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SUPPLEMENTAL EFFECTS OF SILICON NUTRITION ON GROWTH, QUALITY AND SOME PHYSIOLOGICAL CHARACTERS OF POTTED CHRYSANTHEMUM GROWN IN GREENHOUSE

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Abstract. Potted chrysanthemum is one of the most important floriculture plants which commercially produced in greenhouses where silicon (Si) is available in limited concentration because of using several substrates as growing media. Therefore, this study was conducted to investigate the supplemental effects of Si nutrition on growth, flowering, flower longevity as well as shelf life and nutrients content of potted chrysanthemum in relation to Si application. Moreover, the effects of Si treatment on some physiological parameters i.e. chlorophyll content, stomatal resistance, membrane stability index (MSI) and total carbohydrates were also investigated. Si application as K_2SiO_3 was added whether as foliar application at 25, 75 and 125 mg L^{-1} Si or soil drenches at 50, 100 and 150 mg L^{-1} Si. Except plant height and leaf area, the other vegetative growth and flowering characters were improved as a result of both Si supplementation methods compared with untreated control. Flowering was earlier and shelf life was longer in Si-supplemented than non-supplemented plants. Generally, Si application increased the macro and micronutrients concentrations (except Ca) estimated in this study. Chlorophyll content, stomatal resistance, MSI and total carbohydrates were increased among Si treated plants. Improving the floricultural traits, extending longevity and shelf life of greenhouse grown chrysanthemum may give an impact of its greenhouse commercial production if appropriate level was used.

Key words: Potassium silicate, shelf life, chrysanthemum, stomatal resistance, membrane stability

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INTRODUCTION

Chrysanthemum (*Chrysanthemum morifolium* RAM.) is very important flower crop with an economical value in international floral industry. It is considered as one of the main commercial ornamental plants grown in pots with a great deal of market expression. Moreover, it has for many years been ranked second at different auctions in value terms because of its success due to different colors and sizes that adding something new to the consumer [A.I.P.H. 2003]. It has been found that Si has important role in plant growth and hence it was considered one of the important elements in plants [Deng et al. 2011] however plant response to Si levels and its accumulation vary according to plant species and the mode of Si uptake affects its content in different plant organs [Ma and Takahashi 2002, Mattson and Leatherwood 2010].

Most commercial production of potted plants in greenhouses depends on using substrates as growth media instead of normal soil and these substrates have limited Si in an available form to plants [Voogt and Sonneveld 2001]. Si has several beneficial effects on agronomic crops such as improving growth and quality, stimulating photosynthesis and reducing transpiration and consequently increasing plant resistance to abiotic and biotic stresses [Ma and Takahashi 2002, Gao et al. 2004]. Hence, these positive effects generated interest for silicon application with various horticultural plants. Plants that are poor accumulators of silicon can obtain significant benefits like structural rigidity of cell walls even before undergoes biotic and abiotic stresses [Sánchez et al. 2012]. Silicon application improved the growth and quality of several plants grown in greenhouse [Kamenidou et al. 2008]. When silicon was found in the nutrient solution of hydroponically grown gerbera, it improved the growth and flower quality [Savvas et al. 2002]. Moreover, Applications of potassium silicate had beneficial effects on the growth and quality of miniature roses flower in the rock wool culture system [Hwang et al. 2005]. Silicon supplementation of floricultural crops grown in soilless substrates has been found to improve growth, quality and resistance to biotic and abiotic stresses [Kamenidou et al. 2008, Reezi et al. 2009, Dębicz and Wróblewska 2011, Zhao et al. 2013]. The diameter of sunflower stem and its dry weight as well as flower diameter were increased with increasing Si media supplementation rates [Kamenidou et al. 2011].

The plant height of zinnia was not affected by Si treatment however stem as well as flower diameters were improved [Kamenidou et al. 2009]. Silicon supplementation was reported to increase stem diameters of chrysanthemum [Moon et al. 2008], spray rose [Hwang et al. 2005] and herbaceous peony [Zhao et al. 2013]. Moreover, Si additions increased both stem and flower diameter as well as upgraded the flower quality of greenhouse grown sunflower [Kamenidou et al. 2008] and zinnia [Kamenidou et al. 2009]. Gerbera plants treated with Si produced earlier flowering with higher quality than non-treated plants [Kamenidou et al. 2010]. On the other hand, addition of Si partially improved the growth characters of cut rose and significantly increased total chlorophyll content in leaves [Reezi et al. 2009].

De Kreij et al. [1999] recommended Si supplementation for crops hydroponically produced to avoid negative effects of its deprived plants. However, the improvements were depending on the source and concentration of silicon supplied. Silicon supplementation of hydroponically cultured gerbera resulted in a higher percentage of first class flowers and significantly thicker flower stems [Savvas et al. 2002]. Foliar treatment of Si had a beneficial effect on vegetative growth of some seasonal ornamental plants. Moreover increasing number of lateral shoots as well as producing a higher number of buds and flowers or inflorescences with an increased diameter was observed in Si treated plants compared with the control [Dębicz and Wróblewska 2011]. It has been reported that Si treatment also improved the flower quality through its effects on increasing the mechanical strength of inflorescence stem which consider a key index determining its ability to support the fresh flower [Chen et al. 2000], producing thicker flower stem peduncles and its quality [Kamenidou et al. 2010].

Although the great importance of chrysanthemum, and even Carvalho-Zanão et al. [2012] reported that some chrysanthemum varieties were classified as accumulators of Si, few reports have been attempt concerning its response to Si application. In addition, there are no established criteria concerning the positive response of the majority of potted plants to Si supplementation. In addition, the appropriate rate of Si supplementation for floriculture plants grown in greenhouses must be determined [Mattson and Leatherwood 2010]. Moreover, most previous investigations on Si supplementation on greenhouse crops were conducted on hydroponic system [Voogt and Sonneveld 2001, Savvas et al. 2002, Ranger et al. 2009, Reezi et al. 2009] and further studies are needed to investigate the effects of Si on plants grown in substrates. As far as we know, there are few reports related to the physiological effects of Si application especially when it was applied as a fertilizer under normal conditions. Moreover, the nutritional properties of Si in plant growth are also not well established. Therefore the aim of this study was to investigate supplemental effects of silicon nutrition on growth characters, shelf life quality and some physiological parameters of potted greenhouse produced chrysanthemum.

MATERIALS AND METHODS

Plant material. Rooted cuttings of *Chrysanthemum morifolium* RAM. cv. 'White Reagan' were obtained from commercial grower in Saudi Arabia and directly transported to Biology Department, Faculty of Science, Taif University and transplanted into 20 cm (1.6 L) pots with three plants as commonly used in greenhouse production. The pots were contained local soil surface:peat:perlite in a proportion of 1:3:1 (v/v/v) substrate. The physical properties of local soil used were (sand – 80.35%, silt – 8.15% and clay – 11.50%) and chemical properties were (pH, 8.21, EC, 2.19 dSm^{-1}, OM, 0.13%, Total $CaCO_3$, 0.93%, Total N, P, K were 0.18,0.039 and 0.046%, respectively). Plants were grown in greenhouse with night/day set temperatures of 16/19°C and relative humidity around 60–70 %. The experiment was carried out in a greenhouse during 2013 and 2014 seasons.

Silicon treatments. Six Si treatments plus control were investigated in this experiment. Aqueous solutions from potassium silicate (K_2SiO_3) were prepared from the commercial product (Pro-TeKt® 0-0-3, Dyna-Grow™, Richmond, CA 94806) which contains 7.8% silicon (SiO_2) and 3.7% potassium (K_2O). Two Si application methods with three levels each were applied. The first was foliar application at 25, 75 and

125 mg L^{-1} Si and the second one was soil drenching at 50, 100 and 150 mg L^{-1} Si. The spraying was going until whole vegetative growth was completely wet and run off. Soil drench treatment was applied until soil saturation (about 225 mL per pot). Both application methods were done after two weeks from transplanting and continued for six weeks (once a week). In order to equilibrate the alkaline effect of potassium silicate, HCl at 2 mol L^{-1} was added when required to adjust the pH to 5.8–6. A slow release fertilizer (Basacote® Plus LR (16 M) 15-8-12 (+2MgO + 5S + T.E.)) was applied at 5 g per pot for treated and untreated pots. Apical pinching was occurred 15 days after transplanting and was repeated 45 days later for the principal buds. Plants were irrigated when required. The treatments were arranged in a complete randomized block design with four replicates of four plants each.

Growth and flowers characters. After two weeks from the end of K_2SiO_3 treatment: plant height (cm), branch number per plant, stem diameter (cm), dry weight as well as leaf area (cm^2) were measured. In order to determine leaf area, blade area was measured using digital image analysis according to the method of Matthew et al. [2002]. Digital image of the leaf blade was created in digital format using a Hewlett-Packard scanner (Hewlett Packard, Cupertino, ca), image was scanned at dot per inch (100 dpi), the blade area was measured using public domain software (scion image version 4.02).

Flower number per plant, diameter of most widely opened flower (cm), time (days) to first flower (anthesis), flower longevity and shelf life for whole pot (days) were recorded. Shelf life of pot chrysanthemum was the period between the opening of 2–3 flowers and when more than 50% of flowers were wilted.

Physiological and nutritional parameters measurements. Physiological parameters (i.e. chlorophyll content, stomatal resistance, membrane stability index and carbohydrate percentage) and some macro- and micronutrients were determined in recently matured leaves two weeks after K_2SiO_3 treatments as described below.

Total chlorophyll content. Chlorophyll content was determined according to Sadasivam and Manickam [1992] by using spectrophotometer (Pharmacia, LKB-Novaspec II and calculated as (mg g^{-1} FW).

Stomatal resistance. Stomatal resistance was determined by Delta T AP_4 leaf porometer, UK.

Membrane stability index (MSI). Ions leakage was determined by the method of Sairam et al. [1997]. Two leaf samples (0.2 g) were taken and placed in 20 mL of double distilled water in two different 50 mL flasks. The first one was kept at 40°C for 30 min while the second one was kept at 100°C in boiling water bath for 15 min. The electric conductivity of the first (C_1) and second (C_2) samples were measured with a conductivity meter. The leakage of ions was expressed as the membrane stability index according to the following formula, $MSI = [1 - (C_1/C_2)] \times 100$.

Total carbohydrates. Leaf samples were dried in an electric oven at 70°C for 24 hours. Then, the fine powder was used to determine total carbohydrate percentages according to Herbert et al. [1971].

Macro and micronutrients determination. Leaf samples were analyzed for nitrogen using the micro-Kjeldahl method of Black et al. [1965]. Potassium was determined by flame photometer while phosphorus, calcium, magnesium, iron as well as zinc were spectrophotometrically determined as described by A.O.A.C. [1995].

Statistical analysis. Data were means of two years and combined analysis was done (n = 8). The obtained data were subjected to statistical analysis using Michigan Statistical Program Version C (MSTATC). The analysis of variance (ANOVA) was performed to compare means. Means were compared by using LSD test at 0.05 level. Data were presented as means ±S.E. for the average of two independent experiments.

RESULTS

Growth characters. The effects of that Si treatment whether applied as foliar spraying or soil drench on vegetative growth characters of potted chrysanthemum were presented in Table (1). Branch number, stem diameter and dry weight were significantly increased compared with the control as a result of Si application. On the other hand, plant height as well as leaf area were not affected. For both application methods the highest Si level reduced all the previous vegetative parameters relative to the moderate level. Spraying chrysanthemum with 75 mg L^{-1} or applying 100 mg L^{-1} Si as soil drench resulted in the highest growth measurements.

Table 1. Effect of Si supplements on vegetative growth characters of potted chrysanthemum 'White Reagan' grown in greenhouse

Si treatments		Plant height (cm)	Branch number	Stem diameter (cm)	Dry weight (g)	Leaf area (cm^2)
Control	0	44.23 ±0.29a	6.41 ±0.18d	0.54 ±0.09d	112.25 ±0.61d	8.64 ±0.06a
Foliar (mg L^{-1})	25	44.75 ±0.28a	6.92 ±0.12c	0.61 ±0.05c	118.72 ±0.057c	8.86 ±0.07a
	75	44.98 ±0.20a	8.14 ±0.15a	0.74 ±0.06a	122.56 ±0.58ab	8.97 ±0.05a
	125	44.12 ±0.55a	7.61 ±0.11b	0.69 ±0.05b	121.83 ±0.58b	8.12 ±0.06a
Soil drench (mg L^{-1})	50	44.65 ±0.10a	7.15 ±0.12c	0.63 ±0.05c	119.97 ±0.57a	8.92 ±0.23a
	100	44.74 ±0.11a	8.97 ±0.27a	0.79 ±0.06a	124.18 ±0.59a	8.99 ±0.06a
	150	44.09 ±0.09a	7.68 ±0.17b	0.70 ±0.05b	121.57 ±0.61b	8.26 ±0.11a

The values (mean ±SE) are the average of two independent experiments (n = 8). Means within a column followed by different letters significantly differ for each other according to LSD test at P = 0.05

Flower characters and shelf life. The flower numbers per plant as well as flower diameter were increased with increasing Si level up 75 or 100 mg L^{-1} Si applied as foliar or soil drenches, respectively. However, a significant decrease relative to the moderate level was observed thereafter by using the highest level in both methods but still significantly higher than the control (tab. 2). The highest flower number with the highest diameter was obtained when treatments of 75 or 100 mg L^{-1} Si were applied as foliar or soil drench, respectively. Compared with the control, the previous two treatments increased flower number by 32.67 and 43.77% and flower diameter by 28.50 and 31.40%, respectively. The obtained data also showed that some Si treatments accelerated the appearance of the first flower since the time to anthesis was significantly decreased. The earlier flowering was clearly observed with 75 or 100 mg L^{-1} Si treatments applied as foliar or soil drench, respectively. Both treatments significantly reduced this period compared with the control or other Si levels applied. The beneficial effects of Si nutrition were also observed on flower longevity as well as shelf life of plants. The lowest Si level which applied as foliar or soil drench did not extend the flower longevity or shelf life compared with untreated control (tab. 2). However the longest flower longevity and shelf life were recorded by using 75 or 100 mg L^{-1} Si treatments applied as foliar or soil drench. The flower longevity was extended by 24.33 and 36.78% while shelf life was increased by 13.31 and 20.58% when plants treated with both treatments, respectively.

Table 2. Effect of Si supplements on flower characters and shelf life quality of potted chrysanthemum 'White Reagan' grown in greenhouse

Si treatments		Flower number (plant)	Flower diameter (cm)	Time to anthesis (days)	Flower longevity (days)	Shelf life (days)
Control	0	18.21 ±0.89e	3.79 ±0.10d	79.45 ±0.63a	5.22 ±0.08c	21.87 ±0.26c
Foliar (mg L^{-1})	25	20.63 ±0.56d	4.09 ±0.14c	78.19 ±0.53a	5.78 ±0.05c	22.18 ±0.70c
	75	24.16 ±0.59b	4.87 ±0.07a	75.14 ±0.55c	6.49 ±0.18a	24.78 ±0.60b
	125	22.47 ±0.60c	4.34 ±0.09b	77.57 ±0.23b	6.04 ±0.17ab	23.54 ±0.31bc
Soil drench (mg L^{-1})	50	21.15 ±0.57d	4.15 ±0.09c	78.98 ±0.26a	5.98 ±0.13c	23.67 ±0.59bc
	100	26.18 ±0.55a	4.98 ±0.12a	74.16 ±0.57c	7.14 ±0.09a	26.37 ±0.62a
	150	22.86 ±0.56c	4.52 ±0.17b	78.57 ±0.26a	6.16 ±0.26ab	24.35 ±0.51b

The values (mean ±SE) are the average of two independent experiments (n = 8). Means within a column followed by different letters significantly differ for each other according to LSD test at P = 0.05

Table 3. Effect of Si supplem ents on some macro and micronutrients of potted chrysanthemum leaves 'White Reagan' grown in greenhouse

Si treatments		Macronutrients (mg g^{-1} DW) and micronutrients (µg g^{-1} DW)						
		N	P	K	Ca	Mg	Fe	Zn
Control	0	21.5 ±0.17c	3.6 ±0.12d	20.9 ±0.23c	10.6 ±0.17a	5.2 ±0.12c	260 ±2.89c	71 ±1.73c
Foliar (mg L^{-1})	25	21.7 ±0.06c	3.7 ±0.06d	21.1 ±0.18c	10.4 ±0.12a	5.3 ±0.17bc	262 ±1.15c	63 ±2.06d
	75	29.8 ±0.06a	4.6 ±0.17b	28.2 ±0.29a	10.2 ±0.12b	6.0 ±0.29a	314 ±2.31a	85 ±2.03b
	125	24.1 ±0.07b	4.3 ±0.012c	24.8 ±0.17b	9.9 ±0.12b	4.9 ±0.29c	269 ±2.40bc	72 ±2.96c
Soil drench (mg L^{-1})	50	26.5 ±0.12b	4.1 ±0.35c	25.8 ±0.46b	10.3 ±0.23ab	5.6 ±0.17b	295 ±3.06b	71 ±3.48c
	100	31.5 ±0.23a	4.9 ±0.12a	29.8 ±0.15a	9.7 ±0.32bc	6.2 ±0.15a	326 ±3.46a	94 ±2.03a
	150	24.7 ±0.18b	3.8 ±0.17d	24.9 ±0.29b	9.4 ±.012c	5.1 ±0.15c	284 ±2.60b	86 ±2.31b

The values (mean ±SE) are the average of two independent experiments (n = 8). Means within a column followed by different letters significantly differ for each other according to LSD test at P = 0.05

Nutrients content. Chrysanthemum leaf macro and micronutrients analysis showed some differences in relation to Si treatments (tab. 3). Both application methods of Si increased macronutrients estimated (N, P, K, and Mg) relative to untreated plants, while a reduction of the previous macronutrients was observed by using the highest Si level in both methods relative to the moderate levels. Similar trend was observed concerning leaf micronutrients (Fe and Zn) in relation to different Si levels. Compared with the control, the significant increase was recorded by the moderate level of spraying method and the moderate or highest Si levels in soil drenches method. Unlike the previous elements, Ca content was decreased as a result of Si treatment. The moderate and highest levels of both application methods significantly reduced Ca content relative to the control.

Chlorophyll content. Leaf chlorophyll content was significantly increased as a result of Si treatment compared with the control. However, there were no significant differences when lower level of foliar or soil drenches was applied. Relative to the moderate level, a reduction in chlorophyll was observed when the highest level of both application methods was used (fig. 1 A). The highest chlorophyll content was obtained by spraying plants with Si at 75 mg L^{-1} Si or drenching soil with 100 mg L^{-1} Si.

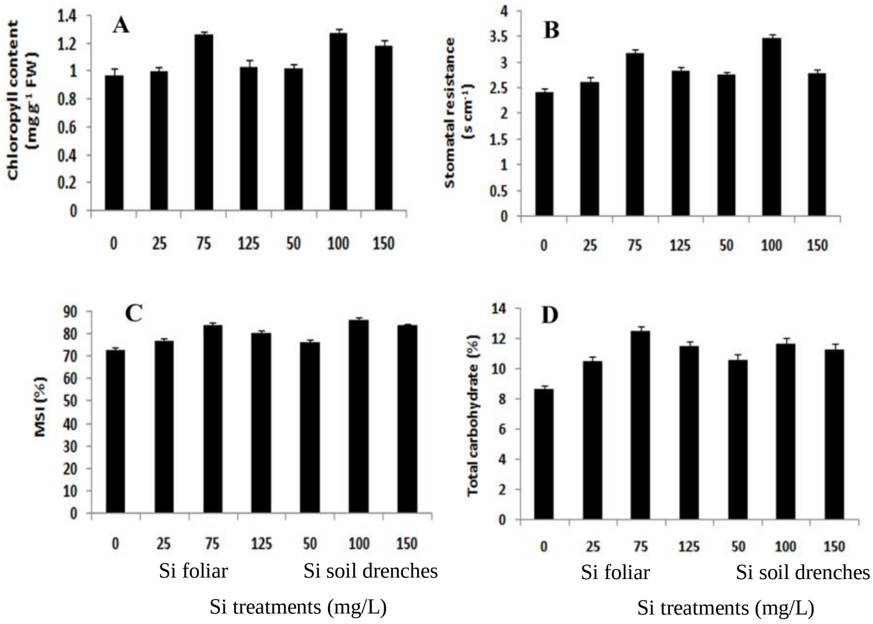

Fig. 1. Effects of Si treatments on (A) chlorophyll content, (B) stomatal resistance, (C) membrane stability index (MSI) and (D) total carbohydrate percentage of chrysanthemum leaves. Bars (mean ±SE) are the average of two independent experiments (n = 8)

Stomatal resistance. Data presented in Figure 1B showed that all Si treatments applied significantly increased leaf stomatal resistance compared with the control. Meanwhile, when Si level was more than 75 or 100 mg L^{-1} as foliar or soil drenches a reduction in stomatal resistance was occurred but its value was still significantly higher than untreated control. Relative to untreated plants, the stoamatal resistance was increased by 8.80, 31.22 and 17.74% when plants sprayed with 25, 75 and 125 mg L^{-1} Si, however soil drenches with 50, 100 and 150 mg L^{-1} Si increased this parameter by 14.31, 43.60 and 14.99%, respectively.

Membrane stability index (MSI). Silicon treatment significantly increased MSI when the moderate or highest levels of both application methods were applied. While, no significant differences were observed between control and the lowest Si level whether used as foliar or soil drenches (fig. 1C). Increasing Si level higher than 75 or 100 mg L^{-1} as foliar or soil drenches, respectively did not add any beneficial effect.

Total carbohydrates. The obtained data showed a significant increase in total carbohydrate percentages of chrysanthemum leaves treated with different Si levels compared with untreated control (fig. 1D). Although the highest Si level reduced carbohydrate percentage, it still significantly higher than the untreated control. The highest carbohydrate percentages were obtained by treatments of 75 or 100 mg L^{-1} Si as foliar or soil drench, respectively. Relative to the control, treatment of Si foliar at 75 mg L^{-1} increased total carbohydrates by 41.53% while it was 42.44% when soil drench was applied at 100 mg L^{-1} Si.

DISCUSSION

The results obtained in this study showed a significant improve in growth, flowering and quality of potted chrysanthemum as a result of Si treatments. Except plant height and leaf area, other vegetative characters were significantly increased. The effect of Si supplements on plant height is not stable since it can increase, decrease or unaffected in some cases [Kamenidou et al. 2008, Kamenidou et al. 2010, Mattson and Leatherwood, 2010, Carvalho-Zanão et al. 2012]. The leaf area index of rose was not affected by Si treatments [Reezi et al. 2009] however Ahmed et al. [2014] reported an increase in leaf area index in relation to Si treatment. It has been reported that Si may involved directly or indirectly in cell metabolism and can affect the morphological and physiological processes in plants through unclear mode of action [Liang et al. 2003, Zhu et al. 2004]. Moreover, some studies showed an enhancement of GA_3 level in relation to Si application [Hwang et al. 2008] and hence an improvement of potted chrysanthemum growth was observed in our study. The promotion effect of Si on vegetative growth i.e. branch number, stem diameter and dry weight are in accordance with the results of Hanafy Ahmed et al. [2008], Kamenidou et al. [2009] and Zhao et al. [2013]. Increased dry weight production is often a plant response to Si supplementation due to stimulated photosynthesis, reduced transpiration rate and increased tissue strength [Ma and Takahashi 2002].

The flowering of potted chrysanthemum was also affected by Si treatment. The flower number and its diameter were significantly increased when Si was applied whether foliar or soil drenches compared with the control (tab. 2). Increasing flower number may be due to the effects of Si on increasing shoot number as our data indicated (tab. 1). Similar results have been reported [Gillman and Zlesak 2000, Hwang et al. 2005]. Silicon application has been found to reduce evapotranspiration [Lu and

Cao 2001], which could have contributed to increased turgor pressure within the flower, resulting in cell swelling and thus larger flower diameters. Increasing flower diameter as a result of Si treatment has been previously reported [Kamenidou et al. 2008, Kamenidou et al. 2009]. On the other hand, Kamenidou et al. [2010] on several floriculture crops reported that although flower diameter was increased in some species, it decreased in others. However, Carvalho-Zanão et al. [2012] found no differences between treated and non-treated chrysanthemum plants in this concern.

Our results also showed a shortening of the time to anthesis, 4 days earlier in the treatment of Si foliar at 75 mg L^{-1} and 5 days for the treatment of soil drenches with 100 mg L^{-1} Si may accelerate the production of potted chrysanthemum under greenhouses. Similar trend has been reported on gerbera [Kamenidou et al. 2010]. The mechanism involved in accelerating or delaying flowering is not clear however, the effects of Si on increasing photosynthesis, decreasing transpiration and hormone changes may accelerate flowering [Ma and Takahashi 2002]. However, an opposite trend was recorded on *Helianthus annus* since Si treatment delayed the flowering compared with the control [Kamenidou et al. 2008] and they reported that delaying the flowering may have been the result of an overall slowing of growth of the whole plant occurred in their case.

The beneficial effects of silicon treatment on vegetative growth and flowering measurements were reflected on improving the flower longevity as well as shelf life. The shelf life of potted chrysanthemum depends on the number of flowers as well as individual flower longevity. Therefore, increasing number of flowers as well as their longevities as a result of Si application may be a reason of increasing the shelf life of whole plant. Under Si treatments the thickness of cell walls and lignin content of inflorescence stem were increased and hence, the mechanical strength of inflorescence stem was enhanced and the flower quality was improved [Zhao et al. 2013]. Moreover, improving flower quality may be a result of an antitranspirant effect created by the foliar deposition of Si [Gillman and Zlesak 2000] or increasing peduncle stem thickness [Savvas et al. 2002]. These positive effects of Si treatment may finally improve the shelf life of potted chrysanthemum. On the other hand, Carvalho-Zanão et al. [2012] reported that Si treatment showed no significant increase in shelf life.

In this experiment, we investigated some physiological parameters i.e. chlorophyll content, stomatal resistance, membrane stability index (MSI) and total carbohydrates in relation to Si treatments and the results were presented in Figures 1 A, B, C and D, respectively. Potted chrysanthemum plants treated with Si showed an increase in chlorophyll content, stomatal resistance, MSI as well as total carbohydrates compared with untreated control. It has been reported that plants treated with Si are often characterized by a more intensive color of leaves resulting from increased chlorophyll content [Wraga and Dobrowolska 2007]. Higher chlorophyll contents in Si treatments may result in photosynthetic activity improvement and higher productivity. Our results support the others obtained by Lu and Cao [2001], Al-Aghabary et al. [2005] and Ahmed et al. [2014] who reported an increase in chlorophyll content as a result of Si application. On the other hand, Reezi et al. [2009] found that there were no significant differences in chlorophyll content between treated and untreated rose plants with silicon.

Stomatal resistance measured in this study showed a significant increase as a result of Si application (fig. 1B). This means that evapotranspiration was reduced by spraying plants or drenching soil with Si, however, foliar application was more effective than the soil drenches treatment. These results may be due to antitranspirant film that occurred by foliar spraying with Si and consequently increased stomatal resistance. Decreasing transpiration and increasing photosynthesis is one of the most controversial Si benefits which has been associated mainly with Si deposition in cell walls and as a double layer of polymerized Si in the cuticle, which may be reduced evapotranspiration [Ma and Takahashi 2002]. Increasing stomatal resistance and hence reduced transpiration as a result of Si treatment has been reported [Lu and Cao 2001, Hattori et al. 2005, Kamenidou et al. 2009]. Moreover, increasing stomatal resistance in relation to Si as soil drenches treatment in our study support the systemic Si-mediated increase in stomatal resistance as previously reported in different crops [Gao et al. 2004]. On the other hand, an inverse trend has been reported in zinnia treated with Si [Kamenidou et al. 2009].

Our results also showed an increase in MSI as well as total carbohydrates when plants treated with Si compared with untreated plants. Our results support the previous findings of Liang et al. [1996] who reported that the membrane permeability was reduced as a result of Si application. It has been reported that Si treatment reduced malondialdehyde and increased antioxidant enzyme activity [Al-Aghabary et al. 2005] and hence the membrane stability may be maintained. The promotion effects of Si on potted chrysanthemum were reflected on increasing total carbohydrates. Consistent with our results, Si addition increased net photosynthetic rate and net assimilation [Liang et al. 1996, Trenholm et al. 2004, Ahmed et al. 2014]. Si is considered an important element because of its role in maintaining leaf water potential, assimilation of CO_2 and reduction in transpiration rates by adjusting plant leaf area [Hattori et al. 2005]. These improvements in physiological parameters investigated in our study added a qualitative impact by improving the quality and extending the flower longevity as well as shelf life of potted chrysanthemum.

Silicon application either as foliar or as soil drenches significantly increased the absorption of macro and micronutrients compared with untreated plants except Ca (tab. 3). The superior treatments in this concern were 75 mg L^{-1} as foliar or 100 mg L^{-1} Si as soil drench which resulted in the highest values. These results are in agreement with Liang et al. [1996] and Hanafy Ahmed et al. [2008] who reported that the absorption of macronutrients was increased as a result of Si treatment. Although Si had no direct effect on P uptake or translocation to the roots, its beneficial effects might be ascribed to the isomorphus replacement of the phosphate ions with the silicate ions [Marschner 1995]. On gerbera, Kamenidou et al. [2010] found an increase in N, K and Mg in some Si treatments however P did not show any difference. These results may suggest that the effect of Si on leaf nutrients is depending on the plant species since no differences in sunflower leaf N and P concentrations have been reported by Kamenidou et al. [2008]. In addition, a decrease trend in N and Mg has been recorded while K was increased in zinnia leaves as a result of Si treatment [Kamenidou et al. 2009]. Our results show a decrease tendency concerning Ca as a result of Si application and this decrease was significant with both moderate and highest levels compared with the control. It has been reported that Ca in plants is transported via the xylem and its transport depends on transpiration [Arndt et al. 2000] and since Si treatment increased stomatal resistance and hence reduced transpiration [Lu and Cao 2001, Hattori et al. 2005, Kamenidou et al. 2009] therefore, the decrease of Ca was occurred.

The elemental analysis of potted chrysanthemum leaves concerning Fe and Zn as micronutrients showed an improvement effect in both elements absorption. Increasing Fe in relation to Si treatment has been previously reported [Kamenidou et al. 2009] while a decrease in Fe was observed in gerbera leaves treated with Si [Kamenidou et al. 2010]. Increasing Zn content obtained in this study support the results of [Kamenidou et al. 2010] who reported an increase in Zn concentrations as a result of Si treatment. However, no differences have been reported in Zn content in sunflower and zinnia plants in relation to Si treatment [Kamenidou et al. 2008, Kamenidou et al. 2009]. Our results may suggest that Si application may improve nutritional balance; thereby vegetative growth promotion and enhancement of flower characters were obtained. Moreover, increasing flower longevity and shelf life may give an impact of its commercial production under greenhouses.

CONCLUSIONS

The vegetative growth and flowering characters of chrysanthemum were improved in response to both Si supplementation methods compared with the control. Chlorophyll content, stomatal resistance, MSI macro and micronutrients concentrations, and total carbohydrates were increased among Si treated plants. Improving the floricultural traits, extending longevity and shelf life of greenhouse grown chrysanthemum may give an impact of its greenhouse commercial production if appropriate level was used. Because silicon's mode of action is not completely understood although it has positive role in plant physiology further investigations were invited to clarify the physiological responses of different plants to Si application and what are mechanisms which Si may have to do these effects. Otherwise, more work is required for determining the optimum Si level in additional species. We think that the role of silicon will be the most interesting and promising research in the next decades.

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SUPLEMENTACYJNY WPŁYW ŻYWIENIA KRZEMEM NA WZROST, JAKOŚĆ I NIEKTÓRE CECHY FIZJOLOGICZNE DONICZKOWYCH CHRYZANTEM UPRAWIANYCH W SZKLARNI

Streszczenie. Chryzantema doniczkowa to jedna z najważniejszych roślin, które są komercyjnie produkowane w szklarniach, gdzie krzem (Si) jest dostępny w ograniczonym stężeniu, gdyż do uprawy używane są różne podłoża. Niniejsze badanie przeprowadzono w celu zbadania skutków suplementacyjnych żywienia Si na wzrost, kwitnienie, długość życia kwiatów, a także żywotność i zawartość składników odżywczych chryzantemy doniczkowej w stosunku do aplikacji Si. Ponadto zbadano skutki zabiegów z użyciem Si na niektóre parametry fizjologiczne, to znaczy zawartość chlorofilu, działanie aparatów szparkowych, wskaźnik stabilności błon (MSI) oraz całkowitą zawartość węglowodanów. Zastosowanie Si w postaci K_2SiO_3 dodano jako aplikację dolistną w ilości 25, 75 i 125 mg L^{-1} Si lub do podłoża przy 50, 100 i 150 mg L^{-1} Si. Z wyjątkiem wysokości roślin i obszaru liścia, w porównaniu z kontrolą bez żadnych zabiegów, wszystkie cechy wzrostu i kwitnienia polepszyły się w wyniku zastosowania obu metod suplementacji. Kwitnienie było wcześniejsze, a żywotność dłuższa u roślin z suplementacją Si niż u roślinach bez suplementacji. Generalnie zastosowanie Si zwiększało stężenie makro- i mikroskładników (z wyjątkiem Ca) ocenianych w niniejszym badaniu. Zawartość chlorofilu, działanie aparatów szparkowych, MSI oraz całkowita zawartość węglowodanów zwiększały się wśród roślin z zastosowaniem Si. Polepszenie cech kwiatowych, zwiększenie długości życia i żywotności chryzantem hodowanych w szklarni może mieć wpływ na komercyjną produkcję szklarniową, jeśli zastosuje się jego odpowiedni poziom.

Słowa kluczowe: krzemian potasu, żywotność, chryzantema, działanie aparatów szparkowych, stabilność błony

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