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Review

Cytokinins and Gibberellins Stimulate the Flowering and Post-Harvest Longevity of Flowers and Leaves of Calla Lilies (*Zantedeschia* Spreng.) with Colourful Inflorescence Spathes

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Abstract: Since the 1990s, the world has seen an increased interest in *Zantedeschia* with colourful inflorescence spathes. In Poland, its cultivation began much later. The reasons for this phenomenon can be traced to the high price of rhizomes reproduced in the United States of America, the Netherlands, New Zealand and Kenya. The area of reproductive plantations is increasing every year, but this does not affect the decrease in the price of rhizomes, which is the main reason that only a few producers are cultivating *Zantedeschia* cultivars in Poland. Producers offer rhizomes in various sizes, with flowering expected only from the largest ones. However, the yield of cut flowers that can be obtained from them is often not very satisfactory and is not compensated by the price that can be obtained from the sale of the flowers. It is the low yield of cut flowers that is the main problem in the cultivation of *Zantedeschia* cultivars, hence research conducted worldwide focuses on the use of growth regulators from the group of cytokinins (CKs) and gibberellins (GAs) in the cultivation of *Zantedeschia* with colourful inflorescence spathes. The post-harvest life of flowers and leaves of cultivated *Zantedeschia* cultivars is also an important problem. This review presents the results of research conducted over the years to improve the flowering and post-harvest life of the flowers and leaves of *Zantedeschia* with colourful inflorescence spathes.

Keywords: *Zantedeschia*; cultivation; vase life; flowers; leaves; growth regulators; mycorrhizae

Citation: Janowska, B.; Andrzejak, R. Cytokinins and Gibberellins Stimulate the Flowering and Post-Harvest Longevity of Flowers and Leaves of Calla Lilies (*Zantedeschia* Spreng.) with Colourful Inflorescence Spathes. *Agronomy* **2022**, *12*, 1859. https://doi.org/10.3390/agronomy12081859

Academic Editors: Fan Zhang, Nan Ma and Likai Wang

Received: 15 July 2022
Accepted: 5 August 2022
Published: 6 August 2022

1. Introduction

Species from the *Zantedeschia* genus, described almost 200 years ago, belong to the numerous picture family Araceae, in which the inflorescence is a spadix with numerous small flowers set on a succulent stem surrounded by a colourful inflorescence spathe [1]. The generic name was given in tribute to the Italian researcher and scientist Giovanni Zantedeschi (1773–1846) [2,3]. Initially, the cultivation was dominated by *Zantedeschia aethiopica* (L.) Spreng. Its importance is currently low and cultivars with colourful inflorescence spathes derived from *Z. rehmanii* Engl., *Z. elliottiana* (W. Wats.) Engl. and *Z. albomaculata* (Hook.) Baill, among others, are becoming increasingly important. Their obtainment was possible thanks to intensive breeding work carried out initially in the United States of America and New Zealand and later in South Africa and the Netherlands. The cultivar range is large. In the 1990s, 120 cultivars were already known and a dozen new ones appear every year (Figure 1). Cultivar breeding focuses primarily on obtaining a high yield of cut flowers, although only a few cultivars meet this criterion [4,5].

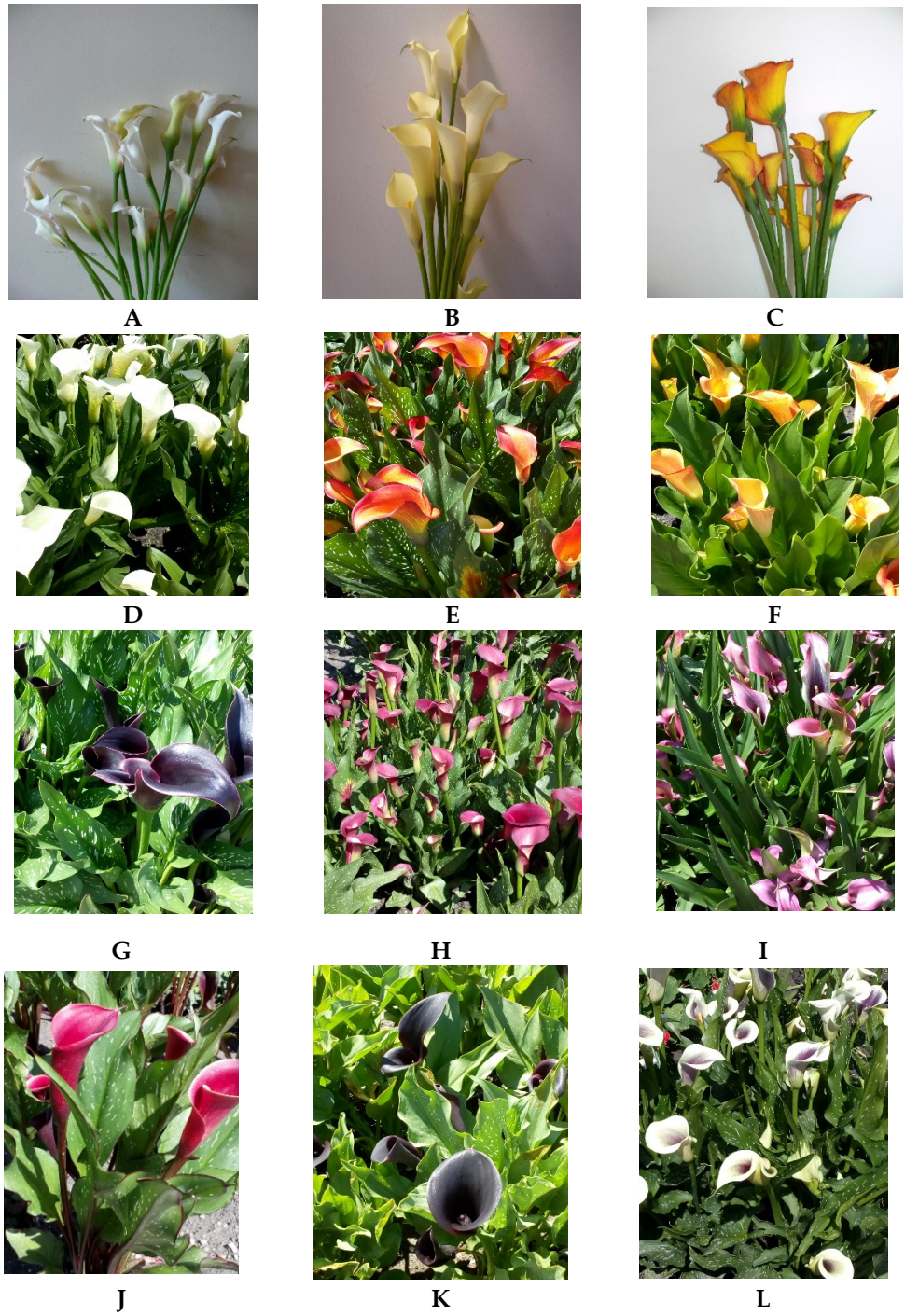

Figure 1. *Zantedeschia* cultivars: (**A**)—'Albomaculata', (**B**)—'Black-Eyed Beauty', (**C**)—'Mango', (**D**)—'Siberia', (**E**)—'Morning Sun', (**F**)—'Mercedes', (**G**)—'Cantor', (**H**)—'Le Chique', (**I**)—'Lavender Gem', (**J**)—'Red Charm', (**K**)—'Black Art', (**L**)—'Picasso' (Beata Janowska 2010–2017).

Since the 1990s, the world has seen an increased interest in *Zantedeschia* with colourful inflorescence spathes. In Poland, its cultivation began much later. The reasons for this phenomenon can be traced to the high price of rhizomes reproduced in the United States of America, the Netherlands, New Zealand and Kenya. The total area of reproductive plantations in these countries occupies 288 hectares. Smaller plantations are also found in Brazil, Zimbabwe, Costa Rica and Israel. The area of reproductive plantations is increasing every year, but this does not affect the decrease in the price of rhizomes, which is the main reason that only a few producers are cultivating *Zantedeschia* cultivars in Poland.

Producers offer rhizomes in various sizes, with flowering expected only from the largest ones. However, the yield of cut flowers that can be obtained from them is often not very satisfactory [6–10] and is not compensated by the price that can be obtained from the sale of the flowers. It is the low yield of cut flowers that is the main problem in the cultivation of *Zantedeschia* cultivars, hence research conducted worldwide focuses on the use of growth regulators from the group of cytokinins (CKs) and gibberellins (GAs) in the cultivation of *Zantedeschia* with colourful inflorescence spathes. The post-harvest life of flowers and leaves of cultivated *Zantedeschia* cultivars is also an important problem. The ageing process is controlled by growth regulators—CKs and GAs—considered ageing inhibitors. During the ageing process, their content in plant tissues decreases, whereas the level of growth regulators, such as ethylene, salicylic acid (SA), brassinosteroids (BR), abscisic acid (ABA), and jasmonic acid (JA), increases and the ageing process accelerates [11]. Recent studies indicate that the post-harvest life of *Zantedeschia* leaves is improved by topolins (Ts). Ts are a new group of endogenous, aromatic cytokinins isolated from poplars at Palacky University Olomouc and at the Institute of Experimental Botany in the Czech Republic. The Ts used are derivatives of benzyl amino purine. In their benzene ring, there is a hydroxyl group in the ortho or meta position. In very few studies conducted so far, Ts have been used only in order to assess their usefulness in in vitro cultures. It was determined in standard biological tests that these substances strongly prevent leaf ageing [12].

GAs are synthesized in active growing tissues, i.e., shoot apices, young leaves and flowers [13]. They are transported through the conducting tissues: xylem and phloem [14]. GAs, which can be found in various plants, have a broad spectrum of activity. They eliminate the hereditary stunting of plants [15], stimulate shoot elongation and flower development [16], interrupt deep dormancy [17], stimulate seed germination [18], accelerate or delay flowering [19], influence the growth of seedless fruits, extend the life of flowers and leaves of various species of ornamental plants [16] and affect the content of chlorophyll and proteins [20,21]. The best-known and most frequently used GA is gibberellic acid (GA_3) [15]. CKs are adenine derivatives. They stimulate cell division and seed germination [22], and, above all, they inhibit the ageing of plants, cut flowers and florists' greens [23–25]. They are mainly produced by the roots, from which they are transported to the aerial parts of the plant [22]. CKs play a key role in various phases of plant growth and development. The basic molecular mechanisms of their biosynthesis and signal transduction have been explained recently [26]. Benzyladenine (BA), which is a synthetic CK, is commonly used in floriculture [27]. BA is primarily used as a growth regulator responsible for the *in vitro* propagation of ornamental plants. In recent years, it has also been applied to plants growing *in vivo* [13].

This review presents the results of research conducted over the years to improve the flowering and post-harvest life of flowers and leaves of *Zantedeschia* with colourful inflorescence spathes using growth regulators from the GA and CK groups.

2. Cultivation of *Zantedeschia* for Cut Flowers

Zantedeschia elliottiana, *Z. rehmanii* and *Z. albomaculata* go through a rest period from October to February. Rhizomes are stored in openwork containers and covered with sawdust in a storage room at 12–15 °C, and for long-term storage, they are stored at only 8 °C [28]. In Poland, *Zantedeschia* flowers with colourful inflorescence spathes are grown primarily under cover—in greenhouses and plastic tunnels (Figure 2). Ground cultivation (Figure 3) is also possible. Its advantage is the better quality of the flowers, which, while shorter, have stiffer stems and better coloured inflorescence spathes. Moreover, rhizomes grow better in the ground [7]. The reasons for this phenomenon can be traced to the intensity of light, which is reduced under cover in order to reduce the temperature, which is often excessively high during the summer for the cultivation of *Zantedeschia*, in which, although it does not show a photoperiodic response, both the colouration of inflorescence spathes and the rigidity of the stems depend on good sunlight [29].

Figure 2. Beginning of flowering 'Mango' cultivar grown in plastic tunnel (Beata Janowska 2010).

Figure 3. *Zantedeschia* cultivars in the botanical garden in Wrocław (Beata Janowska 2017).

In Poland, due to the high demand for flowers in spring and the best light conditions at that time, they are planted in greenhouses from early February to March. In heated plastic tunnels, rhizomes can be planted at the same time. For unheated plastic tunnels, rhizomes can be planted only in April. Plants are grown in ground beds, boxes, pots or cylinders. Cultivation in containers is more advantageous as it allows rapid isolation of diseased plants [28].

Small rhizomes with a circumference of 8–9 cm are planted in the amount of 40 per m^2, while those with a circumference of 16–18 cm are planted in the amount of 20 per m^2. Rhizomes with a circumference of more than 20 cm are planted in the amount of 15 per m^2 [7]. They are covered with a 6–10 cm thick substrate to shield the roots growing out of the upper part of the rhizome. Before planting, the rhizomes are treated with 1% Captan for 20 min [7,28].

The substrate should be humus and permeable, with a pH of 5.8–6.2, enriched with slow-release fertilizers such as Osmocote Plus 3–4 M, in the amount of 3 $g \cdot dm^{-3}$. Substrates

of various compositions are used around the world. In New Zealand, it is a mixture of composted pine bark (70%) and 3 mm diameter pumice (30%). In the Netherlands, coconut husks, high peat or pearlite are added instead of pumice. *Zantedeschia* flowers are also grown in mineral wool, which, on the one hand shortens the cultivation cycle and, on the other hand, enables rapid isolation of diseased plants. Rhizomes are planted in cubes, which are then placed in a special camera for 2–3 weeks for "initial sprouting" (Figure 4) [28]. There is also the possibility of growing in pearlite itself, which does not heat up in hot weather thanks to its white colour [30].

Figure 4. Rhizomes soaking in water solution of growth regulators (Beata Janowska 2010).

Zantedeschia should be grown in large, bright greenhouses or plastic tunnels as, although it is a photoperiodically neutral plant [29], both the colouration of the inflorescence spathes and the rigidity of the stems depend on good lighting. Plants are shaded only on very sunny days to reduce the temperature in the greenhouse. In summer, the temperature should not exceed 24–28 °C during the day and 16–18 °C at night. In spring and autumn, the temperature at night can be lowered to 11–12 °C, and then the inflorescence sheaths will have a better colour. For the first two weeks after planting, the temperature of the substrate should be kept at 15–16 °C, but later it can be raised a few degrees. In summer, the substrate temperature should not exceed 22 °C. Mulching with straw or sawdust effectively prevents the overheating of the substrate. During the growing season, *Zantedeschia* with colourful inflorescence spathes are watered moderately. It is beneficial to use perforated hoses and, in container cultivation, driplines. Flowering begins 8–10 weeks after planting the rhizomes. Inflorescences in which the sheath is well-coloured and the flowers in the lower part of the sheath are ripe are suitable for cutting. The stems are not cut but gently broken off. After flowering, plants should continue to be nurtured to maximize rhizome growth, with watering gradually reduced to bring plants into dormancy [28].

Flowering in *Zantedeschia* depends on the cultivar, the size of the rhizomes and the length of storage [12]. Research conducted around the world focuses on improving flowering through the use of growth regulators as the yield of most *Zantedeschia* cultivars with colourful inflorescence spathes is not very satisfactory. The efficacy of GAs, in particular gibberellic acid (GA_3) [6–8,10,31–37]; CKs, especially benzyladenine (BA) [23]; a mixture of GA_3+BA (Table 1) [23,24,36,38,39]; and from among preparations of Promalin (preparations containing GA_{4+7} and BA [24,40]) has been demonstrated.

Table 1. Flowering (number of inflorescences per 1 rhizome) of *Zantedeschia* cultivars after application of growth regulators. Means followed by the same letter column-wise and row-wise do not differ significantly at $\alpha = 0.05$.

	GA_3 ($mg \cdot dm^{-3}$)				**Source**
	0	50	100	200	
Pink Persuasion	3.2 b	6.4 c	9.0 d	8.2 d	Janowska and Krause [36]
Sensation	2.6 a	3.7 b	5.0 c	3.5 b	
	BA ($mg \cdot dm^{-3}$)				
	0	100	350	600	Janowska and Stanecki [23]
Black Magic	1.2 a	1.9 a	3.0 b	3.2 b	
Mango	1.0 a	1.7 a	4.0 c	4.0 c	
Albomaculata	2.4 a	2.9 a	8.3 c	8.6 c	
	BA+GA_3 ($mg \cdot dm^{-3}$)				
	0	100 + 150	350 + 150	600 + 150	Janowska and Stanecki [24]
Black Magic	1.0 a	4.0 c	3.0 b	3.0 b	
Albomaculata	2.0 a	3.4 b	5.2 c	8.2 d	

2.1. GAs in the Cultivation of Zantedeschia

The origins of research using GAs to improve the flowering of *Zantedeschia* date back to the late 1980s. The results obtained at the time indicate that GA_3 can be used at concentrations ranging from 25 to 500 $mg \cdot dm^{-3}$ [6]. Funnell and Tjia [31] as well as Bent and Croci [41] reported the best flowering when the rhizomes were soaked in a GA_3 solution with a concentration of 50 $mg \cdot dm^{-3}$. Denis et al. [35] found a doubling of the yield of 'Red Sunset' and 'Orange Sunset' *Zantedeschia* as a result of soaking the rhizomes in GA_3 solution with a concentration of 25 and 50 $mg \cdot dm^{-3}$. However, the authors indicated that the best quality of flowers was achieved at the lower GA_3 concentration of 25 $mg \cdot dm^{-3}$. The most abundant flowering as a result of soaking rhizomes in a GA_3 solution with a concentration of 25 $mg \cdot dm^{-3}$ was also obtained by Funnell et al. [42]. In contrast, Corr and Widmer [6] obtained the best flowering when they applied a GA_3 solution with a concentration of 500 $mg \cdot dm^{-3}$. However, such high concentrations caused the deformation of inflorescences. Inflorescence deformations, in which double and triple inflorescence spathes (Figure 5) developed around the spadix after the application of GA_3 (200 $mg \cdot dm^{-3}$), were also reported by Janowska and Krause [36]. The authors further report that the application of GA_3 at such a high concentration does not further increase yield. The authors obtained the best results when GA_3 at a concentration of 100 $mg \cdot dm^{-3}$ was used to soak the rhizomes of the 'Pink Persuasion' and 'Sensation' cultivars. In contrast, Janowska and Schroeter [8] report that the 'Black Magic' cultivars blooms most abundantly when GA_3 is applied at a concentration of 150 $mg \cdot dm^{-3}$. Janowska and Krause [36] also report that the application of GA_3 delays the flowering of the cultivars tested and that the higher its concentration, the later the harvest of flowers of the 'Pink Persuasion' cultivar. In the 'Sensation' cultivar, plants whose rhizomes are soaked in GA_3 at a concentration of 100 $mg \cdot dm^{-3}$ are the latest to flower. However, the application of GA_3 delays the harvest by 2–4 weeks. In a study by Janowska and Schroeter [8], soaking the rhizomes of the 'Black Magic' cultivar in GA_3 delayed but at the same time prolonged flowering by as much as 8–11 weeks, resulting in a significant increase in yield. In this cultivar, the highest yield was obtained by soaking the rhizomes in a GA_3 solution with a concentration of 150 $mg \cdot dm^{-3}$. It is noteworthy that the application of GA_3 at a concentration of 150 $mg \cdot dm^{-3}$ resulted in the emergence of shorter inflorescence stems. In a study by Janowska and Zakrzewski [10], in addition to soaking rhizomes in GA_3, this regulator was also applied foliarly. The 'Black-Eyed Beauty' cultivar showed no effect of GA_3 on early flowering, while the 'Cameo' and 'Treasure' cultivars flowered late after its application. Spraying GA_3 on the leaves

alone proved to be an ineffective method of stimulating the flowering of the cultivars tested. However, a combination of soaking the rhizomes and spraying the leaves with GA_3 significantly increased the flower yield of the 'Black Eyed Beauty' cultivar. In the 'Cameo' and 'Treasure' cultivars, yield increased only when GA_3 was used to soak the rhizomes (Figure 6).

Figure 5. Inflorescence deformities in *Zantedeschia* (Beata Janowska 2017).

Figure 6. Rhizomes in circumference with leaf buds (Beata Janowska 2010).

Soaking the rhizomes in GA_3 caused the formation of longer inflorescence stems in the 'Black-Eyed Beauty' and 'Cameo' cultivars and the formation of shorter inflorescence stems in the 'Treasure' cultivar. Ali and Elkiey [33] showed that spraying *Z. rehmanii* leaves with GA_3 has an adverse effect on flowering. In contrast, in a study by Treder [7], the flowering intensity of the 'Black Magic' and 'Mango' cultivars depended not only on the GA_3 concentration but also on the cultivation site. A higher flower yield was obtained in the ground than in a greenhouse after applying GA_3 at concentrations of 50 and 100 mg·dm^{-3}.

The results of the research conducted indicate that the soaking of rhizomes in GA_3 is an effective method for improving flowering (Table 2), but from the phytosanitary point of view, in *Zantedeschia* it should be replaced by a method that is equally effective but that does not create the possibility of spreading the bacteria *Pectobacterium carotovorum* subsp. *carotovorum* [43], which causes soft rhizome rot—a disease (Figure 7) that causes huge losses in *Zantedeschia*. The symptoms of the disease are easy to recognize. Initially, the bases of the petioles become mucilaginous. Then the leaves break, the rhizomes soften and

a very unpleasant odour begins to be perceptible. Unfortunately, the bacterium is resistant to preparations available on the Polish market. When the disease appears, the diseased plants must be removed and burned. Ongoing research shows that the soaking of rhizomes can be replaced by spraying them. Janowska and Andrzejak [44] showed that in the 'Black Magic' and 'Cameo' cultivars, when it comes rhizomes sprayed with GA_3 before planting, the yield of flowers is comparable to that obtained from rhizomes soaked in a solution of this growth regulator. Jerzy and Janowska [45], on the other hand, conducted a study in which they evaluated the subsequent effect of GA_3 applied at the *in vitro* propagation stage on the flowering and quality of 'Sensation' and 'Treasure' cultivars of *Z. elliottiana*. GA_3 was applied at the final stage of *in vitro* plant micropropagation [46] by introducing it at a concentration of 50 mg·dm^{-3} into a previously sterilized rooting medium. Prior sterilization of the medium was necessary because the activity of GA_3 could be drastically reduced, even to 10%, in the autoclave [47]. In regenerated plants from GA_3-treated cuttings, Jerzy and Janowska [45] observed altered leaf shape as well as reduced rhizome size and weight. The expected increase in flower yield following the use of GA_3 did not occur nor did any other benefits obtained from the use of GA_3 at the *in vitro* stage of *Zantedeschia* cuttings production.

Table 2. Growth regulators and AMF used to improve flowering, change the abundance and size of stomata in the epidermis and to extend the post-harvest longevity of flowers and leaves of *Zantedeschia* with colourful spathes.

Cultivar	Growth Regulator	Concentration (mg·dm^{-3}/mL·dm^{-3}—for Promalin	Source
Improvement in flowering			
'Albomaculata'	GA_3 BA GA_3+BA AMF	150 350, 600 150 + 350–600 spores at an amount of 100 propagation units per plant—2 g of the product per plant	Janowska and Andrzejak [44] Janowska and Stanecki [23,24] Andrzejak and Janowska [16]
'Black-Eyed Beauty'	GA_3	150	Janowska and Zakrzewski [9]
'Black Magic'	GA_3 BA GA_3+BA	50, 100, 150 350, 600 150 + 350–600	Janowska and Schroeter [8], Janowska and Stanecki [23,24,38], Treder [7]
'Cameo'	GA_3	150	Janowska and Andrzejak [44], Janowska and Zakrzewski [9]
'Galaxy'	Promalin	3	Funnell et al. [42]
'Mango'	BA Promalin	350, 600 3	Janowska and Stanecki [23] Treder [7]
'Orange Sunset'	GA_3	25, 50	Dennis et al. [34]
'Pink Persuation'	GA_3	50, 100	Janowska and Krause [36]
'Pink Satin'	GA_3	50	Funnell and Tjia [31]
'Red Sunset'	GA_3	50	Dennis et al. [34]
'Sensation'	GA_3	50, 100	Janowska and Krause [36]
'Treasure'	GA_3	150	Janowska and Zakrzewski [9]
Improvement in post-harvest flower longevity			
'Albomaculata'	8HQS BA	200 50, 100	Janowska and Stanecka [20]
'Black Magic' 'Florex Gold'	GA_3 8HQC	50, 100 200	Janowska and Jerzy [48]

Table 2. *Cont.*

Cultivar	Growth Regulator	Concentration ($mg \cdot dm^{-3}$/$mL \cdot dm^{-3}$—for Promalin	Source
Improvement in post-harvest leaf longevity			
'Albomaculata'	Memt, MemTR MemT+GA_3	25, 50, 75 25–25 + 50–50	Janowska et al. [21]
'Black Magic'	GA_3	50, 100	Janowska et al. [21]
'Florex Gold'	GA_3	200, 300	Janowska and Jerzy [49]
'Sunglow'	GA_3	400	Janowska et al. [21]
Change in the abundance and size of stomata in the upper epidermis			
'Albomaculata'	BA+GA_3	100 + 100, 350 + 350—larger stomata, but less numerous	Janowska et al. [50]
Change in the abundance and size of stomata in the lower epidermis			
'Albomaculata'	BA+GA_3	100 + 100, 350 + 350, 600 + 600—larger stomata, with their abundance decreasing when applied at a concentration of 350 + 350 $mg \cdot dm^{-3}$	Janowska et al. [50]

Figure 7. Soft rhizome rot in *Zantedeschia* (Beata Janowska 2017).

2.2. CKs in the Cultivation of Zantedeschia

In later studies, BA, i.e., synthetic CK, was used to soak *Zantedeschia* rhizomes (Table 2). Janowska and Stanecki [23] obtained the highest flower yield in the 'Black Magic', 'Mango' and 'Albomaculata' cultivars when they used BA at a concentration of 350–600 $mg \cdot dm^{-3}$ to soak the rhizomes. With this treatment, 3–4 times more flowers were harvested from a single rhizome compared to the control treatment. The results obtained confirmed earlier reports by Luria et al. [51]. The authors found that BA at a concentration of 350 ppm (350 $mg \cdot dm^{-3}$) had a positive effect on flower formation in *Z. aethiopica*. However, the use of BA does not always produce the desired results. Ngamau [52] obtained no yield increase in *Z. aethiopica* 'Green Goddess' after its application. Janowska and Stanecki [23] further

showed that BA at a concentration of 100–600 mg·dm^{-3} slightly delays the flowering of the 'Black Magic' cultivar, and at a concentration of 350–600 mg·dm^{-3}, of the 'Mango' and 'Albomaculata' cultivars. However, when applied at a concentration of 100 mg·dm^{-3} in the 'Mango' and 'Albomaculata' cultivars, it causes earlier flowering of the plants. This is partially supported by the research of Tjia and Funnell [53], who achieved earlier flowering by soaking *Z. elliottiana* rhizomes in a 50–100 mg·dm^{-3} BA solution. Information on the earliness of plant flowering is very important for producers as it allows them to plan production for a specific date.

Growth regulators can, both positively and negatively, affect the quality characteristics of flowers, expressed in terms of stem length as well as flower and leaf size and weight. In a study by Janowska and Stanecki [23], BA caused the rhizomes to grow shorter inflorescence stems, with the response to the concentrations used depending on the cultivar. Moreover, it influenced the formation of longer inflorescence sheaths in the 'Albomaculata' cultivar, and in the 'Black Magic' and 'Mango' cultivars, it resulted in the emergence of flowers of lower weight. However, as reported by Janowska and Stanecki [38], at a concentration of 100–600 mg·dm^{-3} in the 'Mango' cultivar and at a concentration of 350–600 mg·dm^{-3} in the 'Albomaculata' cultivar, BA inhibited leaf development but had a positive effect on leaf quality in these cultivars, which recorded a higher greening index as well as higher protein and sugar contents. Proteins are an important component of plant cells. They regulate vital processes and are the building material of cellular structures and tissues. They are also responsible for most biochemical reactions in living organisms. On the other hand, the sugars formed during photosynthesis are the main building and spare materials of plant organisms. Intense photosynthesis promotes the accumulation of more carbohydrates. In the available literature, only residual information can be found on changes in sugar content in *Zantedeschia* due to the application of growth regulators. Kozłowska et al. [54] report changes in the sugar content of *Z. elliottiana* leaves after soaking the rhizomes in GA_3, depending on the stage of development. The authors report that at the initial stage of vegetative development, there was a higher content of hydrocarbons, especially fructose and glucose, in the leaf blades of GA_3-treated plants compared to control plants. Their content increased as the leaves developed but decreased as the plants entered the generative stage. At that time, the total hydrocarbon content in the leaves of the control plants was twice as high.

2.3. A Mixture of GA_3 and BA in the Cultivation of Zantedeschia

In the West, ready-made preparations containing growth regulators of various compositions are often used in floricultural production. These include Promalin (100 mg·dm^{-3} GA_{4+7} + 100 mg·dm^{-3} BA) [25,40]. Unfortunately, due to the costly synthesis of GA_{4+7}, this preparation is expensive, and hence its use is limited. On the basis of a study evaluating the effect of the combined application of GA_3 and BA on the flowering of *Zantedeschia*, Janowska and Stanecki [24] found that soaking rhizomes in a mixture of these growth regulators increased flower yield in the 'Black Magic' and 'Albomaculata' cultivars. The results obtained confirmed the study by Funnell et al. [42], who obtained an increase in cut flower yield in *Zantedeschia* 'Galaxy' by as much as 469% after applying Promalin. Similarly, in *Z. aethiopica* 'Green Goddess', cut flower yield increased after the application of a BA+GA_3 mixture [52]. However, Janowska and Stanecki [24] report that the application of both growth regulators at the tested concentration variants delayed the flowering of *Zantedeschia* cultivars. Furthermore, in the cultivars tested, it was found that the application of the BA+GA_3 mixture caused the growth of flowers with shorter stems from the rhizomes, and in the 'Black Magic' cultivar, the flowers additionally had a lower weight. The authors also report that growth regulators had no effect on leaf yield, with the exception of the 'Albomaculata' cultivar, in which fewer leaves grew from rhizomes. In contrast, in all cultivars tested, the leaves had a higher greening index as well as higher protein and sugar content. It can be assumed that more intensive photosynthesis influenced the increased protein and sugar content in the leaves. Meanwhile, Janowska et al. [50] evaluated the effect

of the mixture of BA and GA_3 on the abundance and size of stomata in the epidermis of *Zantedeschia* leaves. They showed that in the 'Albomaculata' cultivar, after the application of the BA+GA_3 mixture at concentrations of 100 + 100 and 350 + 350 mg·dm^{-3}, stomata in the upper epidermis of leaves were larger than in the leaves of control plants, and that their number decreased. In the lower epidermis, the mixture of BA and GA_3 at the concentrations used had an effect on the formation of larger stomata, with their abundance decreasing when applied at a concentration of 350 + 350 mg·dm^{-3} (Table 2).

2.4. Mycorrhizas in Zantedeschia Cultivation

Recent research suggests that arbuscular mycorrhizal fungi (AMF) can be used instead of growth regulators in *Zantedeschia* cultivation (Table 2). Janowska et al. [55] report that AMFs cause an increase in quality, expressed by the length of the inflorescence stem, and in flower yield in *Z. albomaculata* 'Albomaculata' and have a beneficial effect on nitrogen (N) and manganese (Mn) accumulation in leaves. Andrzejak and Janowska [16], on the other hand, conducted a study evaluating the effect of the combined application of GA_3 and AMF on the flowering and plant quality of the 'Albomaculata' cultivar. The authors soaked the rhizomes in water or a water GA_3 solution of 150 mg·dm^{-3} for 30 min before planting. A week after planting, they applied an AMF mixture to the rhizomes. They showed that the application of AMF increased the inflorescence yield of the 'Albomaculata' cultivar by 100%. The combined application of AMF and GA_3 positively affected the quality of inflorescences, expressed by the length of inflorescence stems, while the application of AMF alone positively affected the length of inflorescence spathes. AMF and GA_3 had no effect on the levels of macronutrients in the leaves of the cultivar tested, except for calcium (Ca). In contrast, the leaves of mycorrhizal plants were characterised by high sodium (Na) and micronutrient content, with the exception of iron (Fe).

3. Vase Life of Cut Flowers

The high demands placed on cut flowers mean that in assessing their quality, in addition to external appearance, their post-harvest life is also taken into account. This also applies to florist's greens. Tjia and Funnell [53] report that the durability after cutting the flowers of *Z. aethiopica* is limited to 6–7 days, while in *Z. elliottiana*, the inflorescence spathes turn green already after 7–8 days, which is a visible sign of a progressive ageing process. Moreover, inflorescence stems inserted into pure water tend to split. To prevent this, the authors recommend adding sugar and 8-hydroxyquinoline citrate (8HQC). In a study by Janowska and Jerzy [48], no splitting of inflorescence stems was observed in the 'Florex Gold' and 'Black Magic' cultivars, and greening of spathes occurred only in the 'Florex Gold' cultivar. In addition, the authors point to the exceptional post-harvest life of the flowers, which retained their decorative qualities for approximately 3–4 weeks after being put in water. An unfavourable phenomenon they observed, however, was the rotting of stem ends in the 'Black Magic' cultivar as a result of conditioning in the 8HQC solution. The conditioning further reduced the post-harvest life of the flowers by 7–8 days. The ornamental qualities in this cultivar were retained the longest in flowers that were placed in a GA_3 solution of 50 and 100 mg·dm^{-3} after cutting. In the 'Florex Gold' cultivar, flowers that were conditioned in the 8HQC solution for 2 h had the longest post-harvest life. In this cultivar, GA_3 also proved effective in extending durability as, regardless of the duration of conditioning in the 8HQC solution, flowers that were then placed in GA_3 solutions retained their ornamental qualities for several days longer. According to Janowska and Stanecka [20], on the other hand, in the 'Albomaculata' cultivar, BA at a concentration of 50–150 mg·dm^{-3} can be used for flower conditioning. According to the authors, it extends the post-harvest life of the flowers of this cultivar by 7–14 days (Table 2).

4. Post-Harvest Life of Leaves

The ageing process of cut leaves is different from that of flowers, which is why measures aimed at extending the vase life of cut flowers are often not very effective for

leaves [56,57]. Therefore, attempts are being made to extend the durability of florists' greens with growth regulators (Table 1). Research on post-harvest life regulation dates back to the 1960s. Back then, focus was placed on the possibility of using CKs to extend the post-harvest life of vegetables. It was shown to be effective in celery and endive [58] as well as lettuce [59]. Later, it began to be applied to cut flowers [60,61] and then to florists' greens [57]. CKs are effective in many cases but, as reported by Cełikel et al. [62], their effectiveness decreases when combined with GA. In a study by Janowska et al. [21] comparing the effectiveness of GA_3 and BA in prolonging leaf vase life of the 'Sunglow' cultivar, it was shown that only GA_3 had a positive effect on this aspect, as the conditioning of leaves in this growth regulator at a concentration of 400 mg·dm^{-3} extended their post-harvest life by 3 days. In addition, GA_3 at a concentration of 300–400 mg·dm^{-3} influenced a higher leaf greening index. Similarly, in the leaves of the 'Black-Eyed Beauty' cultivar, the only effective solution was GA_3, which, when applied at concentrations of 50 and 100 mg·dm^{-3}, extended their post-harvest life. The combined application of both growth regulators at different concentrations had no effect on the post-harvest life of leaves. However, both GA_3 and BA inhibited the breakdown of chlorophyll in leaves, while GA_3 and the GA_3+BA mixture inhibited the breakdown of proteins. A study by Janowska and Jerzy [49,63] confirms the favourable effect of GA_3 on the post-harvest life of leaves and on chlorophyll content in the 'Black Magic' and 'Florex Gold' cultivars. A consequence of the progressive ageing process of leaves is proteolysis, or the breakdown of proteins. In a study by Rabiza-Świder et al. [64], leaves of *Z. aethiopica* and *Z. elliottiana* were subjected to 24 h conditioning in BA and GA_3 solutions. For both cultivars, only GA_3 effectively delayed the degradation of soluble proteins. The standard medium, used to extend the durability of cut flowers, accelerated proteolysis in *Z. aethiopica* leaves but did not have the same adverse effect on *Z. elliottiana* leaves. The decrease in soluble proteins was accompanied by an accumulation of free amino acids. Recent studies indicate that the post-harvest life of *Zantedeschia* leaves is improved by topolins (Ts), new aromatic CKs [12]. According to Janowska et al. [21], *meta*-methoxytopolin (MemT) and its riboside (MemTR) affect the post-harvest life and quality of the leaves of the 'Albomaculata' cultivar. When applied at a concentration of 25–75 mg·dm^{-3} for 4 h conditioning of leaves, they prolong their post-harvest life while inhibiting the breakdown of proteins but have no effect on the greening index. When used for a few seconds' soaking of leaf blades, both Ts at a concentration of 25–50 mg·dm^{-3} are more effective in prolonging the vase life of leaves of the 'Albomaculata' cultivar than 24 h conditioning. When used for a few seconds' soaking of leaf blades, MemT combined with GA_3 at a concentration of 25–25 + 50–50 mg·dm^{-3} prolongs the post-harvest life of leaves of this cultivar by an average of 14–24 days, inhibits protein degradation, but has no effect on the leaf greening index.

5. Conclusions

Flowering in *Zantedeschia* cultivars with colourful inflorescence spathes depends on the cultivar, the size of the rhizomes and the length of storage, with flowering expected only from the largest ones. However, the yield of cut flowers that can be obtained from them is often not very satisfactory and is not compensated by the price that can be obtained from the sale of the flowers. It is the low yield of cut flowers that is the main problem in the cultivation of *Zantedeschia* cultivars. Improvements in flowering intensity are achieved by using GAs, in particular GA_3; CKs, especially BA; a mixture of GA_3+BA; and from among preparations of Promalin, containing GA_{4+7} and BA. However, GA_3 delays the flowering of many cultivars while at the same time extending it by 8–11 weeks. BA, depending on the concentration, accelerates or delays the flowering of *Zantedeschia* cultivars. AMFs can be used instead of growth regulators in *Zantedeschia* cultivation. GA_3 and BA extend the post-harvest life of *Zantedeschia* flowers, while GA_3 and Ts extend the vase life of leaves. Further research should include a larger number of *Zantedeschia* cultivars to demonstrate the effectiveness of growth regulators from the GA and CK group, and it

would be worthwhile to expand research with positive microorganisms, such as species from the *Trichoderma* genus.

Author Contributions: Conceptualization, B.J. and R.A.; methodology, B.J. and R.A.; formal analysis, B.J. and R.A.; writing, B.J. and R.A.; funding acquisition, B.J. and R.A.; writing—original draft, B.J. and R.A.; writing—review and editing, B.J. and R.A. All authors have read and agreed to the published version of the manuscript.

Funding: The publication was co-financed within the framework of the Ministry of Science and Higher Education program "Regional Initiative Excellence" in the years 2019–2022, project no. 005/RID/2018/19, financing amount PLN 12,000,000.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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