ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol. Hortorum Cultus, 17(4) 2018, 157–166

www.acta.media.pl ISSN 1644-0692 e-ISSN 2545-1405 DOI: 10.24326/asphc.2018.4.14

ORIGINAL PAPER

Accepted: 29.01.2018

THE EFFECT OF SILICON ON MORPHOLOGICAL TRAITS AND MECHANICAL PROPERTIES OF *Polygonatum multiflorum* (L.) All. 'VARIEGATUM' CUT SHOOTS

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ABSTRACT

Garden perennials are a source of floristry material produced in field or under covers. A perennial producing long, leafy shoots, which in flower arrangements might successfully substitute fern or palm leaves, is *Polygonatum multiflorum.* The variety characterizing with decorative white margined leaves is 'Variegatum'. To improve their quality, the growth stimulator Actisil Hydro Plus, which contains 0.6% of active silicon in a form of orthosilicic acid was applied. The aim of the conducted experiment was to estimate the influence of silicon and a place of cultivation (tunnel and open field) on post-harvest quality determined with morphological features, vase life longevity and mechanical properties of *Polygonatum multiflorum* (L.) All. 'Variegatum' stems. The plants were sprayed with water solutions of Actisil in concentrations: 0.2%, 0.3%, and 0.4%, six times during the growing season in weekly intervals, starting from the first decade of May, always in the morning. It was stated that cultivation of *Polygonatum* in the unheated foil tunnel increases quality of shoots for cut greenery, determined with morphological features and post-harvest longevity. Cultivation of *Polygonatum* in a foil tunnel and spraying plants with Actisil in concentrations of 0.3 or 0.4% is advantageous due to possibility to increase a number of shoots from 20% to over 31%, their length from 9% to 11% and fresh weight from 52% to 71%, in comparison to control plants. It is advised to treat plants cultivated in a tunnel, with Actisil in concentration of 0.4% as it improved shoots quality evaluated with their diameter and lower leaves blade area. Spraying plants with Actisil in concentrations of 0.2–0.4% in the tunnel and 0.2% in field prolongs post-harvest shoots longevity by 3–4 days. Plants cultivated in the tunnel characterize with higher strength of shoots determined with higher maximum force causing permanent damage and lower stem deflection than plants cultivated in field. Plants grown in a tunnel and sprayed with Actisil in concentrations of 0.4% characterized with the strongest shoots after 14 days of storage, however a similar effect was observed with the concentration of 0.3% and in case of plants cultivated in field and sprayed with 0.4% of Actisil.

Key words: Actisil Hydro Plus, plant growth, cut greenery, mechanical stems strength, vase life

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INTRODUCTION

Garden perennials might be a valuable source of additives to bouquets, and are more and more often produced in glasshouses or foil tunnels for the purpose of cut flowers or cut greenery [Marcinkowski 2013]. The cultivation conditions in a foil tunnel allow to obtain floricultural material of a better quality, in comparison to that obtained in an open field [Puczel and Waźbińska 2003, Pogroszewska and Sadkowska 2008, Laskowska et al. 2010]. Improving the quality of ornamental plants is possible with the use of growth stimulators, such as Actisil preparation, which contains 0.6% of active silicon in a form of orthosilicic acid [Datnoff et al. 2001, Hwang et al. 2005, Startek et al. 2006, Bąbelewski 2008, Kamenidou et al. 2008, Wróblewska and Dębicz 2011, Bayat et al. 2013, Whitted-Haag et al. 2014]. Silicon is a component of cell walls structure and increases mechanical strength of stems, as well as regulates water balance [Kopcewicz and Lewak 2012]. Mechanical strength of inflorescence stems is a feature on which, among other things, depends quality of cut flowers [Zhao et al. 2013]. This feature plays an important role in relation to stems bending and breaking [Chen 2003], to which flowers and cut greenery are vulnerable during storage, trade and handling. Silicon application in form of foliar spraying can enhance the mechanical strength of inflorescence stems of *Paeonia lactiflora,* what is connected with changes in plant morphology [Zhao et al. 2013]. *Gerbera hybrida* 'Acapella' treated with silicon produced thicker flower stem peduncles [Kamenidou et al. 2010]. Treating plants with silicon might be one of the methods mitigating detrimental effects of water stress. This chemical element might influence metabolism and physiological activity of plants, especially those susceptible to unfavourable environmental conditions [Matichenkov and Kosobrukhov 2004, Sacała 2009]. It might result in a better quality and enhanced post-harvest vase life of stems harvested from plants treated with silicon preparations, especially in a view of the fact that a positive effect of conditioning cut flowers in solutions containing silicon on their vase life was stated [Kazemi 2012, Kazemi et al. 2012a].

A perennial that produces long, profusely leafy stems, which in floral arrangements might successfully substitute fern or palm leaves, is *Polygonatum multiflorum*. A specially decorative variety of the species is 'Variegatum', with white marginated leaves. The species has stiff stems, however they might get broken during handling. Their resistance to external forces, that is mechanical damage, might be evaluated with numerical values describing their physical state by means of chosen mechanical parameters [Szot and Rybczyński 2009, Szot et al. 2009, Szot 2010].

The aim of the conducted experiment was to estimate the influence of silicon, in different concentrations, included in the Actisil Hydro Plus preparation and a place of cultivation on post-harvest quality determined with morphological features, fresh weight, vase life and mechanical properties of *Polygonatum multiflorum* 'Variegatum' stems.

MATERIAL AND METHODS

The experiment was conducted in an unheated foil tunnel and in an open field, in two vegetation periods: in 2012 and 2013. The plant material were 5-year old plants of *Polygonatum multiflorum* (L.) All. 'Variegatum'.

Plants were cultivated in soil, at a spacing of 30 × 40 cm. A two-factorial design was set up, in three replications, where a single plot with 6 plants was treated as a replication. The first factor was a place of cultivation: an unheated foil tunnel or an open field. The second factor was a concentration of a growth stimulator Actisil Hydro Plus. The plants were sprayed with water solutions of Actisil containing 0.6% of silicon in the form of H_4SiO_4. The concentrations of Actisil 0.2%, 0.3%, and 0.4%, being an equivalent of 120, 180 and 240 mg $Si \cdot dm^{-3}$ were applied. The foliar spray of distilled water (= no mineral fertilizer treatment) was a control (treatment 0). Plants were treated six times during the growing season in weekly intervals, starting from May 2nd in the tunnel and May 9th in field (in 2012), and from May 7th in tunnel and May 10th in field (in 2013), always in the morning hours. After 7 days from the last application of the preparation: in the second decade of June in the tunnel and in the third decade of June in field, the measurements of stems were done. The following features were estimated: morphological features of plants, fresh weight (directly after cutting), post-harvest vase life and their mechanical properties (after cutting, after 7 and 14 days from cutting).

The following morphological features were observed on 3 randomly chosen stems from each plant: stem length measured from a base to the end of the top leaf (cm), stem diameter measured 5 cm below a lower leaf (mm), leaf blade area (mm^2) of three leaves situated the lowest on the stem. The measurement of a leaf blade area was conducted with the use of ADC BioScientific Ltd. company planimeter. The number of stems per plant were also estimated.

Stems intended for vase life and mechanical properties evaluation were harvested 7 days after the last application of Actisil, cutting 15–45 stems in each combination, respectively. Stems were then inserted into distilled water, in a storage room with a controlled thermal and light conditions: temperature 20 ±1°C, relative air humidity 60%, the light intensity 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$, with a photoperiod of 12 hours of light and 12 hours of darkness. The distilled water was exchanged every day, till the end of the experiment. A storage vase life of leafy stems of *P. multiflorum* was estimated as a number of days from harvest till the loss of decorative value symptoms were visible (30% of leaves per stem yellowed or browned). Each stem was treated as a replication.

Mechanical properties measurements were done in three terms (15 individually marked stems in each term, treated as replications), every 7 days, separating the plants that had been cultivated in the unheated foil tunnel and in the field. The first measurement of mechanical properties was done directly after harvest, the next after 7 days of storage and the last one after 14 days of storage. The analysis were conducted with the use of ZWICK BDO-FB 0.5 H apparatus.

A bottom part of stem (100 mm) was collected for tests. It was placed on supports situated at a distance of 50 mm from each other. The measurements were conducted through pressing the stem in the middle half way between the supports with an arm, at a speed of 50 $mm \cdot min^{-1}$. On the basis of the obtained data the following mechanical parameters were estimated: maximum force causing permanent stem damage (N) and stem deformation (mm).

Statistical analysis of the data. The obtained data was analyzed statistically by two-way and three-way analysis of variance with the use of Statistica 10 software. The significance between the means was estimated with t-Tukey intervals of confidence at the level of significance $\alpha = 0.05$. Means from two years are presented in the tables.

RESULTS AND DISCUSSION

Plants cultivated in the tunnel formed 11.6% more stems in comparison to those cultivated in the field (tab. 1). An increase in a number of inflorescence stems in cultivation of perennial plants under covers was observed in the research of Hetman and Pogroszewska [1996] on *Helleborus hybridus* hort., Pogroszewska [1998] on *Iris sibirica* and Szczepaniak [2000] on *Erigeron* 'Dunkelste Aller'. An increase of seasonal plants yield, as a result of cultivation in a foil tunnel was proved by Ortiz et al. [2012] on *Antirrhinum* 'Potomac Orange', *Celosia*, *Dianthus* and *Zinnia*. In case of *Campanula medium* even four times higher yield was observed [Janowska 2008]. However, cultivation of some perennials under foil cover might lead to lower yield of inflorescence stems [Pogroszewska and Sadkowska 2008].

An application of Actisil Hydro Plus in concentration of 0.4% on plants cultivated in the tunnel increased a number of stems by 31.4% in comparison to control plants (tab. 1). *Polygonatum* cultivated in field and treated with 0.3% of Actisil, formed 15.2% more stems than the control ones. A similar reaction of plants to silicon was observed in case of a 'Madelon' rose [De Kreij et al. 1997]. Plants of *Medicago sativa* produced more stems per plant when the Si was applied [Guo et al. 2006]. Silicon also increased a number of *Calendula officinalis* flowers by 35%, when plants were cultivated in a greenhouse under non-salt conditions, in comparison to the control [Bayat et al. 2013].

Table 1. The effect of cultivation place and Actisil Hydro Plus sprays in different concentrations on yield and morphological parameters of *Polygonatum multiflorum* shoots

Actisil Hydro Plus concentration (%)	Yield (shoots/plant)		Shoot length (cm)		Shoot diameter (mm)	
	tunnel	field	tunnel	field	tunnel	field
0	21.0 cd*	20.5 d	63.4 c	57.9 e	5.4bc	4.7e
0.2	22.3 bcd	21.1 cd	66.6 b	59.5 de	5.5abc	4.9de
0.3	25.2 ab	23.6 bc	70.5 a	62.1 c	5.6ab	5.1cde
0.4	27.6 a	20.6 d	69.2 a	61.4 cd	5.9a	5.2bcd
Mean	24.0 A	21.5 B	67.4 A	60.2 B	5.6A	5.0B

* Values followed by the same letter do not differ significantly at $\alpha = 0.05$

A cultivation in a foil tunnel favours production of longer and better quality shoots, what might result from protecting the plants against precipitation and wind during summer or spring and autumn frost [Wien 2009, Ortiz et al. 2012]. Plants usually develop significantly longer stems in high tunnels as a result of reduced air movement and irradiance [Wien 2009, Wien and Pritts 2009]. In the presented experiment a positive influence of cultivation in the tunnel on length of *Polygonatum* shoots and other properties characterizing their quality was noted. The cultivation in the foil tunnel made the plants to produce longer shoots by 12% in comparison to those cultivated in field (tab. 1), what complies with the results noted by Szot et al. [2009], who obtained longer inflorescence stems of *Allium sphaerocephalon* cultivated in a tunnel than in field. A similar effect of plants cultivation in an unheated tunnel was obtained by Janowska [2008] on *Campanula medium* and Ortiz et al. [2012] in cultivation of *Mathiola* and *Zinnia* in a high tunnel, obtaining 34 and 32% longer stems respectively than the ones growing in a field. The presented data also confirm the results observed by Szczepaniak [2000] on *Erigeron hybridus* 'Dunkelste Aller', who obtained longer shoots in a tunnel, however they characterized with worse quality as they were slender with strongly bent inflorescence branches, what the Author interprets as a reaction of the variety to high temperature in a tunnel. A good quality of the *P. multiflorum* 'Variegatum' stems obtained in the tunnel indicates a significant adaptive capacity of the tested variety to conditions existing in a tunnel. The mean air temperature in a tunnel was 16.8°C in May and 18.9°C in June in the year 2012 and 15.9°C in May and 18.9°C in June in the year 2013 in comparison to 15.0°C in May and 17.3°C in June in the year 2012 and 15.3°C in May and 18.5°C in June in the year 2013 in an open field. The mean air humidity in the tunnel reached 67% in the year 2012 and 81% in the year 2013.

In the conducted experiment spraying the plants with Actisil Hydro Plus in all concentrations favoured growth of shoots (tab. 1). In a tunnel they were 5–11.2% longer than the control ones, and in the field they were from 2.8 to 7.3% longer. The longest shoots were observed when Actisil in concentration of 0.3% and 0.4% was applied in the tunnel. The obtained results confirm the research of other authors who noted that an application of silicate increased height of plants of *Medicago sativa*, *Calendula officinalis*, *Rosa* 'Kardinal' *Gerbera hybrida* 'Acapella' and many other [Walter 2004, Guo et al. 2006, Kamenidou et al. 2010, Bayat et al. 2013, Whitted-Haag et al. 2014, Dębicz et al. 2016]. A reaction of plants and varieties to silicon application might be related to different levels of endogenous gibberellins, what is suggested by Sivanesan et al. [2013]. On the basis of the research of Hwang et al. [2007], who stated that application of Si increased the levels of GA_1 and GA_{20} in rice cultivars, so that advantageous influence of Si might result from a changed level of gibberellins. It is also noted that reaction of plants might depend on forms and concentrations of different products [Kamenidou et al. 2008, Mattson and Leatherwood 2010]. Sivanesan et al. [2013] proved that 50 $mg \cdot dm^{-3}$ of silicon increased plant height of three *Dendranthema grandiflorum* cultivars but 100 $mg \cdot dm^{-3}$ decreased that feature in the two ones.

Plants cultivated in a tunnel formed shoots 12% wider in diameter, in comparison to those obtained in the field (tab. 1). A peduncle diameter of *Allium sphaerocephalon* cultivated in an unheated foil tunnel was also higher than the one grown in a field [Szot et al. 2009]. Ortiz et al. [2012] noted larger stem caliper in case of *Matthiola* and *Zinnia* cultivated in a tunnel as well.

The analysis of a stem diameter showed a positive influence of Actisil Hydro Plus applied in concentration of 0.4% both in the tunnel and in the field. In the tunnel the stem diameter was 9.3% bigger in comparison to stem diameters of plants sprayed with water (tab. 1). In the field stems had 10.6% wider diameter than the control ones. Similarly, application of Si increased the stem diameter of *Paeonia lactiflora* [Zhao et al. 2013] and three *Dendranthema grandiflorum* cultivars as compared to the control [Sivanesan et al. 2013]. *Helianthus annuus* plants treated with Si formed thicker and straighter stems [Kamenidou et al. 2008] and *Zinnia elegans* stems characterized with a higher stem diameter [Kamenidou et al. 2009]. Sivanesan et al. [2010] also reported that Si increased a diameter of marigold stems. *Gerbera hybrida* 'Acapella' treated with Si produced thicker flower stem peduncles [Kamenidou et al. 2010], however silicon treatments decreased the same feature in case of annual bedding plants: impatiens and snapdragon [Whitted-Haag et al. 2014].

Plants cultivated in the tunnel produced leaves characterizing with 29% bigger area in comparison to those grown in the field (tab. 2). The application of Actisil Hydro Plus in concentration of 0.4%, both in the tunnel and in field, was advantageous, as it increased leaves area by 14.9% and 19.7% respectively, in comparison to the control plants. Similarly, Guao et al. [2006] stated, that *Medicago sativa* plants treated with Si produced bigger leaves. Foliar application of Si resulted in a greater leaf area of *Calendula officinalis* plants cultivated in a greenhouse as well as under salt stress as non-saline condition [Bayat et al. 2013].

The cultivation in the foil tunnel allowed to obtain shoots of 17.9% higher fresh weight in comparison to the ones grown in field (tab. 2). Higher fresh weight characterized also inflorescence stems of *Campanula medium* [Janowska 2008], *Liatris spicata* [Pogroszewska and Sadkowska 2008] and *Allium sphaerocephalon* [Szot et al. 2009] cultivated in an unheated foil tunnels, in comparison to plants cultivated in field.

Table 2. The effect of cultivation place and Actisil Hydro Plus sprays with different concentrations on morphological features and postharvest longevity of *Polygonatum multiflorum* shoots

Actisil Hydro Plus concentration (%)	Leaf area (mm^2)		Fresh weight (g)		Longevity (days)	
	tunnel	field	tunnel	field	tunnel	field
0	4472.4 b*	3338.0 d	11.3cd	10.2d	18.2b	13.3d
0.2	4343.8 b	3327.0 d	15.3b	13.9bc	22.1a	16.5bc
0.3	4524.8 ab	3658.6 cd	19.3 a	15.6b	21.4a	15.7bd
0.4	5139.1 a	3993.8 bc	17.2ab	14.0bc	21.3a	14.9cd
Mean	4620.0A	3579.4B	15.8A	13.4B	20.8A	15.1B

* Values followed by the same letter do not differ significantly at $\alpha = 0.05$

The application of Actisil Hydro Plus in all tested concentrations, promoted production of shoots characterizing with higher fresh weight from 35.4 to 70.8%, in comparison to the control plants grown in the tunnel, and by 36.3 to 52.9% to those cultivated in field (tab. 2). The highest fresh weight was noted when plants were treated with Actisil in concentration of 0.3%, both in the tunnel and in field. It might have been connected with the ability of silicon to increase a photochemical efficiency of plants, what was proven by Matichenkov and Kosobrukhov [2004], who studied a salt-stressed wheat plants (*Triticum aestivum*) physiological response in presence of silicon. Basha et al. [2013] as well indicated that increasing levels of nitrogen together with application of diatomite and potassium silicate in a form of spray, increased fresh weight of wheat plants. Zhao et al. [2013] noted higher fresh weight of inflorescence stems of *Paeonia lactiflora* treated with silicon, and Sivanesan et al. [2013] proved the same reaction of *Dendranthema grandiflorum*.

Analyzing a post-harvest longevity of cut *P. multiflorum* shoots, it was observed that shoots harvested from plants cultivated in the unheated tunnel stayed decorative for 37.8% longer, in comparison to those obtained from open field (tab. 2). In the earlier published results [Rubinowska et al. 2014], concerning the influence of a place of cultivation (tunnel, field) and Actisil Hydro Plus, on post-harvest senescence of *Polygonatum multiflorum* it was observed that leafy shoots cultivated in and unheated tunnel, regardless application of Actisil Hydro Plus, characterized with a better longevity. In the presented experiment, analyzing a post-harvest vase life of leafy *P. multiflorum* shoots harvested from plants cultivated in both places and sprayed with Actisil Hydro Plus in different concentrations, it was stated that the longest, over 22 days, were decorative shoots derived from plants sprayed with 0.2% of the preparation and cultivated in the foil tunnel (tab. 2), which in comparison to the control ones, were decorative for 21.4% longer. Similarly, Actisil Hydro Plus in concentration of 0.2% used in a field cultivation, positively affected a vase life of shoots, prolonging their decorative value by 24% in comparison to the ones obtained from control plants. An advantageous influence of Actisil on a post-harvest shoots longevity probably resulted from higher resistance of plants to water stress caused by silicon activity on molecular, tissue and plant levels. Silicon improves the use of water, osmoregulation and reduce transpiration losses [Sacała 2009]. Kamenidou et al. [2009] in the research on *Zinnia* plants indicates, that silicon applied in a form of $NaSiO_3$ foliar sprays, might form an antitranspirant film which increases leaf resistance to water loss but do not play an active role in reducing transpiration. The better leaf resistance of plants treated with Si, may further improve floricultural crops by improving quality and vase life of cut flowers. Silicon also prevents oxidative stress through reducing the amount of reactive oxygen forms in a cell [Sacała 2009]. Application of Si significantly increased a chlorophyll content in three *Dendranthema grandiflorum* cultivars [Sivanesan et al. 2013]. A preservative mixture solution containing silicon, extended a vase life of *Lisianthus* flowers and reduced chlorophyll total degradation [Kazemi et al. 2012a]. Silicon increased a water uptake by *Gerbera jamesonii* cut flowers and delayed their senescence [Kazemi et al. 2012d]. According to Snyder et al. [2007], silicon may form complexes with epidermis cell walls organic elements what enhances their resistance to senescence enzymes. Jamali and Rahemi [2011] noted that silicon inhibited ethylene production during senescence of carnation flowers. A positive influence of conditioning cut flowers in a solution containing silicon on their longevity was noted by Kazemi et al. [2012c] on *Dianthus caryophyllus* L., Kazemi et al. [2012b] on a rose, Kazemi [2012] on *Argyranthemum*, and Kazemi et al. [2012a] on *Eustoma grandiflorum*.

A maximum force causing permanent destruction of stems harvested from the tunnel was 8.8% higher after 14 days in comparison to stems obtained in from field (tab. 3). The application of Actisil in concentration of 0.4% on plants cultivated in both places caused that after 14 days of storage, the force that had to be used to permanently destroy stems was higher in comparison to the force used to destroy shoots of control plants.

The value of stem deflection at the force causing permanent destruction of stems obtained from the tunnel, was lower at any time of measurement in

Table 3. The effect of cultivation place and Actisil Hydro Plus sprays in different concentrations on maximum force causing destruction of *Polygonatum multiflorum* cut shoots (N)

Actisil Hydro Plus concentration (%)	Place of cultivation					
	tunnel			field		
	after cutting	after 7 days	after 14 days	after cutting	after 7 days	after 14 days
0	7.7jkl*	9.7gh	11.3c-f	8.9hij	9.4ghi	10.0fgh
0.2	8.3ijk	10.3efg	11.5cde	6.7l	7.1kl	11.5cde
0.3	8.3ijk	10.5efg	13.1ab	7.9jkl	11.2def	11.4cde
0.4	11.2def	12.1bcd	13.8a	10.3efg	11.3c-f	12.6abc
Mean	8.9E	10.6BC	12.4A	8.5E	9.8CD	11.4B

* Values followed by the same letter do not differ significantly at $\alpha = 0.05$

Table 4. The effect of cultivation place and Actisil Hydro Plus sprays in different concentrations on shoots deflection at maximum force causing destruction of *Polygonatum multiflorum* cut shoots (mm)

Actisil Hydro Plus concentration (%)	Place of cultivation					
	tunnel			field		
	after cutting	after 7 days	after 14 days	after cutting	after 7 days	after 14 days
0	3.9def*	3.0j-m	2.8k-n	5.0a	4.6ab	3.7efg
0.2	3.2h-k	2.7lmn	2.5no	4.4bc	3.8efg	3.7efg
0.3	3.6fgh	2.9k-n	2.7lmn	4.3bcd	4.1cde	3.1i-l
0.4	3.4g-j	3.2h-k	2.1o	3.6fgh	3.5f-i	3.2h-k
Mean	3.5C	2.9D	2.5E	4.3A	4.0B	3.4C

* Values followed by the same letter do not differ significantly at $\alpha = 0.05$

comparison to deflection of stems derived from field, respectively by 18.6, 27.5 and 26.5% (tab. 4). Szot et al. [2009] studied mechanical properties of *Allium sphaerocephalon* stems cultivated in an unheated tunnel and in field and they observed that plants grown in a tunnel formed harder stems, what was noted on the basis of a lower value of deflection. In the tunnel cultivation, application of Actisil in concentration of 0.4% caused that a studied feature was the lowest after 14 days of storage. Plants cultivated in a field and treated with Actisil in concentration of 0.3 and 0.4% characterized with lower deflection at the force causing permanent stem destruction, both directly after harvest and after 14 days of storage. The results suggest that the silicon application made the *Polygonatum* shoots less sensitive to mechanical damage. According to Jamali and Rahemi [2011] it might have been caused by the ability of silicon to bind with cell wall elements leading to formation of a thickened silicon-cellulose membrane, giving an additional strength together with a layer of cuticula. It gives additional mechanical strength to tissues and, in this way, resistance to breaking. It is an important feature during transport, storage and handling of plant material. According to Kamenidou et al. [2009], an application of silicon in cultivation of rice and wheat increased stem strength and resistance to lodging, probably due to deposition of silicon underneath the cuticle. Zhao et al. [2013] treated plants of *Paeonia lactiflora* with silicon and obtained inflorescence stems of higher mechanical strength, what as they indicate might be related to an increased layer of thickened sclerenchyma cells and a thickness of cell walls. An increased lignin content was also observed. Morphologically the shoots characterized with a higher diameter, what was also noted in the presented experiment. According to Weryszko-Chmielewska et al. [2003], a high diameter and a thick layer of sclerenchyma are features guaranteeing a good stability of tulip stems. It follows that silicon used during cultivation of plants might cause morphological and anatomical changes in stems improving their quality, and therefore increase resistance to post-harvest stress.

CONCLUSIONS

1. Cultivation of *Polygonatum multiflorum* 'Variegatum' in an unheated foil tunnel improves quality of shoots intended for cut greenery, determined with their morphological features and post-harvest longevity.

2. Cultivation of *Polygonatum* in a foil tunnel and spraying plants with Actisil 0.3 or 0.4% is advantageous due to possibility to increase a number of shoots respectively by 20% and over 31%; their length respectively by 11% and 9%; fresh weight respectively by 71% and 52%, in comparison to control plants.

3. It is intentional to use Actisil in concentration of 0.4% on plants cultivated in a tunnel due to stems quality determined with their diameter and blade area of lower leaves.

4. Treating plants with Actisil in concentrations of 0.2–0.4% in a tunnel and 0.2% in field guarantees prolonging post-harvest longevity of *Polygonatum* shoots by 3–4 days.

5. Plants cultivated in a tunnel characterize with harder stems what is determined with higher maximum strength causing permanent stem destruction and lower stem deflection in comparison to plants cultivated in field. Plants grown in a tunnel, sprayed with Actisil in concentration of 0.4% produced shoots which were the strongest after 14 days of storage, however a similar effect was observed with the concentration of 0.3% and in case of plants cultivated in field and sprayed with 0.4% of Actisil.

ACKNOWLEDGEMENT

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

REFERENCES

Abou Basha, D.M., El Sayed, S.A.A., El-Aila, H.I. (2013). Effect of nitrogen levels, diatomite and potassium silicate application on yield and chemical composition of wheat (*Triticum aestivum* L.) plants. World Appl. Sci. J., 25(8), 1217–1221.

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.). J. Ornam. Plants, 3(4), 207–214.

Bąbelewski, P. (2008). Wpływ preparatu Actisil na jakość ukorzenionych sadzonek wybranych taksonów jałowca (*Juniperus* sp.). Zesz. Probl. Nauk Roln., 525, 27–32.

Chen, D.S. (2003). Preliminary studies on preservative of cut *Gerbera jamesonii*. J. Hanshan Teach. Coll., 24, 75–78.

Datnoff, L.E., Snyder, G.H., Korndörfer, G.H. (2001). Silicon in agriculture. Elsevier, New York.

De Kreij, C., Voogt, W., van den Bos, A.L., Baas, R. (1997). Voedingsoplossingen voor de teelt van roos in gesloten teeltsystemen. PBG, Naaldwijk. Brochure VG4, 35 pp.

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. J. Elem., 21(3), 681–692.

Dębicz, R., Wróblewska, K. (2011). The effect of silicon foliar application on the development of seasonal ornamental plants. Part II: *Argyranthemum frutescens* 'Blazer Rose', *Xerochrysum bracteatum* 'Gold', *Osteospermum eclonis* 'Grande Pink Blush' and *Gaura lindheimeri* 'Corinas Choise'. Acta Agrobot., 64(4), 99–106.

Guo, Z.G., Liu, H.X., Tian, F.P., Zhang, Z.H., Wang, S.M. (2006). Effects of silicon on the morphology of shoots and roots of alfalfa (*Medicago sativa*). Aust. J. Exp. Agric., 46(9), 1161–1166.

Hetman, J., Pogroszewska, E. (1996). Przyspieszona uprawa ciemiernika ogrodowego (*Helleborus* × *hybridus* hort.) w nieogrzewanym tunelu foliowym i w polu. Materiały XI Ogólnopol. Zjazdu Kwiaciarzy, Skierniewice 16–17 maja, 1996, 43.

Hwang, S.J., Hamayun, M., Kim, H.Y., Na, C.I., Kim, K.U., Shin, D.H., Kim, S.Y., Lee, I.J. (2007). Effect of nitrogen and silicon nutrition on bioactive gibberellins and growth of rice under field conditions. J. Crop Sci. Biotech., 10, 281–286.

Hwang, S.J., Jeong, B.R., Park, H.M. (2005). Effects of potassium silicate on the growth of miniature rose 'Pinocchio' grown on rock wool and its cut flower quality. J. Jpn. Soc. Hort. Sci., 74, 242–247.

Jamali, B., Rahemi, M. (2011). Carnation flowers senescence as influenced by nickel, cobalt and silicon. J. Biol. Environ. Sci., 5, 147–152.

Janowska, B. (2008). Wpływ miejsca uprawy na plonowanie dzwonka ogrodowego (*Campanula medium* L.). Nauka Przyr. Technol., 2, 3, 20.

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. (2009). Evaluation of silicon as a nutritional supplement for greenhouse zinnia production. Sci. Hortic., 119, 297–301.

Kamenidou, S., Cavins, T.J., Marek, S. (2010). Silicon supplements affect floricultural quality traits and elemental nutrient concentrations of greenhouse produced gerbera. Sci. Hortic., 123, 390–394.

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.

Kazemi, M., Gholami, M., Hassanvand, F. (2012d). Effects of silicon on antioxidative defence system and membrane lipid peroxidation in gerbera cut flower. Asian J. Biochem., 7(3), 171–176.

Kopcewicz, J., Lewak, S. (2012). Fizjologia roślin. Wyd. Nauk. PWN, Warszawa, 238–246.

Laskowska, H., Pogroszewska, E., Durlak, W. (2010). Wpływ terminu sadzenia i miejsca uprawy na wzrost I plonowanie czosnku niebieskiego (*Allium caeruleum* Pall.). Zesz. Probl. Post. Nauk Roln., 551, 157–164.

Marcinkowski, J. (2013). Rola bylin na rynku roślin ozdobnych w Polsce. In: Mat. Konf. Nauk. „Ogrodnictwo ozdobne sektorem gospodarki narodowej", 4–5 września 2013, Rabiza-Świder, J., Skutnik, E. (ed.). SGGW, Warszawa, 115–118.

Matichenkov, V.V., Kosobrukhov, A.A. (2004). Si effect on the plant resistance to salt toxicity. 13th International Soil Conservation Organisation Conference – Brisbane, July 2004. Conserving Soil and Water for Society: Sharing Solutions.

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

Ortiz, M.A., Hyrczyk, K., Lopez, R.G. (2012). Comparison of high tunnel and field production of specialty cut flowers in the Midwest. HortScience, 47, 1265–1269.

Pogroszewska, E., (1998). Przyspieszona uprawa kosaćca syberyjskiego (*Iris sibirica* L.) w nieogrzewanym tunelu foliowym. Fol. Univ. Agric. Stetin. Agric., 187(70), 95–105.

Pogroszewska, E,. Sadkowska, P., (2008). The influence of benzyladenine on the flowering of *Liatris spicata* L. 'Alba' cultivated for cut flowers in an unheated plastic tunnel and in the field. Acta Agrobot., 61(1), 153 – 158.

Puczel, U., Waźbińska, J. (2003). Wpływ sposobu uprawy i terminu siewu na plonowanie kraspedii kulistej (*Craspedia globosa* Benth.). Zesz. Probl. Post. Nauk Roln. 491, 217 –222.

Rubinowska, K., Pogroszewska, E., Laskowska, H., Szot, P., Dybel, A., Stasiak, D., Kozak, D. (2014). The subsequent effect of silicon on physiological and biochemical parameters of *Polygonatum multiflorum* (L.) All. 'Variegatum' cut shoots. Acta Sci. Pol. Hortorum Cultus, 13(1), 167–178.

Sacała, E. (2009). Role of silicon in plant resistance to water stress. J. Elementol., 14, 619–630.

Sivanesan, I., Son, M.S, Lee, J.P., Jeong, B.R. (2010). Effect of silicon on growth of *Tagetes patula* L. Boy Orange and Yellow Boy seedlings cultured in an environment controlled chamber. Propag. Ornam. Plants 10, 136–140.

Sivanesan, I., Son, M.S, Song, J.Y., Jeong, B.R. (2013). Silicon supply through the subirrigation system affects growth of three *Chrysanthemum* cultivars. Hort. Environ. Biotechnol., 54(1), 14–19.

Snyder, G.H., Matichenko, V.V., Datnoff, L.E. (2007). Silicone. In : Handbook of plant nutrition, Barker A.V. Pilbeam D.J. (Eds). CRC Taylor and Francis, New York, 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.

Szczepaniak, S. (2000). Plonowanie przymiotna ogrodowego (*Erigeron hybridus* Bergm.) i ostróżki ogrodowej (*Delphinium × cultorum* Voss) w tunelu foliowym. Rocz. AR Pozn. 323, Ogrodn., 31(1), 171–175.

Szot, P. (2010). Wpływ regulatorów wzrostu na jakość pozbiorczą pędów kwiatowych tulipana. Rozpr. Nauk. UP w Lublinie, 342, Lublin, 77 pp.

Szot, P., Pogroszewska, E., Laskowska, H., Durlak, W. (2009). Quality and mechanical properties of inflorescence shoots of selected species of ornamental garlic as dependent on cultivation measures. Ann. War. Univ. Life Sci. Hortic. Landsc. Archit., 30, 67–77.

Szot, P., Rybczyński, R. (2009). Wpływ kondycjonowania na cechy morfologiczne i mechaniczne pędów kwiatowych tulipana. Acta Agrophys., 12(3), 777–790.

Walter, V. (2004). Effects of silicon additive to the growth and postharvest life of hydroponically grown 'Kardinal' roses. HortScience, 39(4), 824.

Weryszko-Chmielewska, E., Laskowska, H., Hetman, J., Michońska, M., Banach, B. (2003). Porównanie struktury łodygi kwiatowej wybranych odmian tulipana (*Tulipa gesneriana* L.). Ann. UMCS, sec. EEE, Horticultura, 13, 143–149.

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 Hortic. J., 7, 6–15.

Wien, H.C. (2009). Floral crop production in high tunnels. HortTechnology, 19, 56–60.

Wien, H.C., Pritts, M.P., (2009). Use of high tunnels in the northern USA: Adaptation to cold climates. Acta Hortic., 807, 55–59.

Wróblewska, K., Dębicz, R. (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 Agrobot., 64(4), 99–106.

Zhao, D., Hao, Z., Tao, J., Han, Ch. (2013). Silicon application enhances the mechanical strength of inflorescence stem in herbaceous peony (*Paeonia lactiflora* Pall.). Sci. Hortic., 151, 165–172.