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ARTICLE

Growth enhancement of *Anthurium* seedlings using Arbolina

Estímulo do crescimento de mudas de antúrio com o uso da Arbolina

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Abstract
Species of the *Anthurium* genus are renowned for their ornamental and landscaping potential. Among native Brazilian species, *Anthurium affine* and *Anthurium maricense* are particularly suited for indoor cultivation due to their shaded-condition tolerance and slow growth. However, accelerating the production cycle presents a significant challenge for producers. Organic carbon nanoparticle-based biostimulants, such as Carbon Dots, have shown promise by enhancing nutrient uptake, water use efficiency, and plant growth. This study evaluated the effects of a biostimulant nanocomposite (Arbolina®) based on organic carbon nanoparticles on seedlings of *A. affine* and *A. maricense*. Seedlings (85 days old) were transplanted and treated with the biostimulant at 60 mg L^{-1} concentration via foliar and soil applications, alongside a control group. Biostimulant treatments were applied biweekly for a total of four applications. Plant height and leaf count were measured every 30 days, while fresh weight, leaf area, root volume, and dry weights of leaves and roots were assessed after 96 days of cultivation. Results showed no significant variations in aerial growth parameters; however, soil application significantly increased root volume in both species. In *A. affine*, differences in root volume were also detected under foliar application. It is concluded that the biostimulant, at the applied concentration, did not accelerate the shoot growth of juvenile seedlings within the experimental period. Nonetheless, soil application was identified as the most effective method for promoting root system development. These findings demonstrate the potential for targeted use of biostimulants to optimize specific growth traits in *Anthurium* cultivation.
Keywords: *Anthurium affine, Anthurium maricense*, Carbon Dots, nanoparticle.

Resumo
Espécies do gênero *Anthurium* são reconhecidas por seu potencial ornamental e paisagístico. Entre as espécies nativas do Brasil, *Anthurium affine* e *Anthurium maricense* destacam-se por sua tolerância a condições de sombra e crescimento lento, características ideais para cultivo em ambientes internos. No entanto, acelerar o ciclo de produção representa um desafio significativo para os produtores. Biostimulantes à base de nanopartículas de carbono orgânico, como os Carbon Dots, têm demonstrado potencial ao melhorar a absorção de nutrientes, a eficiência no uso da água e o crescimento das plantas. Este estudo avaliou os efeitos de um biostimulante nanocompósito (Arbolina®), baseado em nanopartículas de carbono orgânico, em mudas de *A. affine* e *A. maricense*. Mudas com 85 dias de idade foram transplantadas e submetidas a tratamentos com o biostimulante na concentração de 60 mg L^{-1}, aplicados via foliar e via solo, além de um grupo controle. Os substratos foram suplementados com fertilizante de liberação lenta, e as plantas foram irrigadas três vezes ao dia. Os tratamentos com o biostimulante foram aplicados quinzenalmente, totalizando quatro aplicações. A altura das plantas e o número de folhas foram medidos a cada 30 dias, enquanto peso fresco, área foliar, volume radicular e pesos secos de folhas e raízes foram avaliados após 96 dias de cultivo. Os resultados não mostraram variações significativas nos parâmetros de crescimento da parte aérea em ambas as espécies. No entanto, a aplicação via solo aumentou significativamente o volume radicular em ambas espécies. Em *A. affine* diferenças no volume de raiz também foram observados sob a aplicação via foliar. Conclui-se que o bioestimulante, na concentração aplicada, não acelerou o crescimento aéreo das mudas juvenis no período experimental. Ainda assim, a aplicação via solo foi identificada como o método mais eficaz para promover o desenvolvimento do sistema radicular em *A. affine*. Esses achados destacam o potencial do uso direcionado de biostimulantes para otimizar características específicas de crescimento no cultivo de *Anthurium*.
Palavras-chave: *Anthurium maricense, Anthurium affine*, Carbon Dots, nanopartícula.

Introduction

The Araceae family includes diverse species, with those in the genus *Anthurium* playing a prominent role in landscaping and interior decoration, driven by the "Urban Jungle" movement. This trend emphasizes the abundant use of plants in indoor and urban spaces, enhancing aesthetic and environmental quality (Beckmann-Cavalcante, 2021; Sheeran and Rasmussen, 2023). Despite their significant ornamental potential, many *Anthurium* species remain underutilized, often restricted to extractive uses that raise concerns about genetic erosion (Castro et al., 2022).

Anthurium Schott is a genus estimated to comprise 950 species, many of which are endemic to Brazil. The genus currently includes 20 sections, but only five have representatives in Brazil, including *Anthurium sect. Urospadix* (Engler) and *A. sect. Pachyneurium* (Schott) Engler (Camelo et al., 2023).

In Brazil, several native *Anthurium* species exhibit considerable ornamental value, particularly as indoor plants due to their adaptation to low-light conditions and ease of care. *Anthurium maricense* (*sect. Urospadix*) and *Anthurium affine* (*sect. Pachyneurium*) are two outstanding examples (Taniguchi et al., 2018; Silva et al., 2023). These species are appreciated for their slow growth, low maintenance requirements, and longevity, qualities that appeal to consumers seeking sustainable and manageable plant options.

Anthurium maricense Nadruz & Mayo, a terrestrial herb endemic to Brazil, grows in the Atlantic Forest, particularly in coastal vegetation known as "restinga" (Coelho, 2020). It is oval to oblong leaves are green and coriaceous, with barely visible secondary veins (Valadares et al., 2021), making them well suited for potted cultivation by combining compact growth with attractive aesthetics and simple care requirements (Taniguchi et al., 2018). In contrast, *Anthurium affine* Schott, also endemic to Brazil, is a terrestrial to rupicolous plant distributed across diverse vegetation types (Coelho, 2020). It features large, prominently undulated and coriaceous leaves with a distinct mibrid and lateral primary veins

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visible from the adaxial view, enhancing its ornamental appeal for potted displays and landscaping projects (Maia et al., 2020). Additionally, it possesses a remarkable short, densely rooted caudex, a thickened structure acting as a transitional organ between the roots and stem, contributing to both stability and resource absorption (Camelo et al., 2021).

Due to their evolutionary traits, *Anthurium* species naturally exhibit slow growth, especially during early developmental stages (Taniguchi et al., 2018; Artur et al., 2022). While this slow growth is desirable for the final consumer, reducing the need for maintenance and repotting, it can delay profitability in commercial production. To overcome this, technological advancements such as the application of plant growth biostimulants have been explored to enhance growth efficiency. These bioactive formulations, when applied exogenously, promote growth and improve quality and tolerance to environmental stresses (Hakim et al., 2022).

Biostimulants, composed of bioactive compounds or microorganisms, enhance nutrient absorption, strengthen stress resilience, and promote plant vigor through metabolic activation (Franzoni et al., 2022). While their efficacy as growth regulators is well established, it is essential to consider plant species and growth patterns to determine optimal application methods and dosages. Among biostimulant categories, nanoparticles have emerged as innovative tools due to their unique properties, particularly their nanoscale dimensions (< 100 nm). Carbon dots (C-Dots) have garnered attention for their low toxicity, photoluminescence, and biodegradability (Humaera et al., 2021). These nanoparticles can be applied through soil or foliar delivery, with varying effects depending on formulation and concentration (Dong et al., 2024).

C-Dot-enriched carbon-based biostimulants boost growth, productivity, and quality across various crops, offering promising agricultural benefits (Li et al., 2024). Composed primarily of carbon, nitrogen, and oxygen, their nanoscale particles facilitate efficient leaf absorption, especially under adequate humidity conditions. Once absorbed, they activate metabolic pathways linked to photosynthesis, increasing chlorophyll content, enhancing light absorption, and optimizing energy utilization (Guo et al., 2022). These processes contribute to improved plant vigor and stress tolerance. In addition to promoting plant development, these biostimulants are biodegradable, leave no harmful residues, and are environmentally friendly. They maintain soil and aquatic ecosystem health, exhibit biocompatibility, and can be integrated with other agricultural inputs (Vieira et al., 2024).

Based on this context, the present study aimed to evaluate the application of a carbon- and nitrogen-carrying nanotechnology product through two delivery methods (soil and foliar) to enhance the growth of *A. maricense* and *A. affine*.

Material and methods

The experiment was conducted in a greenhouse at Embrapa Agroindústria Tropical (Fortaleza, Ceará State, Brazil; 3°44' S, 38°33' W; 19.5 m a.s.l.). The greenhouse was covered with a black shade cloth providing 80% shading. The region's climate is classified as Aw' according to Köppen.

Seeds of *Anthurium* species were initially collected from mature infructescences. The fruits were separated from the stems, and the pulp was thoroughly removed under running water with the aid of a sieve. The cleaned seeds were then dried on filter paper, placed in Petri dishes, and stored at 5 °C in a refrigerator, for five days, until sowing.

For sowing, plastic trays with 120 cells were filled with a substrate composed of coconut coir and a commercial organic substrate in a 1:1 ratio. Seeds were sown individually per cell onto the moist substrate and maintained in a screened structure with 80% shading. An overhead sprinkler irrigation system watered the plantlets daily for 15 minutes, providing sufficient moisture near the roots without causing drainage or waterlogging. Irrigation was suspended on rainy days.

Germination began three weeks after sowing. At 85 days after sowing (DAS), healthy and uniform seedlings were selected for transplantation into pots. A. affine seedlings were selected with two fully expanded leaves, while *A. maricense* seedlings had only one fully expanded leaf due to their smaller size and slower growth. Seedlings were transplanted into 415 mL polyethylene pots (N° 11) with dimensions of 7.8 × 10.2 × 7.8 cm (height, upper diameter, and lower diameter, respectively). These pots were filled with the same substrate used for initial sowing, enriched with a slow-release fertilizer (SRF). The SRF used was Osmocote® Plus 15-9-12 (N-P-K) 3M by Everris NA Inc., with a three-month release period enabled by its thermosensitive coating. We chose this fertilizer because it has been successfully used in *Anthurium* cultivation, according to Taniguchi et al. (2018).

The experimental design was completely randomized in a 2 × 3 factorial scheme, comprising two species and three application methods of the Arbolina® - carbon-based biostimulant C-Dots (foliar, soil, and control) with 20 replicates each, using one plant per pot as the experimental unit.

The Arbolina® was prepared at a concentration of 60 mg L^{-1}, as previously established for melon cultivation under similar conditions (Vieira et al., 2024). This liquid concentrate is classified as a Class A organomineral fertilizer, composed of carbon nanoparticles [Carbon Dots (C-Dots), 67.4%], nitrogen (11.6%), and oxygen (21%) (Vieira et al., 2024). Five milliliters of the product were applied biweekly, totaling four applications over a 60-day period. Foliar applications were performed using a manual spray bottle, while soil applications were administered near the plant collar with a squeeze bottle, both conducted at 10:00 a.m. Brasília time (BRT).

No pest or disease incidences were observed during the experimental period. Manual weeding was performed monthly. From 30 days after transplanting (DAT) until 90 DAT, monthly evaluations of plant height (PH) and leaf number (LN) were conducted. Plant height was measured with a ruler graduated in centimeters, from the plant base to the tip of the most recently expanded leaf. Leaf number was determined by direct counting.

At 96 days of cultivation, the seedlings were harvested and transported to the laboratory for analysis. Leaves and roots were separated and weighed individually. Leaf area (LA) was measured using a LI-COR® LI-3100C leaf area meter. The leaves and roots were subsequently dried in a forced-air circulation oven at 60-70 °C until constant weight was achieved and re-weighed.

Root volume (RV) was determined using a 100 mL graduated cylinder. The cylinder was filled to the 50 mL mark with water, and the cut roots from each treatment were submerged. The final water volume was recorded, and the root volume was calculated as the difference between the initial and final volumes, then converted from mL to cm³.

Correlation analyses were performed using raw data from the evaluated traits with the *corrplot package* (Wei and Simko, 2024) implemented in R software version 4.03 (R Core Team, 2021). Outliers were identified and removed using the *boxplot.stats* function in the R base package, followed by verification of trait adjustments via QQ-plots. Shapiro tests were conducted to assess data normality using basic functions from the *stats* package. The adjusted dataset was then used for subsequent analyses.

Analysis of variance (ANOVA) was conducted for each trait according to the following model:

$$y_{ijk} = e_i + a_j + ea_{ij} + \varepsilon_{ikj}$$

where, y_{ij}: observation for the *i-th* espécies under the *j-th* application method of Arbolina®, and in the *k-th* repetition; e_i: effect of the *i-th* species; a_j effect of the *j-th* application method of Arbolina®; ea_{ij}: interaction effect between the *i-th* species and the *j-th* application method of Arbolina®; *εikj*: random error associated with the *i-th* species, the *j-th* application method of Arbolina®, and the *k-th* repetition.

For each trait, the performance of *Anthurium* species was analyzed across the different Arbolina® application methods and differences among treatments were detected using Tukey test at $p < 0.05$.

Results and Discussion

The methods of application of Arbolina® and the interaction between species and application methods (S × A) showed no significant effects on aerial part traits up to 90 days after treatment (DAT) (Table 1). However, there was a significant effect of species, underscoring distinct growth rates between *Anthurium affine* and *A. maricense*.

Regarding root system traits, no significant differences were observed except for root volume (RV), which exhibited effects across all sources of variation (Table 2). This observation suggests that both species demonstrate variable responses to the different application methods of Arbolina® (Table 3).

Table 1. Calculated F-values from the analysis of variance for the shoot traits of *A. maricense* and *A. affine* subjected to three treatments: foliar-applied Arbolina®, soil-applied Arbolina, and the control (without Arbolina).

FV	PH_30[1]	PH _60	PH _90	LA	NL_30	NL_60	NL_90	LFM	LDM
Species (S)	356.72***	759.09***	484.23***	457.24***	293.43***	314.31***	147.95***	441.49***	426.77***
Arbolina (A)	0.15	0.11	1.22	0.39	0.34	0.97	0.33	0.80	0.14
S x A	1.28	0.08	0.58	1.14	1.36	1.43	2.69	0.63	0.39
CV (%)	15.5	21.6	22.1	37.5	17.5	13.6	13.9	40.4	42.4
	------------------ cm ------------------			--- cm^2 ---				------- g per plant -------	
Average	3.3	6.1	8.5	193.2	3.5	5.9	7.7	6.8	0.9

*** Significant at $p < 0.001$ by the F-test.

[1] Plant height and number of leaves at 30 (PH_30 and NL_30), 60 (PH_60 and NL_60), and 90 days (PH_90 and NL_90); leaf area (LA); fresh mass (LFM) and dry mass (LDM) of leaves.

Table 2. Calculated F-values from the analysis of variance for root system traits[1] of *A. maricense* and *A. affine* subjected to three treatments: foliar-applied Arbolina®, soil-applied Arbolina®, and the control (without Arbolina®).

FV	RFM	RDM	RL	RV
Species (S)	406.34***	383.45***	28.66***	97.08***
Arbolina (A)	0.88	0.13	0.33	6.87**
S x A	1.88	0.11	2.94	3.65*
CV (%)	39.2	43.8	20.6	34.3
	----------- g per plant -----------		---- cm ----	--- cm^3 ---
Average	25.1	1.2	16.7	37.3

***, **, and * Significant at $p < 0.001$, $p < 0.01$, and $p < 0.05$ by the F-test, respectively.

[1] Fresh mass (RFM) and dry mass (RDM) of roots; root length (RL) and root volume (RV).

Table 3. Means of the shoot and root system traits of the species *A. maricense* and *A. affine* subjected to three treatments: Arbolina® via foliar application (leaves), Arbolina® via soil application, and the control (without Arbolina®).

Treatment	PH_30[1] (cm)		PH _60 (cm)		PH _90 (cm)	
	A. affine	*A. maricense*	*A. affine*	*A. maricense*	*A. affine*	*A. maricense*
Control	4.32±0.21 A	2.30±0.20 B	9.50±0.64 A	2.64±0.42 B	12.10±1.07 A	4.86±0.54 B
Foliar	4.21±0.29 A	2.38±0.27 B	9.49±1.03 A	2.82±0.41 B	12.11±1.41 A	4.32±0.54 B
Soil	4.06±0.29 A	2.43±0.21 B	9.65±0.77 A	2.76±0.27 B	12.97±1.05 A	4.80±0.43 B
	LA (cm^2)		**NL_30**		**NL_60**	
	A. affine	*A. maricense*	*A. affine*	*A. maricense*	*A. affine*	*A. maricense*
Control	321.13±53.66 A	52.15±8.78 B	4.45±0.24 A	2.56±0.39 B	7.20±0.29 A	4.88±0.17 B
Foliar	346.84±53.66 A	42.56±8.40 B	4.55±0.24 A	2.30±0.34 B	7.25±0.30 A	4.25±0.54 B
Soil	337.68±47.29 A	53.31±8.34 B	4.45±0.32 A	2.55±0.28 B	7.20±0.34 A	2.55±0.28 B
	NL_90		**LFM (g per plant)**		**LDM (g per plant)**	
	A. affine	*A. maricense*	*A. affine*	*A. maricense*	*A. affine*	*A. maricense*
Control	9.00±0.50 A	6.40±0.49 B	12.57±2.06 A	1.46±0.32 B	1.66±0.26 A	0.16±0.04 B
Foliar	9.00±0.40 A	5.90±0.74 B	11.60±2.08 A	1.33±0.33 B	1.68±0.31 A	0.16±0.04 B
Soil	8.65±0.37 A	6.85±0.59 B	12.18±1.71 A	1.54±0.34 B	1.64±0.26 A	0.20±0.05 B
	RFM (g per plant)		**RDM(g per plant)**		**RL (cm)**	
	A. affine	*A. maricense*	*A. affine*	*A. maricense*	*A. affine*	*A. maricense*
Control	39.94±6.29 A	7.23±1.51 B	2.15±0.38 A	0.23±0.05 B	21.54±3.57 A	13.42±5.30 B
Foliar	50.50±5.20 A	5.55±1.58 B	2.06±0.34 A	0.21±0.05 B	21.66±4.31 A	10.58±2.29 B
Soil	44.97±6.53 A	6.01±0.86 B	2.09±0.29 A	0.26±0.05 B	18.10±2.87 A	15.12±1.54 B
	RV (cm^3)					
	A. affine	*A. maricense*				
Control	44.00±10.67 Ac	10.00±0.00 Bb				
Foliar	60.00±13.24 Ab	10.00±0.00 Bb				
Soil	84.00±26.14 Aa	16.00±8.37 Ba				

Means followed by the same uppercase letter in the rows and the same lowercase letter in the columns show no significant differences according to the Tukey test ($p < 0.05$).

[1] Plant height and number of leaves at 30 (PH_30 and NL_30), 60 (PH_60 and NL_60), and 90 days (PH_90 and NL_90); leaf area (LA); fresh mass (LFM) and dry mass (LDM) of leaves, fresh mass (RFM) and dry mass (RDM) of roots; root length (RL) and root volume (RV).

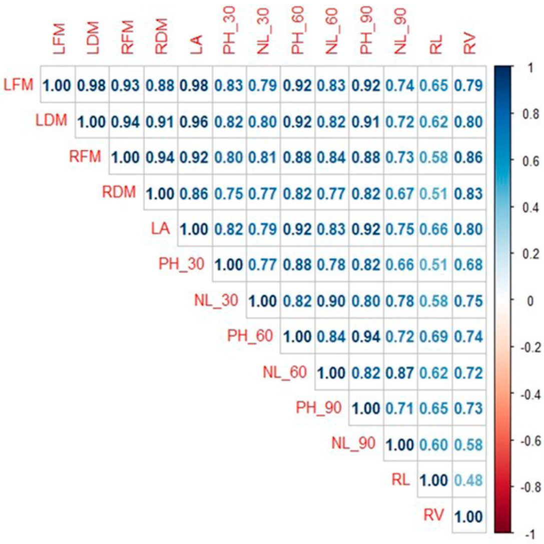
The observed differences were limited to the root volume, likely due to the naturally dense and well-developed root systems characteristic of *Anthurium* species, mainly *A. affine*. These plants are well adapted to environments with low precipitation and nutrient availability through a growth form that includes short-petiolate leaves and a densely rooted caudex. These vegetative structures enable the accumulation of rainwater and organic matter, contributing to their adaptation to environments with low precipitation and nutrient availability (Camelo et al., 2023).

Several factors may have influenced the experimental results, including an insufficient concentration of Arbolina® for the tested species and application during a phenological stage, characterized by slow growth. Although regular fertilization and appropriate irrigation management were maintained, Anthurium plants typically exhibit significant shoot growth only after 180 days of cultivation, coinciding with the emergence of the first inflorescences and increased metabolic activity. Thus, the experiment's duration may have been insufficient to produce statistically significant outcomes. Additionally, the frequency and dosage of Arbolina® applications may have been also insufficient to elicit measurable effects.

The anatomical traits of *Anthurium* roots and leaves likely contributed to the observed variations in treatment responses, particularly in root volume. *Anthurium* roots possess velamen, a specialized multilayered epidermis that enhances water and nutrient capture, reduces transpiration, protects the cortex, and mitigates heat stress on exposed roots (Sheeran and Rasmussen, 2023; Tay et al., 2024). These adaptations may explain the significant variation in root volume, particularly under different application methods of Arbolina®, as velamen could facilitate enhanced nutrient absorption when applied via soil. Conversely, the cuticle on leaves, a waxy protective layer, can limit nutrient absorption (Hong et al., 2021; Khan et al., 2022), potentially reducing the efficacy of foliar applications. This interplay between root and leaf anatomy likely contributed to more pronounced responses in root-related traits compared to aerial traits.

Anthurium leaves typically have a thick cuticle, varying by species and environmental conditions. Cuticle permeability also varies, being higher in species adapted to humid environments and lower in others to minimize water loss through evapotranspiration. This variability reflects the plants' adaptation to diverse humidity levels and sunlight exposure (Fernández et al., 2021). Additionally, the coriaceous epidermis may cause the biostimulant solution to run off along the prominent leaf veins, directing it toward the roots. This effect can be further enhanced by the leaf insertion angle, which may facilitate the downward flow of the solution.

To investigate associations between aerial and root system traits, a Pearson correlation analysis was conducted (Fig. 1). Significant correlations with moderate to high magnitudes were observed, indicating strong associations both within aerial traits and within root traits, as well as cross-associations between these groups. For instance, a correlation of 0.86 was found between root dry mass (RDM) and leaf area (LA).



	LFM	LDM	RFM	RDM	LA	PH_30	NL_30	PH_60	NL_60	PH_90	NL_90	RL	RV
LFM	1.00	0.98	0.93	0.88	0.98	0.83	0.79	0.92	0.83	0.92	0.74	0.65	0.79
LDM		1.00	0.94	0.91	0.96	0.82	0.80	0.92	0.82	0.91	0.72	0.62	0.80
RFM			1.00	0.94	0.92	0.80	0.81	0.88	0.84	0.88	0.73	0.58	0.86
RDM				1.00	0.86	0.75	0.77	0.82	0.77	0.82	0.67	0.51	0.83
LA					1.00	0.82	0.79	0.92	0.83	0.92	0.75	0.66	0.80
PH_30						1.00	0.77	0.88	0.78	0.82	0.66	0.51	0.68
NL_30							1.00	0.82	0.90	0.80	0.78	0.58	0.75
PH_60								1.00	0.84	0.94	0.72	0.69	0.74
NL_60									1.00	0.82	0.87	0.62	0.72
PH_90										1.00	0.71	0.65	0.73
NL_90											1.00	0.60	0.58
RL												1.00	0.48
RV													1.00

Fig. 1. Pearson correlations between the shoot and root system traits[1] of the species *A. maricense* and *A. affine* subjected to three treatments: Arbolina® via foliar application, Arbolina® via soil application, and the control (without Arbolina®).

Significant correlation coefficients ($p < 0.05$) according to the t-test are highlighted in blue.[1]Plant height and number of leaves at 30 (PH_30 and NL_30), 60 (PH_60 and NL_60), and 90 days (PH_90 and NL_90); leaf area (LA); fresh mass (LFM) and dry mass (LDM) of leaves, fresh mass (RFM) and dry mass (RDM) of roots; root length (RL) and root volume (RV).

Previous studies on anthurium have similarly reported positive correlations between leaf area and root dry mass (Taniguchi et al., 2018). Proper cultivation and nutrition practices can enhance anthurium productivity and quality, indirectly affecting the relationship between leaf area and root dry mass (Khawlhring et al., 2019).

Given the high correlation coefficients, certain traits could be excluded to streamline future evaluations. For example, the correlation between fresh leaf weight (FLW) and dry leaf weight (DLW) was 0.98, indicating an almost perfect relationship where one variable explains 98% of the variation in the other. Therefore, only the more practical or easily measurable trait could be assessed. Similarly, measurements at a single time point could suffice for traits such as plant height (PH_30, PH_60, or PH_90) and the number of leaves (NL_30, NL_60, or NL_90), significantly reducing the number of traits and labor required during experimental phases.

Conclusions

The application of the biostimulant Arbolina® at a concentration of 60 mg L^{-1} in juvenile plants of *Anthurium affine* and *Anthurium maricense* did not promote increased foliar growth or development up to 90 days of cultivation.

The soil application of Arbolina® significantly influences root system development, particularly increasing root volume, suggesting it may be the most effective approach for applying biostimulants to maximize plant growth.

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Author contribution

JVBS: Conceptualization, Data Curation, Investigation, Writing – Original Draft. **ACRC**: Conceptualization. Resources, Methodology, Data Curation, Writing – Review & Editing. **CAKT**: Conceptualization, Data Curation, Writing – Review & Editing. **NFM:** Conceptualization, Writing – Review. **FRS**: Conceptualization, Data Curation, Investigation. **JCD**: Conceptualization, Methodology, Validation, Data Analysis, Curation, Writing – Review & Editing**.**

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 of generative AI and AI-assisted technologies in the writing process

The authors declare that the use of AI and AI-assisted technologies was not applied in the writing process.

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