

Full Length Research Paper

Silicon alleviates salt stress, decreases malondialdehyde content and affects petal color of salt-stressed cut rose (*Rosa xhybrida* L.) ‘Hot Lady’

Saeed Reezi*, Mesbah Babalar and Siamak Kalantari

Department of Horticulture, Faculty of Agriculture, University of Tehran, Karaj, Iran.

Accepted 6 March, 2009

A greenhouse experiment was conducted to investigate the effects of different levels of silicon (Si) application on cut rose (*Rosa xhybrida* L.) ‘Hot Lady’ under two levels of salt stress. Four Si concentrations (0, 50, 100 and 150 ppm) as Si were combined with a 25 mM NaCl (EC \approx 3.8) level in the nutrient solution supplied to the plants. Addition of Si partially maintained membrane permeability but only fully restored it to control levels in the Si50 and Si100 treatments. 150 ppm Si with or without NaCl could not alleviate or decrease cell wall damages. Inclusion of Si significantly reduced malondialdehyde content and chlorophyll content of salt-stressed plants in all treatments except that of 150 ppm. Maximum chlorophyll content was noticed when 50 ppm Si was supplied. Addition of 50 ppm Si increased the flower number in both plants grown under salinity and unstressed conditions. However, no significant difference was observed between 100 and 50 ppm Si accompanying with NaCl. Plants treated with NaCl alone showed a reduction in plant leaf area, while the reduction in plants treated with NaCl plus 50 and 100 ppm Si were like control and other unstressed plants.

Key words: CIELAB, cut rose, ion leakage, malondialdehyde, salt stress, silicon.

INTRODUCTION

Silicon (Si) is the second most abundant element on the surface of the earth, yet its role in plant biology has been poorly understood and it is not considered an essential element, but Si can reach levels in plants similar to those of macronutrients (Epstein, 1994). Silicon concentration in the soil solution is controlled by silicate minerals and ranges from 0.01 to 1.99 mM (Karathanasis, 2002). It has been demonstrated to be beneficial for the growth of plants, particularly gramineous plants and to alleviate both biotic and abiotic stresses in plants (Epstein, 1994; Liang et al., 1994; Okuda and Takahashi, 1965). In greenhouse production, most plants are grown in containers using soilless substrates as growth media, which have limited plant-available Si compared to most mineral soils (Voogt and sonneveld, 2001). Further studies indicated that silicon enhanced K:Na selectivity ratio ($S_K:Na$), which mitigated against the toxic effects of sodium (Liang et al., 1996). The nutritional properties of

Si in plant growth are also not well established. The literature on Si in plants is replete with reports that the element promotes plant growth. In most cases however, it is uncertain whether growth stimulation is attributable to a nutritional effect or to the alleviation of biotic or abiotic stresses (Epstein 1994, 2001; Fauteux et al., 2006). Hwang et al. (2005) reported that applications of potassium silicate proved to have beneficial effects on the growth and quality of cut flower miniature rose ‘Pinocchio’ in the rockwool culture system. Hydroponically grown gerbera may also benefit from the inclusion of Si in the nutrient solution due mainly to enhanced flower quality (Savvas et al., 2002).

Salinity toxicity is a worldwide agricultural and eco-environmental problem. Approximately one-third of the world land surface is arid and semi-arid, of which one half is affected by salinity (Liang et al. 1996). Previous studies showed that salt tolerance of wheat (*Triticum aestivum*) (Ahmad et al., 1992), mesquite (*Prosopis juliflora*) (Bradbury and Ahmad, 1990), gerbera, rose and zucchini (Savvas et al., 2002, 2007, 2009), barley (Liang et al., 1996, 1999; Liang and Ding, 2002) and zinnia (*Zinnia*

*Corresponding author. E-mail: sreezi57@yahoo.com.

elegans) (Kamenidou et al., 2009) could be markedly enhanced by the addition of small amounts of soluble Si. The inclusion of 1 mM of Si in the salinized nutrient solution mitigated the salinity-associated suppression of both growth and yield and part of the growth and fruit yield suppression at high salinity was due to restriction of net photosynthesis of zucchini squash (Savvas et al., 2009).

Enhanced production of oxygen free radicals is responsible for stress-dependent peroxidation of membrane lipids (Marchner, 1995). Liang et al. (2003) reported that exogenous silicon can increase antioxidant enzyme activity and reduce lipid peroxidation in roots of salt-stressed barley. One effect of free oxygen radicals accumulation in plant cells under stress is lipid peroxidation via oxidation of unsaturated fatty acids leading to membrane damage and electrolyte leakage (Liu et al., 1987; Marschner, 1995). Malondialdehyde (MDA), a decomposition product of polyunsaturated fatty acids, has been utilized as a biomarker for lipid peroxidation (Mittler, 2002). Content of MDA can serve as an indicator of the rate of oxidative processes in cell (Shakirova, 2007). Under salt stress, malondialdehyde (MDA), the product of peroxidation of membrane lipids, accumulates rapidly (Fadzilla et al., 1997; Hernandez et al., 1993; Lutts et al., 1996), which results in an increase in permeability of plasma membranes. Likewise Liang et al. (1996, 1999) reported that added Si decreased the permeability of plasma membrane of leaf cells and significantly improved the ultra-structure of chloroplasts which were badly damaged by the added NaCl (Liang, 1998). The visual appearance of flowers, fresh fruits and vegetables is one of the first quality determinants made by the consumer. Some kinds of cut flowers present aberrant color changes under the influence of various factors. These color changes, such as blueing and fading, can be correlated with flower quality. It is difficult to define appropriate criteria for the quality of the flower throughout the development of the flower during its vase life (Boesman and Flamee, 1975). Colorimetry can be used objectively to form clearly defined criteria for the judgment of the quality of cut flowers (Boesman and Flamee, 1975). In many countries salinity is one of the most important problems in crop production. It is estimated that about a third of the world's cultivated land is affected by salinity (Perez-Alfocea et al., 1996). This research was designed to investigate the role of Si in alleviating salt stress and MDA content in cut rose in hydroponics.

MATERIALS AND METHODS

Plant materials, treatments, and environmental conditions

Cut rose (*Rosa xhybrida* L.) 'Hot lady' plants were obtained from a local commercial grower in Karaj, Iran. Plants immediately trimmed and each plant placed in a 4 liters pot filled with 30 and 70% cocopeat and perlite, respectively. The pots were distributed over 8 independently operating hydroponic systems, which constituted the

experimental units. Each experimental unit consisted of 5 pots and each treatment 15 plants totally. Trickle irrigation was automatically applied using a timer. Greenhouse temperature for daytime adjusted between 23 - 28°C and between 16 - 18°C for night time and the relative humidity around 60 - 70%. After leaf enrrolling and bud bearing, the plants were pruned by pinching and bending down (arching) all weak stems to maximize the photosynthesizing leaf area. Thereafter, shoots with a diameter less than 4 mm were also bent. Merck company salts were used for nutrient solution preparation. Eight different nutrient solution treatments were established in a randomized complete blocks design with four blocks, which differed in the Si and NaCl concentrations, while the levels of all nutrients was identical. In particular, three Si concentrations (0, 50, 100 and 150 ppm) as Si were combined with a 25 mM NaCl (EC \approx 3.8) level in the nutrient solution supplied to the plants. Salinity and silicon treatments were begun by adding sodium chloride (NaCl) and potassium silicate (K_2SiO_3) (Sanaye Silicate Iran[®]) to the nutrient solution. Additional K introduced by K_2SiO_3 was subtracted from KNO_3 and the resultant nitrate loss was supplemented with dilute nitric acid. Nutrient solution was supplied daily through two snap drippers per plant at 8:30, 10:00, 12:00, 13:30, 15:00 and 17:00 for 1 min each time. Hence about 350 mL solution per plant was supplied daily. In the fertilization plans after the first flowering, the EC adjusted to the values between 1,800 - 2,000 μ s; the values of the pH remain unchanged. The first flowers were harvested on March 22, and harvests continued as required until July 5, a total harvest period of 16 weeks. Flowers harvested in same stage in different treatments and immediately transferred to laboratory to measure physical factors.

Determination of ion leakage percentage and ethylene production

Ion leakage was used to assess membrane permeability and measured using an electrical conductivity meter. The procedure used was based on the method of Pooviah (1973). Petal samples were cut into 1 cm segments and placed in individual stoppered vials containing 25 ml of deionized water after two washes with distilled water to remove surface contamination. These samples were incubated at room temperature (25°C) on a shaker (150 rpm) for 30 min. Electrical conductivity of solution (EC1) was read after shaker. Samples were then placed in thermostatic water bath at 95°C for 15 min and the second reading (EC2) was determined after cooling the solutions to room temperature. Ion leakage percentage was calculated as $EC1/EC2$ and expressed as percent. The ethylene production of flowers was determined in three replicate glass bottles using a GC (Shimadzu C-R4A Chromatopac).

Assays of MDA content (Lipid peroxidation)

MDA determination was followed the method described by Li (2000). Rose fresh leaves (0.2 g) were homogenized in 1.5 mL 5% (w/v) trichloroacetic acid using a mortar and pestle (Heath and Packer, 1968). The homogenates were centrifuged at 13000 \times g for 20 min. A reaction mixture of the supernatant (0.5 mL) and 1 mL TCA 20% (w/v) and thiobarbituric acid (0.5%) was incubated at 95°C in a water bath for 25 min, then cooled immediately before centrifugation. Absorbance of the supernatants was determined at 450, 532 and 600 nm, respectively. Calculation of MDA was based on the following formula: $C(\mu\text{M/l}) = 6.45(A_{532} - A_{600}) - 0.56 A_{450}$.

Chlorophyll concentration and flower color

The chlorophyll content of the leaves was determined after extraction in 80% acetone (Arnon, 1949). Absorption was measured, using a spectrophotometer (Hitachi, U2001), at 645 and 663 nm

Table 1. Effect of different treatments of Si and NaCl on growth and chlorophyll content of *R. xhybrida* 'Hot lady' in soilless culture.

Treatment	Peduncle diameter (mm)	Bud diameter (mm)	Bud length (mm)	Shoot length (cm)	Flower stem diameter (cm)	Flower number	Leaf area Index (mm ²)	Chlorophyll content a+b (mg/g fw)
Control	3.10bc	22.55ab	33.19 a	52.02b	4.22a	1.57b	5054.2a	1.36ab
Si ₅₀	3.35b	23.43abc	33.46 a	55.63ab	4.58a	1.93a	5094.3a	1.50a
Si ₁₀₀	3.76a	24.10a	32.14ab	61.23a	4.66a	1.68ab	5025a	1.40ab
Si ₁₅₀	3.02bc	21.68bcd	31.23ab	54.79ab	4.58a	1.41bc	4780.3ab	1.12b
NaSi ₅₀	2.96bc	21.52bcd	31.76ab	53.29ab	4.49a	1.54b	5008.2a	1.06b
NaSi ₁₀₀	3.03bc	22.95ab	32.14ab	53.20ab	4.11a	1.50b	4995.7a	1.02b
NaSi ₁₅₀	2.96bc	21.24cd	31.19ab	52.11b	4.24a	1.36c	4313.8b	0.66c
Na	2.90c	20.40d	29.87b	51.64b	4.24a	1.34c	4330b	0.73c

Values with different alphabetical superscripts along a row are significantly different at $p < 0.05$.

and chlorophyll content was calculated using the equation: chlorophyll $a + b = 8.02(A_{663}) + 20.21(A_{645})$. Three replicates were made of each treatment.

Petal color was measured with a Minolta Chroma Meter CR-400 portable colorimeter and flower chromaticity was recorded. The colorimeter was calibrated using a standard white plate under normal light conditions. Three flowers were selected from each treatment and three petals from each flower were randomly selected for measurements, resulting in 9 measurements per treatment. The CIELAB scale (Comisión Internationale de l'Eclairage of France) was used to evaluate the color parameters (Voss, 1992).

The a^* and b^* values were used to estimate the intensity or saturation ($Cr^* = (a^{*2} + b^{*2})^{0.5}$) and Hue* [$Hue^* = \arctan(b^*/a^*)$] parameters for each treatment (Francis, 1980) while the second formula divides b^* by a^* , takes the arctangent (in radians) of the remainder, divides this number by an approximation of 2π (the number of radians equivalent to 360°), then multiplies this quotient by 360 to achieve an angle in degrees (McGuire, 1992). Some investigators present the results as L^* , a^* and b^* without transforming them into Cr^* and Hue* values. This is inappropriate because they are not independent variables (Francis, 1980). This method of analysis has been used before in various experiments (Cantwell et al., 2003; Gaviola and Lipinski, 2003, 2008; Gonnet, 1998). More information about the principles of color calculations and the arrangement of the CIELAB system has been presented previously (Gonnet, 1993, 1995). Higher Cr^* values mean more vivid color and higher H° values mean more purplish pink.

Data were analyzed by analysis of variance, and means were separated by Duncan's multiple range test ($P < 0.05$). The software SAS (SAS Institute, Cary, N.C.) were used for statistical analysis.

RESULTS

Growth parameters

As shown in Table 1, peduncle diameter in Si₁₀₀ (100 ppm Si) treatment has a significant difference with control and other treatments. Addition of Si partially improved this factor and could show better results compare to Na treatment (25 mM NaCl). The inclusion of 100 ppm of Si in the nutrient solution significantly mitigated the deleterious effects of salinity on the bud diameter and flower number compare to Na treatment and had no significant differences with control plants. Bud length in

Si₅₀ (50 ppm Si) and control has a significant difference with Na treatment whereas there was no difference between other treatments. In shoot length, Si₁₀₀ treatment had a significant difference with control but in stem diameter, neither salinity nor Si had a significant effect on roses. For flower number, the mean flower per plant in each treatment was measured. As shown, addition of 50 ppm Si in nutrient solution increased the flower number in both plants grown under salinity and unstressed conditions, however no significant difference was between 100 and 50 ppm Si accompanying with NaCl.

For leaf area measurement, three complete young fully expanded leaves were sampled from each replication. Plants treated with NaCl alone showed a reduction in plant leaf area, while the reduction in plants treated with NaCl plus 50 and 100 ppm Si were like control and other unstressed plants (Table 1).

Ion leakage percentage, Lipid peroxidation and ethylene production

Table 2 showed that the effects of Si on the electrolytic leakage percentage of the petals of roses under salt stress compared to the control. Two saline treatments [Na and NaSi₁₅₀ (NaCl + 150 ppm Si)] impaired membrane permeability by increasing electrolyte leakage. Addition of Si partially maintained membrane permeability but only fully restored it to control levels in the Si₅₀ and Si₁₀₀ treatments. 150 ppm Si with or without NaCl couldn't alleviate or decrease cell wall damages (Table 2).

The effects of Si on the data for malondialdehyde (MDA) content are presented in Table 2. Under the effect of NaCl treatment Mda content increased significantly in NaSi₁₅₀ and Na as compared to control (Table 2). Lipid peroxidation was low in 100 and 50 ppm treatments in both salt-stressed and usual conditions. However, inclusion of Si significantly reduced Mda content of salt-stressed plants in all treatments except than 150 ppm compare to Na treatment (Table 2).

Table 2. Effect of different treatments of Si and NaCl on electrolyte leakage percent (EL) of petals and MDA content of the leaves of *R. xhybrida* 'Hot lady' in soilless culture.

Treatment	EL (%)	MDA (μmolg^{-1} FW)
Control	7.93cd ¹	1.01 bc ¹
Si ₅₀	6.82cd	0.89cd
Si ₁₀₀	7.03cd	0.92cd
Si ₁₅₀	13.73ab	1.26ab
NaSi ₅₀	6.65cd	1.02bc
NaSi ₁₀₀	9.11c	1.10b
NaSi ₁₅₀	13.93ab	1.47a
Na	14.84a	1.65a

Values with different alphabetical superscripts along a row are significantly different at $p < 0.05$.

No significant promotion of ethylene production above control levels was detected and it was non-detectable in various treatments.

Chlorophyll content and color evaluation

Chlorophyll contents were lower in both NaSi150 and Na treatments compared to control values; Si50 improved chlorophyll content in plants under non-saline treatments and Si nearly restored chlorophyll levels in the Si treatments unless in NaSi150 treatment. Maximum increase was noticed when 50 ppm Si supplied (Table 3).

Considering all various treatments, NaSi150 (Hue*:14.90) developed the deepest purplish pink color and control (Hue*:5.73) was the treatment with the lightest purplish pink color. In high concentrations of Si, a significant difference was in hue between control. As estimated by Cr* value with respect to the other treatments, Si150 (Cr*:29.55) and Si100 (Cr*:27.83) had a deep color intensity. In chroma value, Na had a significant difference between other salt-stressed treatments and trends to a dull color, however Si treatments could increase color saturation in all treatments in high concentrations (100 and 150 ppm). There was a trend toward a deep color as the silicon rate increased in nutrient solution (Table 3). The Na (L*:66.73) and Control (L*:63.63) treatments and Si in low concentration (50 ppm) presented a high luminosity compared to the rest treatments. As Si increased in nutrient solution, lightness decreased in petals (Table 3).

DISCUSSION

The results presented in this study suggest that an increase of silicon concentration about 50 - 100 ppm in the medium of roses is capable of enhancing their vegetative growth, regardless of external salinity. This finding is in agreement with previous reports that Si promotes the

Table 3. Effect of different treatments of Si and NaCl on petal color parameters (Cr*, Hue* and L*) in *R. xhybrida* 'Hot lady' plants grown with various treatments.

Treatment	L* ¹	Cr* ¹	Hue* ¹
Control	63.63a	20.17c	5.73e
Si ₅₀	64.03a	21.21c	8.60de
Si ₁₀₀	55.35b	27.83ab	13.05ab
Si ₁₅₀	55.88bc	29.55ab	12.13ab
NaSi ₅₀	64.31a	21.69c	7.45e
NaSi ₁₀₀	57.78b	24.94b	11.72ab
NaSi ₁₅₀	55.9b	26.33ab	14.90a
Na	66.73a	15.54d	8.02de

¹Hue*= hue angle; L*= lightness, Cr*= chroma. Values with different alphabetical superscripts along a row are significantly different at $p < 0.05$.

growth of various higher plant species (Emadian and Newton, 1989; Gillman and Zlesak, 2000; Hwang et al., 2005; Miyake and Takahashi, 1978, 1983; Savvas et al., 2007, 2009; Voogt and Sonneveld, 2001; Zhu et al., 2004). The simulation of growth by silicon may be either indirect, owing to the protective effects of Si against pathogens (Blanger et al., 1995; Blanger and Benyagoub, 1997), or direct originating from implications of Si to both morphological changes and physiological processes in plants. It seems that silicon is involved directly or indirectly in cell metabolism as well, although in most cases the mode of action is still unclear (Liang et al., 2003; Zhu et al., 2004). It has been observed that GA₁ and its precursor GA₂₀ level enhanced with N and Si application in rice cultivars (Hwang et al., 2008). Gibberellins are a group of naturally occurring plant hormones that affect cell enlargement and division which leads to internode elongation in stems. Physiological and biochemical studies have shown that the GA hormones are involved in controlling plant height (Potts et al., 1985). It is possible that Si could increase total GA content and increase shoot height. The results of the present experiment were in line with these findings (Table 1). In this study, Si in high concentration (150 ppm) showed no or sometimes slightly negative effects on growth parameters. Hwang et al. (2005) related that dissolved potassium silicate is alkaline and it can affect plant growth in high levels. Although the pH in some solutions (High Si concentrations) in this experiment had pH higher than this optimum range (data not shown), no element deficiency or toxicity symptoms were observed. Unfortunately, soluble Si polymerizes rapidly if the concentration of Si increases above 2 mmol L⁻¹ (Iler, 1979). In contrast, large molecules of polysilicates in the form of colloids, are very stable, but unfortunately, have shown to be less accessible to the plant (Voogt and Sonneveld, 2001). This consideration is in agreement with the appearance of the rose plants receiving nutrient solution with high Si concentration in the present study. Similar results were

reported in mist-applied rose cuttings by Gillman and Zlesak (2000). Similarly, Hwang et al. (2007) observed that Si application enhanced plant height and quality but high doses of Si above a critical level may be less effective in maintaining higher growth rates.

Morgan et al. (1999) reported that plants supplied with Si resist lodging (drooping, leaning, or becoming prostrate). It can increase mechanical strength of plants, which enables them to achieve and maintain an upright growth habit and allows maximum light interception, comes from the structural components of the plants cell walls. Likewise, these treatments (50 and 100 ppm Si) could increase flower number per plant. Gillman and zlesak (2000) and Hwang et al. (2005) reported similar results on roses. It is may that higher chlorophyll contents in Si treatments resulted in photosynthetic activity improvement and higher productivity (Table 3). Wang et al. (1997) reported a high accumulation of Na^+ in organs of *Atriplex prostrata* when plants were grown in saline solutions, while the concentration of K^+ , Ca^{2+} and Mg^{2+} decreased, and decreased the photosynthesis. In molecular structure of chlorophyll, the Mg atom had an important role. It is may that Mg deficiency in Na treatment resulted in low chlorophyll content and Si in high concentration (NaSi150) could not alleviates this effect of salinity because of some reasons that before mentioned. Lorenzo et al. (2000) reported a negative effect of salinity on rose plants, although no external symptoms of toxicity were observed.

In our study 50 and 100 ppm Si could alleviate saltstress effects on leaf area. The reduction in leaf area was in other Na treatments (Table 1). Greenway and Munns (1980) suggested that salinity exerts its effect directly on cell extension and/or division, which is in line with our observation that the main effect of salinity was a reduction in leaf area. For several halophytes it has also been shown that the main effects of salinity are on leaf area development (Pearcy and Ustin, 1984; Rozema, 1991). Reduced leaf expansion and stomatal conductance at high salinity observed in Marcelis and Hooijdonk (1999) experiment, too. Saline ions are continuously transported to the aboveground plant by transpirational flow, inducing deleterious effects in the tissues when the saline ion content reaches a toxic threshold. Any factor that can retard to reach the toxic threshold is important to increase tolerance to salinity. The higher leaf area and plant water content of salinized plants treated with Si could have contributed to salt dilution and consequently to reduce deleterious effects of saline ions. The higher leaf area recorded in salinized plants treated with Si suggest that in addition to benefits of Si to keep water and to increase cell turgor, Si could be involved in cell wall metabolism improving the ability of the cell wall to expand and consequently enhancing cell enlargement (Romero-Aranda et al., 2005). Likewise Si in 50 and 100 ppm could alleviate saltstress effects on flower number. Savvas et al. (2009) reported that the inclusion of 1 mM

of Si in the salinized nutrient solution mitigated the salinity-associated suppression of both growth and yield in zucchini. They mentioned that it could mitigate the inhibitory effect of salinity on net photosynthesis and this effect was associated with lower Na and Cl translocation to the epigeous plant tissues (Savvas et al., 2009). Liang (1998) reported that added Si enhances the growth of salt-treated barley and improves the chlorophyll content and photosynthetic activity of leaf cell organelles of barley. It is possible that Si enhanced chlorophyll content and more photosynthesis resulted in more flower production in treated plants.

Peroxidation of membrane lipids is an indication of membrane damage and leakage under salt stress conditions (Katsuhara et al., 2005). Table 2 showed a decrease in content of MDA and a decrease in ion leakage as well, suggesting that oxidative damage induced by salt be alleviated by the addition of Si (Table 2). Koca et al. (2007) related that Salt stress affected two sesame cultivars by means of lipid peroxidation but, had higher rates of increment under NaCl treatments. Growth inhibition under salinity is in good correlation with increased lipid peroxidation levels and this result is in good correlation with the increase in MDA content under salinity. A lower lipid peroxidation resulting from elevated activities of antioxidants under salt stress was also reported on salt-tolerant wild tomato species (Shalata and Tal, 1998) and wheat cultivars ((Dionisio-Sese and Tobita, 1999). The results of the present experiment were in line with the findings of Liang (1999) in barley which showed that added Si decreased the permeability of the plasma membrane of leaf cells and decreased LPO level. It was reported that Si enhanced the stability of lipids in cell membranes of rice plants exposed to drought and heat stresses, suggesting that Si prevented the structural and functional deterioration of cell membranes when rice plants were exposed to environmental stress (Agarie et al., 1998). The evidence suggests that Si decreases the permeability of plasma membranes and membrane lipid peroxidation and maintains the membrane integrity and functions of salt-stressed roses, thus mitigating against salt toxicity and improving the growth of plants.

Reid et al. (1989 a,b), suggested that ethylene is an important natural regulator of flower senescence, at least in some rose cultivars. Very low ethylene detected in 'Hot lady' cultivar in various treatments in this study. Reid et al. (1989a and b) reported that ethylene may promote or inhibit flower opening in a cultivar dependent manner in roses. Likewise, Muller et al. (1998) reported that flower senescence in some miniature rose cultivars was accompanied by a clear climacteric rise in ethylene production, in others there was only moderate or very low and ethylene production in long-lived cultivars like 'Vanilla' or 'Charming,' is very low. The magnitude of ethylene effects and the plant part affected was found to be variety dependent. Short lasting varieties were consistently found to be sensitive to ethylene, while most, but not all,

long lasting varieties were tolerant (Leonard et al., 2005). 'Hot lady' is a long-live cultivar and it seems that had a very low ethylene production.

Color differences in petals showed in Table 3. Flower color is mainly due to the chemical structures of different pigments such as anthocyanins and carotenoids (Junka et al., 2007). Anthocyanins are in the stable and colored form of flavylium cation in very acidic solutions only. As the pH increases, the anthocyanic nucleus is affected by important structural changes (Brouillard and Dubois, 1977). In weakly acidic solutions corresponding to the pH values most frequently recorded in the vacuoles of flower petal cells (Stewart et al., 1975), pure anthocyanins are predominantly accumulated as virtually colourless pseudobases. Consequently, the vivid colours displayed by flowers result from a phenomenon protecting or restoring stable and strongly absorbing forms of the anthocyanins, known as co-pigmentation (Robinson and Robinson, 1931). As reported before (Gonnet, 1998) pH can affect anthocyanins concerning a spectral bathochromic shift (shifted either yellow or blue) depending on the pH and concentration of pigments. Likewise, Uddin et al. (2002) reported that the paler (and less saturated) colors are generally coupled with lower pigmentation levels, including combined effects of anthocyanins, that is, copigment concentration and pH. It seems that in high concentrations of Si, pH increased and affected vacuoles pH and resulted in different color expression. Si could increase potassium absorption by plants (Li et al., 2004; Liang et al., 1996; Liang, 1999). Phosphorus is antagonizes of aluminum uptake and helps assure pink flowers in hydrangeas (Bailey, 1992), therefore it can occur in rose in this study and increased color saturation (Cr^*) in Si treatments in this study (Table 3). Na treatment showed a dull color ($Cr^* = 15.54$) and increased MDA content and decreased chlorophyll content in related plants (Tables 1, 2 and 3) and it is may in other salt-stress treatments, Si could alleviate salt effects on this factor (Table 3), therefore this treatment resulted in paler or low pigmentation. Silicon can directly or indirectly affect other elements absorption in plants (Datnoff et al., 2001). Excess concentrations of various ions associated with salinity can cause enzyme inhibition and therefore alter metabolism or physiological function (Flowers and Dalmond, 1992). Thus, the toxicity or deficiency of ions and the imbalance among various ions may affect some important mechanisms in plant cells and affect plant growth and pigment production in cells.

Conclusion

In this study, application of silicon in nutrient solution proved to have beneficial effects on growth and quality of hydroponically-produced roses. We found that higher quality and yield could be obtained when silicon was applied to the nutrient solution in 50 and 100 ppm as Si. However, Potassium silicate in high concentrations

caused problems with pH fluctuations in the nutrient solution and plant growth and quality. The results of the present experiment showed that Si could affect flower color and alleviated the dull color induced by NaCl that means affected pH and other elements absorption by plants. It may act to alleviate salt stress in rose by decreasing permeability of plasma membranes and membrane lipid peroxidation, and maintaining the membrane integrity and function.

REFERENCES

- Agarie S, Hanaoka N, Ueno O, Miyazaki A, Kubota F, Agata W, Kaufman PB (1998). Effects of silicon on tolerance to water deficit and heat stress in rice plants (*Oryza sativa* L.), monitored by electrolyte leakage. *Plant Prod. Sci.* 1: 96-103.
- Ahmad R, Zaheer S, Ismail S (1992). Role of silicon in salt tolerance of wheat (*Triticum aestivum* L.). *Plant Sci.* 85: 43-50.
- Arnon D (1949). Copper enzymes in isolated chloroplasts. Phenoloxidase in *Beta vulgaris*. *Plant Physiol.* 24: 1-15.
- Bailey DA (1992). Hydrangeas. In: Larson RA (ed.). *Introduction to Floriculture*, Second Edition. Academic Press. San Diego, California. pp. 365-383.
- Boersman G, Flamee M (1975). Quality evaluation of cut flowers by means of objective colour measurement. *Acta Hort.* 41: 227-237.
- Bradbury M, Ahmad R (1990). The effect of silicon on the growth of *Prosopis juliflora* growing in saline soil. *Plant Soil* 125: 71-74.
- Brouillard R, Dubois JE (1977). Mechanism of structural transformations of anthocyanins in acidic media. *J. Am. Chem. Soc.* 99: 1359-1364.
- Cantwell M, Hong G, Kang J, Nie X (2003). Controlled atmospheres retard sprout growth, affect compositional changes, and maintain visual quality attributes of garlic. *Acta Hort.* 600: 791-794.
- Datnoff LE, Snyder GH, Korndörfer GH (2001). *Silicon in Agriculture*. Elsevier, Amsterdam.
- Dionisio SML, Tobita S (1999). Antioxidative responses of shoots and roots of wheat to increasing NaCl concentration. *J. Plant Physiol.* 155: 274-280.
- Emadian SF, Newton RJ (1989). Growth enhanced of loblolly pine (*Pinus taeda* L.) seedlings by silicon. *J. Plant. Physiol.* 134: 98-103.
- Epstein E (1994). The anomaly of silicon in plant biology. *Proc. Natl. Acad. Sci. USA.* 91: 11-17.
- Epstein E, (2001). Silicon in plants: Facts vs. concepts. In Datnoff L.E., Snyder G.H., Korndörfer, G.H., (Eds.), *Silicon in Agriculture*. Elsevier, Amsterdam, pp. 1-15.
- Fadzilla NM, Finch RP, Burdon RH (1997). Salinity, oxidative stress and antioxidant responses in shoot cultures of rice. *J. Exp. Bot.* 48: 325-331.
- Fauteux F, Chain F, Belzile F, Menzies JG, Bélanger RR (2006). The protective role of silicon in the Arabidopsis-powdery mildew pathosystem. *Proc. Natl. Acad. Sci. USA.* 103: 17554-17559.
- Flowers TJ, Dalmond D (1992). Protein synthesis in halophytes: the influence of potassium, sodium and magnesium *in vitro*. *Plant Soil.* 146: 153-161.
- Gaviola S, Lipinski VM (2008). Effect of nitrogen fertilization on yield and color of red garlic (*Allium sativum*) cultivars. *Cien. Invasion Agric.* 35: 57-64.
- Gillman JH, Zlesak DC (2000). Mist applications of sodium silicate to rose (*Rosa* L. x 'Nearly Wild') cuttings decrease leaflet drop and increase rooting. *Hort. sci.* 117: 500-503.
- Gonnet JF (1998). Colour effects of co-pigmentation of anthocyanins revisited-I. A calorimetric definition using the CIELAB scale. *Food Chem.* 63: 409-415.
- Gonnet JF (1993). CIELAB measurement, a precise communication in flower colour: an example with camation (*Dianthus caryophyllus*) cultivars. *J. Hort. Sci.* 68: 499-510.
- Gonnet JF (1995). A calorimetric look at the RHS Chart- Perspectives for an instrumental determination of codes. *J. Hort. Sci.* 70:191-206.
- Greenway H, Munns R (1980). Mechanisms of salt tolerance in nonhalophytes. *Ann. Rev. Plant Physiol.* 31: 149-190.

- Heath RL, Packer L (1968). Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. Arch. Biochem. Biophys. 125:189-198.
- Hernandez JA, Corpass FJ, Gomez M, del Río LA, Sevilla F (1993). Salt-induced oxidative stress mediated by active oxygen species in pen leaf mitochondria. Physiol. Plant. 89: 103-110.
- Hwang SJ, Hamayun M, Kim HY, Na CI, Kim KU, Shin DH, Kim SY, Lee IJ (2008). Effect of nitrogen and silicon nutrition on bioactive gibberellin and growth of rice under field conditions. J. Crop Sci. Biotech. 10: 281-286.
- Hwang SJ, Jeong BR, Park HM (2005). Effects of Potassium Silicate on the Growth of Miniature Rose 'Pinocchio' Grown on Rockwool and its Cut Flower Quality. J. Jpn. Soc. Hort. Sci. 74: 242-247.
- Iler RK (1979). The Chemistry of Silica: Solubility, Polymerization, Colloid and Surface Properties and Biochemistry of Silica. Wiley Interscience. New York.
- Junka N, Wongs-Aree C, Kanlayanarat S, Thanomchit K (2007). Predominance of cyanidin found in flower from two species of *Aerides* orchids. Acta Hort. 755: 549-556.
- Kamenidou S, Cavins TJ, Marek S (2009). Evaluation of silicon as a nutritional supplement for greenhouse zinnia production. Scientia. Horticult. 119: 297-301.
- Karathanasis AD (2002). Mineral equilibria in environmental soil systems. In: Dixon JB, Weed SB (eds) Soil mineralogy with environmental applications. Soil Science Society of America, Madison, pp. 109-151.
- Koca H, Melike B, Filiz O, Ismail T (2007). The effect of salt stress on lipid peroxidation, antioxidative enzymes and proline content of sesame cultivars. Environ. Exp. Bot., 60: 344-351.
- Leonard RT, Nell TA, Hoyer L (2005). Response of potted rose varieties to short-term ethylene exposure. VIII International Symposium on Postharvest Physiology of Ornamental Plants. Acta Hort. 669: 373-380.
- Li HS (2000). Principles and techniques of plant physiological biochemical experiment. Higher Education Press, Beijing, pp. 260-263 (in Chinese).
- Li ZH, Sugaya S, Gemma H, Iwahori S (2004). The effect of calcium, nitrogen and phosphorus on anthocyanin synthesis in 'Fuji' apple callus. Acta Hort. 653: 209-214.
- Liang Y, Chen Q, Liu Q, Zhang W, Ding R (2003). Exogenous silicon (Si) increases antioxidant enzyme activity and reduces lipid peroxidation in roots of saltstressed barley (*Hordeum vulgare* L.). J. Plant Physiol. 160: 1157-1164.
- Liang YC (1998). Effects of silicon on leaf ultrastructure, chlorophyll content and photosynthetic activity in barley under salt stress. Pedosphere. 8: 289-296.
- Liang YC (1999). Effects of silicon on enzyme activity and sodium, potassium and calcium concentration in barley under salt stress. Plant Soil. 209: 217-224.
- Liang YC, Ma TS, Li FJ, Feng YJ, (1994). Silicon availability and response of rice and wheat to silicon in calcareous soils. Commun. Soil Sci. Plant Anal. 25: 2285-2297.
- Liang YC, Shen QR, Shen ZG, Ma TS (1996). Effects of silicon on salinity tolerance of two barley cultivars. J. Plant Nutr. 19: 173-183.
- Liu YL, Mao CL, Wang LJ, (1987). Advances in salt tolerance in plants. Commun. Plant Physiol. 23: 1-7. (in Chinese).
- Lorenzo H, Cid MC, Siverio JM, Ruano MC (2000). Effects of sodium on mineral nutrition in rose plants. Ann. appl. Biol. 137: 65-72.
- Lutts S, Kinet JM, Bouharmont J (1996). NaCl-induced senescence in leaves of rice (*Oryza sativa* L.) cultivars differing in salinity resistance. Ann. Bot. 78: 389-98.
- Marcelis LFM, Van Hooijdonk J (1999). Effect of salinity on growth, water use and nutrient use in radish (*Raphanus sativus* L.). Plant Soil. 215: 57-64.
- Marschner H, (1995). Part I. Nutritional physiology. In: Marschner H, (ed) Mineral Nutrition of Higher Plants. Academic Press, London. Second ed. Pp. 18-30, 313-363.
- McGuire R (1992). Reporting for objective color measurements. Hort. Sci. 27: 1254-1255.
- Mittler R (2002). Oxidative stress, antioxidants and stress tolerance. Trends Plant Sci. 7: 405-410.
- Miyake Y, Takahashi E (1978). Silicon deficiency of tomato plant. Soil. Sci. Plant Nutr. 24: 175-189.
- Miyake Y, Takahashi E (1983). Effect of silicon on the growth of solution-cultured cucumber plant. Soil Sci. Plant Nutr. 29: 71-83.
- Müller R, Andersen AS, Serek M, (1998). Differences in postharvest characteristics of miniature potted roses (*Rosa hybrida* L.). Sci. Hortic. 76: 59-71.
- Okuda A, Takahashi E, (1965). The role of silicon. In The Mineral Nutrition of the Rice Plant. Proc. Symposium of the International Rice Research Institute. Johns Hopkins Press. Baltimore, MD. pp. 123-146.
- Pearcy RW, Ustin SL, (1984). Effects of salinity on growth and photosynthesis of three California tidal marsh species. Oecologia. 62: 68-73.
- Perez-Alfocea F, Balibrea ME, Santa Cruz A, Estan MT (1996). Agronomical and physiological characterization of salinity tolerance in a commercial tomato hybrid. Plant Soil. 180: 251-257.
- Poovaliah BW, Leopold AC, (1973). Deferral of leaf senescence with calcium. Plant Phys. 52: 236-239.
- Potts WC, Reid JB, Murfet IC (1985). Internode length in Pisum. Gibberellins and the slender phenotype. Physiol. Plant. 63: 357-364.
- Reid MS, Dodge LL, Mor Y, Evans RY (1989a). Effects of ethylene on rose opening. Acta Hort. 261: 215-220.
- Reid MS, Evans RY, Dodge LL, Mor Y (1989b). Ethylene and silver thiosulfate influence opening of cut rose flowers. J. Am. Soc. Hort. Sci. 114: 436-440.
- Robinson GM, Robinson R (1931). CLXXXII. A survey of anthocyanins. Biochem. J. 25: 1687-1705.
- Romero-Aranda, MR, Jurado O, Cuartero J, (2005). Silicon alleviates the deleterious salt effect on tomato plant growth by improving plant water status. J. Plant. Physiol. 163: 847-855.
- Rozema J (1991). Growth, water and ion relationships of halophytic monocotyledonae and dicotyledonae; a unified concept. Aquat. Bot. 39: 17-33.
- Savvas D, Giotis D, Chatzieustratiou E, Bakea M, Patakioutas G (2009). Silicon supply in soilless cultivations of zucchini alleviates stress induced by salinity and powdery mildew infections. Environ. Exp. Bot. 65: 11-17.
- Savvas D, Gizas G, Karras G, Lydakakis-Simantiris N, Salahas G, Papadimitriou M, Tsouka N (2007). Interactions between silicon and NaCl-salinity in a soilless culture of roses in greenhouse. Eur. J. Hort. Sci. 72: 73-79.
- Savvas D, Manos G, Kotsiras A, Souvaliotis S, (2002). Effects of silicon and nutrient-induced salinity on yield, flower quality, and nutrient uptake of gerbera grown in a closed hydroponic system. J. Appl. Bot. 76: 153-158.
- Shakirova FM (2007). Role of hormonal system in the manifestation of growth promoting and antistress action of salicylic acid. In: Hayat S, Ahmad A, Salicylic Acid- A Plant Hormone, Springer, pp. 69-89.
- Shalata A, Tal M (1998). The effect of salt stress on lipid peroxidation and antioxidants in the leaf of the cultivated tomato and its wild salt-tolerant relative *Lycopersicon pennellii*, Physiol. Plant. 104: 167-174.
- Stewart RN, Norris KH, Asen S (1975). Microspectrophotometric measurement of pH and pH effects on color of petal epidermal cells. Phytochemistry. 14: 937-942.
- Uddin AFMJ, Hashimoto F, Nishimoto S, Shimizu K, Sakata Y (2002). Flower growth, coloration and petal pigmentation in four lisianthus cultivars. J. Jpn. Soc. Hort. Sci. 71: 40-47.
- Voogt W, Sonneveld C (2001). Silicon in horticultural crops grown in soilless culture. In: Datnoff LE, Snyder GH, Korndorfer, GH (Eds.), Silicon in Agriculture. Elsevier, Amsterdam, pp. 115-131.
- Voss DH, (1992). Relating colorimeter measurement of plant color to the Royal Horticultural Society Colour Chart. Hort. Sci. 27: 1256-1260.
- Wang L, Showalter AM, Ungar IA (1997). Effect of salinity on growth, ion content, and cell wall chemistry in *Atriplex prostrata* (Chenopodiaceae). Am. J. Bot. 84: 1247-1255.
- Zhu Z, WEI G, LI J, Qian Q, YU J, (2004). Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumis sativus* L.). Plant Sci. 167: 527-533.