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Effect of growth regulators on mechanical properties of strelitzia leaves

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A b s t r a c t. A study was performed on the effect of strelitzia leaves spraying with ethephon at concentrations of 500, 1 000, 2 000, 4 000 mg dm^{-3} and with GA_3 at concentrations of 100, 200, 400, 800 mg dm^{-3} on their postharvest quality and mechanical properties. One year old plants were sprayed with the preparations in March and April for three consecutive years. Leaves grown during that period were cut and their morphological features and mechanical properties were determined with the help of the following apparatus: INSTRON 6022, AREA METER Delta – T Devices Ltd., DYNSTAT. It was found that application of GA_3 – 800 mg dm^{-3} caused elongation of the leaf petiole and lamina by more than 100 and 40%, respectively, as well as an increase in petiole diameter. Elongated leaves were characterized by higher values of mechanical properties, which indicates their greater resistance to deformation and damage. GA_3 caused the occurrence of the highest values of maximum stress during petiole bending in static test, and the highest strain and energy in measurements made on the lamina. Leaves treated with ethephon at concentrations of 1 000 and 2 000 mg dm^{-3} were characterized by higher values of petiole and whole lamina deformations. In dynamic tests, the energy appearing in petiole shearing was the greatest for leaves sprayed with GA_3. Higher energy values were characteristic of petiole under the leaf sheath with relation to that at the lamina base. In the course of static tests performed for the lamina, higher values of maximum force, deformation and energy were recorded for leaves with whole lamina compared to those with the lamina partially removed.

K e y w o r d s: *Strelitzia reginae*, ethephon, gibberellic acid, mechanical properties

INTRODUCTION

Strelitzia (*Strelitzia reginae* Banks) is a plant with a variety of applications in floristics (Hetman and Pogroszewska, 1990). In plant compositions the inflorescence shoots can be used as well as the large, durable, lancet-shaped leaves. Smaller leaves of young plants (2-3 years old) may provide floristic material for small flower compositions. The leaf lamina of older plants frequently exceeds 60 cm in length, and the petiole can grow to a length of 110 cm. Such leaves can be used in large compositions, arranged for decoration of church interiors, hotels, and conference rooms.

The dimensions of strelitzia leaves depend not only on the genetic features and age of the plants, but also on the method of their cultivation. The main treatment regulating the growth and blooming of decorative plants is the application of bioregulators. Gibberellins participate in certain processes related with the development of the plants and initiate several important phenomena, such as elongation of stems, faster and more uniform blooming, and also increase the number and size of the flowers (Hopkins, 1995).

Ethephon and ethylene-releasing compounds are used to limit the growth of stems, initiation of lateral bifurcations (Dole and Wilkins, 1999), and to control the time of blooming (Semeniuk and Taylor, 1970). Ethephon has been applied successfully to limit the height of narcissus (Moe, 1980) and hyacinth (Shoub and DeHertogh, 1975). Ethylene, or ethephon, applied exogenously has been used in numerous studies concerned with hormonal regulation of the growth of *eg* the flower shoot of tulip (Saniewski and Kawa-Miszczak, 1992; Saniewski *et al*., 2000). It was demonstrated that ethylene inhibits the elongation of internodes of shoots of that species (Kawa-Miszczak, 1997; Saniewski and Kawa, 1988) and improves its rigidity in the vase (Rasmussen, 1982). More rigid stems are more resistant to damage in the course of plant material turnover, which may be reflected in higher values of certain parameters of the mechanical properties.

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The effectiveness of growth regulators depends, among other things, on their concentration and on the method of their application. The most popular method of application of regulators is foliar spraying or substrate wetting, though foliar application, due to lower labour requirements, is used at a greater scale (Latimer *et al*., 2001).

The objective of the experiment reported herein was to study the effect of strelitzia leaves spraying with bioregulators (ethephon and GA_3 at various concentrations) on their postharvest quality as estimated through their mechanical properties.

MATERIALS AND METHODS

The experiment was conducted at the Felin Experimental Farm of the University of Life Sciences in Lublin, in the years 2005-2007. The experimental material were one-year old plants of strelitzia grown in pots in a greenhouse. The plants were sprayed with ethephon (in the form of the Ethrel preparation containing 48% of active substance) at concentrations of 500, 1 000, 2 000, and 4 000 mg dm^{-3}, or with gibberellic acid (GA_3) at concentrations of 100, 200, 400, and 800 mg dm^{-3}. Control treatment comprised plants sprayed with distilled water. The sprayings were applied twice at one-month intervals (in March and April) for three consecutive years. Leaves grown during that period were cut after three years and their morphological features – petiole length and diameter and width of the leaf lamina as well as of their mechanical properties were deterimed.

Measurements of the mechanical properties of the plant material were conducted at the Institute of Agrophysics PAS in Lublin on an Instron model 6022 strength tester.

For the tests, sections (10 cm long) were taken from the petiole at two points – above the leaf sheath and below the lamina. Next, the petiole sections were placed on two supports, spaced at 50 mm from each other, and subjected to bending by means of a lever, at mid-point between the supports, at the rate of 50 mm min^{-1} (Figs 1, 2). Measurements of the tested sections were made in two ways, as the petiole cross-section has a shape close to the ellipse – placing them on the supports flat-wise – position 'a' (greater diameter parallel to the support) or upright – position 'b' (small diameter parallel to the support) (Fig. 3).

Studying the mechanical strength of the petiole above the leaf sheath and under the lamina under static conditions, the energy and deformation were determined at the maximum force causing its permanent deformation. At the points of application of the force, samples were cut out and the cross-section area of the petiole was measured using an area meter – AREA METER Delta-T Devices Ltd. Based on the cross section area and the maximum value of force causing permanent deformation of the petiole, determination was made of the maximum bending stress above the sheath and under the lamina. Also, the value of shearing energy was determined for those samples (with known diameter) in dynamic test on the DYNSTAT apparatus. The apparatus operates on the principle of a pendulum hammer to which a cutting edge is attached. The energy of dynamic shearing was expressed by the value of kinetic energy lost by the arm of the apparatus in the course of shearing a sample fixed in a grip.

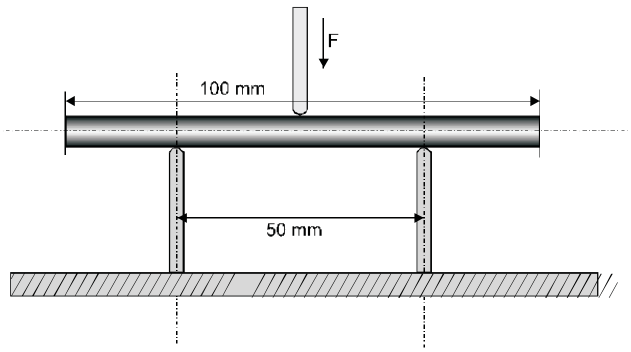

Fig. 1. Schematic presentation of test applied in static testing of the mechanical properties of strelitzia leaves.

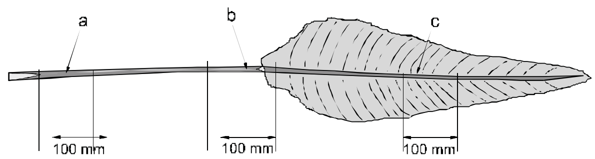

Fig. 2. Sampling points on strelitzia leaf: a – above leaf sheath, b – under leaf lamina, c – at mid-point of lamina length.

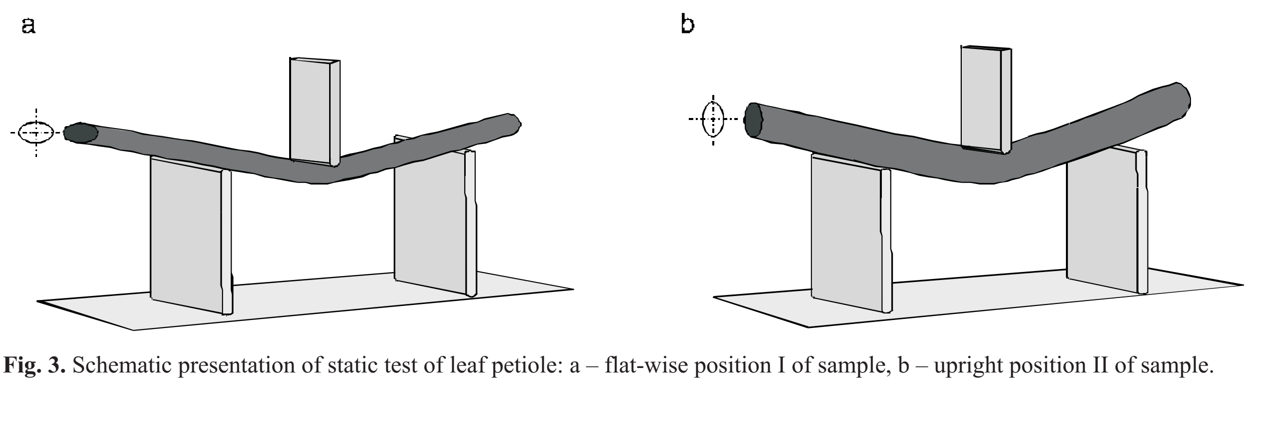

Fig. 3. Schematic presentation of static test of leaf petiole: a – flat-wise position I of sample, b – upright position II of sample.

In static tests performed for leaves with the whole lamina (in the middle of the leaf length) as well as for leaves with the lamina partially removed (prepared leaves). The maximum force causing permanent damage, and of the strain and energy occurring in the course of bending were determined (Figs 2, 4).

The results were processed statistically using analysis of variance for triple classification (physical properties in static test for the petiole and for the leaf), double classification (petiole diameter and energy in dynamic test), and for single classification (morphological features of leaf). The significance of differences between mean values was estimated by means of T-Tukey's intervals of confidence at significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

It was observed that the length of the petiole and the leaf lamina varied significantly following the application of gibberellin (Table 1). Gibberellin, at the highest concentration of 800 mg dm^{-3}, caused the formation of the longest petiole and lamina (61.3 and 38 cm, respectively), which indicates sensitivity of the species under study to that bioregulator. The positive response to the preparation may suggest the possibility of application of GA_3 for elongation of inflorescence shoots and thus for improvement of their post-harvest vigour, which supports the results obtained by Bayogan *et al*. (2008) according to whom longer stem ensures greater durability of flowers in the vase.

A similar response to gibberellic acid, manifested in petiole elongation, was noted by Henny (1981, 1995), Henny and Fooshee (1989) and Pogroszewska (2002), in studies on *Spathiphyllum* Schott. In the experiment reported herein, no effect of the growth regulator on the width of leaf lamina was observed, although numerous authors observed narrower lamina after the application of GA_3 on plants of spathifyllum (Blacquiere and Koster, 1990; Henny, 1981; Henny and Fooshee, 1989).

The effect of ethephon on the growth of plants depends on the plant species. In an experiment by Hayashi *et al.* (2001), triple application of that bioregulator (at concentration of 1 000 mg dm^{-3}) on plants of *Achillea, Echinacea, Leucanthemum, Monarda* and *Physostegia* resulted in a reduction of their height by 23, 42, 46, 40 and 46%, respectively. In our experiment, application of ethephon had no effect on the length and width of the lamina with relation to the control.

Petiole diameter of the control plants did not differ significantly at the two points of measurement – above the sheath and under the leaf lamina (Table 2). However, petiole

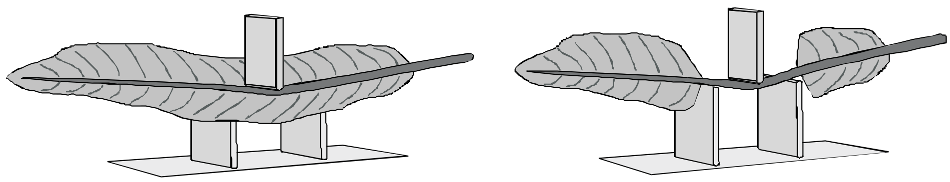

Fig. 4. Schematic of static test of leaf lamina at mid-point of its length: a – whole lamina, b – leaf with the lamina partially removed (prepared).

T a b l e 1. Morphological features of strelitzia leaves (cm)

Preparation (mg dm^{-3})	Length of leaf petiole	Mean	Width of leaf lamina	Mean	Length of leaf lamina	Mean
Control	29.38 a*	29.38 A	13.17 a	13.17 A	26.97 a	26.97 A
Ethephon, 500	29.78 a	29.68 A	13.13 a	12.39 A	25.95a	26.54 A
Ethephon, 1 000	33.40 a		12.05 a		27.43 a	
Ethephon, 2 000	29.35 a		12.08 a		26.98 a	
Ethephon, 4 000	26.18 a		12.33 a		25.83 a	
GA_3 100	44.93 b	51.88 B	13.34 a	12.51 A	33.10 b	35.11 B
GA_3 200	51.50 bc		13.25 a		35.60 b	
GA_3 400	49.78 b		11.55 a		33.75 b	
GA_3 800	61.30 c		11.90 a		38.00 b	

*Values marked with the same letter do not differ significantly at significance level $\alpha = 0.05$ (in columns).

diameter above the sheath, without taking into account the effect of the type of preparation applied, was notably smaller (8.99 mm) than under the lamina (10.32 mm). Estimating the effect of the point of measurement and of the type of preparation applied it was found that, for plants sprayed with gibberellin and with ethephon, the petiole diameter under the lamina was considerably greater than when the measurements were taken above the sheath. The highest values of petiole diameter were recorded following the application of gibberellin (9.90 mm), while significantly lower values were obtained after the application of ethephon (9.44 mm).

Modification of plant dimensions using gibberellin may be favourable (Pogroszewska and Sadkowska, 2006; Pogroszewska *et al*., 2007), yet Neumaier *et al*. (1987) emphasize that excessive elongation of stem results in deterioration of plant quality. Treatment with gibberellic acid applied to plants at their early development phase was the cause of stem bending in lettuce (Kochankov *et al*., 1996), and in the case of spathifyllum it caused the formation of deformed inflorescence peduncles (Pogroszewska, 2002). This indicates a possibility of deterioration of strelitzia leaves elongated under the effect of gibberellin. The quality of leaves, and thus their breaking strength, is characterized very well by their mechanical parameters. Some researchers emphasize the sense of giving the values of certain mechanical properties per unit of surface area of *eg* the petiole or the leaf lamina, which facilitates the application of research results in practice. Read *et al.* (2005), when describing the mechanical properties of xerophytes, made use of such concepts as *eg* leaf strength *ie* the value of force required to break a leaf in an impact test, in conversion per unit of surface area. In this study, for the definition of the mechanical properties of strelitzia leaf petiole, in static tests the concept of bending strain was applied *ie* conversion of the maximum force per unit of petiole cross section area. Petioles of the control plants, both under the lamina and above the sheath, at both measurement positions, were characterized by similar values of maximum stress (Table 3). However, comparison of the effect of the point of measurement on the petiole and of the sample position during the measurement revealed, irrespective of the type and concentration of growth regulator applied, the highest stress values occurred at the lower section of the petiole, above the leaf sheath, with the sample in the upright position (3.42 kPa). In the remaining experimental combinations, the values of the feature in question were significantly lower. The highest values of the stress, having taken into account the effect of measurement point and the type of preparation applied, were recorded for the petiole section above the sheath, after the application of gibberellin (3.09 kPa). Only petioles of plants sprayed with ethephon, on the section below the lamina, were characterized by notably lower values of the feature under discussion (2.48 kPa). Petioles of plants sprayed with gibberellin showed considerably higher values of stress (2.91 kPa) relative to those treated with ethephon (2.63 kPa).

Plants that were not treated with the preparations were characterized by similar values of deformation of petiole sections from both above the leaf sheath and under the lamina, at both positions of samples during the measurements (positions I and II) (Table 4). However, comparing the effect of the measurement point on the length of the petiole, irrespective of the plant spraying method, notably higher values of deformation occurring at maximum force, for petiole section from above the sheath and from under the lamina, were

T a b l e 2. Strelitzia leaf petiole diameter (mm)

Preparation (mg dm^{-3})	Above leaf sheath	Under leaf lamina	Mean (preparation x point of measurement)		Mean (preparation)
			Above leaf sheath	Under leaf lamina	
Control	9.10 a-d*	10.16 c-f	9.10 AB	10.16 BC	9.63 AB
Ethephon, 500	9.22 a-e	10.52 ef	8.73 A	10.15 BC	9.44 A
Ethephon, 1 000	8.63 ab	10.36 d-f			
Ethephon, 2 000	8.38 a	9.70 b-f			
Ethephon, 4 000	8.68 ab	10.01 c-f			
GA_3 100	9.01 a-c	10.72 f	9.13AB	10.66 C	9.90 B
GA_3 200	9.15 a-e	10.81 f			
GA_3 400	9.00 a-c	10.29 c-f			
GA_3 800	9.38 a-e	10.80 f			
Mean (point of measurement)	8.99 A	10.32 B			

*Explanations as in Table 1.

T a b l e 3. Maximum bending stress of strelitzia leaf petiole (kPa)

Preparation (mg dm^{-3})	Position of sample				Mean (preparation x point of measurement)		Mean (preparation)
	I	II	I	II			
	Under leaf lamina		Above leaf sheath		Under leaf lamina	Above leaf sheath	
Control	2.38a-f*	3.01 a-f	2.50 a-f	3.24 a-f	2.69 AB	2.87 AB	2.78 AB
Ethephon, 500	1.96 a-c	2.89 a-f	2.32 a-f	3.45 d-f	2.48 A	2.78 AB	2.63 A
Ethephon, 1 000	2.08 a-d	3.23 a-f	2.26 a-e	3.77 f			
Ethephon, 2 000	1.91 a-b	2.91 a-f	2.22 a-e	3.19 a-f			
Ethephon, 4 000	1.77a	3.08 a-f	1.84 a-c	3.14 a-f			
GA_3 100	2.32 a-f	3.06 a-f	2.60 a-f	3.51 d-f	2.73 AB	3.09 B	2.91 B
GA_3 200	1.79 ab	3.11 a-f	2.51 a-f	3.30 c-f			
GA_3 400	2.62 a-f	3.26 b-f	2.74 a-f	3.62 ef			
GA_3 800	2.65 a-f	3.01 a-f	2.94 a-f	3.54 d-f			
Mean (point of measurement)	2.17 A	3.06 B	2.44 A	3.42 C			

Position of samples: I - flat-wise, II - upright. *Other explanations as in Table 1.

T a b l e 4. Deformation of strelitzia leaf petiole (kPa)

Preparation (mg dm^{-3})	Position of sample				Mean (preparation x point of measurement)		Mean (preparation)
	I	II	I	II			
	Under leaf lamina		Above leaf sheath		Under leaf lamina	Above leaf sheath	
Control	5.84 ab*	6.90 a-g	6.08 a-c	5.47 a	6.38 AB	5.78 A	6.07 A
Ethephon, 500	8.59 gh	7.05 a-g	7.96 d-h	8.65 gh	7.31 CD	7.61 D	7.46 C
Ethephon, 1 000	8.19 f-h	6.70 a-f	8.98 h	6.86 a-g			
Ethephon, 2 000	8.03 e-h	6.25 a-e	8.95 h	6.54 a-f			
Ethephon, 4 000	7.64 b-h	5.99 ab	7.27 a-h	5.68 a			
GA_3 100	6.65 a-f	5.82 ab	6.88 a-g	6.49 a-f	6.92 AB	6.88 BC	6.90 B
GA_3 200	7.56 b-h	6.71 a-f	8.06 e-h	6.16 a-d			
GA_3 400	8.04 e-h	5.81 ab	6.93 a-g	5.97 ab			
GA_3 800	8.18 f-h	6.61 a-f	7.91 c-h	6.69 a-f			
Mean (point of measurement)	7.63 B	6.43 A	7.74 B	6.42 A			

*Explanations as in Table 3.

observed when the sections measured were placed in position I (7.74 and 7.63 mm) as compared to those measured in position II (6.42 and 6.43 mm). Estimating the effect of the type of preparation and point of measurement, leaving out the position of the petiole section, it was found that the highest values of the feature under discussion occurred in the case of petiole sections from above the sheath when the plants were sprayed with ethephon (7.61 mm). Notably lower values of deformation were characteristic of petiole sections from above the sheath and below the lamina, as well as of petiole sections from plants sprayed with gibberellin (5.78, 6.38, 6.88 and 6.92 mm, respectively). The type of preparation had a significant effect on the value of deformation at maximum force causing permanent damage to petiole

T a b l e 5. Energy at maximum force during bending of strelitzia leaf petiole (mJ)

Preparation (mg dm^{-3})	Position of sample				Mean (preparation x point of measurement)		Mean (preparation)
	I	II	I	II			
	Under leaf lamina		Above leaf sheath		Under leaf lamina	Above leaf sheath	
Control	61.8 a*	90.0 ab	145.7 ab	221.8 b	75.9 A	183.8 B	129.9 A
Ethephon, 500	83.8 ab	90.7 ab	120.7 ab	154.1 ab			
Ethephon, 1 000	68.0 a	99.8 ab	130.1 ab	139.6 ab			
Ethephon, 2 000	71.4 a	75.0 ab	118.8 ab	106.4 ab	78.1 A	126.0 AB	102.1 A
Ethephon, 4 000	61.4 a	74.9 a	70.1 a	167.8 ab			
GA_3 100	65.4 a	73.9 a	97.3 ab	167.6 ab			
GA_3 200	70.9 a	101.0 ab	121.9 ab	115.3 ab			
GA_3 400	85.6 ab	80.9 ab	98.7 ab	109.0 ab	83.6 A	122.2 A	102.9 A
GA_3 800	103.7 ab	87.4 ab	136.5 ab	131.1 ab			
Mean (point of measurement)	74.7 A	86.0 AB	115.5 BC	145.9 C			

*Explanations as in Table 3.

sections studied. The highest value was recorded after application of ethephon (7.46 mm), and the lowest in the case of control plants (6.07 mm).

The values of energy, measured under static conditions in the case of control plants, occurring in tests of the lower section of the petiole, above the leaf sheath, positioned upright (II), were notably higher (221.8 mJ) in relation to petiole sections taken from under the base of the lamina, tested in the flat-wise position (61.8 mJ) – position I (Table 5). Plants that were not sprayed with the preparations were characterized by higher values of energy obtained in tests of petiole sections from above the sheath, compared to plants sprayed with gibberellin. Leaf petiole sections from under the lamina of the control plants, as well as of plants sprayed with ethephon or gibbereilin, displayed considerably lower values of energy (75.9, 78.1 and 83.6 mJ, respectively) compared to petiole sections of control plants taken from above the leaf sheath (183.8 mJ). The type of preparation applied had no significant effect on the value of energy characterising the petiole sections tested.

In the course of dynamic tests of petiole sections (DYNSTAT), plants not treated with the preparations were characterized by similar values of the shearing energy at both the points of measurement (Table 6). However, comparing the effect of the measurement point on the leaf petiole, irrespective of the type of preparation applied, considerably higher values of shearing energy were recorded for the section above the sheath – 0.68 J, compared to the section from under the lamina – 0.55 J. Estimating the effect of the type of preparation and of the measurement point it was found that the highest values of the parameter is question occurred in the case of petiole sections from above the sheath, when the plants were sprayed with gibberellin (0.75 J). Notably lower values of shearing energy were characteristic of petiole sections from under the lamina, and of those sections from plants sprayed with ethephon and gibberellin (0.51, 0.54 and 0.60 J). The type of preparation had a significant effect on the value of energy generated in shearing of leaf petiole. The highest value was recorded after the application of gibberellin (0.68 J), and significantly lower values – in the case of control plants and those sprayed with ethephon (0.57 and 0.59 J, respectively).

The mechanical properties of leaves play a very important role as they determine their resistance to unfavourable external conditions (Onoda *et al*., 2008). In this experiment, the leaf lamina of control plants was characterized by similar values of maximum force occurring during its damage, both in measurements of the whole lamina and for leaves with the lamina partially removed (prepared lamina) (Table 7). However, as a result of measurements made on leaves with the lamina intact, with the type of preparation not taken into account, notably higher values of the maximum force (10.26 N) were obtained with relation to tests made on leaves with the lamina partially removed (8.64 N). Onoda *et al*. (2008), in experiments on leaves of *Plantago minor*, demonstrated that phenotype-related changes in mechanical properties depend on dry matter distribution and on the anatomy of the leaf.

Table 6. Energy of dynamic shearing of strelitzia leaf petiole (J)

Preparation (mg dm^{-3})	Above leaf sheath	Under leaf lamina	Mean (preparation x point of measurement)		Mean (preparation)
			Above leaf sheath	Under leaf lamina	
Control	0.64 a-d*	0.51 a	0.64 A-C	0.51 A	0.57 A
Ethephon, 500	0.66 a-d	0.56 ab	0.65 BC	0.54 A	0.59 A
Ethephon, 1 000	0.71 b-d	0.54 a			
Ethephon, 2 000	0.65 a-d	0.56 ab			
Ethephon, 4 000	0.59 a-c	0.52 a			
GA_3 100	0.67 a-d	0.56 ab	0.75 C	0.60 AB	0.68 B
GA_3 200	0.79 d	0.60 a-c			
GA_3 400	0.75 cd	0.66 a-d			
GA_3 800	0.81 d	0.57 ab			
Mean (point of measurement)	0.68 B	0.55 A			

*Explanations as in Table 1.

Table 7. Maximum force of shearing of strelitzia leaf petiole (N)

Preparation (mg dm^{-3})	Leaf lamina		Mean (preparation x point of measurement)		Mean (preparation)
	Whole lamina	Prepared lamina	Whole lamina	Prepared lamina	
Control	9.77 a-c*	6.54 a	9.77 B-D	6.54 A	8.16 A
Ethephon, 500	11.71 c	8.57 a-c	10.71 D	8.10 AB	9.41 A
Ethephon, 1 000	11.43 bc	8.83 a-c			
Ethephon, 2 000	10.83 a-c	8.04 a-c			
Ethephon, 4 000	8.87 a-c	6.98 ab			
GA_3 100	9.14 a-c	9.91 a-c	9.93 D	9.70 BC	9.81 A
GA_3 200	11.10 bc	10.03 a-c			
GA_3 400	9.50 a-c	8.86 a-c			
GA_3 800	9.99 a-c	9.99 a-c			
Mean (point of measurement)	10.26 B	8.64 A			

*Explanations as in Table 1.

Estimating the effect of the point of measurement and of the type of substance applied on the value of maximum force it was found that the highest value of the force occurred in the case of tests made for the whole leaf lamina of plants sprayed with ethephon and gibberellin (10.71 and 9.93 N). In the other subclasses, in tests on leaves with the lamina partialy removed, significantly higher values of the maximum force were obtained. No effect of the type of preparation on that feature was found.

The values of force and deformation occurring during the bending of plant material play also a significant role during the postharvest treatment of plants. Geerdink *et al.* (2007), in a study on *Ctenanthe setosa*, demonstrated that leaves destined for decorative arrangements should be characterized by high elasticity, as rolling them is one of the methods for reducing transpiration in storage.

In this experiment, leaves of control plants were characterized by similar values of deformation occurring at the maximum force, both in tests with whole leaf lamina and with the lamina partially removed (Table 8). Comparing the value of that feature for leaves with whole lamina and with the lamina partially removed, without taking into account the type of regulator applied, notably higher values of deformation (7.33 mm) were obtained in measurements on whole leaf lamina compared to those on leaves with the lamina partially removed (6.54 mm). Estimating the effect of preparation of leaf lamina (leaf with the lamina partially removed) and of the type of preparation applied, it was found that the highest value of the feature occurred in tests on leaves with whole lamina, from plants sprayed with gibberellin. In most of the other treatments, apart from that in which the measurement was made on intact leaf lamina after the application of ethephon, notably lower values of deformation were obtained. Leaves of control plants were characterized by notably lower values of that feature (5.88 mm) relative to leaves of plants sprayed with ethephon and gibberellin (6.97 and 7.17 mm).

T a b l e 8. Deformation occurring during bending of main rachis of strlitzia leaf with the lamina intact or partially removed (prepared) (mm)

Preparation (mg dm^{-3})	Leaf lamina		Mean (preparation x point of measurement)		Mean (preparation)
	Whole	Prepared	Whole	Prepared	
Control	5.73 ab*	6.03 a-c	5.73 A	6.03 A	5.88 A
Ethephon, 500	7.43 b-e	6.06 a-c	7.44 BC	6.50 A	6.97 B
Ethephon, 1 000	7.87 de	7.40 b-e			
Ethephon, 2 000	7.72 c-e	7.18 b-e			
Ethephon, 4 000	6.73 a-e	5.37 a			
GA_3 100	7.12 a-e	6.02 a-c	7.63 C	6.71 AB	7.17 B
GA_3 200	8.10 e	6.49 a-e			
GA_3 400	7.20 b-e	6.23 a-d			
GA_3 800	8.09 e	8.09 e			
Mean (point of measurement)	7.33 B	6.54 A			

*Explanations as in Table 1.

T a b l e 9. Energy occurring during bending of main rachis of strelitzia leaf with the lamina intact or partially removed (prepared) (mJ)

Preparation (mg dm^{-3})	Leaf lamina		Mean (preparation x point of measurement)		Mean (preparation)
	Whole lamina	Main rachis of leaf	Whole	Prepared	
Control	39.8 ab*	27.5 a	39.8 AB	27.5 A	33.7 A
Ethephon, 500	59.7 b	35.7 a	54.7 B	36.7 A	45.7 B
Ethephon, 1 000	61.6 b	45.9 ab			
Ethephon, 2 000	56.9 b	40.7 ab			
Ethephon, 4 000	40.6 ab	24.6 a			
GA_3 100	46.6 ab	40.6 ab	51.9 B	45.1 AB	48.5 B
GA_3 200	57.7 b	46.3 ab			
GA_3 400	46.8 ab	36.9 ab			
GA_3 800	56.5 b	56.5 b			
Mean (point of measurement)	51.8 B	39.4 A			

*Explanations as in Table 1.

Leaves of control plants, not sprayed with the preparations, did not differ significantly in the values of energy occurring in measurements of leaves with the lamina intact and partially removed during static tests on the Instron tester (Table 9). However, comparing the effect of partial removal of the lamina on the feature under study, leaving out the type of preparation applied, it was noted that the value of energy for the whole lamina was considerably higher (51.8 mJ) than that for the prepared lamina (39.4 mJ). Estimating the effect of interaction of the two factors it was found that the value of energy in measurements of the whole lamina was much higher after the application of ethephon and gibberellin (54.7 and 51.9 mJ) with relation to measurements on control leaves with the lamina partially removed and on leaves sprayed with ethephon (27.5 and 36.7 mJ). Leaves of control plants were characterized by notably lower values of the feature under discussion (33.7 mJ) compared to leaves of plants sprayed with ethephon and gibberellin (45.7 and 48.5 mJ).

Based on the presented results one can state that the bioregulators used in the cultivation of strelitzia had different effects on the morphological features of leaves and on their mechanical strength. Probably, therefore, the durability of the leaves in decorative compositions would also be different. Metabolic changes taking place in ageing leaves involve losses in the content of chlorophyll and proteins, and increased permeability of cell membranes (Kar and Feierabend, 1984; Pastori and del Rio, 1997; Smart, 1994). Therefore, further studies on more accurate determination of the postharvest quality of strelitzia leaves, apart from determination of their physical properties should also be concerned with their anatomy and biochemical transformations taking place at the cell level.

CONCLUSIONS

1. Gibberellic acid at concentration of 800 mg dm^{-3} caused elongation of strelitzia leaf petioles and lamina by more than 100 and 40%, respectively, and an increase in the petiole diameter. No effect of GA_3 on the width of leaf lamina was observed.

2. Foliar application of gibberellic acid caused the occurrence of the highest values of maximum stress during petiole bending in static test, and of the highest strain and energy in measurements performed on the leaf lamina.

3. In dynamic tests, the energy occurring during leaf petiole shearing was significantly higher in the case of leaves sprayed with GA_3, compared to those treated with ethephon and to the control. Measurement point had a significant effect on the value of the feature. Higher values of energy were characteristic of leaf petiole above the leaf sheath compared to the base of the leaf lamina.

4. In static tests made on the leaf lamina significantly higher values of maximum force, deformation and energy were recorded for leaves with the lamina intact compared to leaves with the lamina partially removed.

5. Strelitzia leaves elongated by means of gibberellic acid were characterized by higher values of the mechanical features, which indicates their greater resistance to deformation and damage.

6. Strelitzia leaves spraying with ethephon had no effect on their morphological features and on most of the mechanical properties. Leaves treated with ethephon at concentrations of 1 000 and 2 000 mg dm^{-3}, however, were characterized by greater values of deformation of the petiole and of the whole lamina.

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