Ornamental Horticulture
ISSN 2447-536X | WWW.ORNAMENTALHORTICULTURE.COM.BR
SBFPO Sociedade Brasileira de Floricultura e Plantas Ornamentais

ARTICLE

Improving flowering and vegetative growth in *Oncidium baueri* Lindl. through gibberellic acid application: insights into physiological parameters

Potencializando o florescimento e crescimento vegetativo em *Oncidium baueri* Lindl. com a aplicação de ácido giberélico: aspectos fisiológicos em destaque

Kauê Alexandre Monteiro[1,*], Gilmar Silva Gonçalves[2], Carlos Eduardo Orlandini Bazalha[2], Jean Carlo Baudraz Paula[2], Hugo Roldi Guariz[3], Gabriel Danilo Shimizu[2] and Ricardo Tadeu Faria[2]

[1]Universidade de São Paulo, Piracicaba-SP, Brasil.
[2]Universidade Estadual de Londrina, Londrina-PR, Brasil.
[3]Instituto Federal de Educação, Ciência e Tecnologia Baiano, Guanambi-BA, Brasil

Abstract: Plant regulators are studied because they can alter commercially significant aspects of plant growth. Gibberellic acid (GA_3) exemplifies this, as it plays a crucial role in the growth and flowering processes of various vegetables. Thus, the present study sought to verify the effects caused by the exogenous application of different doses of the plant regulator GA_3 on the floral, vegetative, and physiological patterns of the orchid *Oncidium baueri*. The experimental treatments (T1; T2; T3; T4; and T5) had 10 replicates, each containing one plant, with the respective sprayed doses: 0, 50, 100, 200, and 400 mg L^{-1} of GA_3. The parameters measured were: pseudobulb length (PL) and width (PW), leaf length (LL), leaf width (LW), number of leaves per plant (NL); time for flower spike to sprout (TFSS), time for flowers to open fully (TFOF), and time for flowers to fall (TFF), these measured in days; flower stem length (FSL), number of flowers per stem (NFS), chlorophyll *a* fluorescence (fv/fm), and stomatal conductance (G_s). Data were compared using the Tukey test at a significance of 5%. The concentration of 200 mg L^{-1} of GA_3 increased PL and LL by 3 cm on average, and NL showed an increasing trend with treatment 4 compared to doses other than 0 mg L^{-1}. Regarding floral aspects, this same dose showed the lowest TFSS, distinguishing itself from the other treatments. For physiological parameters, this dose also resulted in higher fv/fm (0.826) and G_s (65.340 mmol m^{-2} s^{-1}). Therefore, the use of 200 mg L^{-1} of GA_3 is recommended for *O. baueri* plants to optimize vegetative and floral promotion.
Keywords: gibberellin, Orchidaceae, physiology, plant hormone.

Resumo: Reguladores vegetais são alvos de estudos por terem a capacidade de modificar aspectos de interesse comercial nas plantas. É o caso do ácido giberélico (AG_3), um dos hormônios responsáveis pelo crescimento e que está envolvido no processo de floração de muitos vegetais. Dessa maneira, o presente estudo buscou verificar os efeitos causados pela aplicação exógena de diferentes doses do regulador vegetal AG_3 nos padrões florais, vegetativos e fisiológicos da orquídea *Oncidium baueri*. Os tratamentos experimentais (T1; T2; T3; T4; e T5) tiveram 10 repetições, cada uma contendo uma planta, com as respectivas doses pulverizadas: 0, 50, 100, 200 e 400 mg L^{-1} de AG_3. Os parâmetros mensurados foram: comprimento (CP) e largura de pseudobulbo (LP), comprimento e largura de folhas (CF e LF), número de folhas por planta (NF), tempo para emissão de hastes florais (TEHF), tempo para abertura total (TATF) e tempo de queda de flores (TQF), com período mensurado em dias. O tamanho de haste floral (THF), o número de flores por haste (NFH), fluorescência da clorofila *a* (fv/fm) e a condutância estomática (G_s) também foram mensurados. A concentração de 200 mg L^{-1} de AG_3 incrementou 3 cm na média em CP, CF. O NF apresentou tendência de aumento com o tratamento 4 em relação às doses diferentes de 0 mg L^{-1}. Para os aspectos florais a mesma dose apresentou menor TEHF, sendo o único em destaque dentre os demais tratamentos. Para os parâmetros fisiológicos, essa mesma dose respondeu com maior valor de fv/fm (0,826) e G_s (65,340 mmol m^{-2} s^{-1}). Dessa maneira o uso de 200 mg L^{-1} de AG_3 é recomendado em plantas de *O. baueri* para otimização da promoção vegetativa e floral.
Palavras-chave: fisiologia, giberelina, hormônio vegetal, Orchidaceae.

Introduction

The Brazilian ornamental flower industry is highly relevant and dynamic, with both imports and exports of flowers moving a large volume of capital. The production area is estimated to be 15,600 hectares of flowers, representing 8% of global production, with around 800,000 indirect jobs and 272,000 direct jobs. The industry's revenue in 2023 reached 19.8 billion reais which includes not only floriculture, but also decoration, landscaping, and related areas (IBRAFLOR, 2024).

In addition to creating numerous jobs, the flower market is attractive to growers because of its higher profitability per area compared to other cash crops. Ornamental activities can be performed on a small piece of land, making the flower exploitation in urban areas an attractive niche for growers due to easier distribution to supermarkets, funeral homes, and shopping centers (Brainer, 2019). According to the IBRAFLOR (2024), Brazil has the potential to rank among the 10 largest flower producers in the world. Currently, the two most prominent categories in the ornamental market are cut flowers and potted flowers. Orchids stand out from the potted flower category, which represents 58% of the total production area.

Orchidaceae is the largest family among the monocotyledons, with more than 30 thousand species described throughout the world (World flora online, 2024). In Brazilian territory, 2,666 species have been cataloged across 249 genera of which 23 are endemic to Brazil (Reflora, 2024). Such numbers are a direct reflection of the country's tropical climate, which favors the cultivation of orchids, with data showing that several orchids respond satisfactorily to the country's environmental conditions (Endres et al., 2018; WCSP, 2019).

Oncidium Sw. is one of the largest genera in the Orchidaceae family that originates from the American continent and is found from the United States to Argentina. The species *Oncidium baueri* Lindl., known as "golden rain," is an orchid native to Brazil that occurs in various states of the country, especially in the Amazon and Atlantic Forest regions. It is known for its long floral stems with numerous flowers featuring yellow lips, greenish petals, and sepals with brown spots. This species has great ornamental potential, being one of the most economically important species in floriculture. It is cultivated and marketed in pots, although the use of its floral stems as cut flowers and its use in landscaping projects

Corresponding Author: kauwmonteiro@gmail.com | https://doi.org/10.1590/2447-536X.v30.e242783 | Editor: Michele Carla Nadal, Universidad Viña del Mar, Chile | Received: July 19, 2024 | Accepted: Sep 10, 2024 | Available online: Nov 8, 2024

have been gaining prominence in floriculture (Faria and Colombo, 2015; Nadal et al., 2022).

Meeting a wide demand for quality flowers at a low cost depends on planning and the proper use of resources by employing adequate production technologies. Plant growth regulators are widely used in flower induction and allow for increased production while extending the flowering period (Verdolin et al., 2021).

Gibberellins, popular plant growth regulators in the production process of commercial flowers, especially orchids, are used to replace natural flowering induction, to enhance vegetative growth, qualitative and quantitative flower characteristics, and to reduce or avoid poor flower formation (Khairul-Anuar et al., 2021; Lee, et al., 2021; Tejeda-Sartorius et al., 2021; Verdolin et al., 2021). Gibberellins form a class of hormones that modulate plant development at all stages, mainly in organs of rapid growth, such as germinating seeds, fruits, young leaves, stem apices and, in some cases, roots, with GA_3 being the gibberellins most used exogenously to manipulate plant growth (Paixão et al., 2021; Guariz et al., 2022; Peixoto et al., 2024).

In orchids, it has been reported that gibberellin promotes the release and elongation of buds (Mezzalira and Kuhn, 2021). Additionally, it is effective in controlling flowering through exogenous application, with beneficial effects in various genera. For example, in *Miltoniopsis* God.-Leb., its application during the first flowering season accelerated the emergence of the inflorescence and increased the number of floral stems. In *Phalaenopsis hybrida*, it is effective in promoting floral development under high temperatures, which are generally inhibitory. Endogenous gibberellins are also believed to promote the development of the floral stem and floral buds under low temperatures and induce effective flowering in *Brassocattleya marcella* Koss when combined with restrictive irrigation. Furthermore, the application of gibberellins accelerates flowering in *Paphiopedilum praestans* (Rchb. F.) Pfitzer and can promote the development of the vegetative shoot apex into a terminal inflorescence in *Aranda* cv. Deborah. In *Bletilla striata*, *Cattleya*, and *Cymbidium*, gibberellins also induce flowering (Huang et al., 2021).

Therefore, the objective of this study was to evaluate the effects of spraying GA_3 at different concentrations on flowering, vegetative growth, stomatal conductance, and chlorophyll *a* fluorescence of *Oncidium baueri* Lindl.

Material and methods

The experiment was carried out in a greenhouse, from March to December 2022. Four-year-old *O. baueri* plants having three unflowered pseudobulbs and uniform size were used (Fig. 1). Light incidence inside the greenhouse was measured using a digital light meter model LX1010B (Polyterm), which, in full sun and at noon, recorded a value of 11×10^5 lux. The seedlings were grown in polypropylene pots (12.5×9.3×9.1cm, volume: 725 cm^3) containing *Pinus* sp. bark (Imperial®) and charcoal (1:1), and the pots were placed on a cemented bench. Irrigation was done weekly, manually, directly on the growing medium, throughout the experiment. Foliar fertilizations were carried out every two weeks using 3g L^{-1} of Forth® NPK 20-20-20.

Fig. 1. Inflorescence of the *Oncidium baueri* orchid (Authors' archives).

Gibberellic acid (GA_3) was obtained from Sigma-Aldrich® with purity ≥ 90%. The growth regulator was dissolved into 4 mL of alcohol (92.8% alcohol/weight), a common organic solvent for dissolving the product, followed by dilution in distilled water to the desired concentrations. 1 mL L^{-1} of Ethoxylated Sorbitan Monolaurate (Tween 20®) was added to each solution as a surfactant to facilitate the dispersion of the plant growth regulator on the leaves (Rieger, 2020).

Ten manual sprays were carried out in 7-day intervals at GA_3 concentrations of 50 (T2), 100 (T3), 200 (T4), and 400 (T5) mg L^{-1}. Control plants 0 mg L^{-1} (T1) were sprayed with distilled water and 1 mL L^{-1} of Tween 20®. Applications were carried out in the morning, between 8 and 9 am, to favor absorption due to the higher relative humidity. The plants were separated individually and placed under protection from direct sunlight for application of the product. After application, the pots were returned to their corresponding place on the bench. They were sprayed evenly on both sides of the leaves and exposed roots using a 5-L knapsack sprayer, applying a volume of 70 mL of solution per plant (Silveira and Stefanello, 2013).

One week after the last application, the main orchid vegetative growth parameters were measured: pseudobulb length (PL) and width (PW), leaf length (LL) and width (LW), and number of leaves per plant (NL). Plant flowering measurements were time for flower spike to sprout (TFSS), time for flowers to open fully (TFOF), and time for flowers to fall (TFF), these measured in days; and flower stem length (FSL), and number of flowers per stem (NFS). Measurements were quantified with a graduated tape/ruler and caliper.

Chlorophyll *a* fluorescence was measured in the middle third of a fully expanded leaf, on the abaxial side, avoiding the central vein, at night (between 7 pm and 8 pm), using a 0S1p fluorometer (Opti Sciences), which allowed for the observation of the maximum efficiency of photosystem II (ratio fv/fm). For measurements, specific clips were used to measure the initial fluorescence (F0). Then, the maximum fluorescence (fm) was analyzed after a saturating irradiance pulse, so that the variable fluorescence could be measured: (fv) (fv = fm – f0) (Shimizu et al., 2006).

Stomatal conductance (G_s) was measured in the middle third of the first fully expanded leaf, on the abaxial side, in the morning (between 8 am and 9 am), using the LEAF SC-1 porometer (METER Group).

The experiment was carried out in a completely randomized design with five treatments and 10 replicates, with one plant per replication. The data were tested by analysis of variance and, if significant, the means were compared using the Tukey test at a significance of 5%. The assumptions of normality and homogeneity of variances were tested by Shapiro-Wilk and Levene, respectively, and the independence of errors was tested by Durbin-Watson, all at 5% significance. If one of the assumptions was not met, the data were transformed according to the methodology proposed by Box and Cox (1964). Vegetative (PL, PW, LL, LW, and NL) and physiological parameters were also subjected to quadratic regression analysis to represent dose-response variation. Flowering parameters were analyzed using the non-parametric log-Rank test through survival analysis, which assesses the plants' response to the doses based on the time of application. All analyses were carried out using the R software (R Core Team, 2024).

Results

Exogenous application of GA_3 resulted in different responses as shown in the survival analysis for the stem sprouting (TFSS). Treatment 4 (200 mg GA_3 L^{-1}) led to the shortest time for flower to sprout (Fig. 2A), resulting, therefore, in more flower spike and a higher average percentage of reproductive buds. The other treatments did not differ from each other for both variables, with lower averages to T4.

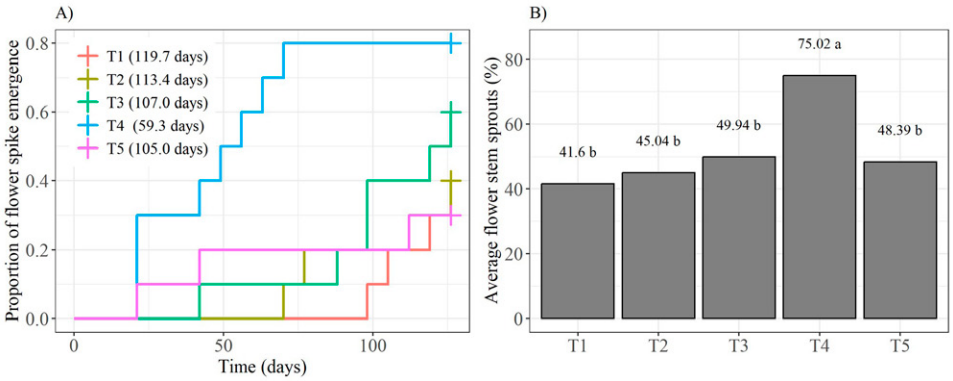
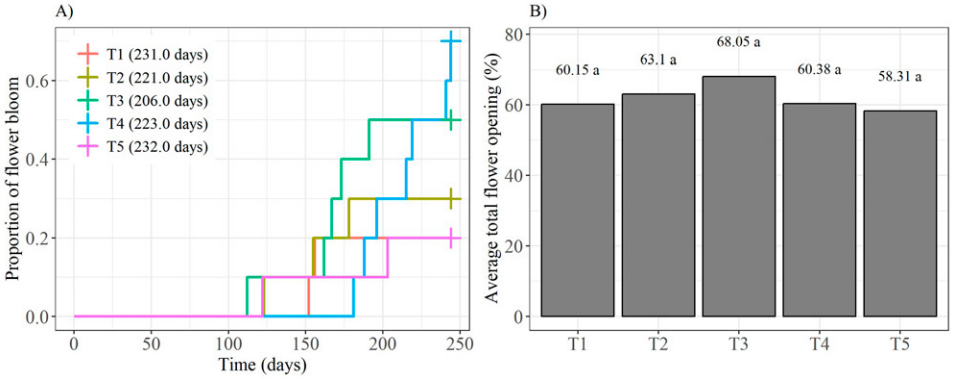


Fig. 2. Survival analysis for flower spike (A) and average flower stem sprouts (B) as a function of different doses of GA_3: T1: 0, T2: 50, T3: 100, T4: 200, and T5: 400 mg L^{-1}. Means followed by the same lowercase letter in the column do not differ using the non-parametric log-Rank test. *p*-value=0.0029.

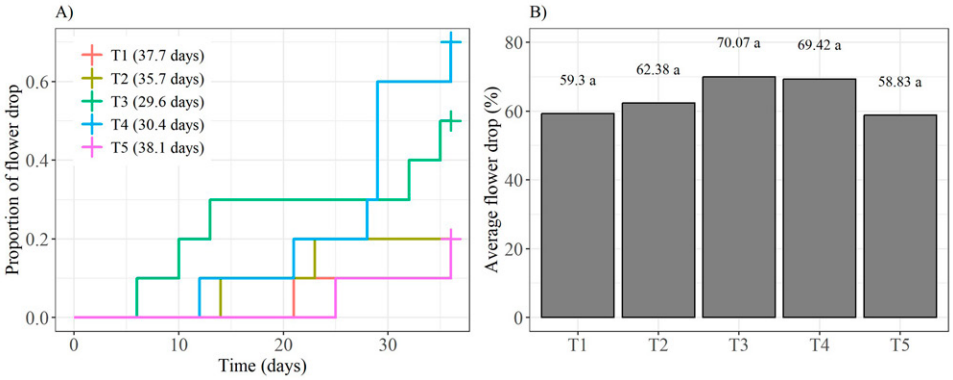
The proportion of opened flowers (TFOF) ranged between 206 and 232 days after bud initiation, represented by treatments 3 and 5, respectively (Fig. 3A). However, these same treatments showed both shorter and longer period to reach total flower drop (TFF), respectively, with the time ranging from 29 (T3) to 38 (T5) days (Fig. 4A). The percentage of average flower opening in relation to the plant with the greatest flower bud opening ranged from 58.31% (T5) to 68.05% (T3) (Fig. 3B) and the average percentage of flower drop between plants with the longest maintenance of flowers ranged from 58.83% to 70.07% for treatments 5 and 3, respectively (Fig. 4B). However, the values of these four parameters showed no statistical difference based on the non-parametric log-Rank test.

Fig. 3. Survival analysis for opened flower rate (A) and average



total flower opening (B) as a function of different doses of GA_3: T1: 0, T2: 50, T3: 100, T4: 200, and T5: 400 mg L^{-1}. Means followed by the same lowercase letter in the column do not differ based on the non-parametric log-Rank test. *p*-value = 0.23.

Fig. 4. Survival analysis for total flower drop (A) and average flower drop (B) as a function of different doses of GA_3: T1: 0, T2: 50, T3: 100,



T4: 200, and T5: 400 mg L^{-1}. Means followed by the same lowercase letter in the column do not differ based on the non-parametric log-Rank test. *p*-value=0.05.

The concentration of 200 mg GA_3 L^{-1} led to the highest average flower stem length (FSL), with a value of 177.6 cm (Table 1). As for the number of flowers per stem (NFS), the concentration of 50 mg GA_3 L^{-1} (T2) resulted in an average of 126, the highest among the treatments. The values in Table 1 were obtained using descriptive statistics because the data did not meet the ANOVA assumptions.

Table 1. Average values for flower stem length (FSL), in cm, and number of flowers per stem (NFS) according to the concentration of GA_3.

Treatments	mg L^{-1} GA_3	FSL	NFS
T1	0	146.5	90.5
T2	50	145.6	126.0
T3	100	123.3	63.6
T4	200	177.6	102.9
T5	400	154.0	57.5

Regarding vegetative growth parameters, the doses of GA_3 did not influence PW and LW, according to Tukey's mean comparison test at 5% significance. Applying 200 mg GA_3 L^{-1} led to a higher mean PL value (13.97 cm), while 400 mg L^{-1} resulted in a lower mean length (9.20 cm). The treatments with 0, 50, and 100 mg GA_3 L^{-1} did not differ from each other, being 11.02, 11.50 and 12.26 cm, respectively. These showed no difference from the dose that led to the highest (200 mg L^{-1}) and lowest (400 mg L^{-1}) results. The distribution of results in the dose-response graph (Fig. 5A) was fit to a quadratic function and showed its maximum point close to 200 mg L^{-1}.

The highest LL averages were 44.22, 43.60 and 42.97 cm at concentrations of 50, 100, and 200 mg L^{-1}, which did not differ from each other, but differed from 400 mg L^{-1}, which had a lower average (32.02 cm). For LL, the control treatment did not differ from the other treatments. Mean NL was higher under 0, 100, and 200 mg GA_3 L^{-1}, (14.60, 11.60, and 12.20 cm respectively) whereas 50 mg GA_3 L^{-1} (10.40 cm) did not differ from these, but it was also indistinguishable from 400 mg GA_3 L^{-1}, which had a smaller average number of leaves (7.0 cm). Table 2 shows the averages of the mentioned parameters according to the different GA_3 doses applied to *O. baueri* plants.

Table 2. Means of pseudobulb length (PL) and width (PW), leaf length (LL) and width (LW) and number of leaves per plant (NL). Treatments were T1: control (0), T2: 50, T3: 100, T4: 200 and T5: 400 mg GA_3 L^{-1}.

Treatments	mg L^{-1} GA_3	PL	PW	LL	LW	NL
T1	0	11.02 ab	3.78 a	39.88 ab	3.20 a	14.60 a[t]
T2	50	11.50 ab	3.58 a	44.22 a	2.94 a	10.40 ab
T3	100	12.26 ab	3.30 a	43.60 a	3.38 a	11.60 a
T4	200	13.97 a	3.05 a	42.97 a	3.33 a	12.20 a
T5	400	9.20 b	3.31 a	32.02 b	2.72 a	7.00 b
--	CV (%)	18.25	18.60	10.85	14.10	11.43
--	p-value	0.03	0.43	0.01	0.13	0.01

Means followed by the same lowercase letter in the column do not differ by the Tukey test at 5% significance. CV - coefficient of variation. [t]Data transformed to *log*.

The variables in Table 2 were subjected to quadratic regression analysis to represent the dose-response variation of the parameters, The quadratic function provided the best fit for the data. Figure 5 shows the behavior of the variables Pseudobulb Length (A), Pseudobulb Width (B), Leaf Length (C), Leaf Width (D) and Number of Leaves (E) for the different doses of GA_3. The ideal doses, based on the highest outcomes for PL, PW, LL, LW and NL parameters, were estimated at 182, 0, 137, 156, and 0 mg GA_3 L^{-1}, respectively.

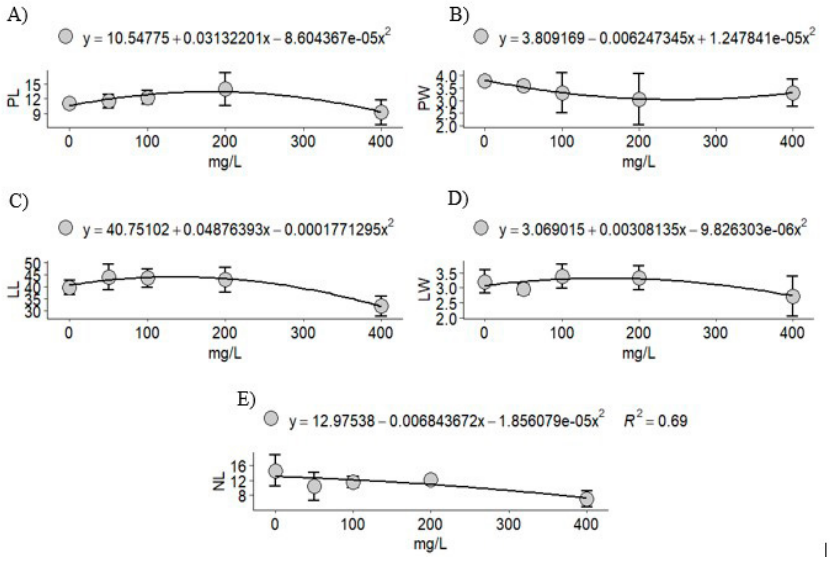


Fig. 5. Response curve for Pseudobulb Length (A), Pseudobulb Width (B), Leaf Length (C), Leaf Width (D) (cm) and Number of Leaves (E) at different GA_3 concentrations.

In relation to the physiological parameters represented in Fig. 6, the results obtained for fv/fm showed that treatment 4 (200 mg GA_3 L^{-1}) resulted in the highest overall average of 0.826. The doses of GA_3 at 0, 100 and 400 mg L^{-1} did not differ from treatment 4 and treatment 2 (50 mg GA_3 L^{-1}), the latter being responsible for the lowest mean. For G_s, 200 mg GA_3 L^{-1} resulted in the highest average (65.340 mmol m^{-2} s^{-1}). The treatments with 50 and 400 mg GA_3 L^{-1} resulted in lower averages, however, they did not differ from the treatments with 0 and 100 mg GA_3 L^{-1}, these in turn also did not differ from the average of the treatment with 200 mg GA_3 L^{-1}.

These parameters were fitted to quadratic models (Fig. 6). The estimated dose to obtain the highest fv/fm value (0.82), represented by the y axis, is 241 mg GA_3 L^{-1} (Fig. 6A). For G_s, the maximum point of the curve is 57.3 mmol m^{-2} s^{-1} (y axis) with the estimated dose of 176 mg GA_3 L^{-1}. These ideal values were estimated using the models, but among the doses tested in the work, treatment 4 (200 mg GA_3 L^{-1}) is the dose that represented the closest value for the best responses in both physiological analyses.

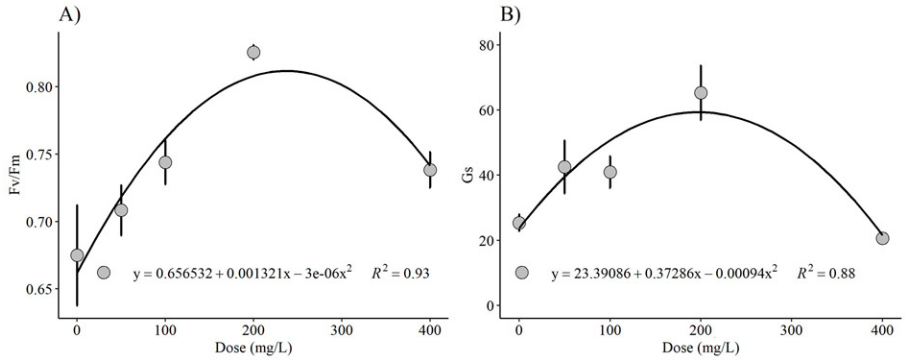


Fig. 6. Response curve for chlorophyll *a* fluorescence (fv/fm) (A) and stomatal conductance (G_s) (B) in mmol m^{-2} s^{-1} at different GA_3 concentrations.

Discussion

The environment governs flowering in orchids, and temperature is an important factor in floral transition of most Orchidaceae species, being essential and vital for plant growth and development (Nunes et al., 2020; Menegaes et al., 2022). Conversely, endogenous hormonal regulation plays an important role in flower regulation; therefore, several studies have been carried out to explore how exogenous applications of plant regulators can induce flowering (Wang et al., 2019).

According to Ahmad et al. (2022b), the regulation of flowering is a complex process involving multiple pathways regulated by intrinsic and extrinsic stimuli. The long juvenile phases of orchids pose a challenge for researchers aiming to achieve continuous flowering, which could not only accelerate the market success of orchid flowers but also bring about an ornamental revolution. The present study provides data indicating possible effects of synthetic GA_3 on the reproductive, morphological, and physiological parameters of *O. baueri*.

Exogenous applications of GA_3 in orchids interact with kinetin (KIN), increasing plant growth. The two substances show an opposite behavior when plants undergo flower induction. While induced plants show an increase in GA_3 and a decrease in KIN by around 30%, non-induced plants respond in an opposite way, with a higher concentration of KIN and a lower concentration of GA_3 (Tejeda-Sartorius et al., 2022).

Gibberellins regulate many plant development processes, including the main flowering stage. The differentiation of vegetative buds in flowering plants is related to the balance between polyamines and gibberellins (Verdolin et al., 2021). Tejeda-Sartorius et al. (2021) when treating *Laelia anceps* Lindl. plants with exogenous GA_3 showed significant consistency in reducing the days to visible flower induction, days to anthesis, and increasing the floral lifespan and floral stems, with no floral malformations, confirming the beneficial effects on various evaluated aspects of flowering. Similar to this report, our study found that *O. baueri* plants sprayed with 200 mg GA_3 L^{-1} shortened by half the time for flower spike to sprout (TFSS) in relation to the control treatment (Fig. 2). For TFOF and TFF, despite the lack of significant statistical effects, there was a tendency towards a reduction in the period for flower opening in 25 days with the dose of 100 mg GA_3 L^{-1} in relation to the control (Fig. 3) and the dose of GA_3 at 400 mg L^{-1} revealed a trend towards a longer flowering period (38 days) according to the log-Rank test (Fig. 4).

The formation of flower meristems is governed by a hormonal balance of several plant regulators, including gibberellin. In this process, genes responsible for the events resulting from the action of phytohormones are activated. Flower bud initiation and flowering time are modulated by the SVP regulator, and through its interaction with FLC and FLM (*flowering locus*), SVP coordinates gibberellin in reproductive processes (Ordoñez-Herrera et al., 2018). Ahmad et al. (2022b) found that gibberellin 20 oxidase 1-4 and gibberellin 2-beta dioxygenase 8 genes are highly upregulated during the biosynthesis of GA_3, and their expression is linked to both the species and the environment. Tejeda-Sartorius et al. (2021) also report the effect of regulators on flower promotion is more evident in wild species, which corroborates our results because *O. baueri* is not yet a domesticated species (Faria and Colombo, 2015).

The application of GA_3 has shown to double the number of flowers in inflorescences and increase the size of floral pedicels by approximately 1.7 times of *Dendrobium* sp. plants compared with controls (Khairul-Anuar et al., 2021). Silveira and Stefanello (2013) reported that a dose of GA_3 at 50 mg L^{-1} resulted in greater stem length in *M. flavescens*. Increases in reproductive traits from using GA_3 application were also observed in this work, with 50 mg L^{-1} resulting in an average of 126 flowers per stem, and 200 mg L^{-1} in an average of 177.6 cm for flower stem length.

Gibberellin promotes cell division in vegetative meristems, thereby affecting plant morphology (de Paula et al., 2023). It also favors flower development in Phalaenopsis, can restore the blockage of flower development in *Phalaenopsis hybrida* due to high temperatures, and controls important processes such as stem elongation, induces bud release, regulates bud opening, and flowering time (Ahmad et al., 2022a). For vegetative measurements, pseudobulb length (PL), leaf length (LL) and number of leaves (NL) were favored by GA_3 use. Verdolin et al. (2021) applied GA_3 to *Impatiens hawkeri* W.Bull and also reported greater number of leaves and contribution to plant height. Higher values of PL, LL and NL were also observed when using GA_3 in *Phalaenopsis* Blume plants (Lee et al., 2021). Lakshmaiah et al. (2019) also reported an increase in plant height, number of lateral shoots and leaves in Lisianthus (*Eustoma grandiflorum* [Raf.] Shinn.) when sprayed with 150 mg L^{-1} GA_3.

Miltonia flavescens Lindl. treated with GA_3 showed no difference for the variables PW and LL; however, LW and NL were higher when treated with 25 mg L^{-1} (Silveira and Stefanello, 2013). The authors reported the NL decreased with increasing GA_3 concentration, which corroborates our results (Table 2). This suggests that possible toxicity could result from the regulator's ability to induce stress, as well as metabolic and hormonal imbalances in the plant. In line with these results, our study demonstrated the plants showed yellowing of older leaves in the first weeks of application, and when measuring the LL and LW of leaves, early senescence of leaves could have directly interfered with these variables because the highest dose (400 mg L^{-1} of GA_3) had few mature, well-developed leaves.

GA_3 can reduce photochemical quenching, which is the proportion of open FSII reaction centers, which affects electron transport. The potential of this hormone to stretch tissues can alter chlorophyll levels, which contributes to light use efficiency (Li et al., 2021). Therefore, the different fv/fm results obtained from the doses may vary with the response of each species to exogenous hormonal applications. Khandaker et al. (2015) treated *Syzygium samarangense* plants with GA_3 and concluded that this regulator may increase chlorophyll fluorescence and quantum yield of this species. The application of gibberellin can increase chlorophyll fluorescence by promoting leaf growth, stimulating chlorophyll production, and improving the overall health of the plant, which results in a larger leaf area and better light absorption. This hormonal potential could also be evidenced in this work, with doses of GA_3 at 100 and 200 mg L^{-1} resulting in higher average values of fv/fm.

Lower concentrations of GA_3 can activate genes associated with plant tolerance to different types of stress. Furthermore, the lower GA_3 activity is associated with abscisic acid, which has an antagonistic effect on gibberellin and promotes stomatal closure through a cascade of reactions, reducing stomatal conductance. It is worth mentioning that the results also indicated a reduction in stomatal conductance at higher concentrations (400 mg L^{-1}), which can be explained by the upregulation of genes that modulate and deactivate GA_3 production, thus affecting the hormone's response (Illouz-Eliaz et al., 2020).

Conclusions

Exogenous application of GA_3 to *O. baueri* plants can replace environmentally driven flower induction and promote vegetative growth. The concentration of 200 mg L^{-1} showed a greater tendency for good results in the dose response curves for pseudobulb and leaf length, number of leaves, time for flower spike to sprout, and physiological traits, with greater chlorophyll *a* fluorescence and stomatal conductance. The use of GA_3 is recommended to *O. baueri* for improving vegetative growth and flowering.

Acknowledgements

I would like to express my gratitude to my academic colleagues involved in the work, for their assistance in conducting the experiment. To my advisor Dr. Ricardo Faria for his teachings. To the State University of Londrina (UEL) for the excellent academic structure and which allowed the meeting with the people involved in the work, and to Araucária Foundation for promoting education in the state of Paraná.

Author Contribution

KAM: conception and project development, methodology and writing of the manuscript; **GSG** and **CEOB**: conducting the experiment and writing; **GDS**: data interpretation and statistical analysis; **JCBP**: setting up the experiment; **HRG**: data collection; **RTF**: design, guidance on conducting, designing and collecting data for the experiment. All authors reviewed and approved the manuscript.

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 on request.

References

AHMAD, S.; PENG, D.; ZHOU, Y.; ZHAO, K. The genetic and hormonal inducers of continuous flowering in orchids: An emerging view. **Cells**, v.11, n.4, p.1-17, 2022a. https://doi.org/10.3390/cells11040657

AHMAD, S.; YANG, K.; CHEN, G.; HUANG, J.; HAO, Y.; TU, S.; PENG, D. Transcriptome mining of hormonal and floral integrators in the leafless flowers of three cymbidium orchids. **Frontiers in Plant Science**, v.13, p.1043099, 2022b. https://doi.org/10.3389/fpls.2022.1043099

BOX, G.E.; COX, D.R. An analysis of transformations. **Journal of the Royal Statistical Society: Series B (Methodological)**, v.26, n.2, p.211-243, 1964.

BRAINER, M.S.C.P. **Flores e plantas ornamentais**. Cadernos setorial ETENE n.95. Fortaleza: Banco do Brasil, 2019.

DE PAULA, J.C.B.; GUARIZ, H.R.; DE MORAES, K.A.M.; SHIMIZU, G.D.; DE FARIA, R.T.; DE OLIVEIRA, H.C.; FRACETO, L.F.; SANTO PEREIRA, A.E. Enhanced germination of seeds native to Brazil: A comparative analysis between free and nanoencapsulated gibberellic acid in *Dyckia* sp. (Bromeliaceae). **Folia Horticulturae**, v.35, n.2, p.1-16, 2023. https://doi.org/10.2478/fhort-2023-0029

ENDRES, D.; SASAMORI, M.H.; SCHMITT, J.L.; DROSTE, A. Survival and development of reintroduced *Cattleya intermedia* plants related to abiotic factors and herbivory at the edge and in the interior of a forest fragment in South Brazil. **Acta Botanica Brasilica**, v.32, n.4, p.555-566, 2018. https://doi.org/10.1590/0102-33062018abb0009

FARIA, R.T.D.; COLOMBO, R.C. *Oncidium*: the expanding orchid in the flowering scene. **Horticultura Brasileira**, v.33, n.4, p.533-533, 2015. https://doi.org/10.1590/S0102-053620150000400022

GUARIZ, H.R.; SHIMIZU, G.D.; PAULA, J.C.; SPERANDIO, H.V.; RIBEIRO JUNIOR, W.A.; OLIVEIRA, H.C.; JUSSIANI, E.I.; ANDRELLO, A.C.; MARUBAYASHI, R.Y.P.; PICOLI, M.H.S.; RUEDIGER, J.; COUTO, A.P.S.; MORAES, K.A.. Anatomy and Germination of *Erythrina velutina* Seeds under a different imbibition period in gibberellin. **Seeds**, v.1, n.3, p.210-220, 2022. https://doi.org/10.3390/seeds1030018

HUANG, J.Z.; VILLEGAS, P.B.; CHEN, F.C. Regulation of flowering in orchids. In: CHEN, F.C.; CHIN, S.W. **The Orchid Genome**. Compendium of Plant Genomes. Cham: Springer, 2021. p.73-94. https://doi.org/10.1007/978-3-030-66826-6_6

IBRAFLOR (Instituto Brasileiro de Floricultura). O mercado de flores no brasil (01/2024). Available at: <https://www.ibraflor.com.br/_files/ugd/5bcab9_1de516ce08144d058bd8167c5db12ca8.pdf. Accessed on: August 19th, 2024.

ILLOUZ-ELIAZ, N.; NISSAN, I.; NIR, I.; RAMON, U.; SHOHAT, H.; WEISS, D. Mutations in the tomato gibberellin receptors suppress xylem proliferation and reduce water loss under water-deficit conditions. **Journal of Experimental Botany**, v.71, n.12, p.3603-3612, 2020. https://doi.org/10.1093/jxb/eraa137

KHAIRUL-ANUAR, M.A.; MAZUMDAR, P.; LUM, S.; HARIKRISHNA, J.A. *Dendrobium* hybrid flower number and pedicel curvature is influenced by the application of gibberellic acid and indole-3-acetic acid. **Biology Bulletin**, v.48, n.6, p.740-745, 2021. https://doi.org/10.1134/S1062359021130057

KHANDAKER, M.M.; MAJRASHI, A.; BOYCE, A.N. The influence of gibberellic acid on the chlorophyll fluorescence, protein content and PAL activity of wax apple (*Syzygium samarangense* var. *jambu madu*) fruits. **Australian Journal of Crop Science**, v.9, n.12, p.1221-1227, 2015. https://search.informit.org/doi/abs/10.3316/informit.769396779143664.

LAKSHMAIAH, K.; SUBRAMANIAN, S.; GANGA, M.; JEYAKUMAR, P. Optimization of pinching and GA3 application to improve growth and flowering of lisianthus (*Eustoma grandiflorum*). **Journal of Pharmacognosy and Phytochemistry**, v.8, n.6, p.614-616, 2019.

LEE, H.B.; IM, N.H.; AN, S.K.; KIM, K.S. Changes of growth and inflorescence initiation by exogenous gibberellic acid3 and 6-benzylaminopurine application in *Phalaenopsis* Orchids. **Agronomy**, v.11, n.2, p.1-10, 2021. https://doi.org/10.3390/agronomy11020196

LI, W.; XIANG, F.; SU, Y.; LUO, Z.; LUO, W.; ZHOU, L.; XIAO, L. Gibberellin increases the bud yield and theanine accumulation in *Camellia sinensis* (L.) Kuntze. **Molecules**, v.26, n.11, p.1-14, 2021. https://doi.org/10.3390/molecules26113290

MENEGAES, J.F.; FERREIRA, C.F.; MOCCELLIN, R. **Plantas ornamentais: conceitos básicos de cultivo**. Nova Xavantina: Pantanal Editora, 2022. 144p. https://doi.org/10.46420/9786581460549

MEZZALIRA, F.K.; KUHN, B.C. 2021. Padronização de um protocolo para assepsia de segmentos nodais de *Phalaenopsis* para clonagem in vitro. **Colloquium Agrariae**, v.17, n.1. p.10-17, 2021. https://doi.org/10.5747/ca.2021.v17.n1.a415

NADAL, M.C.; ASSIS, A.M.; SCHUCH, M.W.; FARIA, R.T. Grape-based residue as a substrate in Oncidium baueri Lindl. acclimatization. **Ornamental Horticulture**, v.28, n.2, p.239-245, 2022. https://doi.org/10.1590/2447-536X.v28i2.2477

NUNES, E.L.; PELUZIO, L.E.; PERUSSO, G.; CARVALHO, T.S. Monitoramento ambiental de área controlada para produção de orquídeas: caracterização sazonal das variáveis climáticas. **Revista Ponto de Vista**, v.9, n.2, p.37-53, 2020. https://doi.org/10.47328/rpv.v9i02.10822.

ORDOÑEZ-HERRERA, N.; TRIMBORN, L.; MENJE, M.; HENSCHEL, M.; ROBERS, L.; KAUFHOLDT, D.; HOECKER, U. The transcription factor COL12 is a substrate of the COP1/SPA E3 ligase and regulates flowering time and plant architecture. **Plant Physiology**, v.176, n.2, p.1327-1340, 2018. https://doi.org/10.1104/pp.17.01207

PAIXÃO, M.V.S.; GROBÉRIO, R.B.C.; HOFFAY, A.C.N.; CORREA, A.C.; CREMONINI, G.M. Ácido giberélico na germinação de sementes e desenvolvimento inicial de plântulas de mamoeiro. **Agrotrópica**, v.33, n.2, p.143-148, 2021. https://doi.org/10.21757/0103-3816.2021v33n2p143-148

PEIXOTO, P.H.P.; PIMENTA, M.R.; REIS, L.B. **Fisiologia Vegetal: Uma abordagem prática em multimídia**. Juiz de Fora: Instituto de Ciências Biológicas, 2024. 88p.

R CORE TEAM. R: A language and environment for statistical computing. **R Foundation for Statistical Computing**, 2024. Available from: <https://www.R-project.org>.

REFLORA. **Orchidaceae in Flora e Funga do Brasil**. Rio de Janeiro: Jardim Botânico do Rio de Janeiro, 2024. Available from: https://floradobrasil.jbrj.gov.br/FB179. Accessed: feb. 10, 2024.

RIEGER, M.M. Surfactants. In: LIEBERMAN, H.; RIEGER, M.; BANKER, G.S. **Pharmaceutical Dosage Forms**. New York: CRC Press., 2020. p.211-286.

SHIMIZU, M.; ISHIDA, A.; TANGE, T.; YAGI, H. Leaf turnover and growth responses of shade-grown saplings of four Shorea rain forest species to a sudden increase in light. **Tree physiology**, v.26, n.4, p.449-457, 2006. https://doi.org/10.1093/treephys/26.4.449

SILVEIRA, E.V.; STEFANELLO, S. Growth and Flowering of *Miltonia flavescens* LINDL. plants. (ORCHIDACEAE) treated with Giberellic acid. **Revista em Agronegócio e Meio Ambiente**, v.6, n.2, 2013. https://doi.org/10.17765/2176-9168.2013v6n2p%25p

TEJEDA-SARTORIUS, O.; SOTO-HERNÁNDEZ, R.M.; SAN MIGUEL-CHÁVEZ, R.; TREJO-TÉLLEZ, L.I.; CAAMAL-VELÁZQUEZ, H. Endogenous hormone profile and sugars display differential distribution in leaves and pseudobulbs of *Laelia anceps* plants induced and non-induced to flowering by exogenous gibberellic acid. **Plants**, v.11, n.7, p.845, 2022. https://doi.org/10.3390/plants11070845

TEJEDA-SARTORIUS, O.; VAQUERA-HUERTA, H.; TREJO-TÉLLEZ, L.I.; SOTO-HERNÁNDEZ, R.M.; SÁNCHEZ-ESCUDERO, J. Gibberellic acid and 6-benzyladenine reduce time to flowering and improve flower quality of *Laelia anceps*. **Folia Horticulturae**, v.33, n.1, p.121-133, 2021. https://doi.org/10.2478/fhort-2021-0009

VERDOLIN, L.G.; MARIZ, M.L.; DIAS, L.L.C. Gibberellin and polyamines effects in growth and flowering of New Guinea impatiens. **Ornamental Horticulturae**, v.27, n.2, p.247-254, 2021. https://doi.org/10.1590/2447-536X.v27i2.2255

WANG, S.L.; VISWANATH, K.K.; TONG, C.G.; AN, H.R., JANG, S.; CHEN, F.C. Floral induction and flower development of orchids. **Frontiers in Plant Science**, v.10, n.1258, p.1-15, 2019. https://doi.org/10.3389/fpls.2019.01258

WCSP (WORLD CHECKLIST OF SELECTED PLANTS FAMILIES). **Ochidaceae**, 2019. Royal Botanic Gardens, Kew. Available at: < https://powo.science.kew.org/>. Accessed on: Feb. 10, 2024.

World Flora Online – WFO. (2024). **Published on the Internet**; Available at: http://www.worldfloraonline.org. Accessed on: 10 de jan. de 2024.