MORPHOLOGICAL AND MECHANICAL PROPERTIES OF *Strelitzia reginae* FLOWERS DEPENDING ON THE SOLUTION USED FOR CONDITIONING

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**ABSTRACT**

*Strelitzia reginae* is an important cut flower native to South Africa. The effect of silicon and gibberellic acid with sucrose as conditioners on the post-harvest quality of *Strelitzia* cut flowers was investigated. Inflorescence shoots were conditioned for 24 hours in: water solutions of Actisil 0.2% or gibberellic acid (GA3) – 200 mg∙dm−3 + sucrose 10% or distilled water (control). The shoots were then placed in distilled water or Chrysal Clear Professional 2 (10%). It was found that GA3 + sucrose and Actisil increased the size of orange sepals and blue petals when after conditioning, the shoots were placed in water or Chrysal. Conditioning in Actisil and storage in Chrysal increased the value of mechanical parameters of flowers, leading to greater flexibility and lower susceptibility to fracture. Conditioning the shoots in Actisil and keeping them in Chrysal extended the life of flowers by 2 days.

**Key words:** Actisil, bird of paradise, Chrysal, gibberellic acid, mechanical damage, post-harvest, vase longevity

**INTRODUCTION**

*Strelitzia reginae*, a sub-tropical herbaceous plant native to South Africa, is widely used as a flower crop. The plants form inflorescences of exotic appearance. Each flower has 3, upright orange outer tepals and 3 modified blue inner tepals [Kew Species Profiles]. The inflorescence consists of 4–6 flowers, from which only some develop [Reinten et al. 2011]. The durability of the inflorescence is 6–16 days [Bayogan et al. 2008]. As an ornamental plant it is intended for ceremonial, personal or commercial use and therefore the decorative value and quality requirements of the plant play an important role [Zaidi et al. 2016, Sajjad et al. 2017]. In the case of ornamental cut flowers, longevity seems a deciding feature. Preparations recommended for prolonging the post-harvest duration of *Strelitzia* flowers usually contain sucrose. According to Finger et al [1999, 2003], conditioning shoots in 40% sucrose solution for 24 hours extends the period of inflorescence decoration by increasing the number of open flowers. The treatment of inflorescences with a sucrose solution at a lower concentration (5%) is also beneficial [Bayogan et al. 2008]. To maintain the highest quality of *Strelitzia* flower inflorescences after cutting, it is proposed to use
media, in which the sucrose content is 10% [Jaroenkit and Paull 2003, Hassan 2009]. Maintenance of cut flowers of many plant species in an optimal condition at all marketing stages is often ensured by the Chrysal Clear Professional series [Balas et al. 2006], which may be additionally supplemented with gibberellic acid. The post-harvest application of gibberellic acid positively affects the quality of *Strelitzia* flowers [El-Saka et al. 1995].

The mechanical strength of is another feature that determines the quality of cut flowers [Zhao et al. 2013]. It plays a role to the stems or flowers bending and breaking, which may occur during storage and handling [Chen 2003]. According to Onoda et al. [2015], leaves should be stiff and strong to maintain mechanical stability. Mechanical damage may also occur to flowers in the form of abrasion, cutting surface, kneading, and tearing of petals [Dias et al. 2013].

In the case of *Strelitzia*, the inflorescence shoots are ready for harvest when the orange sepals are visible at the top of the bract [Criley and Paull 1993]. Undeveloped inflorescences require opening. It is possible to cut shoots at a more advanced stage of inflorescence development, but then the flowers are more vulnerable to damage [Bayogan et al. 2008]. Mechanical strength of plant tissues may be enhanced with the use of growth stimulators containing active silicon, such as Actisil preparation [Kamenidou et al. 2008, 2010, Zhao et al. 2013, Whitted-Haag et al. 2014]. It may also enhance the better quality and post-harvest longevity of stems [Wraga and Dobrowolska 2008, Kazemi 2012, Kazemi et al. 2012c].

The purpose of the experiment was to investigate the effect of silicon and gibberellic acid (GA$_3$) used together with sucrose as a conditioner for post-harvest treatment of *Strelitzia* flower shoots, on the post-harvest quality of flowers assessed by their morphological characteristics and mechanical properties.

**MATERIALS AND METHODS**

The research material consisted of inflorescence shoots of *Strelitzia reginae* Banks ex Aiton obtained from plants cultivated in a glasshouse, in the ground, with the natural light. The inflorescence shoots were cut in the phase of the first developed flower, just before the development of the second flower (visible color). Shoots were cut to the length of 80 cm and conditioned in the following solutions:

1. Water solutions of Actisil containing 0.6% of silicon in the form of H$_2$SiO$_4$; the concentration of Actisil was 0.2%, being an equivalent of 120 mg Si·dm$^{-3}$,

2. Gibberellic acid (GA$_3$) water solution – 200 mg·dm$^{-3}$ + sucrose 10%,

3. Distilled water (control).

The conditioning took 24 hours in a growing room with controlled thermal-light conditions: temperature 20 ±1°C, relative air humidity 60%, light intensity PPFD 35 μmol·m$^{-2}$·s$^{-1}$ with a photoperiod of 12 hours of light and 12 hours of darkness. After conditioning, the shoots were placed in distilled water or in Chrysal Clear Professional 2 (10%) under the same conditions. There were 15 inflorescence shoots per treatment with 3 repetitions.

After 5 days of storage, the following morphological characteristics of flowers were determined: length and width of the green bract, length of orange sepals (cm), length of dark blue petals together measured with the stigma (cm), length of the receptacle (cm), cross-sectional area of the receptacle above the ovary (mm$^2$) – Figure 1, as well as mechanical properties of the first 3 flowers in the inflorescence on 5 inflorescence shoots. Another 10 inflorescences in each combination were separately marked and treated as replicates served to test their durability. The moment, when petals began to discolor or dry out, was assumed as the loss of decorative value.

Measurements of mechanical properties of plant material were carried out on the Zwick BDO-FB 0.5H strength device. Examining the mechanical properties of flowers, the maximum force was determined, causing the receptacle to break under static conditions and deformation and energy at the above-mentioned maximum force. For the tests, single flowers taken out from the inflorescence were placed in a holder, and then bent by pressing the arm at a speed of 50 mm·min$^{-1}$ just above the ovary, in the place of the narrowing (Fig. 1). The force at which the irreversible damage to the tissue was done was estimated.

Results of the study were statistically analyzed using the ANOVA analysis of variance for two factorial orthogonal classification. The significance of differences between means was estimated using T-Tukey confidence intervals at the significance level of
α = 0.05. The statistical analyses were performed using Statistica 13.0 (StatSoft, Cracow, Poland).

RESULTS AND DISCUSSION

The effect of Actisil silicon solution, GA$_3$, and Chrysal, on *Strelitzia* inflorescence size was noted. Conditioning shoots in GA$_3$ + sucrose 10% solution and then inserting them to Chrysal, resulted in a lengthening of the green bract (21.9 cm) in comparison to control shoots (19.0 cm) – Table 1. The beneficial influence of all the treatments on the size of orange sepals and blue petals was also proved, in comparison to the control (Tab. 2).

The positive effect of different biostimulation solutions on the growth and development of other plant species was proved by many authors. Silicon application increased the flower diameter of *Paeonia lactiflora* [Zhao et al. 2013], length of petals in *Alstroemeria* [Yeat et al. 2012], and lily (*L. longiflorum × Asiatic hybrid, ‘Richmond’) [Song et al. 1996]. The longest petals and sepals of *Strelitzia* were observed when inflorescence shoots were conditioned in GA$_3$ + sucrose solution and stored in Chrysal. Similar results were noted by El-Saka et al. [1995] in *Strelitzia reginae* and by Szot [2010] in tulips.

The treatments used during conditioning and storage influenced the post-harvest longevity of inflorescences as well (Tab. 2). The vase life of *Strelitzia* flowers was the shortest in the case of the control flowers, conditioned and stored in water (6.1 days). Significantly longer storage life was noted when inflo-

![Fig. 1. The morphological characteristics of a flower: 1 – length of orange sepals, 2 – length of blue petals, 3 – length of the receptacle, 4 – place of the maximum force measurement](image-url)
The influence of H$_2$O, Actisil, GA$_3$ conditioning treatments on morphological features and vase life of cut *Strelitzia reginae* flowers

| Conditioning treatments | Storage 5 days (B) | Length of green bracts (cm) | Mean for A | Width of green bracts (cm) | Mean for A | Length of the receptacle (cm) | Mean for A |
|-------------------------|-------------------|----------------------------|------------|---------------------------|------------|-------------------------------|------------|
| H$_2$O (control)        | H$_2$O            | 19.0a*                     | 19.4A      | 2.7a                      | 2.8A       | 5.0a                          | 5.2A       |
|                         | Chrysal           | 19.8ab                     |            | 2.9a                      |            | 5.3a–c                        | –          |
| Actisil                 | H$_2$O            | 19.6ab                     | 19.1A      | 2.9a                      | 2.9A       | 5.1ab                         | 5.4A       |
|                         | Chrysal           | 18.6a                      |            | 2.9a                      |            | 5.6bc                         | –          |
| GA3 + sucrose           | H$_2$O            | 20.1ab                     | 21.0B      | 2.8a                      | 2.9A       | 5.6bc                         | 5.7B       |
|                         | Chrysal           | 21.9b                      | 3.1A       |                           |            | 5.7c                          | –          |
| Mean B                  | H$_2$O            | 19.6A                      | 2.8A       |                           |            | 5.2A                          | –          |
|                         | Chrysal           | 20.1A                      | 2.9A       |                           |            | 5.5A                          | –          |

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

| Conditioning treatments | Storage 5 days (B) | Length of blue petals (cm) | Mean for A | Length of orange sepals (cm) | Mean for A | Vase life of the flowers (days) | Mean for A |
|-------------------------|-------------------|----------------------------|------------|-----------------------------|------------|--------------------------------|------------|
| H$_2$O (control)        | H$_2$O            | 10.4a*                     | 10.9A      | 10.7a                       | 11.1A      | 6.1a                           | 6.9A       |
|                         | Chrysal           | 11.2bc                     |            | 11.4b                       |            | 7.6bc                          | –          |
| Actisil                 | H$_2$O            | 11.1bc                     | 11.1A      | 11.4b                       | 11.4AB     | 7.6bc                          | 7.9A       |
|                         | Chrysal           | 11.0b                      |            | 11.3b                       |            | 8.2c                           | –          |
| GA3 + sucrose           | H$_2$O            | 11.0b                      | 11.3A      | 11.5b                       | 11.6B      | 6.7ab                          | 6.8A       |
|                         | Chrysal           | 11.5c                      |            | 11.7b                       |            | 6.8ab                          | –          |
| Mean B                  | H$_2$O            | 10.8A                      | 11.2A      | 11.2A                       |            | 11.2A                          | –          |
|                         | Chrysal           | 11.2B                      | 11.5A      | 11.5A                       |            | 11.5A                          | –          |

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

rescence shoots were conditioned in Actisil and stored in water (7.6) or Chrysal (8.2) or conditioned in water and stored in Chrysal (7.6).

Commercial preparations, like Chrysal, are often used for conditioning and storage of cut plants. They contain nutrients, anti-ethylene agents, bactericides, fungicides, and hormonal substances. They improve water conductance, lower pH of the solution, inhibit chlorophyll degradation, provide nutrients [Rabiza-Świder et al. 2015], and delay the degradation of soluble proteins [Rabiza-Świder et al. 2012]. The sucrose water solution is also often recommended to extend the vase life of cut flowers. Koley et al. [2017] noted that 2% sucrose with 300 mg dm$^{-3}$ Al(SO$_4$)$_3$ increased the number of florets opened per stem, vase life, and other post-harvest traits in *Strelitzia*. Inser-
tion of flower shoots into the 5% sucrose solution had a beneficial effect on the stability of the inflorescences after cutting. It was also beneficial to use a mixture of 10% sucrose, 250 mg·dm\(^{-3}\) 8-hydroxy-2-quinoline-carboxylic acid (8HQC), and 10 mg·dm\(^{-3}\) AgNO\(_3\) for 24 h [Bayogan et al. 2008]. According to Arrom and Munné-Bosch [2012], sucrose in the solution exerts an influence on flower tissue. The addition of 2% sugar significantly increased the opening of small Oriental Lily ‘Stargazer’ buds [Han 2003]. The author recommends, in addition to inserting flower shoots into a 2% sucrose solution, the use of leaf spraying with gibberellic acid. This kind of combination treatment with growth regulators considerably increased the quality of Lilium ‘Alma Ata’ too [Krstulović et al. 2018]. The mixture of 10% sucrose with GA\(_3\) in the present experiment, however, did not increase the post-harvest flower stability.

The longest vase life of Strelitzia flowers in the presented experiment was noted when shoots were conditioned in Actisil, however, the difference was not significant. The beneficial effect of conditioning the cut flowers in silicon solution for their post-harvest durability was reported by Kazemi et al. [2012a] in Dianthus caryophyllus, Kazemi et al. [2012b] in rose, Kazemi [2012] on Argyranthemum, Kazemi et al. [2012a] in Eustoma grandiflorum. The beneficial effect of silicon may be related to increasing the resistance of plants to water stress (improving water use, osmoregulation, and reducing transpiration) [Sacała 2009], and as Babak and Majid [2011] stated, inhibiting the influence of silicon on ethylene production, as well as silicon counteracting the oxidative stress in the cell [Sacała 2009], and retardation of chlorophyll as well as carbohydrate degradation during the post-harvest life [Kazemi et al. 2012a]. In addition, silicon can form complexes with organic components of epidermal cell walls, thereby enhancing their resistance to enzymes produced during aging [Snyder et al. 2007].

The applied preparations affected the mechanical properties of Strelitzia flowers (Tab. 3). It was noted that they were more resistant to the destruction maximum force when the inflorescence shoots were conditioned in Actisil (9.6 mm) in comparison to the control (8.3 mm) and to the deformation force when inflorescence shoots were conditioned in Actisil (4.3 mm) or GA\(_3\) + sucrose solution (4.2 mm) in comparison to the control (3.7 mm). The obtained values of mechanical properties parameters indicate that the above treatments allow obtaining flowers characterizing with greater flexibility, less fragile, and thus less susceptible to breaking during storage, packaging, and handling. This elasticity of tissues can protect the Strelitzia flowers from breaking off the inflorescence. The increased resistance to the destructive force of flowers can be related to the ability of silicon to connect to

| Conditioning 24 hours (A) | Storage 5 days (B) | Destruction maximum force (N) | Mean for A | Deformation at maximum force (mm) | Mean for A | Permanent damage energy (mJ) | Mean for A |
|--------------------------|-------------------|------------------------------|------------|----------------------------------|------------|-------------------------------|------------|
| H\(_2\)O (Control)       | H\(_2\)O          | 7.7a                         | 8.3A       | 3.6a                             | 3.7A       | 18.0a                         | 18.6A      |
|                          | Chrysal           | 8.8a                         |            | 3.8a                             |            | 19.1a                         |            |
| Actisil                  | H\(_2\)O          | 8.1a                         | 9.6B       | 3.9ab                            | 4.3B       | 20.1a                         | 25.7B      |
|                          | Chrysal           | 11.0b                        |            | 4.6b                             |            | 31.2c                         |            |
| GA\(_3\) + sucrose      | H\(_2\)O          | 9.2ab                        | 9.3AB      | 4.1ab                            | 4.2B       | 23.7ab                        | 25.2B      |
|                          | Chrysal           | 9.4ab                        |            | 4.3ab                            |            | 27.5bc                        |            |
| Mean B                   | H\(_2\)O          | 8.3A                         |            | 3.9A                             |            | 20.6A                         |            |
|                          | Chrysal           | 9.7B                         |            | 4.2B                             |            | 25.9B                         |            |

* Means followed by the same letter do not differ significantly at \(\alpha = 0.05\).
the cell wall elements, thereby producing a hard silicon-cellulose layer giving additional reinforcement along with the cuticle layer, hence the tissues gained additional resistance to mechanical damage [Babak and Majid 2011]. The increased mechanical strength of inflorescence stems was obtained after using silicon as foliar spraying by Zhao et al. [2013] on Paeonia shoots. The author noted that the silicon content in the inflorescence stem was significantly increased and it was distributed mainly in the cortex and xylem. Isa et al. [2010] found that silicon was present in tissues involved in the rigidity of plants. Resistance of shoots and flowers to mechanical damage is extremely important during transport and storage of plant material, although modern methods of flower packaging have been developed, including the use of cardboard boxes during the transport [Dias et al. 2013].

CONCLUSIONS

The vase life and quality of Strelitzia reginae flower shoots and flowers depend on the treatment after cutting. The size of the sepals and petals increases when inflorescence shoots are conditioned in 200 mg·dm$^{-3}$ GA$_3$ + 10% sucrose or 0.2% Actisil. Conditioning of flower shoots in 0.2% Actisil and storing in 10% Chrysal increases the vase life by 2 days and increases the value of mechanical parameters of flowers, which translates into greater flexibility, lower brittleness, and thus the lower susceptibility to breaking.

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