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ARTICLE

Gibberellic acid application protocols, concentrations, and rhizome size in potted colored calla lily

Protocolos de aplicação, concentrações de ácido giberélico e tamanho de rizomas em copo-de-leite colorido cultivado em vaso

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Abstract
To induce and accelerate vegetative development and flowering in colored calla lily, the use of gibberellic acid (GA_3) is recommended, although information on cultivar responses, application protocols, and rhizome size is still limited. The objective was to evaluate the development of calla cultivars subjected to different GA_3 application protocols and the effect of concentrations of this growth regulator on rhizomes of different sizes. In this regard, two experiments were conducted. In the first experiment, a randomized complete block design was used in a 3 × 3 factorial arrangement, with three GA_3 application protocols (foliar application at 30 days after planting, rhizome immersion, and substrate application) and three cultivars ('Mango', 'Hawaii', and 'Black Star'), with three replicates and two rhizomes per replicate. In the second experiment, a 4 × 4 factorial arrangement was used, with four GA_3 concentrations (0, 150, 300, and 600 mg L^{-1}) and four rhizome size classes of cv. 'Mango' (72 × 55, 52 × 45, 34 × 30, and 27 × 23 mm), with five replicates. The 'Mango' cultivar showed greater vegetative development. Rhizome immersion in GA_3 promoted earlier flowering and greater floral stem production than the foliar application protocol, performed 30 days after planting. In the second experiment, the fitted model indicated earlier sprouting for rhizomes of size class I at approximately 330.6 mg L^{-1} GA_3, whereas 600 mg L^{-1} resulted in the highest estimated floral stem production for size class II within the evaluated range.
Keywords: *Zantedeschia* sp., potted flower, plant growth regulator, flowering induction.

Resumo
Para induzir e acelerar o desenvolvimento vegetativo e o florescimento do copo-de-leite colorido, recomenda-se o uso de ácido giberélico (GA_3), embora ainda sejam limitadas as informações sobre respostas de cultivares, protocolos de aplicação e tamanho dos rizomas. Objetivou-se avaliar o desenvolvimento de cultivares de callas submetidas a diferentes protocolos de aplicação de GA_3 e o efeito de concentrações desse regulador em rizomas de diferentes tamanhos. Nesse sentido, foram conduzidos dois experimentos. No primeiro, utilizou-se delineamento em blocos ao acaso, em esquema fatorial 3 × 3, com três protocolos de aplicação de GA_3 (foliar aos 30 dias após o plantio, imersão dos rizomas e aplicação via substrato) e três cultivares ('Mango', 'Hawaii' e 'Black Star'), com três repetições e dois rizomas por repetição. No segundo, adotou-se esquema fatorial 4 × 4, com quatro concentrações de GA_3 (0, 150, 300 e 600 mg L^{-1}) e quatro classes de tamanho de rizomas da cv. 'Mango' (72 × 55, 52 × 45, 34 × 30 e 27 × 23 mm), com cinco repetições. A cultivar 'Mango' apresentou maior desenvolvimento vegetativo. A imersão dos rizomas em GA_3 promoveu florescimento mais precoce e maior produção de hastes florais que o protocolo foliar, realizada 30 dias após o plantio. No segundo experimento, o modelo ajustado indicou brotação mais precoce para rizomas da classe I em aproximadamente 330,6 mg L^{-1} de GA_3, enquanto 600 mg L^{-1} resultou na maior produção estimada de hastes florais para a classe II, dentro da faixa avaliada.
Palavras-chave: *Zantedeschia* sp., flor de vaso, regulador de crescimento vegetal, indução floral.

Introduction

Among ornamental species of commercial importance cultivated worldwide, colored calla lily (*Zantedeschia* sp.), also known as calla lily, stands out for having led New Zealand's exports of cut flowers and rhizomes for more than three decades, while also contributing significantly to the horticultural export markets of the Netherlands and the United States (Sun et al., 2023; Wang et al., 2026). Its economic relevance is evidenced by the increasing volume traded in major international markets. According to Royal FloraHolland, the number of calla lily stems marketed increased from approximately 34 million in 2018 to 54 million in 2023, and in the second quarter of 2026, *Zantedeschia* ranked eighth among the main categories of potted indoor plants (AIPH, 2024; Royal FloraHolland, 2026).

The expansion of commercialization is directly related to advances achieved through breeding programs, which have promoted the expansion of commercial cultivation through the development of new hybrids and cultivars with desirable ornamental traits. Calla lilies are widely used because of their long flowering period and high ornamental value, associated with the diversity of cultivars with spathes of different colors, including pink, yellow, and purple (Chandel et al., 2023; Aboksari et al., 2026).

Despite its ornamental potential, knowledge regarding its propagation remains limited and further information is needed. Colored calla lily is usually propagated asexually through rhizome multiplication (Aboksari et al., 2025). Rhizomes play a fundamental role during the initial cultivation stage; however, growth and flowering may remain non-uniform because rhizomes vary in size (Janowska and Andrzejak, 2022). In this context, productivity is still considered unstable and low, ranging from 1.26 to 7.29 floral stems rhizome^{-1} (Akshitha et al., 2023). However, under favorable conditions and with the use of plant growth regulators, the production potential may exceed nine floral stems per rhizome (Janowska and Andrzejak, 2022).

Among plant growth regulators, gibberellic acid (GA_3) can be used as a strategy to physiologically stimulate plants and enhance their productive performance (Andrzejak and Janowska, 2021), due to its ability to promote cell division and elongation through the regulation of genes involved in cell wall loosening and expansion (Feng et al., 2023). After absorption, the phytohormone is transported through the vascular system to actively growing tissues, where it contributes to dormancy release and floral differentiation, as well as extending the vase life of inflorescences (Kumar et al., 2022; Chandel et al., 2023).

However, the response to plant growth regulators varies according to cultivar, light conditions, temperature, nutrient availability, as well as concentration and application method, which may include pre-plant immersion, irrigation, and foliar application, among others. The effectiveness of GA_3 may vary depending on the application protocol,

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since absorption efficiency and transport to target tissues directly influence the physiological response of plants (Kumar et al., 2022).

The response of colored calla lily to plant growth regulators may also vary among cultivars due to their genetic and physiological characteristics. In particular, the 'Mango' cultivar has been used in studies involving plant growth regulators and exhibits vegetative and reproductive responses that depend on the type and concentration of the regulator applied (Janowska and Andrzejak, 2022). However, information on how rhizome size influences the response to different GA_3 concentrations remains limited.

Therefore, the study was based on the hypothesis that the vegetative and reproductive responses of colored calla lily to GA_3 depend on the application protocol and the characteristics of the plant material, as well as on the regulator concentration and rhizome size. It was expected that protocols providing greater initial contact of GA_3 with the rhizomes would favor plant development compared with foliar application performed after planting, and that, in the 'Mango' cultivar, the response to GA_3 concentrations would vary according to rhizome size.

Thus, this study aimed to evaluate the vegetative and reproductive development of colored calla lily cultivars subjected to different GA_3 application protocols, as well as the effects of different regulator concentrations applied to rhizomes of different sizes.

Materials and Methods

Two experiments were conducted concurrently between August 2020 and February 2021, for 210 days, counted from rhizome planting after vernalization, in a seedling nursery belonging to a public university, located at 24°46′ S, 54°22′ W, and 420 m altitude. The experiments were carried out under protected conditions, in a shade house consisting of eucalyptus posts, with a black shading screen with 30% solar retention, installed on the top and sides. The experimental units were arranged on steel benches.

The local climate is classified, according to Köppen, as Cfa, a subtropical climate with an average temperature below 18 °C in the coldest months (mesothermal) and above 22 °C in the warmest months (Alvares et al., 2013). Summers are hot, with infrequent frosts in winter and a tendency for rainfall to be concentrated during the summer months, although there is no defined dry season (Caviglione et al., 2000). During the experimental period (August 2020 to February 2021), regional mean monthly temperatures ranged from 20 °C in August to 25 °C in October. Mean temperatures were 24 °C in September and from November to February, according to data from the National Institute of Meteorology (INMET, 2021).

The rhizomes used in the experiments were obtained from a commercial grower in Holambra, São Paulo, Brazil. After arrival, the plant material was subjected to vernalization for 90 days at 12 °C and a constant relative humidity of 50%-60% in a refrigerator to overcome dormancy.

Plants were grown in 3 dm^{-3} polyethylene pots containing a substrate mixture of Red Latosol, washed medium-textured sand, and substrate conditioner (well-composted cattle manure) (2:1:1, v/v/v), with the following chemical attributes: pH = 7.09; cation exchange capacity at pH 7.0 = 12 cmolc dm^{-3}; base saturation = 81%; and organic matter = 15.90 g dm^{-3}.

During plant development, manual irrigation was performed once a day by applying approximately 200 mL of water directly to the substrate of each pot using a graduated container. Pots had drainage holes at the base to allow excess water to drain. Weed control was performed manually.

Both experiments were conducted in a randomized complete block design with a factorial arrangement. The blocks were established according to the spatial position of the experimental units on the steel benches, aiming to control possible environmental variations within the protected environment. Within each block, all treatment combinations were randomly assigned to the experimental units.

Experiment I - Cultivars and GA_3 application protocols

Experiment I was conducted in a 3 × 3 factorial arrangement, consisting of three GA_3 application protocols (foliar-application, rhizome-immersion, and substrate-application) and three colored calla lily cultivars ('Mango', 'Hawaii', and 'Black Star'), with three replicates and two rhizomes per experimental unit.

Rhizomes of the cultivars 'Mango', 'Hawaii', and 'Black Star' were used, which produce orange, yellow, and purple inflorescences, respectively (Fig. 1), with an average fresh mass of approximately 20 g, a transverse diameter of 25 mm, and a longitudinal diameter of 35 mm.

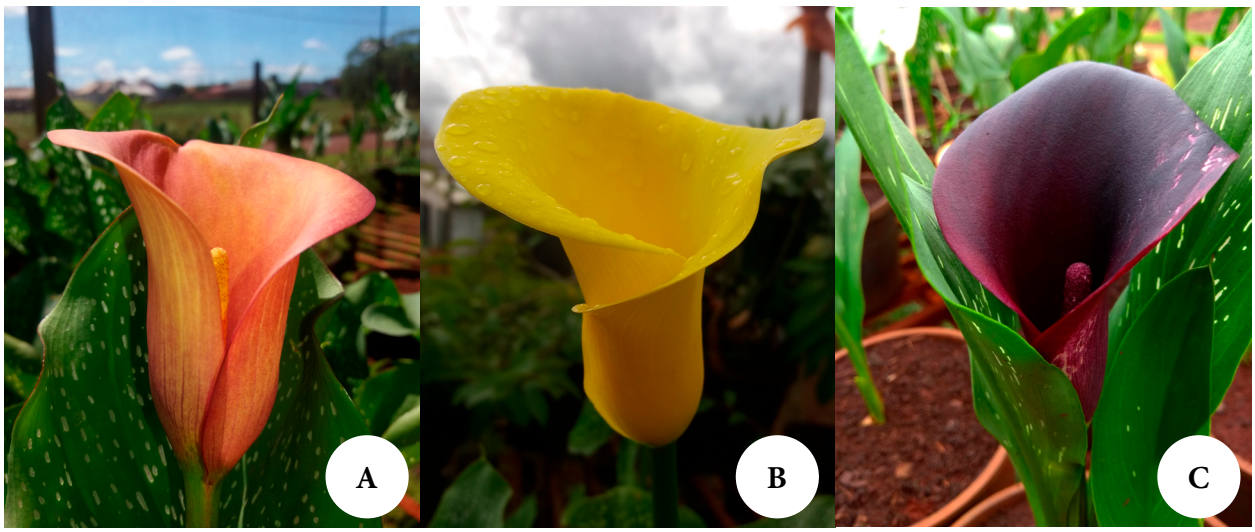

Fig. 1. Inflorescences of colored calla lily cv. 'Mango' (A), 'Hawaii' (B), and 'Black Star' (C). Source: Authors.

All three application protocols used a GA_3 concentration of 300 mg L^{-1} and applications were performed between 08:00 and 09:00 a.m.

The solutions were prepared from the commercial product ProGibb® (Sumitomo Chemical 40% w/w GA_3). The amount of commercial product required was calculated considering this proportion of active ingredient so that the concentration used in the experiment corresponded to the effective GA_3 concentrations. The product was diluted in a 50:50 (v/v) hydroalcoholic solution in a 2 dm^{-3} glass beaker until complete homogenization of the solution.

For the rhizome-immersion protocol, 1.5 L of the solution was prepared, and the vernalized rhizomes were, immersed for 120 min before planting in 2 dm^{-3} plastic beakers. For substrate-application protocol, 150 mL of the GA_3 solution was applied directly to the substrate surface of each pot immediately after the rhizomes were placed and planted. For the foliar-application protocol, 150 mL of the solution was applied per plant with a manual sprayer, when the plants had two to four leaves, 30 days after planting.

Experiment II - GA_3 concentrations and rhizome size classes

Experiment II was conducted in a 4 × 4 factorial arrangement, consisting of four GA_3 concentrations (0, 150, 300, and 600 mg L^{-1}) and four rhizome size classes of the cultivar 'Mango', with five replicates.

The 'Mango' cultivar was selected because of its availability in different sizes at the time the propagative material was acquired and its recognized responsiveness to plant growth regulators (Janowska and Andrzejak, 2022).

Before treatment application, the rhizomes were measured for longitudinal and transverse diameters using a digital caliper and were subsequently grouped into four experimentally defined size classes according to the variation observed in the available batch. The use of propagule size as an experimental criterion was based on previous studies with colored calla lily, such as Halligan et al. (2004), who used rhizomes measuring 3 and 5 cm. The mean longitudinal x transverse dimensions were 72 x 55 mm (Class I), 52 x 45 mm (Class II), 34 x 30 mm (Class III), and 27 x 23 mm (Class IV).

The GA_3 solutions were prepared using ProGibb® (Sumitomo Chemical; 40% w/w GA_3). The amount of commercial product required for each treatment was determined based on the GA_3 concentration in the formulation and weighed using an analytical balance with a precision of 0.000 g. The product was dissolved in a hydroalcoholic solution composed of water and 70% alcohol at a 50:50 (v/v) ratio until complete homogenization, resulting in final GA_3 concentrations of 0, 150, 300, and 600 mg L^{-1}. The same water-to-alcohol ratio was used in all treatments, including the control (0 mg L^{-1} GA_3). Rhizomes from each size class were immersed in their respective GA_3 solutions for 120 min in 2 dm^{-3} plastic beakers before planting.

Plant growth, flowering evaluations and statistical analysis

The same variables and evaluation procedures were adopted in both experiments. Throughout the experimental period (210 days), the sprouting onset (days after planting) and the emergence of the first floral stem (days after planting) were recorded. Sprouting onset was considered when the first shoot had two fully expanded leaves, whereas the emergence of the first floral stem was recorded when the first inflorescence appeared.

During the flowering period, the number of floral stems produced per rhizome was recorded cumulatively. Floral stem length (cm) and spathe diameter (cm) were measured on inflorescences with fully open spathes and with the spadix still showing no visible pollen, a stage considered suitable for harvest (Salgado et al., 2025). Floral stem length was measured from the base of the stem to the inflorescence using a millimeter ruler, whereas spathe diameter was measured at its midpoint using a digital caliper.

At the end of the experimental period, at 210 days after planting, the number of shoots $rhizome^{-1}$ was determined, considering only shoots with at least two fully expanded leaves, as well as plant height (cm), length of the longest shoot (cm), and length of the longest floral stem (cm). To determine the length of the longest shoot and the longest floral stem, all shoots and floral stems produced by each rhizome were measured from the base to the apex using a millimeter ruler, and the greatest value was selected in each case.

For variables related to inflorescence dimensions, only the structures that were actually produced were considered. When flowering did not occur, a value of zero was assigned exclusively to the variable number of floral stems per rhizome. For floral stem length, length of the longest floral stem, and spathe diameter, plants that did not flower were treated as missing data in order to avoid underestimating treatment responses and to provide a more biologically appropriate interpretation of the results. In the regression analyses, treatments without floral stem production were excluded from model fitting for these variables and were identified in the graphs as "No flowering (NF)".

For the variable emergence of the first floral stem, experimental units that did not flower within 210 days after planting were not assigned a value for this variable. Treatment means were estimated based on the available observations, and multiple comparisons among treatments were adjusted using the Sidak method in R version 4.4.1.

The data were subjected to the Shapiro-Wilk normality test. As all variables met the assumption of normality, they were subjected to analysis of variance (ANOVA). In Experiment I, the effects of cultivar, GA_3 application protocol, and the cultivar × application protocol interaction were evaluated for all variables. In Experiment II, the effects of GA_3 concentration, rhizome size class, and the GA_3 concentration × rhizome size class interaction were evaluated.

When significant effects were detected, the means of qualitative factors were compared using Tukey's test at the 5% probability level with SISVAR software (Ferreira, 2019). Quantitative factors were subjected to regression analysis using SigmaPlot®. Different regression models were evaluated, and model selection was based on the coefficient of determination (R^2), statistical significance, and the biological plausibility of the response.

Results and Discussion

Experiment I

The analysis of variance showed no significant cultivar × GA_3 application protocol interaction for any of the variables evaluated. Therefore, the effects of cultivar and GA_3 application protocol were analyzed separately. Among cultivars, differences were observed for sprouting onset, number of shoots $rhizome^{-1}$, and plant height, whereas among application protocols, differences were observed only for the number of floral stems $rhizome^{-1}$ and emergence of the first floral stem.

Most colored calla lily cultivars result from continuous crosses among individuals of different species (Wang et al., 2023), resulting in considerable genetic and phenotypic variability among cultivars. This variability may be reflected in growth-related traits, including sprouting onset, shoot production, and plant height. In the present study, differences among cultivars were observed for these variables, with the 'Mango' cultivar standing out for its vegetative growth performance (Table 1).

Table 1. Sprouting onset, number of shoots $rhizome^{-1}$, and plant height as a function of calla lily cultivars.

Cultivar	Sprouting onset (days after planting)	Number of shoots $rhizome^{-1}$	Plant height (cm)
'Mango'	12.56 a	2.22 a	38.86 a
'Black Star'	19.44 b	2.00 ab	32.72 b
'Hawaii'	22.89 b	1.00 b	33.00 ab
CV (%)	26.58	48.78	14.16

Means followed by the same letter within a column do not differ according to Tukey's test at the 5% probability level. CV (%) = coefficient of variation (%).

The 'Mango' cultivar is included in the core germplasm of *Zantedeschia* and is considered one of the 42 cultivars most representative of the genetic diversity of the genus, reinforcing its relevance for genetic conservation and as plant material for physiological, agronomic, and breeding studies (Wang et al., 2023).

This genetic variability among cultivars may be directly reflected in plant growth and development traits. In this context, recent studies have shown that calla lily cultivars may exhibit distinct shoot formation responses when subjected to the same combinations of plant growth regulators, indicating that genotype contributes to determining this response (Prakasha et al., 2026).

The number of shoots and plant height differed among cultivars, indicating variation in the vegetative growth patterns of the evaluated plant materials (Table 1). Morphological differences among *Zantedeschia* genotypes have also been reported in recent studies. Akshitha et al. (2023) found a significant cultivar effect on plant height at different developmental stages, whereas Aboksari et al. (2025) also observed differences in plant height among cultivars grown under similar conditions.

Similarly, differences in shoot formation among cultivars were reported by Prakasha et al. (2026), indicating a response dependent on the genetic material. This variation is consistent with the broad phenotypic and genetic diversity recently described among *Zantedeschia* accessions and genotypes (Niyokuri et al., 2025; Rana et al., 2026). Thus, the greater number of shoots observed in 'Mango' and the differences in plant height among cultivars may be associated with the specific genetic characteristics of each plant material.

Consistent with these findings, Rana et al. (2026), studying 102 *Zantedeschia* accessions, observed variation in all 12 agro-morphological traits evaluated. The authors reported substantial variability for most traits and identified plant height as one of the characteristics relevant for differentiating among genotypes.

A greater number of shoots and, consequently, greater plant volume in potted ornamentals, as observed in the 'Mango' cultivar, is commercially desirable because it allows the plants to fill most of the container, positively influencing consumers' purchase preference (Carvalho-Zanão et al., 2018). Additionally, according to Sari et al. (2023), plant size is considered one of the key attributes influencing the purchase of the final product.

Although the application protocols did not significantly affect the vegetative growth of colored calla lily plants, rhizome immersion and substrate application resulted in greater floral stem production compared with the foliar application protocol, which produced approximately 83% fewer floral stems (Table 2).

Table 2. Number of floral stems rhizome^{-1} and emergence of the first floral stem as a function of gibberellic acid application protocols in calla lily plants.

Application protocols	Number of floral stems rhizome^{-1}	Emergence of the first floral stem (Days after planting)
Foliar	0.33 b	52.0 b
Substrate	1.5 a	51.7 b
Rhizome immersion	1.94 a	42.7 a
CV (%)	45.05	15.39

Means followed by the same letter within a column do not differ according to Tukey's test at the 5% probability level. For the variable emergence of the first floral stem, considering the experimental units that did not flower during the evaluation period, comparisons among treatments were adjusted using the Sidak method. CV (%) = coefficient of variation (%).

This reduction in floral stem production may be associated not only with the application route but also with the timing of GA_3 exposure. Rhizome immersion was performed before planting, and substrate application immediately after planting, whereas foliar application was carried out 30 days later. Thus, in addition to possible differences in phytohormone absorption and translocation efficiency (Monteiro et al., 2024), the duration of regulator action throughout plant development may also have contributed to the observed differences.

The response to GA_3 depends on the developmental stage at which the regulator is applied, since its action is associated with the physiological status of the plant and the responsiveness of the tissues at the time of treatment (Haifaa and Moses, 2022; Chandel et al., 2023). In addition, leaf maturation promotes changes in cuticle composition and increased deposition of cuticular and intracuticular waxes, which may alter surface wettability and limit the penetration of compounds applied to the leaves (Simões et al., 2022; Chen et al., 2023). Thus, the later foliar application may have reduced the period of GA_3 activity during the early stages of development and possibly limited its absorption, jointly contributing to the lower reproductive response observed under this protocol.

In contrast, prolonged rhizome immersion may have promoted greater contact between GA_3 and the storage organ responsible for shoot emergence and, subsequently, inflorescence development, while also providing earlier exposure to the regulator. This combination of greater contact with the rhizome and a longer period of action may have favored the onset of reproductive development, resulting in earlier floral stem production. This response is particularly relevant for the production of potted ornamental plants, since earlier flowering may increase the predictability of the production cycle and facilitate harvest and marketing planning (Andrzejak and Janowska, 2021).

Possibly, foliar application exhibited limited mobility, reducing its redistribution and, consequently, its physiological effect, thereby limiting its efficiency in processes requiring prolonged action, such as flowering and floral stem development. Accordingly, a longer period was required for floral differentiation and, consequently, for the emergence of the first floral stem, which occurred approximately nine days later than under the rhizome immersion treatment. This response may also have resulted from product losses through runoff or evaporation, reducing the amount absorbed by the plant and, consequently, the efficiency of the application

Overall, the results indicate that both cultivar and GA_3 application protocol influence the performance of colored calla lily. Rhizome immersion, performed at planting, resulted in earlier flowering and greater floral stem production compared with foliar application, which was carried out only 30 days after planting, following shoot emergence.

For foliar applications, an alternative may be to apply the regulator earlier or increase the number of applications, as reported by Chandel et al. (2023), who obtained better results with two GA_3 sprays in potted colored calla lily. These findings reinforce the importance of selecting an appropriate hormonal application protocol to improve the efficiency and predictability of commercial production.

Experiment II

According to the analysis of variance, a significant GA_3 concentration × rhizome size class interaction was observed for sprouting onset, plant height, number of floral stems rhizome^{-1}, length of the longest floral stem, and spathe diameter.

Plant responses to GA_3 concentrations depended on rhizome size; therefore, the regulator affected vegetative and reproductive traits differently (Fig. 2).

For sprouting onset, only class I rhizomes responded to GA_3 concentrations, with sprouting estimated at 25 days after planting at a concentration of approximately 330.6 mg L^{-1}, whereas, in the absence of the phytohormone, sprouting occurred at approximately 33 days (Fig. 2A). Similar results were reported by Rai et al. (2022), who observed a seven-day advance in sprouting in *Zantedeschia* after rhizome immersion in a solution containing 300 mg L^{-1} GA_3.

In geophytic species, such as calla lilies, sprouting is directly related to the release of bud dormancy, a process regulated by genetic and hormonal mechanisms (Busov, 2019). In this context, exposing rhizomes to low temperatures during vernalization may promote physiological changes favorable to growth resumption, including the activation of genes associated with gibberellin biosynthesis, such as Gibberellin 20-oxidase, thereby increasing the endogenous availability of these hormones (Yuxi et al., 2021).

In this context, exogenous GA_3 application may have acted complementarily to the physiological processes triggered by vernalization, favoring the resumption of bud growth through antagonism to abscisic acid and by stimulating cell division and expansion, soluble sugar mobilization, energy metabolism, and intercellular communication via plasmodesmata (Yuxi et al., 2021).

Therefore, the observed response suggests that intermediate concentrations may be sufficient to complement the hormonal signaling required for bud activation, without higher concentrations necessarily promoting earlier sprouting. However, the lack of response in the other classes indicates that the effect of the regulator on sprouting may depend on the characteristics of the propagative material, including rhizome size and physiological status.

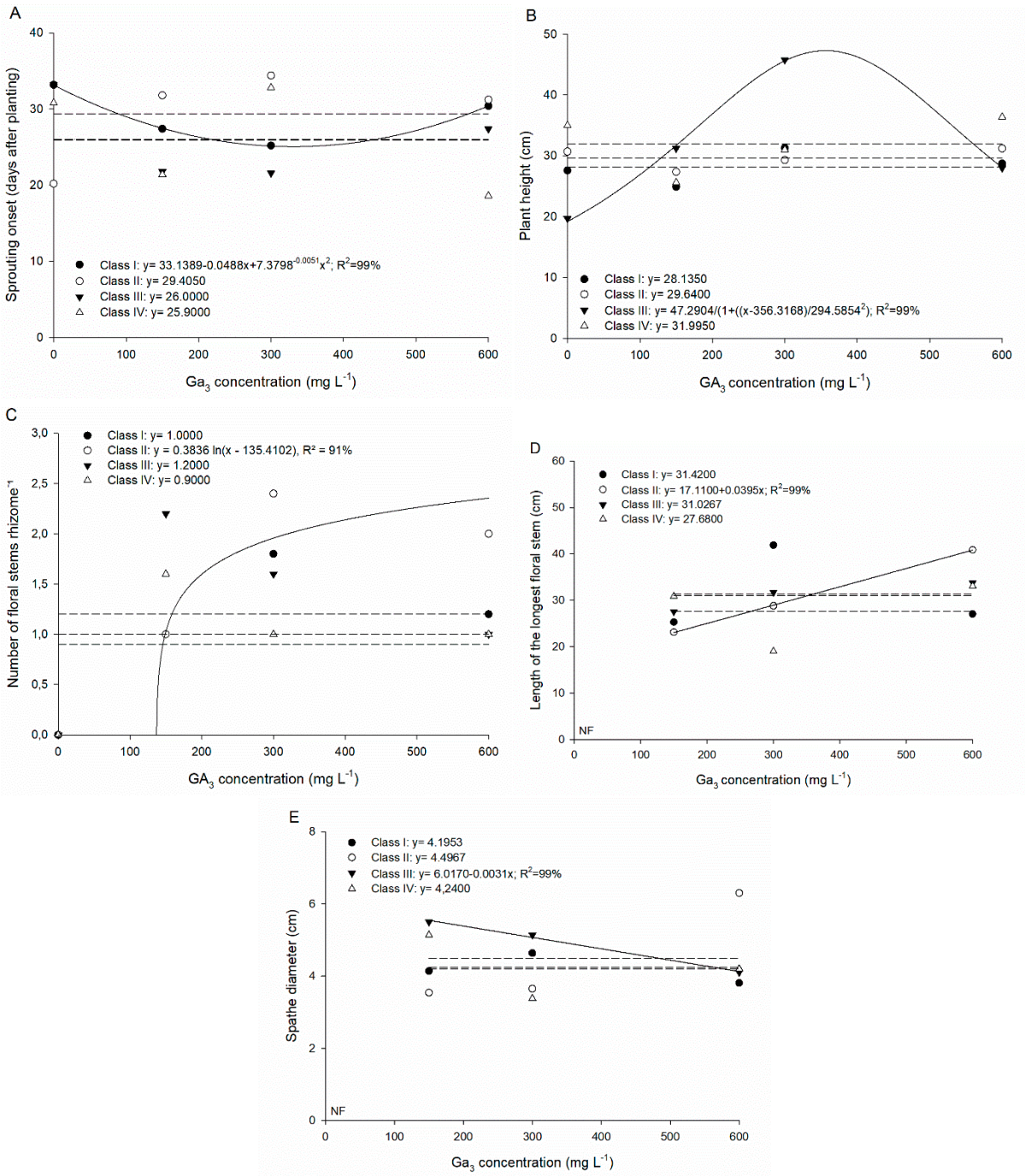

Fig. 2. Sprouting onset (A), plant height (B), number of floral stems (C), length of the longest floral stem (D), and spathe diameter (E) of calla lily rhizome size classes subjected to gibberellic acid concentrations. Class I = 72 × 55 mm, Class II = 52 × 45 mm, Class III = 34 × 30 mm, Class IV = 27 × 23 mm, NF = No flowering.

Similar results were reported by Yuxi et al. (2021), who, after applying GA_3 and GA_4, observed that both were able to promote dormancy release in buds of reproductive structures, particularly GA_3, which promoted accelerated sprouting and a greater number of flowers in peony plants when combined with prior rhizome vernalization. In addition, in studies conducted by Zhao et al. (2023), vernalization of lily bulbs for 12 weeks, associated with the application of abscisic acid and GA3, had a positive effect on bud sprouting.

Regarding plant height, only class III responded to GA_3 concentrations, reaching an estimated maximum height of approximately 47.3 cm at a concentration of 356.3 mg L^{-1} (Fig. 2B), whereas, in the absence of the regulator, the estimated height was 19.2 cm, a value 59.4% lower. The increase in plant height may have resulted from the action of gibberellins on cell elongation. In *Zantedeschia*, GA_3 applications have also promoted increases in plant growth and height, with the magnitude of the response varying according to concentration and application conditions (Chandel et al., 2023; Akshitha et al., 2025).

In addition to its influence on vegetative traits, GA_3 may also affect reproductive traits, since, under the present experimental conditions, plants not treated with GA_3 did not produce floral stems, regardless of rhizome size class (Fig. 2C, 2D, and 2E). Therefore, for the length of the longest floral stem and spathe diameter, the concentration of 0 mg L^{-1} does not represent a zero value for these variables, but rather the absence of flowering.

The absence of flowers in untreated plants demonstrates the importance of GA_3 for the induction or progression of reproductive development under the evaluated experimental conditions. Supporting this, Janowska and Andrzejak (2022) stated that gibberellins may increase flowering intensity in *Zantedeschia*, although the response depends on the cultivar, the concentration used, and rhizome size.

Among the plants that flowered, class II showed the clearest reproductive response to increasing GA_3 concentrations. Floral stem production increased markedly at the lower concentrations, with a tendency to stabilize at the higher concentrations. Within the evaluated range, the highest value estimated by the equation was 2.36 stems at the highest concentration tested. For the length of the longest floral stem, there was a linear increase from approximately 23.0 cm at 150 mg L^{-1} to 40.8 cm at 600 mg L^{-1} (Fig. 2D). This indicates that, for class II rhizomes, increasing exogenous GA_3 availability simultaneously favored floral stem emergence and elongation.

In this context, when applied at appropriate concentrations, GA_3 may stimulate the expression of enzymes involved in cell wall loosening and genes controlling cell division, in addition to promoting microtubule rearrangements associated with cell expansion (Purba et al., 2021), thereby contributing to floral stem elongation. The positive effect of GA_3 on flower number and the growth of floral structures has also been reported by Chandel et al. (2023).

On the other hand, the response of class III indicates that greater vegetative growth does not necessarily result in increases in reproductive traits. Despite the greater increase in plant height with GA_3 (Fig. 2B), spathe diameter decreased linearly with increasing concentrations, from approximately 5.55 cm at 150 mg L^{-1} to 4.16 cm at 600 mg L^{-1} (Fig. 2E), indicating that plant response to gibberellin depends on the concentration and the morphological trait evaluated. Similar results for spathe diameter were reported by Chandel et al. (2023), who observed greater spathe expansion at 100 mg L^{-1} GA_3.

Given the importance of this topic and the scarcity of available information, further studies are needed to elucidate the efficiency of different GA_3 application protocols in distinct genetic materials and under different conditions, as well as to evaluate concentrations and phenological stages that may contribute to a better understanding of the vegetative and reproductive responses of the species.

Conclusions

The 'Mango' cultivar exhibited greater vegetative growth and earlier sprouting.

The rhizome-immersion GA_3 application protocol resulted in earlier flowering and greater floral stem production compared with the foliar application protocol.

For rhizome size class I, the fitted regression model estimated the earliest sprouting at approximately 330.6 mg L^{-1} GA_3.

The concentration of 600 mg L^{-1} resulted in the highest estimated floral stem production in rhizome size class II within the evaluated concentration range.

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Authors' Contribution

LHKS: Conceptualization, Investigation, Methodology, Data Curation, Writing – Original Draft, Writing – Review & Editing. **RAS:** Conceptualization, Writing – Original Draft, Writing – Review & Editing. **DFS:** Investigation, Writing – Original Draft, Writing – Review & Editing. **GABS:** Investigation, Methodology, Writing – Review & Editing. **FV:** Investigation, Writing – Review & Editing. **LSSM:** Investigation, Writing – Review & Editing. GL: Writing – Review & Editing. **MLBC:** Writing – Original Draft.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data will be made available upon request to the authors.

Declaration on the Use of Generative AI and AI-Assisted Technologies in the Writing Process

The authors declare that they did not use generative AI or AI-assisted technologies in the preparation of this manuscript.

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