Journal of Horticultural Research 2017, vol. 25(1): 35–45
DOI: 10.1515/johr-2017-0004

DE GRUYTER
OPEN

THE INFLUENCE OF SILICON AND MULTINUTRIENT FERTILIZER ON THE QUALITY AND CHEMICAL COMPOSITION OF *GAZANIA RIGENS* 'KISS YELLOW', *SALVIA FARINACEA* 'FAIRY QUEEN' AND *VERBENA* 'OBSESSION LILAC' PLANTS

Regina DĘBICZ, Anna PAWLIKOWSKA*, Katarzyna WRÓBLEWSKA, Przemysław BĄBELEWSKI
Wrocław University of Environmental and Life Sciences
pl. Grunwaldzki 24a, 53-363 Wrocław, Poland

Received: April 2017; Accepted: June 2017

ABSTRACT

Silicon supplementation may lead to positive changes in plant quality, including their appearance. The two-factorial experiment with three ornamental plant taxa *Gazania rigens* 'Kiss Yellow', *Salvia farinacea* 'Fairy Queen' and *Verbena* 'Obsession Lilac' was conducted in the years 2012–2013. The first factor was foliar application of Si in form of ortho-silicic acid stabilized with choline (YaraVita Actisil) at the concentrations of 60, 120 and 180 mg·dm^{-3}, while the second was soil application of multinutrient fertilizer (Insol U) at the concentrations of 0.25% and 0.50%. Biometric measurements of plants were carried out at the beginning of flowering. The laboratory analyses included the determination of the content of P, K, Ca, Mg and Si as well as chlorophyll content in the leaves. Silicon had a beneficial influence on a majority of the analysed morphological features. Plants reacted best to high silicon doses (120 and 180 mg·dm^{-3}). Particularly beneficial effects were noted with respect to improved flowering of all analysed plant taxa and to the vegetative development of *Salvia* and *Gazania.* Insol U supplementation noticeably improved the flowering of *Verbena.*

Key words: ortho-silicic acid, growth, flowering, nutritional status

INTRODUCTION

The interest in silicon supplementation to plants has been growing constantly in recent years, yet the mechanism of silicon absorption by plants and its role in plant physiology are not fully known (Ma et al. 2006; Chen et al. 2011). Dicotyledons absorb silicon passively (Ma & Yamaji 2006), while monocotyledons do it actively, with the use of special transporters (Mitani & Ma 2005). Silicon accumulation in plant tissues is noted much more often in monocotyledons than in dicotyledones (Zuccinni 2008) and its distribution within the aboveground parts of plants depends on transpiration intensity. This process results in concentration of silicic acid in the xylem, which creates hydrated amorphous silica gel during polymerization. This form of silicon may reach up to 90% of the total silicon content in shoots (Ma & Yamaji 2006).

The source of silicon are water-soluble chemical compounds, including silicic acids and potassium, sodium, calcium and ammonium silicates (Górecki & Danielski-Bush 2009; Reezi et al. 2009; Kamenidou et al. 2010; Soundararajan et al. 2013) as well as organic compounds, including rice husk ash (Kamenidou et al. 2008). Silicon is also present in certain fertilizers such as Actisil, where ortho-silicic acid H_4SiO_4 is stabilised by choline. The application of biostimulators is particularly effective when plants are properly nourished with macro- and micronutrients (Komosa 2012). Silicon is the only element safe to plants in case of excessive uptake. It

*Corresponding author:
e-mail: anna.pawlikowska@upwr.edu.pl

may be applied in the nutrition of plants in field cultivation (soil and foliarly) and in soilless systems (Jarosz 2014). Silicon compounds have different properties, thus can play a various role in plant physiological processes. It has been proved that silicon actively participates in the development of plant resistance to biotic and abiotic stresses. The main properties of Si include improving resistance to: salt stress (Savvas et al. 2007; Reezi et al. 2009; Bayat et. al 2013; Soundararajan et al. 2013; Sivanesan & Jeong 2014), water stress (Fauteux et al. 2005; Henriet et al. 2006; Grzebisz et al. 2010; Mieszkalska & Łukaszewska 2011) as well as to diseases and pests (Brecht et al. 2007; Korndörfer et al. 2010; Shetty et al. 2012; Cho et al. 2013). It also mitigates the toxicity of heavy metals, such as aluminium (Prabagar et al. 2011), manganese and chromium (Ali et al. 2013; Kleiber 2014; Tripathi et al. 2015). By impregnating cell walls not only significantly strengthens the grass (Barboni et al. 2014) but also increases the rigidity of ornamental plant shoots (Zhao et al. 2012; Cho et al. 2013). According to Kamenidou et al. (2008, 2010) it may accelerate or delay blossom. Silicon also significantly affects the growth and flowering of plants. It was demonstrated, among others, by Sivanesan et al. (2013) in *Chrysanthemum cultivars*, Bayat et al. (2013) in *Calendula officinalis*, Mattson and Leatherwood (2010) on such popular flowerbed species as *Bracteantha bracteata, Fuchsia hybrid, Impatiens hawkeri, Lobelia erinus, Petunia* × *hybrida, Portulaca grandiflora*, and *Torenia fournieri*. It influences the colouring of leaves in *Perilla frutescens* by increasing the content of anthocyanins (Zhong et al. 1992) as well as the colour and gloss of flowers, e.g. in *Rosa* × *hybrida* 'Hot Lady' (Reezi et al. 2009) and in *Dianthus caryophyllus* (Jamali & Rahemi 2011). According to Dębicz i in. (2016) silicon has beneficial influence on most of the analysed morphological features of *Gazania rigens, Salvia farinacea, Verbena hybrida*. It is also important in tissue cultures, e.g. it increases the number of shoots in *Cattleya loddigesii* (Soares et al. 2012) and *Phalaenopsis hybrida* (Zhou 1995). The aim of the study was to analyse the influence of silicon in form of ortho-silicic acid stabilized with choline (YaraVita Actisil) and liquid multinutrient fertilizer on the quality and macronutrient content of three bedding plant species cultivated for commercial purposes.

MATERIAL AND METHODS

In the years 2012-2013, a pot experiment including three taxa of ornamental bedding plants: *Gazania rigens* 'Kiss Yellow', *Salvia farinacea* 'Fairy Queen' and *Verbena* 'Obsession Lilac' was carried out in the greenhouse belonging to the Department of Horticulture, Wroclaw University of Environmental and Life Sciences. Seedlings originating from a licensed horticultural farm were transplanted on the 15th of March 2012 and 2013, from multipots to pots of 500 cm^3 volume, filled with peat substrate of a pH 6.47, containing (mg·dm^{-3}): 145 N-NO_3^-, 119 P, 263 K, 90 Mg, 1120 Ca. Pots were placed on cultivating tables at a density of 24 plants per 1 m^2. The temperature in the greenhouse was 16-18 °C during a day and 14-16 °C at night. Plants were watered with a watering can (according to their needs). The two-factorial experiment was established using the randomized block design in 3 replications each containing 9 plant. The first factor was the foliar application of YaraVita Actisil (Yara Poland, Szczecin) containing 0.6% silicon in the form of ortho-silicic acid but also Ca and choline. Silicon was applied at doses (after calculation from fertilizer): 0 mg·dm^{-3}, 60 mg·dm^{-3}, 120 mg·dm^{-3} and 180 mg·dm^{-3} Si, 4 ml per plant, weekly from April 2nd to May 7th (in both years of the experiment). The second factor was soil application of multinutrient liquid fertilizer Insol U (INS Puławy) at solutions: 0%, 0.25% and 0.50%. Fertilizer composition was as follow (%): 10.5 N-NH_2, 1.5 N-NO_3, 4 P_2O_5, 6 K_2O, 0.010 B, 0.010 Cu, 0.020 Fe, 0.010 Mn, 0.005 Mo, 0.010 Zn. Insol U was applied to the roots every 10 days (50 cm^3 per pot). Control treatment were given with water.

Biometric measurements including height and diameter of plants, diameter of inflorescences and their number, number of flowers per one inflorescence and, additionally, in *Gazania*, the number of leaves, were taken during flowering (28-29 May, 10 weeks after planting). Well-developed, young leaves were collected for laboratory analysis from

each treatment at the end of May 2012 and 2013. Each sample of fresh plant material weighed approximately 20 g. Magnesium and phosphorus content was determined with the use of colorimetric method, calcium and potassium content with the use of flame photometric method and silicon using the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The chlorophyll content of leaves was determined after extraction in 80% acetone (Arnon 1949). Absorption was measured using a spectrophotometer (WPA, S106) at 645 and 663 nm and chlorophyll content (mg g^{-1} f.w) was calculated according to the following equation: chlorophyll $a + b = 8.02\ (A_{663}) + 20.21\ (A_{645})$.

The obtained results of biometric features were statistically analysed with use of the ANOVA variance analysis method for two-factorial experiments, set up in form of randomized blocks. The significance of differences was determined basing on the Duncan test on the level p = 0.05. The results of laboratory analyses were processed statistically with use of the ANOVA variance analysis method in randomized blocks. The significance of differences was determined basing on the Tukey test on level p = 0.05. Due to the lack of significant differences in interaction, results of nutrient content are shown for main factors.

RESULTS AND DISCUSSION

The experiment demonstrated a significant influence of foliar application of Si containing fertilizer on all analysed morphological features of the three plant species, with the exception of inflorescence diameter in *Gazania rigens* 'Kiss Yellow' (Table 1) and plant height in *Verbena* 'Obsession Lilac' (Table 3). For all plant species silicon in concentration 120 and 180 mg·dm^{-3} was beneficial for growth and flowering (with the exception of *Gazania* diameter). Silicon supplementation in such doses contributed to increase of leaves number of *Gazania* (up 83% more at 120 mg·dm^{-3} and 73% more at 180 mg·dm^{-3} in comparison to the control), which significantly improved the ornamental value of this species. Si supplementation in concentration 180 mg dm^{-3} caused the increase in the number of inflorescences in *Gazania* by 26%, in *Salvia* by 96% and in *Verbena* by 76% in comparison to the control plants (Table 1–3), and the increase in number and diameter of *Verbena* flowers. Thus, silicon in concentration 120 and 180 mg·dm^{-3} influenced the flowering abundance, i.e. the property of plants that is decisive for wide application. Similar reactions to silicon were noted in *Argyranthemum frutescens* 'Blazer Rose', *Portulaca umbraticola* 'Duna Red' *Sanvitalia speciosa* 'Sunbini'and *Verbena* 'Patio Blue' (Dębicz & Wróblewska 2011), *Gaura lindheimeri* 'Corinas Choice', *Osteospermum ecklonis* 'Grande Pink Blush', *Xerochrysum bracteatum* 'Gold' (Wróblewska & Dębicz 2011). Plants of these species and cultivars, sprayed with a water solution of silicon at the concentration of 120 and 180 mg·dm^{-3} produced more shoots as well as more flowers/inflorescences in comparison to the control group and the group treated with the solution of 60 mg·dm^{-3} concentration. Studies by other authors demonstrated that also other doses of Si influence better growth and flowering of plants. Bayat et al. (2013) proved the beneficial effects of Si applied at dose of 100 mg·dm^{-3} on the growth and flowering of *Calendula officinalis* and Mattson and Leatherwood (2010) on the height of *Impantiens hawkeri, Lobelia erinus* and *Portulaca grandiflora* as well as on size of flowers in *Fuchsia hybrida*, *Portulaca grandiflora, Petunia* x *hybrida* and *Torenia fournieri.* At the same time, these authors noted a significant decrease in the flower diameter in other plant species as *Lobelia erinus, Sutera grandiflora* and the number of inflorescences of *Argyranthemum frutescens* as compared to plants that did not receive Si supplementation. The experiments by Whitted-Haag et al. (2014) showed that the same biometric parameters in five tested plant species were positively affected by various Si doses (up to 200 mg·dm^{-3}). However, the results of studies by Mattson and Leatherwood (2010) showed that certain species and cultivars of ornamentals did not respond to Si supplementation. This group include, among others, *Begonia* x *tuberhybrida* 'Nonstop Rose Petticoat', *Vinca major* 'Variegata' and some cultivars of *Pelargonium peltatum* L.

The above studies confirmed the conclusion of Ma and Yamaji (2006) that Si treatment can be beneficial for the appearance of plants, although this effect may vary depending on the species and cultivar.

The plants reactions to Insol U supplementation were varied. Its application had a positive effect only on the flowering of *Verbena.* Insol U at concentration 0.25 and 0.50% caused development of more inflorescences and more flowers in comparison to the control (Table 3). On the other hand, this fertilizer decreased leaves number in *Gazania* by 11% (Table 1) and plant diameter in *Salvia* (Table 2). The values of the other biometric features in all of the tested species were not significantly different. Thus, it turned out that supplementation of *Gazania* and *Salvia* with Insol U was pointless and that peat substrate satisfied the nutritional needs of plants on this phase of growth and flowering. However, treatment with Insol U was beneficial for *Verbena*.

Table 1. The influence of silicon dose ($mg \cdot dm^{-3}$) and concentration of multinutrient fertilizer Insol U (%) on morphological features of *Gazania rigens* 'Kiss Yellow' (mean from 2012-2013)

Dose of Si ($mg \cdot dm^{-3}$)	Concentration of Insol U (%)	Plant features				
		plant diameter (cm)	plant height (cm)	inflorescence diameter (cm)	inflorescence number	leaves number
0	0	13.30	12.93	6.00	2.17	12.77
0	0.25	13.43	11.97	6.07	2.43	12.73
0	0.50	13.47	12.40	6.27	2.37	13.77
60	0	16.07	12.40	5.93	2.43	12.77
60	0.25	16.77	12.30	6.13	2.53	13.03
60	0.50	15.97	14.20	6.57	2.50	13.90
120	0	15.83	14.43	6.47	3.67	29.40
120	0.25	14.00	14.13	5.47	2.66	21.97
120	0.50	11.93	14.43	6.27	3.40	21.53
180	0	13.63	16.33	6.07	2.73	23.57
180	0.25	13.47	14.80	6.07	3.13	22.80
180	0.50	13.67	13.97	5.93	2.93	21.47
$LSD_{0.05}$		1.34	n.s*	n.s	n.s	3.28
(± SE)		0.46	0.67	0.21	0.25	1.12
Means for dose of silicon						
0		13.40	12.43	6.11	2.32	13.09
60		16.27	12.97	6.21	2.49	13.23
120		13.92	14.33	6.07	3.24	24.30
180		13.59	15.03	6.02	2.93	22.61
$LSD_{0.05}$		0.73	1.13	n.s	0.41	1.90
(± SE)		0.26	0.38	0.12	0.14	0.65
Means for concentration of Insol U						
0		14.71	14.02	6.12	2.75	19.62
0.25		14.42	13.30	5.93	2.69	17.63
0.50		13.76	13.75	6.26	2.80	17.67
$LSD_{0.05}$		0.67	n.s	n.s	n.s	1.67
(± SE)		0.23	0.33	0.10	0.12	0.56

*n.s – non significant differences

Table 2. The influence of silicon dose (mg·dm^{-3}) and concentration of multinutrient fertilizer Insol U (%) on morphological features of *Salvia farinacea* 'Fairy Queen' (mean from 2012-2013)

Dose of Si (mg·dm^{-3})	Concentration of Insol U (%)	Plant features			
		plant diameter (cm)	plant height (cm)	shoot number	inflorescence number
0	0	9.80	9.57	3.30	1.67
0	0.25	10.00	12.30	5.30	1.83
0	0.50	10.17	13.97	3.93	1.57
60	0	9.73	13.10	4.37	1.37
60	0.25	9.93	13.57	4.27	1.30
60	0.50	9.37	11.67	5.13	1.47
120	0	12.50	24.17	4.63	2.60
120	0.25	9.83	16.13	4.37	2.53
120	0.50	11.17	17.33	3.97	2.13
180	0	13.73	17.70	5.27	3.20
180	0.25	13.97	23.73	6.00	3.97
180	0.50	11.50	21.83	5.23	2.80
$LSD_{0.05}$		1.03	3.40	n.s*	n.s
(± SE)		0.35	1.15	0.47	0.33
Mean for dose of silicon					
0		9.99	11.94	4.18	1.69
60		9.68	12.78	4.59	1.38
120		11.17	19.21	4.32	2.42
180		13.07	21.09	5.50	3.32
$LSD_{0.05}$		0.59	1.96	0.81	0.55
(± SE)		0.20	0.67	0.27	0.19
Mean for concentration of Insol U					
0		11.44	16.13	4.39	2.21
0.25		10.93	16.43	4.98	2.41
0.50		10.55	16.20	4.57	1.99
$LSD_{0.05}$		0.51	n.s	n.s	n.s
(± SE)		0.17	0.58	0.24	0.16

*n.s – non significant differences

According to Soundararajan et al. (2014) the ability to accumulate silicon in plant tissues depends also on the applied form and concentration and the method of its application. In *Salvia splendens* 'Vista Red' and 'Sizzler Red' the highest accumulation in the leaves was observed when Si was applied to soil in the form of K_2SiO_3 at a dose of 100 mg·dm^{-3}. According to Kamenidou et al. (2008, 2010) the highest silicon accumulation was noted in the leaves of *Helianthus annuus* and *Gerbera* 'Acapella' following the soil application in form of K_2SiO_3 at a dose of 200 mg·dm^{-3}.

It this study, YaraVita Actisil supplementation, in particular at 180 mg Si·dm^{-3}, significantly increased the content of Ca and P in *Gazania* (by 28% and 32% respectively), Mg in *Salvia* (by 48%) and P, K and Mg in *Verbena* – (by 52, 27% and 48% respectively) in comparison to the control plants. Similar results were reported by Kamenidou et al. (2010) (in *Gerbe*ra), Sivanesan et al. (2013) (in three *Chrysanthemum* cvs) and Tesfagiorgis and Laing (2013) (in *Zinnia elegans* and *Cucurbita pepo*).

Table 3. The influence of silicon dose ($mg \cdot dm^{-3}$) and concentration of multinutrient fertilizer Insol U (%) on morphological features of *Verbena* 'Obsession Lilac (mean from 2012-2013)

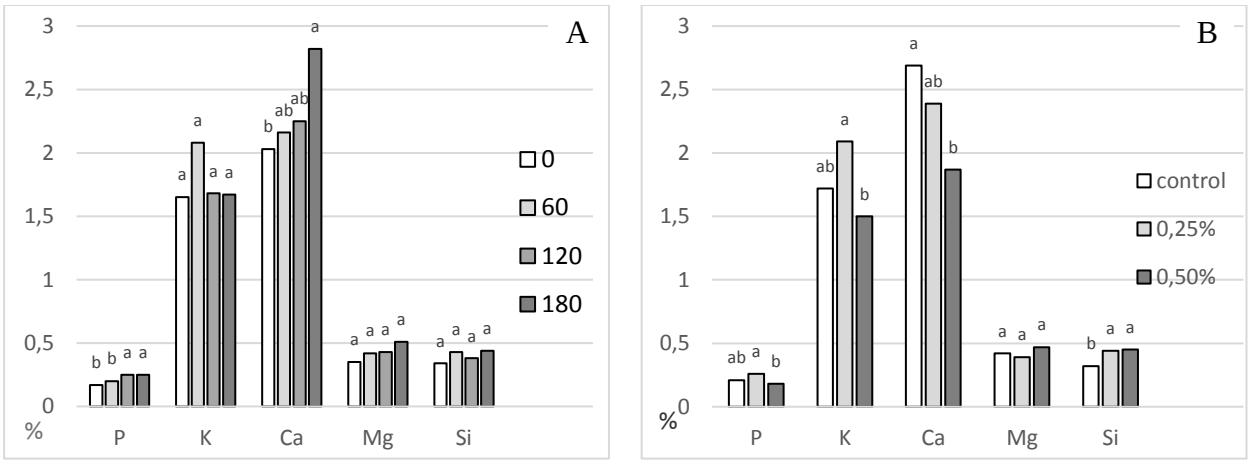
Dose of Si ($mg \cdot dm^{-3}$)	Concentration of Insol U (%)	Plant features				
		Plant diameter (cm)	Plant height (cm)	Inflorescence diameter (cm)	Inflorescences number	Flowers number per inflorescence
0	0	20.23	10.33	4.23	2.03	11.77
0	0.25	20.63	9.77	4.27	2.06	10.33
0	0.50	20.50	9.53	4.37	2.43	12.00
60	0	21.47	10.40	4.03	2.57	9.83
60	0.25	22.70	10.30	4.20	3.03	9.73
60	0.50	19.67	10.13	4.43	2.77	11.17
120	0	23.40	10.63	4.23	1.93	12.23
120	0.25	26.57	10.83	5.67	4.50	19.13
120	0.50	23.80	9.57	5.07	4.70	14.77
180	0	22.67	8.93	4.63	2.07	11.77
180	0.25	25.37	10.43	5.57	4.03	13.20
180	0.50	27.77	11.87	5.53	5.43	14.70
$LSD_{0.05}$		3.02	1.44	0.37	0.95	1.89
(± SE)		1.03	0.49	0.12	0.32	0.64
Mean for dose of silicon						
0		20.45	9.88	4.29	2.18	11.37
60		21.28	10.28	4.22	2.79	10.24
120		24.59	10.34	4.99	3.71	15.38
180		25.27	10.41	5.24	3.84	13.22
$LSD_{0.05}$		1.74	n.s*	0.21	0.55	1.09
(± SE)		0.59	0.28	0.07	0.19	0.37
Mean for concentration of Insol U						
0		21.94	10.07	4.28	2.15	11.40
0.25		23.82	10.33	4.92	3.41	13.10
0.50		22.93	10.27	4.85	3.83	13.16
$LSD_{0.05}$		n.s	n.s	0.18	0.47	0.94
(± SE)		0.51	0.24	0.06	0.16	0.32

*n.s – non significant differences

Farshidi et al. (2012) and Mehrabanjoubani et al. (2014) reported higher accumulation of elements in plant tissue in result of Si application. However, also contrary opinions were published. For example, Ma and Takahashi (2002) and Chen et al. (2011) claimed that silicon decreases the content of some nutrients in plants, while Yin et al. (2013) demonstrated the beneficial influence of silicon on the content of some elements, in particular K, however only under salt stress conditions.

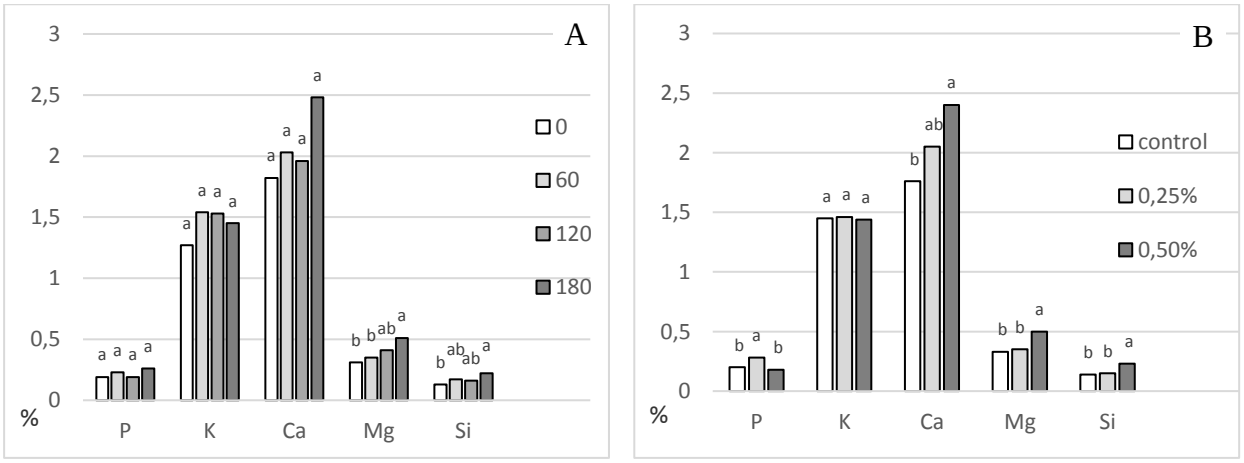
In this study, soil application of Insol U had a varied influence on the accumulation of the analysed elements in leaves. The application of 0.5% water solution of fertilizer noticeably increased the content of Ca, Mg and Si in *Salvia* (Fig. 2B), while *Verbena* reacted to the same dose of Insol U only with a higher accumulation of Mg (by 34% in comparison to the control plants). Supplementation of *Verbena* with fertilizer of 0.25% concentration did not have a significant influence on the nutrient level (Fig. 3B). In *Gazania* treated with Insol U at concentration 0.25% the contents of P, K and Si were higher in comparison with control (Fig. 1B), whereas at application with 0.5% content of K and

Ca decreased their content. Insol U applied to *Salvia* at 0.5% increased content of Ca, Mg and Si (Fig. 2B). The interaction of both experimental factors on nutritional status was not demonstrated. Few studies concerning this fertilizer have been published so far. One of them is the paper by Borowski and Michałek (2009), who concluded that foliar treatment of spinach with Insol U led to a significant increase in potassium and phosphorus content.



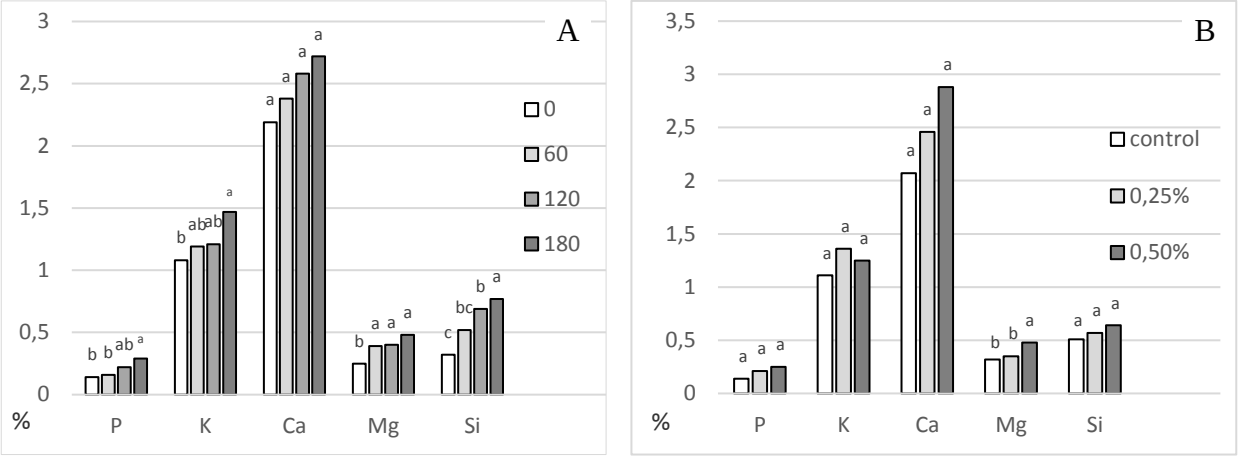
Means followed by the same letter for each nutrient do not differ significantly at p = 0.05
Standard error mean (± SE) for dose of Si ± 0.33; multinutrient fertilizer ± 0.24; P ± 0.01; K ± 0.11; Ca ± 0.16; Mg ± 0.03; Si ± 0.02

Fig. 1 A-B. The influence of silicon dose (mg·dm^{-3}) (A) and concentration of multinutrient fertilizer (%) (B) on nutrients and silicon contents (% d.w.) in leaves of *Gazania rigens* 'Kiss Yellow' (mean from 2012-2013)



Means followed by the same letter for each nutrient do not differ significantly at p = 0.05
Standard error mean (± SE) for dose of Si ± 0.33; multinutrient fertilizer ± 0.24; P ± 0.2; K ± 0.07; Ca ± 0.13; Mg ± 0.04; Si ± 0.02

Fig. 2 A-B. The influence of silicon dose (mg·dm^{-3}) (A) and multinutrient fertilizer (%) (B) on nutrients and silicon contents (% d.w.) in leaves of *Salvia farinacea* 'Fairy Queen' (mean from 2012-2013).



Means followed by the same letter for each nutrient do not differ significantly at p = 0.05
Standard error mean (± SE) for dose of Si ± 0.33; multinutrient fertilizer ± 0.24; P ± 0.2; K ± 0.06; Ca ± 0.15; Mg ± 0.03; Si ± 0.06

Fig. 3 A-B. The influence of silicon dose (mg·dm^{-3}) (A) and concentration of multinutrient fertilizer (%) (B) on nutrients and silicon contents (% d.w) in leaves of *Verbena* 'Obsession Lilac' (mean from 2012-2013).

The analysed experimental factors did not have a significant effect on the chlorophyll content in leaves. Regardless of the silicon concentration, the chlorophyll level in the analysed plant species was similar. However, studies by other authors demonstrated that silicon may cause an increase in the chlorophyll content in leaves and support the synthesis of sugars (Mikiciuk & Mikiciuk 2009; Jarosz 2014). The research conducted by Mieszkalska and Łukaszewska (2011) showed that regardless of the cultivation conditions (water stress or lack thereof), chlorophyll *a* and *b* content in the leaves of *Pelargoniom hortorum* L.H. Bailey was higher with silicon supplementation. Similar results were shared by Sivanesan et al. (2013) in chrysanthemum. Higher chlorophyll content was also found in plants subjected to foliar treatment with Insol U (Borowski & Michałek 2009).

CONCLUSIONS

1. Silicon in the form of ortho-silicic acid stabilized with choline and Ca (YaraVita Actisil) applicated foliarly had a significant influence on a majority of the analysed morphological features of *Gazania rigens* 'Kiss Yellow', *Salvia farinacea* 'Fairy Queen' and *Verbena* 'Obsession Lilac'.
2. Plants reacted best to 120 and 180 mg·dm^{-3} Si concentration, which led to improve flowering of all three plant taxa, enhanced growth of *Salvia* and *Gazania* and increased number of leaves of *Gazania.*
3. Insol U applied to soil was beneficial for *Verbena* 'Obsession Lilac' as it noticeably affected the flowering of this cultivar.
4. No interaction between silicon applied foliarly and Insol U applied to soil was found.
5. Silicon and Insol U did not have a stimulating effect on accumulation of chemical elements in leaves of studied plants.

REFERENCES

Ali S., Farooq M.A., Yasmeen T., Hussain S., Arif M.S., Abbas F. et al. 2013. The influence of silicon on barley growth, photosynthesis and ultra-structure under chromium stress. Ecotoxicology and Environmental Safety 89: 66–72. DOI: 10.1016/j.ecoenv.2012.11.015.

Arnon D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris.* Plant Physiology 24: 1–15. DOI: 10.1104/pp.24.1.1.

Barboni D., Anwar ul Haq M., Meunier J.-D., Keller C., Huc R. 2014. Si-accumulation in durum wheat and drought-stress: impact on the plant morphology and its leaf phytolith content. 9th International Meeting on Phytolith Research, Brussels. DOI: 10.13140/rg.2.1.3861.0081.

Bayat H., Alirezaie M., Neamati H., Saadabad A.A. 2013. Effect of silicon on growth and ornamental traits of salt-stressed calendula (*Calendula officinalis* L.). Journal of Ornamental Plants 3(4): 207–214.

Borowski E., Michałek S. 2009. The effect of placement and light conditions during foliar application of Insol U fertilizer on gas exchange, yield and the quality of spinach (*Spinacia oleracea* L.) Folia Horticulturae 21(1): 61–71. DOI: 10.2478/fhort-2013-0126.

Brecht M.O., Datnoff L.E., Kucharek T.A., Nagata R.T. 2007. The influence of silicon on the components of resistance to gray leaf spot in St. Augustinegrass. Journal of Plant Nutrition 30: 1005–1021. DOI: 10.1080/01904160701394287.

Chen W., Yao X., Cai K., Chen J. 2011. Silicon alleviates drought stress of rice plants by improving plant water status, photosynthesis and mineral nutrient absorption. Biological Trace Element Research 142(1): 67–76. DOI: 10.1007/s12011-010-8742-x.

Cho R.H., Joung H.Y., Lim K-B., Kim K.S. 2013. Effect of calcium and silicate application on pathogenicity of *Erwinia carotovora* subsp. *carotovora* in *Zantedeschia* spp. Horticulture, Environment, and Biotechnology 54(4): 364–371. DOI: 10.1007/s13580-013-0059-1.

Dębicz R., Wróblewska K. 2011. The effect of silicon foliar application on the development of seasonal ornamental plants. Part I: *Sanvitalia speciosa* 'Sunbini', *Verbena* 'Patio Blue' and *Portulaca umbraticola* 'Duna Red'. Acta Agrobotanica 64(4): 99–106. DOI: 10.5586/aa.2011.051.

Dębicz R., Pawlikowska A., Wróblewska K., Bąbelewski P. 2016. Influence of foliar treatment with silicon contained in the Actisil Hydro Plus preparation on the growth, flowering and chemical composition of *Gazania rigens* (L.) Gaertn., *Salvia farinacea* Benth and *Verbena hybrida* Voss. Journal of Elemntology 21(3): 681–692. DOI: 10.5601/jelem.2015.20.2.909.

Fauteux F., Rémus-Borel W., Menzies J.G., Bélanger R.R. 2005. Silicon and plant disease resistance against pathogenic fungi. FEMS Microbiology Letters 249: 1–6. DOI: 10.1016/j.femsle.2005.06.034.

Farshidi M., Abdolzadeh A., Sadeghipour H.R. 2012. Silicon nutrition alleviates physiological disorders imposed by salinity in hydroponically grown canola (*Brassica napus* L.) plants. Acta Physiologiae Plantarum 34(5): 1779–1788. DOI: 10.1007/s11738-012-0975-1.

Górecki R.S., Danielski-Busch W. 2009. Effect of silicate fertilizers on yielding of greenhouse cucumber (*Cucumis sativus* L.) in container cultivation. Journal of Elemntology 14(1): 71–78. DOI: 10.5601/jelem.2009.14.1.08.

Grzebisz W., Gaj R., Przygocka-Cyna K. 2010. Role of nutrients in build-up of plant resistance mechanisms to pathogens pressure. Progress in Plant Protection/Postępy w Ochronie Roślin 50(2): 517–532. [in Polish with English abstract]

Henriet C., Draye X., Oppitz I., Swennen R., Delvaux B. 2006. Effects, distribution and uptake of silicon in banana (*Musa* spp.) under controlled conditions. Plant and Soil 287: 359–374. DOI: 10.1007/s11104-006-9085-4.

Hogendorp B.K., Cloyd R.A., Swiader J.M. 2012. Determination of silicon concentration in some horticultural plants. HortScience 47(11): 1593–1595.

Jamali B., Rahemi M. 2011. Carnation flowers senescence as influenced by nickel, cobalt and silicon. Journal of Biological and Environmental Sciences 5(15): 147–152.

Jarosz Z. 2014. The effect of silicon application and type of medium on yielding and chemical composition of tomato. Acta Scientiarum Polonorum, Hortorum Cultus 13(4): 171–183.

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

Kamenidou S., Cavins T.J., Marek S. 2010. Silicon supplements affects floricultural quality traits and elemental nutrient concentration of greenhouse produced gerbera. Scientia Horticulturae 123: 390–394. DOI: 10.1016/j.scienta.2009.09.008.

Kleiber T. 2014. The effect of choline-stabilized orthosilicic acid application under Mn excessive nutrition on yielding of hydroponically grown lettuce (*Lactuca sativa* L.). Aparatura Badawcza i Dydaktyczna 19(3): 219–226.

Komosa A. 2012. Odżywianie dolistne w połączeniu z biostymulatorami wzrostu. In: Żywienie roślin ogrodniczych. Podstawy i perspektywy. PWRiL, Poznań. [in Polish]

Korndörfer A.P., Grisoto E., Vendramim J.D. 2010. Introduction of insects plant resistance to the spittlebug *Mahanarva fimbriolata* Stål (Hemiptera: Cercopidae) in sugarcane by silicon application. Neotropical Entomology 40(3): 387–392. DOI: 10.1590/s1519-566x2011000300013.

Ma J.F., Takahashi T. 2002. Silicon uptake and accumulation in plants. Chapter 6. In: Soil, Fertilizer, and Plant Silicon Research in Japan. Elsevier Science, The Netherlands, pp. 73–82.

Ma J.F., Tamai K., Yamaji N., Mitani N., Konishi S., Katsuhara M. et al. 2006. A silicon transporter in rice. Nature 440: 688–691. DOI: 10.1038/nature04590.

Ma J.F., Yamaji N. 2006. Silicon uptake and accumulation in higher plants. Trends in Plant Science 11(8): 392–397. DOI: 10.1016/j.tplants.2006.06.007.

Mattson N.S., Leatherwood W.R. 2010. Potassium silicate drenches increase leaf silicon content and affect morphological traits of several floriculture crops grown in a peat-based substrate. HortScience 45(1): 43–47.

Mehrabanjoubani P., Abdolzadeh A., Sadeghipour H.R., Aghdasi M. 2014. Impacts of silicon nutrition on growth and nutrient status of rice plants grown under varying zinc regimes. Theoretical and Experimental Plant Physiology 27: 19–29. DOI: 10.1007/s40626-014-0028-9.

Mieszkalska K., Łukaszewska A. 2011. Effect of the silicon and phosphorus-containing fertilizer on geranium (*Pelargonium hortorum* L.H. Bailey) response to water stress. Acta Scientiarum Polonorum, Hortorum Cultus 10(3): 113–121.

Mikiciuk G., Mikiciuk M. 2009. The influence of foliar application of potassium and silicon fertilizer on some physiological features of strawberry (*Fragaria ananassa* Duch.) variety Elvira. Annales UMCS, Sectio E – Agricultura 64(4): 19–27. DOI: 10.2478/v10081-009-0039-4. [in Polish with English abstract]

Mitani N., Ma J.F. 2005. Uptake system of silicon in different plant species. Journal of Experimental Botany 56(414): 1255–1261. DOI: 10.1093/jxb/eri121.

Prabagar S., Hodson M.J., Evans D.E. 2011. Silicon amelioration of aluminium toxicity and cell death in suspension cultures of Norway spruce (*Picea abies* (L.) Karst). Environmental and Experimental Botany 70: 266–276. DOI: 10.1016/j.envexpbot.2010.10.001.

Reezi S., Babalar M., Kalantari S. 2009. Silicon alleviates salt stress, decreases malondialdehyde content and affects petal color of salt-stressed cut rose (*Rosa xhybrida* L.) 'Hot Lady'. African Journal of Biotechnology 8(8): 1502–1508. DOI: 10.5897/ajb09.180.

Savvas D., Gizas G., Karras G., Lydakis-Simantiris N., Salahas G., Papadimitriou M., Tsouka N. 2007. Interactions between silicon and NaCl-salinity in a soilless culture of roses in greenhouse. European Journal of Horticultural Science 72(2): 73–79.

Shetty R., Jensen B., Shetty N.P., Hansen M., Hansen C.W., Starkey K.R., Jørgensen H.J.L. 2012. Silicon induced resistance against powdery mildew of roses caused by *Podosphaera pannosa*. Plant Pathology 61: 120–131. DOI: 10.1111/j.1365-3059.2011.02493.x.

Sivanesan I., Jeong B.R. 2014. Silicon promotes adventitious shoot regeneration and enhances salinity tolerance of *Ajuga multiflora* Bunge by altering activity of antioxidant enzyme. Scientific World Journal, ID 521703, 10 p. DOI: 10.1155/2014/521703.

Sivanesan I., Son M.S., Song J.Y., Jeong B.R. 2013. Silicon supply through the subirrigation system affects growth of three chrysanthemum cultivars. Horticulture, Environment, and Biotechnology 54(1): 14–19. DOI: 10.1007/s13580-013-0120-0.

Soares J.D.R., Pasqual M., de Araujo A.G., de Castro E.M., Pereira F.J., Braga F.T. 2012. Leaf anatomy of orchids micropropagated with different silicon concentrations. Acta Scientiarum, Agronomy 34: 413–421. DOI: 10.4025/actasciagron.v34i4.15062.

Soundararajan P., Sivanesan I., Jo E.H., Jeong B.R. 2013. Silicon promotes shoot proliferation and shoot growth of *Salvia splendens* under salt stress in vitro. Horticulture, Environment, and Biotechnology 54: 311–318. DOI: 10.1007/s13580-013-0118-7.

Soundararajan P., Sivanesan I., Jana S., Jeong B.R. 2014. Influence of silicon supplementation on the growth and tolerance to high temperature in *Salvia splendens*. Horticulture, Environment, and Biotechnology 55: 271–279. DOI: 10.1007/s13580-014-0023-8.

Tesfagiorgis H.B., Laing M.D. 2013. The effects of silicon level in nutrient solution on the uptake and distribution of silicon in zucchini and zinnia, and its interaction with the uptake of selected elements. African Journal of Biotechnology 12(14): 1617–1623. DOI: 10.5897/ajb2012.3038.

Tripathi D.K., Singh V.P., Prasad S.M., Chauhan D.K., Dubey N.K., Rai A.K. 2015. Silicon-mediated alleviation of Cr(VI) toxicity in wheat seedlings as evidenced by chlorophyll florescence, laser induced breakdown spectroscopy and anatomical changes. Ecotoxicology and Environmental Safety 113: 133–144. DOI: 10.1016/j.ecoenv.2014.09.029.

Whitted-Haag B., Kopsell D.E., Kopsell D.A., Rhykerd R.L. 2014. Foliar silicon and titanium applications influence growth and quality characteristics of annual bedding plants. Open Horticulture Journal 7: 6–15. DOI: 10.2174/1874840601407010006.

Wróblewska K., Dębicz R. 2011. The effect of silicon foliar application on the development of season ornamental plants. Part II: *Argyranthemum frutescens* 'Blazer Rose', *Xerochrysum bracteatum* 'Gold', *Osteospermum ecklonis* 'Grande Pink Blush' and *Gaura lindheimeri* 'Corinas Choice'. Acta Agrobotanica 64(4): 107–114. DOI: 10.5586/aa.2011.052.

Yin L., Wang S., Li J., Tanaka K., Oka M. 2013. Application of silicon improves salt tolerance through ameliorating osmotic and ionic stresses in the seedling of *Sorghum bicolor*. Acta Physiologiae Plantarum 35: 3099–3107. DOI: 10.1007/s11738-013-1343-5.

Zhao D., Hao Z., Tao J., Han Ch. 2012. Silicon application enhances the mechanical strength of inflorescence stem in herbaceous peony (*Paeonia lactiflora* Pall.). Scientia Horticulturae 151: 165–172. DOI: 10.1016/j.scienta.2012.12.013.

Zhong J.-J., Seki T., Kinoshita S.-I., Yoshida T. 1992. Effects of surfactants on cell growth and pigment production in suspension cultures of *Perilla frutescens*. World Journal of Microbiology and Biotechnology 8: 106–109. DOI: 10.1007/BF01195826.