicides, stem disease incidence was lower with sodium and potassium silicate foliar sprays (Table XIII). When half-rate fungicide was used, the foliar sprays and the potassium silicate drench decreased stem disease incidence. In combination with full rate fungicide only substrate calcium silicate reduced stem disease incidence to zero. Full rate fungicide gave the best control of stem disease incidence for all the Si-treatments compared to the half-rate and untreated controls. Increased fungicide rate had a negative correlation with S.I for all treatments except the $NaSiO_3$ foliar spray.

Flower disease incidence

Neither silicon treatments nor fungicide rates had any effect on flower disease incidence. The only exception was a weak negative correlation between fungicide rate and F.I for the $CaSiO_3$ substrate incorporation (Table XIII).

Leaf disease incidence

Fungicide application was less effective in decreasing leaf disease incidence than stem disease incidence (Table XIII). Leaf disease incidence decreased with increased fungicide rate only with $CaSiO_3$ and $KSiO_3$ flake substrate incorporation. With no fungicide use, $NaSiO_3$ and $KSiO_3$ foliar application, $KSiO_3$ drench, and $CaSiO_3$ substrate incorporation had lower leaf disease incidence than the Si-untreated controls. $KSiO_3$ gave the best results with a 2.5 and 2.2 fold decrease in leaf disease incidence compared to control when combined with zero and half fungicide rates, respectively. $CaSiO_3$ gave the best control of L.I when used in combination with full fungicide rate (6 fold decrease compared to Si-untreated control).

Stem disease severity

When no fungicide was used, $NaSiO_3$ and $KSiO_3$ foliar applications were the treatments with the lowest stem severity index (Fig.12). Ashed rice hulls and $CaSiO_3$ also decreased the stem severity in the absence of fungicide but were less effective compared to $NaSiO_3$ and $KSiO_3$ foliar applications. Even though $KSiO_3$ drench used in combination with half and full rate of fungicide was effective, it failed to reduce stem disease severity by itself.

In combination with half rate fungicide, $KSiO_3$ drench, $NaSiO_3$ and $KSiO_3$ foliar application had a lower stem disease severity index than the untreated control, but at full rate fungicide there was no difference among the treatments.

Mortality

Table XIV describes the mortality rate one week after the inoculation and one week after postharvest conditions of sunflowers. In both cases there was no difference in the percent mortality across Si-treatments compared to Si-untreated control. Increasing the fungicide rate resulted in lower mortality rates especially one week after inoculation for most treatments.

Discussion

The prophylactic effects against pathogens induced by Si are hypothesized to act through tissue fortification at the sites of deposition, and are believed to activate defense mechanisms against pathogens (Cherif et al., 1992; Datnoff et al., 2001).

In this study, one week after inoculation the pathogen symptoms were obvious and the pathogen was well established. None of the tested Si supplements impaired flower quality. Silicon supplementation decreased disease incidence on the stem and leaf but not the flower. The flower was the most susceptible plant part and neither the Si treatments nor the fungicide rates suppressed pathogen symptom expression. Foliar sprays with $NaSiO_3$ and $KSiO_3$, $KSiO_3$ drench and $CaSiO_3$ were the most effective Si sources against stem and leaf incidence alone or in combination with fungicide. $CaSiO_3$ fertilization of roses was previously shown to reduce Botrytis blight (Volpin and Elad, 1991). Also Ca^{2+} in combination with epiphytic yeast reduced gray mold of apple better than the yeast treatments alone (Fan and Tian, 2001). So, in the case of $CaSiO_3$ it is difficult to say whether the beneficial effect is attributed to Ca, Si or a synergistic effect.

Reduced stem severity was also observed with several of the Si treatments with $NaSiO_3$ and $KSiO_3$ providing the best results. In the previous chapter Si foliar sprays showed evidence of acting as film forming antitranspirants that increased leaf resistance of recently mature leaves, and may act as a physical barrier obstructing pathogen infection.

Increased synthesis level of gibberellic acid was a response of rice to Si fertilization (Jang et al., 2003), and suppression of cut rose Botrytis blight was achieved with GA application. Increased GA levels due to Si supplementation may be one of the mechanisms that decreased disease incidence of this study. The more rapid maturity of Si-treated plants may indicate higher levels of GA were induced.

Botrytis cinerea can further negatively influence the marketability of flowers under cold storage conditions. Postharvest losses for fruits, vegetables and flowers can be great and fungicides are widely used. However, pathogen resistance to fungicides and environmental concerns provide reasons for search of alternative means of control. Nutrient competitors like yeasts and growth regulators like methyl jasmonate are shown to suppress Botrytis (Fan and Tian, 2001; Meir et al., 1998). However fungicides are still reported to provide the most consistent and suppressive results (Sansone et al., 2004).

Si supplementation as a protective postharvest treatment against *B.cinerea* failed to decrease mortality rate one week after harvest. Thus though Si can act as a physical barrier inhibiting pathogen penetration on stem and leaf surfaces, it fails to protect the highly susceptible flower. Also, no evidence of systemic protection against this pathogen was observed, since once plants were infected there was no difference in mortality rate of Si-treated and untreated plants.

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Figure 10. *Botrytis cinerea* inflorescence symptoms in sunflower in an early (A) and later stage (B).

Figure 11. *Botrytis cinerea* symptoms sunflower; In decaying cotyledons, senescence leaves and attached leaf surfaces.

TABLE XIII
Incidence % of B.cinerea on Stem, Flower and Leaf of Si Treated Sunflowers Compared to Untreated Controls One Week After Inoculation

	Disease incidence (% symtomatic plants)											
	STEM				LOWER				LEAF			
	Fungicide rate				Fungicide rate				Fungicide rate			
Silicon Sources	0	Half	Full	**r**	0	Half	Full	**r**	0	Half	Full	**r**
Control- Si untreated	94	56	28	-0.55***	11	11	0	-0.17 NS	83	72	61	-0.20 NS
KSiO$_3$ flakes in substrate	94	33	17	-0.64***	0	11	6	-0.10 NS	56	67	28▣	-0.23*
Rice Hulls in substrate	83	44	11	-0.59***	0	0	0	---	67	50	44	-0.18 NS
CaSiO$_3$ in substrate	72	39	0▣	-0.61***	28	0	6	-0.29*	39▣	39▣	11▣	-0.25*
KSiO$_3$ drench	100	11▣	11	-0.87***	11	17	11	-0.00 NS	39▣	56	33	-0.05NS
NaSiO$_3$ foliar	39▣	17▣	17	-0.21 NS	22	22	11	-0.12 NS	44▣	44	28▣	-0.14 NS
KSiO$_3$ foliar	50▣	11▣	6	-0.44***	28	28	11	-0.16 NS	33▣	33▣	33	0.00 NS

▣ Significant from the control in the same column at the 5% level by the chi-square test

^{NS}, *, **, ***: Not significant (NS) or significant at 5% (*), 1% (**), or 0.1% (***)

TABLE XIV
Mortality % of Si Treated Sunflowers Compared to Untreated Controls One Week After Inoculation with *B.cinerea* and One Week After Harvesting

	One week after inoculation				One week after harvest			
	Fungicide rate				Fungicide rate			
Silicon Sources	0	Half	Full	r	0	Half	Full	r
Control- Si untreated	61	28	11	-0.43***	94	67	50	-0.40***
KSiO3 flakes in substrate	39	28	6	-0.32**	72	44	44	-0.18 NS
Rice Hulls in substrate	33	17	11	-0.23*	78	39	33	-0.36**
CaSiO3 in substrate	44	22	6	-0.37**	83	72	28	-0.47***
KSiO3 drench	56	17	17	-0.35**	94	50	50	-0.38***
NaSiO3 foliar	44	22	17	-0.26*	78	72	56	-0.20 NS
KSiO3 foliar	44	44	28	-0.14 NS	83	67	61	-0.20 NS

^{NS}, *, **, ***: Not significant (NS) or significant at 5% (*), 1% (**), or 0.1% (***)

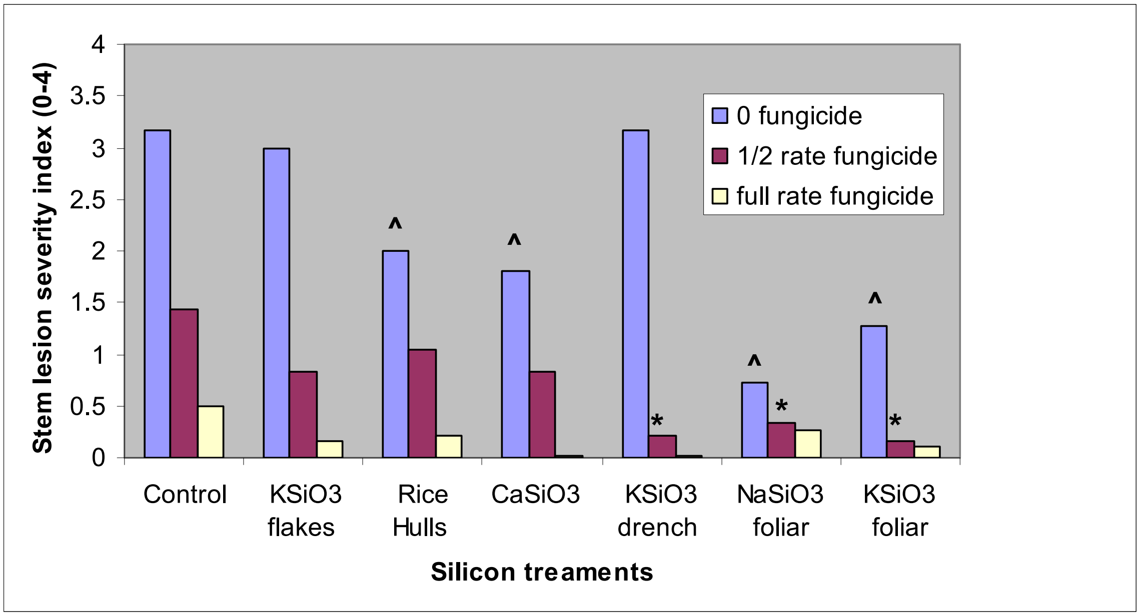

Figure 12. Effects of Si supplementation and fungicide application rate on stem lesion severity.

^: Silicon treatment significantly different from untreated control according to LSD test (p=0.05) for 0 fungicide rate.

*: Silicon treatment significantly different from untreated control according to LSD test (p=0.05) for 1/2 fungicide rate.

CHAPTER VII

SUMMARY

Silicon is a non-essential element for most plants. However, silicon effects on plant growth, crop quality, stimulation of photosynthesis, reduction of transpiration, and enhancement of plant resistance to abiotic and biotic stresses has been reported in agricultural crops. In floriculture greenhouse production, most of plants are cultivated using soilless substrates where Si concentration is limited and Si supplementation may benefit greenhouse production.

In our first study, the goal was to investigate Si supplementation effects in cut flower production. Three plant species and several Si sources were used. Silicon concentration of Si-treated plants increased compared to untreated controls for all species. The concentration of Si and the deposition in plant tissue varied among the species. Depending on source and rate, several horticultural traits were improved due to Si supplementation. Thick straight stems, increased flower diameter, and early flowering in Si optimum treatments upgraded cut flower quality compared to untreated controls.

In a following study *Helianthus annuus* ‘Ring of Fire’ was used to investigate the relationship of Si tissue and substrate concentration, since guidelines for acceptable tissue and substrate levels are not established for floriculture greenhouse production. A positive correlation between leaf Si concentration and SME soilless substrate samples existed (r=0.75). The correlation indicates potential use of leaf samples or SME values in establishment of acceptable Si levels for floriculture soilless greenhouse production.

Reduction of transpiration rate can further benefit floriculture production and the goal of our leaf resistance study was to examine the effect of Si supplementation in stomatal conductance of zinnia leaves under normal greenhouse conditions. The results can not support an active role of Si in stomata movement but there was an indication that foliar sodium silicate spray acts as film-forming antitranspirant that increases leaf resistance.

Finally in a plant pathology study, the effect of Si supplementation on suppression of *Botrytis cinerea* was investigated. None of the tested Si supplements impaired flower quality. Silicon supplementation decreased disease incidence on the stem and leaf but not the flower. The obtained results failed to support Si supplementation as a protective postharvest treatment for cut flowers against *B.cinerea*. These results suggest that Si acts as a physical barrier by inhibiting pathogen penetration on stem and leaf surfaces, however it can not provide evidence of a systemic protection against this pathogen since once plants were infected there was no difference in mortality rate of Si treated and untreated plants.

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VITA

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Title of Study: SILICON SUPPLEMENTATION AFFECTS GREENHOUSE PRODUCED CUT FLOWERS

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Scope and Method of Study: Ours study objective was the evaluation of silicon (Si) supplements to enhance cut flower production quality. This was achieved by determination of optimum application methods, sources, and Si rates for improving crop quality of cut flowers. Effects of Si supplementation on transpiration and management of *Botrytis cinerea* in cut flowers greenhouse production was also investigated.

Findings and Conclusions: Depending on Si source and rate, several horticultural traits of selected cut flowers were improved. Thick straight stems, increased flower diameter, and early flowering upgraded cut flower quality of Si-treated flowers. Silicon concentration and deposition in plant tissue varied among different species. A positive correlation between leaf Si concentration and SME soilless substrate samples existed (r = 0.75). Silicon foliar application acted as a film-forming antitranspirant. Decreased disease incidence of *B.cinerea* on stem and leaves of Si treated plants was observed.

Advisor's Approval:……………………………………………………………………