ACTA Acta Sci. Pol., Hortorum Cultus 13(1) 2014, 167-178

THE SUBSEQUENT EFFCT OF SILICON ON PHYSIOLOGICAL AND BIOCHEMICAL PARAMETERS OF *Polygonatum multiflorum* (L.) All. 'Variegatum' CUT SHOOTS

Katarzyna Rubinowska, Elżbieta Pogroszewska, Halina Laskowska, Paweł Szot, Adam Zdybel, Dariusz Stasiak, Danuta Kozak
University of Life Sciences in Lublin

Abstract. The aim of the undertaken research was to establish the subsequent effect of silicon, which is the component in Actisil Hydro Plus preparation, and the place of cultivation on the postharvest quality of Solomon's Seal (*Polygonatum multiflorum* 'Variegatum'). Plants were cultivated directly in the field or in an unheated foil tunnel. The preparation was used as a sixfold spray in three concentrations: 0.2, 0.3 and 0.4% during the plants vegetation, at weekly intervals. The control were plants sprayed with distilled water. Leafy shoots were cut at the moment of becoming morphologically mature and placed in distilled water in a controlled thermal-lightning conditions: temperature was 21/18ºC (day/night) and photoperiod of 12 h light/12 h darkness. The condition of cytoplasmic membrane was evaluated with the use of analysis of electrolyte leakage and determining the level of peroxidation of membrane lipids. The analyses of assimilation pigments (chlorophyll a + b) and proline content, the relative water content as well as postharvest longevity were established. Leafy shoots of *P. multiflorum* cultivated in an unheated tunnel, regardless of the spray with Actisil Hydro Plus, characterized with longer lasting decorative value. The lowest proline content in tissues after 30 days were observed in leaves obtained from plants cultivated in foil tunnel and sprayed with Actisil Hydro Plus in concentration of 0.2 and 0.3%. During the analysis conducted 30 days after starting the experiment, the most effective stop of membrane lipids peroxidation was observed in shoots obtained from plants cultivated in foil tunnel and sprayed with Actisil in concentration of 0.2%. Cultivation of *P. multiflorum* in foil tunnel and spray with preparation in concentration of 0.3% inhibited assimilation pigments degradation the most effectively.

Key words: chlorophyll, electrolyte leakage, longevity, MDA, proline, RWC, silicon

Corresponding author: Katarzyna Rubinowska, Department of Plant Physiology, University of Life Sciences in Lublin, Akademicka 15, 20-950 Lublin, Poland, e-mail: katarzyna.rubinowska@up.lublin.pl

INTRODUCTION

The cut foliage used in floral arrangements must retain longevity at least as long as other elements of the bouquet. The longevity of cut foliage to certain degree depends on conditions of cultivation such as fertilization, temperature, light intensity and photoperiod. During storage of cut plant material there comes to blocking of vascular tissues, including air, mechanical, physiological and biological blockades. As an effect of inhibition of water uptake transpiration process via leaves or leafy shoots, there occurs secondary water stress which is one of the main reasons of the loss of decorative value of cut plant material [Jones and Hill 1993].

Actisil Hydro Plus is a liquid fertilizer, easily water-soluble, intended for fertigation and foliar fertilization of plants. Moreover, the preparation is a source of easily digestible for plants silicon (Si), present in a form of orthosilicic acid and free silica. The active silicon contained in the discussed preparation, after foliar spray diffuses through cuticle and epidermis and is then stored in cell walls in leaves, what results in their thickening and increasing mechanical defense reaction [Adamiak and Hetman 2006]. Silicon contained in the preparation removes the harmful activity of drought stress through improved osmoregulation, better water status of tissues related to reduction in water loss during transpiration. Deposition of Si in the roots reduces apoplastic bypass flow and provides bindings sites for metals, resulting in decreased uptake and translocation of toxic metals and salts from the roots to the shoots. Under drought, Si-alleviated effects have been associated with an increase in antioxidant defense abilities [Liang et al. 2003, Zhu et al. 2004, Gong at al. 2005, Sacała 2009]. Silicon provided in an ion form also increases resistance of plants against fungicidal diseases, insect attack and spad index [Startek et al. 2006]. Si acts as a physical barrier, is deposited beneath the cuticle to form a cuticle-Si double layer, which can mechanically impede penetration by fungi and, thereby, disrupt the infection process [Fauteux at al. 2005]. Soluble Si can also acts as a modulator of host resistance to pathogens. Several studies in monocots and dicots have shown that plants supplied with Si can produce phenolics and phytoalexins in response to fungal infection [Fawe at al. 1998, Belanger at al. 2003, Remus-Borel at al. 2005, Rodrigues at al 2004]. Additionally silicon influences morphological features of plants and improves postharvest quality of cut plant material [Adamiak and Hetman 2006].

The aim of the undertaken research was to estimate the subsequent influence of silicon, contained in Actisil Hydro Plus preparation, and the place of cultivation on the physiological and biochemical parameters of *P. multiflorum* shoots during senescence. The state of cytoplasmic membranes was evaluated by means of electrolytes leakage and estimation of membrane lipids peroxidation. The analysis of contents of assimilation pigments (chlorophyll $a + b$) and proline was conducted and the relative water content and postharvest quality of shoots were evaluated as well.

MATERIAL AND METHODS

The leafy shoots of Solomon's Seal (*Polygonatum multiflorum* (L.) All. 'Variegatum') used in the experiments were cultivated in an unheated tunnel and in the field.

During the cultivation, either in a tunnel or in the field, plants were divided into 4 plots and sprayed with water solutions of Actisil Hydro Plus in concentrations of 0.2, 0.3 and 0.4% for six times. Sprays were done in a weekly intervals, starting from the second of May 2012 in a tunnel and the ninth of May 2012 in the field, always in the morning hours. The control were plants sprayed with distilled water. The moment plants became morphologically mature (two weeks after the last spray), plant material was harvested in the morning hours, placed into plastic containers and transported to a growth room, where the further step of the research was undertaken. The experiment was conducted in a controlled thermal-lightning conditions: temperature was 21/18°C (day/night), relative air humidity was 60%, the light intensity was 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$, with the photoperiod of 12 h light/12 h darkness. The experiment consisted of 4 combinations, with 20 leafy shoots in each. Leafy shoots were individually marked and they were treated as replicates. Distilled water, that shoots were kept in, was exchanged daily till the end of the experiment.

The postharvest quality of *P. multiflorum* shoots was evaluated on the basis of number of days from the appearance of loss of decorative value (30% of leaves per shoot getting brown and dry). The level of damage of cytoplasmic membranes was established by means of electrolytes leakage (E_L) from tissues, according to the method given by Kościelniak [1993], with the use of microcomputer conductometer CC-317 produced by Elmetron, as well as through marking the content of malonodialdehyde (MDA) as a product of membrane lipids peroxidation, according to the method given by Heath and Packer [1968]. A relative water content (RWC) in leaves tissues was marked according to the Barrs' method [1968]. The content of assimilative pigments (chlorophyll *a*, chlorophyll *b* and carotenoides) in leaves was evaluated by the means of the extraction in 80% acetone and absorbance measurement at 3 wavelengths (λ): 470 nm (carotenoides), 646 nm (chlorophyll *b*) and 663 nm (chlorophyll *a*), with the use of spectrophotometer Cecil CE 9500. The content of pigments was converted according to the methods given by Lichtenthaler and Wellburn [1983]. The content of free proline was marked according to the method of Bates et al. [1973].

3 leaves harvested from the middle part of 5 randomly chosen shoots from each combination were taken for chemical analysis. All analyses and measurements were done in 5 replicates after 1, 17 and 30 days of *P. multiflorum* storage in distilled water. All obtained data was analyzed statistically with the use of SAS, 9.1.3. version, software. The significance of differences were established with the use of Duncan confidence intervals at $p = 0.05$.

RESULTS AND DISCUSSION

Analysis of the postharvest longevity of cut *P. multiflorum* shoots showed the positive effect of cultivation in a tunnel on the measured value (tab. 1). Tunnel cultivated leaves of the examined species preserved decorative value by 26.6% longer in comparison to longevity of leaves harvested from field cultivation. The results obtained from this study suggest that tunnel production offers several benefits over field production when growing high-quality florists green. Wien [2009] and Wien and Pritts [2009] noted that high crops in high tunnels receive a lower daily light integral and altered air temperature compared with crops in the field, cut flowers usually develop significantly longer stems in high tunnels as a result of reduced air movement and irradiance. Unheated tunnels offer protection from frost and low temperatures, extending the growing season by several weeks in both spring and fall [Wien 2009, Ortiz at al. 2012]. Tunnels also protect crops from rain and reduce disease incidence, so leaf quality is maintained. Analysis of postharvest longevity of leafy shoots of *P. multiflorum* sprayed with Actisil Hydro Plus with different concentrations, proved that there were any significantly differences between examined combinations. The positive effect of conditioning in silicon solution on longevity of cut flowers was observed by Kazemi et al. [2012c] on carnation, Kazemi et al. [2012b] on rose, Kazemi [2012] on *Argyranthemum frutescens* and Kazemi et al. [2012a] on *Eustoma grandiflorum*. Silicon is not classified as element essential for growth and development of plants, but it's presence significantly influences regulation of many processes, for example it increases biotic and abiotic stress resistance in plants. Babak and Majid [2011] also noted inhibiting influence of silicon on ethylene production during carnation flowers senescence. Authors explain this phenomenon with ability of silicon to join to other cell membrane elements, what causes formation of hard silicone-cellulose layer that together with cuticle makes additional thickening, thanks to which tissues get another mechanical resistance against damages during transport and storage of plant material. Moreover, silicon may form complexes with other organic elements of epidermis cell walls what improves their resistance to enzymes produced during senescence [Snyder et al. 2007].

Table 1. The effect of cultivation conditions and Actisil Hydro Plus sprays with different concentrations on longevity of *P. multiflorum* cut shoots

Place of cultivation	Actisil Hydro Plus concentration (%)	Longevity (days)	Mean for the place of cultivation
Tunnel	0	27.9b–d[1]	28.2B
	0.2	29.2d	
	0.3	28.4c–d	
	0.4	27.2a–d	
Field	0	22.7a–b	22.3A
	0.2	22.2a	
	0.3	23.6a–c	
	0.4	24.5a–d	

[1]Values followed by the same letter do not differ statistically at $\alpha = 0.05$

On the basis of analysis of water content in tissues of *P. multiflorum* leaves determined by means of a relative water content coefficient (RWC) a decrease in RWC during storage of plant material was stated (tab. 2). These changes indicate increasing water stress in leafy shoots, due to cutting them off the mother plant. Pogroszewska et al.

[2009], Lü et al. [2010] and Rubinowska et al. [2012a] inform in their works about disorders in water management of shoots that quicken senescence. Leaves obtained from plants cultivated in the unheated tunnel characterized with higher water content, RWC was higher by 12.6% in comparison to the one marked in leaves obtained from plants cultivated in the field. Analysis of coefficient values after 30 days of storage in distilled water showed that the lowest RWC value was obtained when cut plant material was obtained from plants cultivated in the field and sprayed with Actisil solution in concentration of 0.2%. Reduction in water loss during storage of cut rose flowers as a result of conditioning in a silicon solution was also observed by Kazemi et al. [2012b]. Kaya et al. [2006] confirm in their research the positive effect of silicone on RWC coefficient value in case of corn plants subjected to drought stress. This element in conditions of water stress positively influences osmoregulation and decreases water loss during transpiration process, what increases RWC coefficient value.

Table 2. The effect of cultivation conditions and Actisil Hydro Plus sprays in different concentrations on relative water content coefficient (RWC) in leaves during senescence of cut *P. multiflorum* shoots

Place of cultivation	Actisil Hydro Plus concentration (%)	RWC (%) on day:			Mean for place of cultivation
		1	17	30	
Tunnel	0	82.89b–d[1]	82.43b–d	74.82b–d	82.22B
	0.2	86.04d	81.33b–d	75.99b–d	
	0.3	87.13d	84.58c–d	75.07b–d	
	0.4	86.91d	85.88d	83.59b–d	
Field	0	81.83b–d	69.80a–d	63.87a–b	72.99A
	0.2	79.78b–d	71.79a–d	53.30a	
	0.3	79.11b–d	78.79b–d	73.49b–d	
	0.4	80.47b–d	79.04b–d	64.61a–c	
Mean for the term		83.02B	79.21B	70.60A	

[1]Values followed by the same letter do not differ statistically at $\alpha = 0.05$

Together with ongoing senescence of *P. multiflorum* shoots, the increase of proline accumulation in leaves cells was noted (tab. 3). A higher synthesis of this amino acid is observed as a response of plants to environmental stresses, especially osmotic one, which accompanies senescence of cut leaves. Free proline protects cell structures, especially proteins and cytoplasmic membranes, against damages caused by stressor [Sacała 2009]. In conditions of conducted experiment, significantly higher proline content was observed in *P. multiflorum* shoots cultivated in the field. Analysis of results obtained after 30 days of lasting the research showed, that silicone provided in a form of Actisil Hydro Plus preparation spray caused decrease in proline content in *P. multiflorum* leaves and the lowest content of analyzed amino acid was noted in a variant, when plants were sprayed with the 0.2% and 0.3% solution and they were cultivated in a foil tunnel. Similar decrease in proline content under the influence of silicone was observed by Kaya et al. [2006], who cultivated corn in the conditions of drought stress and Tuna et al. [2008] while examining wheat plants grown in conditions of salinity stress.

Table 3. The effect of cultivation conditions and Actisil Hydro Plus sprays in different concentrations on proline content in leaves during senescence of *P. multiflorum* cut shoots

Place of cultivation	Actisil Hydro Plus concentration (%)	Proline ($mg \cdot g^{-1}$ FW) on day:			Mean for place of cultivation
		1	17	30	
Tunnel	0	42.16a[1]	147.09b–d	387.50f	99.32A
	0.2	44.79a	46.19a	72.25a	
	0.3	46.34a	59.36a	61.69a	
	0.4	44.48a	58.12a	181.81d	
Field	0	87.73a–b	164.30c–d	262.57e	138.62B
	0.2	59.05a	170.34c–d	201.65d–e	
	0.3	81.06a–b	105.09a–c	202.43d–e	
	0.4	80.75a–b	86.49a–b	161.97c–d	
Mean for the term		60.80A	104.63B	191.49C	

[1]Values followed by the same letter do not differ statistically at $\alpha = 0.05$

Table 4. The effect of cultivation conditions and Actisil Hydro Plus sprays in different concentrations on electrolyte leakage coefficient (E_L) in leaves during *P. multiflorum* shoots senescen

Place of cultivation	Actisil Hydro Plus concentration (%)	E_L (%) on day:			Mean for place of cultivation
		1	17	30	
Tunnel	0	14.03a–b[1]	14.70a–b	24.47d	17.02A
	0.2	12.69a	15.22a–b	17.56a–d	
	0.3	14.45a–b	17.01a–d	21.02b–d	
	0.4	14.70a–b	18.20a–d	20.20a–d	
Field	0	13.86a–b	18.78a–d	23.63c–d	17.13A
	0.2	12.72a	16.94a–d	20.56b–d	
	0.3	15.88a–b	17.08a–d	19.05a–d	
	0.4	12.56a	16.68a–c	17.84a–d	
Mean for the term		13.86A	16.83B	20.54C	

[1]Values followed by the same letter do not differ statistically at $\alpha = 0.05$

Proceeding senescence process leads to biochemical and biophysical changes in cell membranes [Leurentz et al. 2002], additionally intensified with water stress emerging as a result of cutting the leafy shoots off the mother plant. Water stress, like other stress factors, causes numerous dysfunctions of cytoplasmic membrane, inter alia changes in its permeability and liquidity as well as disturbances in activity of enzymes localized in plasmalemma [Sacała 2009]. The stability of cell membranes is also influenced by cell lipids peroxidation resulting from oxidation of unsaturated fatty acids connected with cell membrane, what is proven by the fact of increase in malondialdehyde content [Sacała 2009]. Analyzing the state of cytoplasmic membranes during the experiment the progress in their degradation was observed on the basis of electrolyte leakage coefficient (E_L) and malondialdehyde (MDA) content in *P. multiflorum* leaves (tabs 4, 5). Increase in E_L coefficient during storage of cut plant material is shown in previous research of Rubinowska et al. [2012a, b] on leaves of *Weigela florida* and *Rosa multiflora*. Analysis of electrolyte leakage from leaves of *P. multiflorum* after 30 days of experiment did not proved any statistical differences depending on the concentration of Actisil Hydro Plus preparation used in the experiment (tab. 4). However, it has to be noted that the lowest value of E_L characterized leaves sprayed with the 0.2% solution, cultivated in the tunnel and sprayed with 0.4% solution cultivated in the field (value decreased by 28.2 and 24.5% appropriately in comparison to control).

Table 5. The effect of cultivation conditions and Actisil Hydro Plus sprays in different concentrations on malondialdehyde (MDA) content in leaves during *P. multiflorum* cut shoots senescence

Place of cultivation	Actisil Hydro Plus concentration (%)	MDA (nmol·g^{-1} FW.) on day:			Mean for place of cultivation
		1	17	30	
Tunnel	0	31.48a–c[1]	42.96d–e	51.35e–h	36.55A
	0.2	22.06a	30.50a–c	34.32c–d	
	0.3	22.76a–b	29.93a–c	52.51e–h	
	0.4	33.44b–d	36.12c–d	51.09e–h	
Field	0	29.67a–c	51.61e–h	55.35f–h	44.95B
	0.2	27.10a–c	55.97g–h	58.32g–h	
	0.3	29.41a–c	44.36d–f	47.87e–g	
	0.4	26.58a–c	51.33e–h	61.80h	
Mean for the term		27.81A	42.85B	51.58C	

[1]Values followed by the same letter do not differ statistically at $\alpha = 0.05$

Analysis of MDA content in leaves of *P. multiflorum* showed significant differences depending on the place of cultivation. Cultivation in the conditions of the unheated foil tunnel was more advantageous for state of cytoplasmic membranes, expressed in malondialdehyde content (tab. 5). After 30 days of storage of leafy shoots in distilled water, the lowest MDA value was observed in shoots obtained from plants sprayed with Actisil Hydro Plus in concentration of 0.2% cultivated in the tunnel (value lower by 32.2% in comparison to the control). Decrease in MDA content under the influence of conditioning of cut shoots in silicone solution was observed by Kazemi et al. [2012a] on *Lisianthus* and Kazemi et al. [2012b] on *Rosa*. On the other hand Liang et al. [2003]

noted positive influence of silicone used in a form of foliage spray on MDA content in *Hordeum vulgare* plants, which had been subjected to salinity stress. Authors explain this advantageous effect of examined element with its activity leading to lowering permeability of membranes resulting from stimulation of antioxidative enzymes synthesis which deactivate reactive forms of oxygen that cause cell lipids peroxidation. Moreover, silicone influences stability of cell membranes through changes in ratio of unsaturated and saturated fatty acids, what allows to keep integrity and functionality of plasmatic membranes.

Table 6. The effect of cultivation conditions and Actisil Hydro Plus sprays in different concentration on chlorophyll $a + b$ content in leaves during senescence of *P. multiflorum* cut shoots

Place of cultivation	Actisil Hydro Plus concentration (%)	Chl. $a + b$ (mg·g^{-1} FW) on day:			Mean for place of cultivation
		1	17	30	
Tunnel	0	1.75f–j	1.70f–j	1.09a–c	1.55B
	0.2	1.81h–j	1.76g–j	1.17a–d	
	0.3	1.61f–j	1.53d–h	1.40c–g	
	0.4	1.91j	1.70f–j	1.22b–e	
Field	0	1.60f–j	1.39c–f	0.81a	1.43A
	0.2	1.58e–j	1.58e–j	1.00a–b	
	0.3	1.80h–j	1.54e–j	1.07a–c	
	0.4	1.90i–j	1.66f–j	1.17a–d	
Mean for the term		1.75C	1.61B	1.12A	

[1]Values followed by the same letter do not differ statistically at $\alpha = 0.05$

One of the most often used parameter to evaluate the postharvest quality of cut foliage is analysis of assimilative pigments (chlorophyll *a* and *b*). During senescence and as an effect of drought and oxidative stress, correlated with this process, the decrease in chlorophyll content in leaves in favor of carotenoides which synthesis increases, is observed [Park et al. 2007]. The results presented in Table 6 confirm the decrease in chlorophyll sum content during the experiment as it was described by Skutnik et al. [2004, 2006], Pogroszewska et al. [2009] and Rubinowska et al. [2012a, b]. The analysis of chlorophylls content in the 30th day of experiment showed significant influence both the place of cultivation and Actisil Hydro Plus sprays in different concentrations on value of measured parameter during storage of *P. multiflorum* shoots. Higher sum content of chlorophylls characterized leaves obtained from plants cultivated in the unheated foil tunnel (value higher by 8.4% in comparison to leaves obtained from plants cultivated in the field). While the highest amount of analyzed pigments was noted in leaves obtained from plants sprayed with the solution in concentration of 0.3% cultivated in tunnel (value higher by 28.4% in comparison to the control). Silicone added to the media conditioning cut flowers of *Argyranthemum frutescens* [Kazemi 2012], *Rosa* [Kazemi et al. 2012b], *Eustoma grandiflorum* [Kazemi et al. 2012c] and carnation [Kazemi et al. 2012c] inhibited chlorophyll degradation in a similar way. Treating plants with exogenous silicone during vegetation causes increase in photosynthesis active pigments content both in plants cultivated in optimal conditions and exposed to drought stress [Silva et al. 2012]. Silicone stimulates production of new pigments and inhibits degradation of those already produced so that higher content of chlorophyll *a* and *b* can be observed in leaves treated with this element. The interaction of silicone with a cell membrane and increase in mechanical resistance of tissues, enhances rigidity of leaves and their better positioning towards light, what increase photosynthetic efficiency of plants. Silicone protects also photosynthetic apparatus against damages caused by environmental stress, including drought stress [Silva et al. 2012].

CONCLUSIONS

1. Decrease in leaves tissues water and chlorophyll $a + b$ content and increase in proline content, as well as cytoplasmic membranes degradation expressed in malondialdehyde content and electrolyte leakage from cell is observed in senescent *Polygonatum multiflorum* shoots.
2. Cultivation of *P. multiflorum* for use as a cut foliage in an unheated tunnel advantageously influenced postharvest quality of shoots what is proved by their higher longevity, higher relative water content coefficient (RWC) and sum of chlorophylls *a* and *b* as well as lower content of proline and malondialdehyde (MDA).
3. Silicone treatment during *P. multiflorum* cultivation in a foil tunnel in a form of spray with Actisil Hydro Plus solution in concentration of 0.2% and 0.3% demonstrates antistressful activity towards plants as it decreases proline content. Actisil in concentration of 0.2% the most effectively inhibits cytoplasmic membranes degradation.

ACKNOWLEDGMENT

The research carried out in the framework of the research project KBN N N310 771340.

REFERENCES

Adamiak J., Hetman J., 2006. Dolistna aplikacja tytnu w uprawie okulantów róż odmiany ‘Flamingo’. Zesz. Probl. Post. Nauk Roln. 510, 25–30.

Babak J., Majid R., 2011. Carnation flowers senescence as influenced by nickel, cobalt and silicon. J. Biol. Environ. Sci. 5, 147–152.

Barrs H.D., 1968. Determination of water deficits in plant tissues. In: Water deficits and plant growth, Vol. I: Development, control and measurement, T.T. Kozlowski (ed.). Academic Press New York, 235–368.

Bates L.S., Waldren R.R., Teare I.D.,1973. Rapid determination of free proline or water-stress studies. Plant Soil 39, 205 – 207.

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

Fauteux F., Remus-Borel W., Menzies J.G., 2005. Silicon and plant disease resistance against pathogenic fungi. FEMS Microbiol. Lett. 249, 1–6.

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

Gong H., Zhu X., Chen K., Wang S., Zhang C., 2005. Silicon alleviates oxidative damage of wheat plants in pots under drought. Plant Sci. 169, 313–321.

Heath R.L., Packer L., 1968. Effect of light on lipid peroxidation in chloroplasts. Biochem. Biophys. Res. Commun. 19, 716–720.

Jones R.B., Hill M., 1993. The effect of germicides on the longevity of cut flowers. J. Amer. Soc. Hort. Sci. 118, 350–354.

Kaya C., Tuna L., Higgs D., 2006. Effect of silicon on plant growth and mineral nutrition of maize grown under water-stress conditions. J. Plant Nutr. 29, 1469–1480.

Kazemi M., 2012. Effect of cobalt, silicon, acetylsalicylic acid and sucrose as novel agents to improve vase-life of *Argyranthemum* flowers. Trends App. Sci. Res. 7, 579–583.

Kazemi M., Asadi M., Aghdasi S., 2012a. Postharvest life of cut *Lisianthus* flowers as affected by silicon, malic acid and acetylsalicylic acid. Res. J. Soil. Biol. 4, 15–20.

Kazemi M., Gholami M., Asadi M., Aghdasi S., 2012b. Efficiency of silicon, nickel and acetylsalicylic acid reduced senescence and extended vase life of cut rose flowers. Trends App. Sci. Res. 7, 590–595.

Kazemi M., Gholami M., Bahmanipour F., 2012c. Effect of silicon and acetylsalicylic acid on antioxidant activity, membrane stability and ACC-oxidase activity in relations to vase life of carnation cut flowers. Biotechnology 11, 87–90.

Kościelniak J., 1993. Wpływ następczy temperatur chłodowych w termoperiodyzmie dobowym na produktywność fotosyntetyczną kukurydzy (*Zea mays* L.). Zesz. Nauk. AR Kraków, Rozpr. hab. 174.

Leurentz K., Wagstaff C., Rogers H.J., Stead A.D., Chanasul U., Silkowski H., Thomas B., wei C.H., Feussner I., Griffiths G., 2002. Characterization of a novel lipoxygenase independent senescence mechanism in *Alstroemeria peruviana* floral tissue. Plant Physiol. 130, 273–283.

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 salt-stressed barley (*Hordeum vulgare* L.). J. Plant Physiol. 160, 1157–1164.

Lichtenthaler H.K., Wellburn A., 1983. Determination of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. Biochem. Soc. Trans. 603, 591–592.

Lü P., Cao J., He S., Liu J., Li H., Cheng G., Ding Y., Joyce D.C., 2010. Nano-silver pulse treatments improve water relations of cut rose cv. Movie Star flowers. Post. Biol. Tech. 57, 196–202.

Ortiz M.A., Hyrczyk K., Lopez R.G., 2012. Comparizon of high tunnel and field production of specialty cut flowers in the Midwest. Hort. Sci. 47, 1265–1269.

Park S.Y., Yu J.W., Park J.S., Li J., Yoo S.C., Lee N.Y., Lee S.K., Jeong S.W., Seo H.S., Koh H.J., Jeon J.S., Park Y.I., Paek N.C., 2007. The senescence – induced staygreen regulates chlorophyll degradation. Plant Cell. 19, 1649–1664.

Pogroszewska E., Rubinowska K., Michałek W., 2009. Influence of selected growth regulators and chitosan on senescence of *Paeonia lactiflora* Pall. flowers. Ann. Warsaw Univ. Life Sci. – SGGW, Horticult. Landsc. Architect. 30, 31–39.

Remus-Borel W., Menzies J.G., Belanger R.R., 2005. Silicon induces antifungal compounds in powdery mildew-infected wheat. Physiol. Mol. Plant Pathol. 66, 108–115.

Rodrigues F.A., McNally D.J., Datnoff L.E., Jones J.B., Labbe C., Benhamou N., Menzies J.G., Belanger R.R., 2004. Silicon enhances the accumulation of diterpenoid phytoalexins in rice: a potential mechanism for blast resistance. Phytopathology 94, 177–183.
Rubinowska K., Michałek W., Pogroszewska E., 2012a. The effect of chemical substances on senescence of *Weigela florida* (Bunge) A. DC. 'Variegata Nana' cut stems. Acta Sci. Pol., Hortorum Cultus 11, 17–28.
Rubinowska K., Pogroszewska E., Michałek W., 2012b. The effect of polyamines on physiological parameters of post-harvest quality of cut stems of *Rosa* 'Red Berlin'. Acta Sci. Pol., Hortorum Cultus 6, 81–94.
Sacała E., 2009. Role of silicon in plant resistance to water stress. J. Elementol. 14, 619–630.
Silva O.N., Lobato A.K.S., Avila F.W., Costa R.C.L., Oliveira Neto C.F., Santos Filho B.G., Martins Filho A.P., Lemos R.P., Pinho J.M., Medeiros M.B.C.L., Cardos M.S., Andrade I.P., 2012. Silicon-induced increase in chlorophyll is modulated by leaf water potential in two water-deficient tomato cultivars. Plant Soil Environ. 58, 481–486.
Skutnik E., Rabiza-Świder J., Wachowicz M., Łukaszewska A.J., 2004. Senescence of cut leaves of *Zantedeschia aethiopica* and *Z. elliottiana*. Part I. Chlorophyll degradation. Acta Sci. Pol., Hortorum Cultus 3, 57–65.
Skutnik E., Rabiza-Świder J., Łukaszewska A., 2006. Evaluation of several chemical agents for prolonging vase life in cut asparagus greens. J. Fruit Ornam. Plant Res. 14, 233–240.
Snyder G.H., Martichenkov V.V., Datnoff L.E., 2007. Silicone. In: Handbook of plant nutrition, A.V. Barker, D.J. Pilibean (eds). CRC Taylor and Francis, New York, USA, 551–568.
Startek L., Placek M., Wraga K., 2006. Wpływ preparatu Actisil na niektóre cechy chryzantem uprawianych w doniczkach. Zesz. Probl. Nauk Roln. 510, 619–626.
Tuna A.L., Kaya C., Higgs D., Murillo-Amador B., Aydemir S., Girgin A.R., 2008. Silicon improves salinity tolerance in wheat plants. Environ. Exp. Bot. 62, 10–16.
Wien H.C., 2009. Floral crop production in high tunnels. Hort. Tech. 19, 56–60.
Wien H.C., Pritts M.P., 2009. Use of high tunnels in the northern USA: Adaptation to cold climates. Acta Hort. 807, 55–59.
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.

NASTĘPCZY WPŁYW KRZEMU NA PARAMETRY FIZJOLOGICZNE I BIOCHEMICZNE CIĘTYCH PĘDÓW *Polygonatum multiflorum* (L.) All. 'Variegatum'

Streszczenie. Celem podjętych badań było określenie następczego wpływu krzemu zawartego w preparacie Actisil Hydro Plus oraz miejsca uprawy na jakość pozbiorczą kokoryczki wielkokwiatowej (*Polygonatum multiflorum* 'Variegatum'). Rośliny uprawiano bezpośrednio w polu oraz w nieogrzewanym tunelu foliowym. Preparat zastosowano w formie 6-krotnego oprysku w trzech stężeniach: 0,2; 0,3 i 0,4% w trakcie wegetacji roślin, w odstępach tygodniowych. Kontrolę stanowiły rośliny opryskane wodą destylowaną. Ulistnione pędy ścinano w momencie osiągnięcia dojrzałości morfologicznej, wstawiano do wody destylowanej i umieszczono w kontrolowanych warunkach termiczno-świetlnych: temperatura 21/18ºC (dzień/noc), przy fotoperiodzie 12 h światła/12 h ciemności. Oceniano stan błon cytoplazmatycznych poprzez analizę wypływu elektrolitów i oznaczenie poziomu peroksydacji lipidów błonowych. Przeprowadzono analizy zawartości barwników asymilacyjnych (chlorofilu *a* + *b*), proliny, a także określono względną zawartość wody i trwałość pozbiorczą. Dłuższym okresem dekoracyjności charakteryzowały się ulistnione pędy *P. multiflorum* uprawiane w nieogrzewanym tunelu foliowym, niezależnie od zastosowanego oprysku preparatem Actisil Hydro Plus. Najmniejszą ilością proliny po 30 dniach trwania eksperymentu charakteryzowały się liście pozyskane z roślin uprawianych w tunelu foliowym i opryskiwane roztworem Actisilu Hydro Plus w stężeniu 0,2 i 0,3%. Podczas analizy wykonanej po 30 dniach trwania eksperymentu stwierdzono najefektywniejsze zatrzymanie peroksydacji lipidów błonowych w wariancie, w którym pędy pozyskano z roślin uprawianych w tunelu foliowym i opryskano Actisilem w stężeniu 0,2%. Natomiast uprawa *P. multiflorum* w tunelu foliowym i oprysk preparatem w stężeniu 0,3%, najkorzystniej zahamowało degradację barwników asymilacyjnych.

Słowa kluczowe: chlorofil, krzem, MDA, prolina, RWC, trwałość, wypływ elektrolitów

Accepted for print: 18.09.2013