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ARTICLE

Banana pulp and peel as biostimulants under LED lighting for the *in vitro* growth of *Laelia gloriosa* Rchb.f.

Polpa e casca de banana como bioestimulantes sob luz LED no crescimento *in vitro* de *Laelia gloriosa* Rchb.f.

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Abstract
The efficiency of *in vitro* culture of native orchids still depends on the optimization of culture media and lighting conditions, particularly regarding the use of organic supplements with biostimulant potential. This study aimed to evaluate the effect of biostimulants based on the pulp and peel of different banana cultivars, combined with different LED light color temperatures, on the *in vitro* growth of *Laelia gloriosa* (Rchb. f.). The experiment was conducted in a completely randomized design in a 2 × 9 factorial arrangement, consisting of two LED lighting systems (3,000 K and 6,500 K) and nine MS media, either unsupplemented or supplemented with pulp or peel of the banana cultivars 'Nanica', 'Maçã', 'Prata', and 'da terra', with four replicates. After 120 days, the following variables were evaluated: plant height, longest root length, longest leaf length, fresh mass, number of pseudobulbs, number of leaves, and number of roots. A significant interaction between the factors was observed for all variables analyzed. Overall, LED lighting at 3,000 K promoted greater plantlet growth. The medium supplemented with nanica banana pulp stood out for vegetative growth and biomass accumulation, whereas nanica banana peel favored rooting. For the number of pseudobulbs and leaves, the unsupplemented MS medium showed the best results. Growth patterns reflected differences in banana nutritional composition, especially in carbohydrate and mineral contents. In conclusion, the use of banana-based biostimulants associated with 3,000 K LED lighting represents an efficient and low-cost strategy for the *in vitro* propagation of *L. gloriosa*.
Keywords: Banana-derived biostimulants, *in vitro* culture, native orchids, photomorphogenesis, sustainable propagation.

Resumo
A eficiência do cultivo *in vitro* de orquídeas nativas ainda depende da otimização de meios de cultura e condições de iluminação, especialmente quanto ao uso de suplementos orgânicos atuando como bioestimulantes. Este trabalho teve como objetivo avaliar o efeito de biostimulantes à base de polpa e casca de diferentes cultivares de banana, associados a distintas temperaturas de cor de luz LED, no crescimento *in vitro* de *Laelia gloriosa* (Rchb.f.). O experimento foi conduzido em delineamento inteiramente casualizado, em esquema fatorial 2 × 9, composto por dois sistemas de iluminação LED (3.000 K e 6.500 K) e nove meios MS, sem suplementação ou suplementados com polpa ou casca de banana 'Nanica', 'Maçã', 'Prata', e 'da terra', com quatro repetições. Após 120 dias, foram avaliadas as variáveis altura de planta, comprimento da maior raiz, comprimento da maior folha, massa fresca, número de pseudobulbos, número de folhas e número de raízes. Houve interação significativa entre os fatores para todas as variáveis analisadas. De modo geral, a iluminação com LED de 3.000 K promoveu maior crescimento das plântulas. O meio suplementado com polpa de banana nanica destacou-se para crescimento vegetativo e acúmulo de biomassa, enquanto a casca de banana nanica favoreceu o enraizamento. Para número de pseudobulbos e folhas, o meio MS sem suplementação apresentou os melhores resultados. Os padrões de crescimento refletiram diferenças na composição nutricional das bananas, sobretudo nos teores de carboidratos e minerais. Conclui-se que a utilização de banana como bioestimulante, associada à iluminação com LED de 3.000 K, constitui uma estratégia eficiente e de baixo custo para a propagação *in vitro* de *L. gloriosa*.
Palavras-chave: Bioestimulantes derivados da banana, cultura *in vitro*, fotomorfogênese, orquídeas nativas, propagação sustentável.

Introduction

Orchids constitute one of the botanical groups of greatest ornamental and commercial interest due to their morphological diversity, wide range of colors, and good postharvest durability (Tiruwa et al., 2024). Among the Brazilian native species with ornamental potential, *Laelia gloriosa* (Rchb.f.) stands out for its wide distribution, occurring in the North, Northeast, Midwest, Southeast, and South regions, in domains such as the Amazon, Cerrado, and Atlantic Forest, and in different vegetation types, including campinaranas, riparian forests, seasonal forests, and rocky environments (Van den Berg, 2026).

As a native species of ornamental interest, *L. gloriosa* requires propagation strategies capable of reconciling *ex situ* conservation with seedling production. In this context, *in vitro* culture has been widely adopted for orchid propagation, serving both conservation and commercial production purposes. Its advantages include the production of a large number of plants in limited space, within a shorter period, and with good sanitary quality (Soares et al., 2020; Nongdam et al., 2023; Sarmah et al., 2025; Utami et al., 2026).

One of the fundamental factors affecting the performance of *in vitro* plantlets is the composition of the culture medium. In addition to meeting the nutritional requirements of the species, this medium can be adjusted with supplements that promote growth. The MS medium, proposed by Murashige and Skoog (1962), is widely used, but its response can be modified by the addition of organic supplements (Nowakowska et al., 2022; Nongdam et al., 2023).

In recent years, biostimulants have received increasing attention in horticultural production systems, as they can improve physiological processes and plant growth. These compounds may contribute to production efficiency and greater tolerance to adverse conditions, in addition to supporting more sustainable practices through the use of plant extracts and agricultural by-products (De Stefano et al., 2022; Nongdam et al., 2023; Gonçalves et al., 2025).

In this context, banana pulp has been used in the *in vitro* culture of Orchidaceae due to its ability to provide carbohydrates, lipids, amino acids, vitamins, minerals, and other compounds related to plant development. These materials may promote germination, elongation, and the formation of vegetative structures, acting as accessible and readily available biostimulant sources (Utami and Hariyanto, 2020; De Stefano et al., 2022; Nunes et al., 2025). Positive responses to banana pulp have been reported in *Cattleya nobilior* (Freitas et al., 2021; Nunes et al., 2025)

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and *Phalaenopsis* hybrids (Colombo et al., 2012). In contrast, banana peel remains underexplored in the *in vitro* culture of orchids, although it also shows potential as a source of nutrients and organic compounds. In addition, its use may expand the alternatives for culture medium supplementation and contribute to the utilization of an agro-industrial residue.

Another determining factor in *in vitro* culture is light. Spectral quality influences physiological, anatomical, and morphological processes (Fan et al., 2022; Ribeiro et al., 2022). In addition to lower energy consumption, LED technology allows spectral characteristics to be adjusted and enables the evaluation of how different color temperatures modulate plant development (Nadal et al., 2023; Magalhães et al., 2025). More recently, Syifa et al. (2026) demonstrated that banana extract combined with different LED wavelengths improved shoot emergence, plantlet height, and chlorophyll content in *Paphiopedilum glaucophyllum*, highlighting the potential of integrating organic supplements with light quality control for orchid micropropagation.

Despite advances in the *in vitro* culture of Orchidaceae, to the best of our knowledge, no study has yet evaluated the combination of banana peel biostimulants with different LED light color temperatures for the *in vitro* propagation of native orchid species. Considering that banana pulp and peel have distinct nutritional compositions, and that LED light can modulate morphogenic responses, it is hypothesized that different banana cultivars, used as organic supplements, influence plantlet growth, and that this effect is modulated by light quality. Thus, this study aimed to evaluate the effect of culture medium supplementation with pulp or peel from different banana cultivars, combined with different LED light color temperatures, on the *in vitro* growth of *L. gloriosa*.

Materials and Methods

Laelia gloriosa plants were obtained from seeds derived from mature fruits originating from manual pollination performed on stock plants maintained in the orchid house of the Faculty of Agricultural Sciences at the Federal University of Grande Dourados (UFGD). The stock plants were cultivated under two 50% shade screens, with a mean irradiance of 235 µmol m^{-2} s^{-1}, temperature of 22.6 ± 5 °C, relative air humidity of 73.9 ± 10%, and irrigation provided by oscillating microsprinklers, with a daily water depth of 1 mm.

Seed viability was evaluated by the tetrazolium test, and for *in vitro* culture establishment, 0.005 g of seeds were weighed and subjected to surface disinfestation, both according to the methodology proposed by Soares et al. (2020). Then, 1 mL of the suspension containing the seeds was transferred to flasks containing MS culture medium (Murashige and Skoog, 1962) with half-strength mineral salts (½ MS). The cultures remained under these conditions for 120 days for the initial development of the plantlets. After this period, the plants were subcultured in MS medium and maintained for an additional 90 days.

Mature fruits of the banana cultivars 'Nanica', 'Maçã', 'Prata', and 'da terra' (*Musa* spp.), selected at the onset of senescence, characterized by peel darkening, were used to obtain the pulp and peel employed as organic supplements in the culture media and in the chemical analyses. After the *in vitro* establishment period, *L. gloriosa* plantlets approximately 2 ± 0.5 cm in length were transferred to the following treatments: 1) MS; 2) MS + 100 g L^{-1} of 'Nanica' banana pulp (BNP); 3) MS + 100 g L^{-1} of 'Nanica' banana peel (BNC); 4) MS + 100 g L^{-1} of 'Maçã' banana pulp (BMP); 5) MS + 100 g L^{-1} of 'Maçã' banana peel (BMC); 6) MS + 100 g L^{-1} of 'Prata' banana pulp (BPP); 7) MS + 100 g L^{-1} of 'Prata' banana peel (BPC); 8) MS + 100 g L^{-1} of 'da terra' banana pulp (BTP); and 9) MS + 100 g L^{-1} of 'da terra' banana peel (BTC). The concentration of 100 g L^{-1} was selected based on previous studies (Freitas et al., 2021; Nunes et al., 2025).

The culture media were supplemented with 30 g L^{-1} sucrose and solidified with 7.0 g L^{-1} bacteriological agar. Subsequently, 60 mL of medium were dispensed into each flask, and the pH was adjusted to 5.8 before autoclaving at 121 °C for 20 min. Six plantlets were placed in each flask, corresponding to approximately 10 mL of medium per plantlet.

The cultures were maintained under a 16-h photoperiod, at a temperature of 25 ± 2 °C, and under two LED light color temperatures: 3,000 K and 6,500 K, both with a PPFD of 19.8 µmol m^{-2} s^{-1}. The spectral composition of the light sources used is shown in Fig. 1. The plantlets remained under these conditions for 120 days.

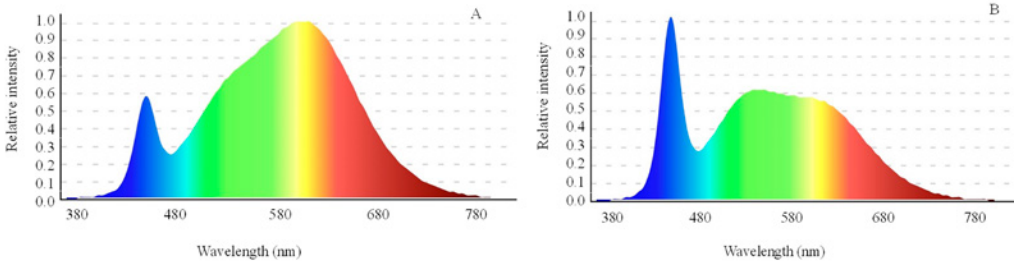

Fig. 1. Spectral distribution of the light emitted by the LEDs used in the *in vitro* culture of *L. gloriosa*: (A) 3,000 K LED and (B) 6,500 K LED.

At the end of the experimental period, the plants were removed from the flasks, washed under running water, and evaluated for plant height (PH), longest root length (LRL), longest leaf length (LLL), number of pseudobulbs (NP), number of leaves (NL), number of roots (NR), and fresh mass (FM).

A proximate analysis of the banana pulps and peels was performed, as shown in Table 1. Moisture content was determined by the gravimetric method, with oven drying at 70 °C until constant weight. Ash content was determined by incineration in a muffle furnace at 550 °C. Lipid content was determined by the cold extraction method according to Bligh and Dyer (1959). Protein content was determined by the micro-Kjeldahl method (Latimer, 2003). Crude fiber content was determined by digestion in acidic and alkaline solutions using a semi-industrial digester (Horwitz and Latimer, 2005). Total reducing sugars and starch were determined by the Lane-Eynon method, according to the methodologies described in the Analytical Standards of the Adolfo Lutz Institute (Zenebon et al., 2008).

The chemical analysis of the pulp and peel of the different banana cultivars (Table 2) was performed according to the methodology proposed by Malavolta et al. (1997).

Table 1. Proximate analysis of the pulp and peel of different banana cultivars.

Proximate composition of different banana cultivars				
Components (%)	**'Nanica' banana**		**'Maçã' banana**	
	Pulp	**Peel**	**Pulp**	**Peel**
Moisture	76.03 ± 0.43	85.93 ± 0.02	74.43 ± 0.19	79.82 ± 0.18
Ash	0.68 ± 0.05	1.20 ± 0.19	0.57 ± 0.10	1.01 ± 0.29
Lipids	0.69 ± 0.03	1.73 ± 0.06	0.61 ± 0.09	1.90 ± 0.03
Proteins	0.70 ± 0.11	0.60 ± 0.06	1.37 ± 0.19	1.69 ± 0.21
Fiber	0.25 ± 0.05	2.58 ± 0.11	0.48 ± 0.03	3.13 ± 0.53
Carbohydrates[1]	-	-	-	-
Starch	9.09 ± 0.76	4.07 ± 0.86	10.82 ± 3.18	5.96 ± 0.21
Total reducing sugars	16.44 ± 0.82	3.00 ± 0.31	16.22 ± 2.84	5.43 ± 0.91
Components (%)	**'Prata' banana**		**'da terra' banana**	
	Pulp	**Peel**	**Pulp**	**Peel**
Moisture	70.99 ± 0.25	88.16 ± 0.20	64.23 ± 0.32	86.75 ± 0.02
Ash	0.68 ± 0.03	1.68 ± 0.16	0.64 ± 0.03	1.24 ± 0.19
Lipids	0.66 ± 0.07	2.24 ± 0.12	0.40 ± 0.07	1.20 ± 0.06
Proteins	0.66 ± 0.05	1.23 ± 0.06	0.52 ± 0.05	1.45 ± 0.06
Fiber	0.44 ± 0.02	1.21 ± 0.52	0.37 ± 0.03	1.57 ± 0.11
Carbohydrates[1]	-	-	-	-
Starch	10.71 ± 1.08	4.05 ± 0.77	17.91 ± 1.43	4.50 ± 0.86
Total reducing sugars	12.93 ± 8.95	2.90 ± 0.13	8.20 ± 1.75	2.65 ± 0.31

[1] Carbohydrates calculated by difference: 100 – (moisture + ash + lipids + proteins + fiber).

Table 2. Chemical analysis of the pulp and peel of different banana cultivars.

Banana cultivars	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn
	..... g kg^{-1}						..... mg kg^{-1}			
BNP	1.00	3.45	1.36	0.33	1.24	0.24	30.33	28.49	1.50	4.53
BNC	1.40	5.28	4.57	1.73	1.15	0.49	87.40	51.02	1.71	14.40
BMP	0.90	2.94	1.33	0.23	1.09	0.26	14.19	109.86	1.99	0.03
BMC	1.50	3.72	3.18	0.85	1.16	0.92	44.40	37.49	2.62	15.43
BPP	0.90	2.84	1.39	0.39	1.06	0.33	14.00	66.85	42.78	0.00
BPC	1.40	8.42	5.00	5.08	2.72	0.47	56.84	37.26	0.00	15.80
BTP	1.00	2.30	1.29	0.25	0.76	0.19	2.19	27.61	0.00	0.00
BTC	1.00	5.38	4.70	1.01	0.90	0.65	30.40	41.67	0.00	12.04

BNP = 'Nanica' banana pulp; BNC = 'Nanica' banana peel; BMP = 'Maçã' banana pulp; BMC = 'Maçã' banana peel; BPP = 'Prata' banana pulp; BPC = 'Prata' banana peel; BTP = 'da terra' banana pulp; BTC = 'da terra' banana peel; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; Mn = manganese; Fe = iron; Cu = copper; and Zn = zinc.

The experimental design was completely randomized, in a 2 × 9 factorial arrangement (two LED color temperatures × nine culture media), with four replicates. The experimental unit consisted of one flask containing six plantlets, and the mean of the six plantlets per flask was used as the experimental unit for statistical analysis. The data were subjected to analysis of variance (ANOVA), and when significant differences were observed at the 5% probability level, the means were compared using Tukey's test. In the presence of a significant interaction between factors, the analyses were performed separately within each factor.

Results and Discussion

There was a significant interaction between MS media supplemented with banana pulp and peel and LED light color temperature for all evaluated traits ($p \leq 0.05$). *L. gloriosa* plantlets grown in MS medium supplemented with 'Nanica' banana pulp (BNP) under 3,000 K LED showed the highest mean values for plant height (PH = 35.65 mm), longest root length (LRL = 46.15 mm), longest leaf length (LLL = 24.42 mm), and fresh mass (FM = 3.306 g) (Table 3).

Table 3. Plant height (PH), longest root length (LRL), longest leaf length (LLL), and fresh mass (FM) of *L. gloriosa* as affected by different culture media and LED light color temperatures.

Growing media	PH (mm)		LRL (mm)		LLL (mm)		FM (g)	
	LED 3,000 K	LED 6,500 K	LED 3,000 K	LED 6,500 K	LED 3,000 K	LED 6,500 K	LED 3,000 K	LED 6,500 K
BNP	35.65 aA	17.75 bB	46.15 aA	33.73 aB	24.42 aA	12.03 aB	3.306 aA	0.786 aB
BNC	25.56 cA	17.59 bB	41.92 aA	24.87 bB	17.75 bA	8.10 bB	2.834 aA	0.998 aB
BMP	16.13 eA	14.20 cB	14.99 dA	17.50 cA	4.70 dA	7.44 bA	0.434 dA	0.407 bA
BMC	14.38 eA	8.47 dB	20.31 cA	14.07 dA	7.75 dA	6.17 bA	0.534 dA	0.351 bA
BPP	30.41 bA	15.99 bB	31.25 bA	23.00 bB	11.74 cA	6.74 bB	1.879 bA	0.939 aB
BPC	25.52 cA	12.13 cB	33.72 bA	20.12 cB	8.33 dA	4.99 bB	1.785 bA	0.611 bB
BTP	17.12 eA	13.05 cB	39.49 aA	17.65 cB	8.71 dA	4.52 bB	1.121 cA	0.265 bB
BTC	13.51 eA	9.56 dB	12.29 dA	8.93 dA	6.94 dA	6.39 bA	0.310 dA	0.194 bA
MS	21.22 dA	24.05 aA	20.20 cA	26.41 bA	5.93 dA	7.15 bA	3.083 aA	1.257 aB
Average	22.17	14.75	28.92	20.70	10.70	7.06	1.698	0.645
CV. (%)	15.93		22.35		21.26		18.21	

Means followed by the same lowercase letter within a column and the same uppercase letter within a row do not differ by Tukey's test ($p \leq 0.05$). CV. (%) = coefficient of variation.

For the number of roots (NR), the highest value was observed in MS medium supplemented with 'Nanica' banana peel (BNC) under 3,000 K LED, with a mean of 35.74 roots, not differing statistically from MS medium under the same color temperature (31.39). Regarding the number of pseudobulbs (NP) and the number of leaves (NL), MS medium showed the highest means under 3,000 K LED, with 15.96 pseudobulbs and 72.09 leaves, respectively (Table 4).

Table 4. Number of pseudobulbs (NP), number of leaves (NL), and number of roots (NR) of *L. gloriosa* as affected by different culture media and LED light color temperatures.

Growing media	NP		NL		NR	
	LED 3,000 K	LED 6,500 K	LED 3,000 K	LED 6,500 K	LED 3,000 K	LED 6,500 K
BNP	4.87 cA	4.67 bA	38.96 cA	24.34 cB	22.22 bA	15.26 aB
BNC	10.70 bA	8.21 aB	58.35 bA	37.83 bB	35.74 aA	14.92 aB
BMP	4.08 dA	3.50 bA	20.71 dA	17.09 cA	13.79 cA	9.69 bB
BMC	3.31 dA	2.12 cA	13.65 dA	7.31 dA	10.56 cA	5.30 cB
BPP	5.70 cA	6.56 aA	23.29 dB	34.10 bA	18.64 bA	18.99 aA
BPC	6.38 cA	8.00 aA	42.98 cA	44.42 aA	20.12 bA	17.00 aA
BTP	4.02 dA	4.27 bA	19.73 dA	23.04 cA	13.63 cA	10.62 bA
BTC	5.32 cA	2.29 cB	21.76 dA	10.15 dB	4.38 dA	4.57 cA
MS	15.96 aA	8.56 aB	72.09 aA	47.80 aB	31.39 aA	14.83 aB
Average	6.70	5.35	34.61	27.34	18.94	12.38
CV. (%)	24.34		26.12		25.82	

Means followed by the same lowercase letter within a column and the same uppercase letter within a row do not differ according to Tukey's test ($p \leq 0.05$). CV. (%) = coefficient of variation.

The significant interaction between culture media and LED light color temperature for all variables demonstrates that the *in vitro* development of *L. gloriosa* is influenced both by the nutritional and organic composition of the banana-supplemented media and by the spectral quality of light. In general, 3,000 K LED lighting promoted better results for most of the variables analyzed, especially when associated with media containing 'Nanica' banana pulp or peel.

Previous studies indicate that, in *in vitro* culture, a higher proportion of wavelengths in the red region may favor cell elongation, biomass accumulation, and vegetative growth through their action on phytochromes and photomorphogenic processes (Paradiso and Proietti, 2022; Howe, 2024; Huo et al., 2024). Although 3,000 K light does not correspond to a monochromatic red source, its warmer spectral composition may present a greater relative contribution of long wavelengths, which helps explain the better results observed under this treatment, as shown in Fig. 1A.

The highest values of PH, LRL, LLL, and FM were observed in MS medium supplemented with BNP under 3,000 K LED (Table 3). This performance may be related to the proximate composition of 'Nanica' banana pulp, which showed the highest content of total reducing sugars (16.44%) among the cultivars used, in addition to a starch content of 9.09% (Table 1). Under *in vitro* conditions, carbohydrates represent the main source of energy and carbon for respiration, biosynthesis, and cell expansion, thereby favoring vegetative growth and biomass accumulation (Pasternak and Steinmacher, 2024; Akyüz, 2025). In the proximate analysis of this study, 'Nanica' banana pulp showed an ash content of 0.68% and moisture content of 76.03%, characteristics that may contribute to mineral solubilization and availability in the culture medium.

Although BNP did not show the highest macronutrient contents in the chemical analysis (Table 2), the following concentrations were observed: P (3.45 g kg^{-1}), Mg (1.24 g kg^{-1}), and Mn (30.33 mg kg^{-1}), all of which are essential nutrients for plant metabolism. Phosphorus is involved in energy transfer and ATP formation; magnesium is a component of the chlorophyll molecule and acts as an enzymatic cofactor; and manganese is involved in processes related to photosynthesis and the structure of the photosynthetic apparatus (Khan et al., 2023; Messant et al., 2023; Sarraf et al., 2026). In addition, banana pulp is considered a natural source of vitamins and growth regulators, such as cytokinins, auxins, and gibberellins, which could potentially act on cell division and expansion, and may have contributed to *in vitro* growth (Dolce et al., 2020). The combination of available carbohydrates, minerals, and bioactive organic compounds may have contributed to the greater vegetative growth and biomass accumulation observed in the BNP treatment under 3,000 K.

For the number of roots (NR), plants grown in medium containing 'Nanica' banana peel (BNC) under 3,000 K LED showed the highest mean (35.74 roots), with no statistical difference in relation to MS medium under the same color temperature (31.39 roots) (Tab. 4). Although it did not differ statistically from MS medium, the higher mean observed in the BNC treatment may be related to the high levels of potassium (4.57 g kg^{-1}) and manganese (87.40 mg kg^{-1}) present in 'Nanica' banana peel (Table 2), in addition to the ash content of 1.20% in the proximate composition (Table 1). Potassium is essential for cellular osmotic potential, ionic balance, and photoassimilate transport, whereas manganese is involved in metabolic processes, and its homeostasis is associated with root growth (Gao et al., 2018; Mostofa et al., 2022; Messant et al., 2023). Therefore, the greater mineral availability in the peel may have favored root emission in this treatment.

Regarding the number of pseudobulbs (NP) and number of leaves (NL), MS medium under 3,000 K LED provided the highest values (Table 4). This result suggests that the mineral formulation of MS medium favored shoot emission and the differentiation of aerial structures, resulting in greater pseudobulb and leaf formation. For these variables, the defined and balanced mineral composition of MS medium may have been more efficient than the banana-supplemented media, which, although they provide organic compounds and minerals, have a more variable composition and may alter nutrient uptake and *in vitro* growth (Munthali et al., 2022). Pseudobulbs function as storage organs, and their formation is influenced by both nutritional and light conditions. In *Cattleya walkeriana*, higher irradiance (128 µmol m^{-2} s^{-1}) under 3,000 K LED increased pseudobulb number and diameter compared to lower irradiance (Ramos et al., 2022), while in *Bletilla striata*, blue and white LED light promoted thicker pseudobulbs (Kocot et al., 2026). The higher pseudobulb formation observed in MS medium under 3,000 K in the present study is consistent with these findings and may benefit plantlet performance during acclimatization.

Although 'Prata' banana peel (BPC) showed the highest levels of phosphorus (8.42 g kg^{-1}), calcium (5.08 g kg^{-1}), and magnesium (2.72 g kg^{-1}) in the chemical analysis (Table 2), this treatment did not show superior performance for the evaluated variables. In addition, high or unbalanced nutrient concentrations may alter nutritional interactions and impair element uptake by the explants, affecting *in vitro* development (Munthali et al., 2022). Moreover, BPC showed a high lipid content (2.24%) and one of the lowest levels of total reducing sugars (2.90%) (Table 1), which may have limited energy availability for growth.

'Maçã' banana pulp (BMP), although it showed a high level of total reducing sugars (16.22%) and the highest protein content among the pulps (1.37%) (Table 1), also did not result in superior growth. This result indicates that the *in vitro* growth of *L. gloriosa* does not depend only on carbohydrate availability, but also on the balance among mineral nutrients, organic compounds, and regulators present in the culture medium. According to Pasternak and Steinmacher (2024), the interaction among the carbon source, mineral nutrients, and natural regulators present in organic additives directly influences the morphogenic response in *in vitro* culture.

These results reinforce that the morphogenic response of *L. gloriosa* to banana-supplemented culture media depends on the specific requirements of the species, since species of the Orchidaceae family have particular nutritional and physiological demands. In *Cattleya nobilior* Rchb.f., the use of medium supplemented with 'Nanica' banana pulp favored *in vitro* growth (Freitas et al., 2021), whereas a similar effect was observed with 'Maçã' banana pulp (Nunes et al., 2025). In *Cattleya walkeriana*, the combination of banana pulp with 3,000 K LED promoted *in vitro* growth, with lower irradiance favoring subsequent *ex vitro* survival (Ramos et al., 2022). Supplementation with banana pulp also promoted better development in a *Phalaenopsis* hybrid (Colombo et al., 2012). More recently, Syifa et al. (2026) also demonstrated that banana extract combined with different LED wavelengths improved growth of *Paphiopedilum glaucophyllum*, further supporting the potential of integrating organic supplements with spectral quality control in orchid micropropagation. These findings corroborate the interaction between organic supplements and spectral quality observed in the present study and highlight that the response to both factors is species-specific.

The results obtained in this study make it possible to infer that the different supplementations of MS medium, combined with LED light color temperatures, influenced the *in vitro* growth of *L. gloriosa*, with distinct responses depending on the type of organic supplement and the spectral quality of light, as shown in Fig. 2. In general, media containing 'Nanica' banana pulp and peel under 3,000 K LED promoted greater vegetative and root growth, corroborating the biometric results observed in Tables 3 and 4, whereas treatments under 6,500 K LED mostly resulted in lower plantlet development.

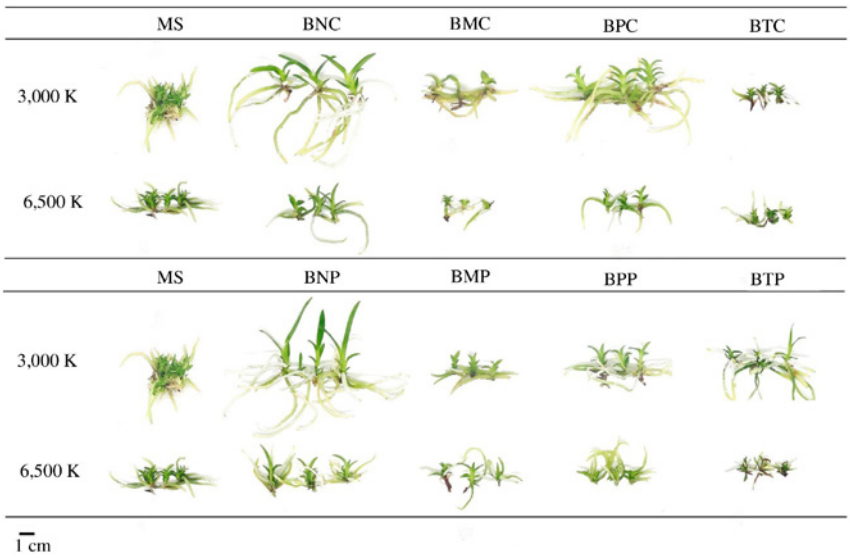

Fig. 2. *L. gloriosa* plants as a function of different culture media (MS = MS medium; BNC = 'Nanica' banana peel; BMC = 'Maçã' banana peel; BPC = 'Prata' banana peel; BTC = 'da terra' banana peel; BNP = 'Nanica' banana pulp; BMP = 'Maçã' banana pulp; BPP = 'Prata' banana pulp; BTP = 'da terra' banana pulp) and LED light color temperature after 120 days of *in vitro* culture.

In addition, the results indicate that unsupplemented MS medium was more efficient for variables associated with multiplication, such as NP and NL, whereas banana-supplemented media favored vegetative growth, elongation, and biomass accumulation. Thus, banana pulp and peel can be used as organic supplements with biostimulant potential, being more advantageous when the goal is to produce more vigorous plantlets that may present better performance during the *ex vitro* phase, whereas MS medium remains more appropriate when greater emission of propagation structures is desired. In addition to the use of the pulp, the use of the peel, which is normally discarded as waste, expands the possibilities for culture medium supplementation and reinforces the potential for the full utilization of the fruit. The association of these organic supplements with 3,000 K LED lighting constitutes a promising and potentially sustainable strategy for the *in vitro* propagation of *L. gloriosa*, with the potential to reduce costs and promote the use of agro-industrial residues.

Conclusions

The *in vitro* development of *L. gloriosa* was influenced by the interaction between culture media and LED light color temperature. 3,000 K LED provided the best performance for most of the evaluated variables. The medium supplemented with 'Nanica' banana pulp (BNP) favored vegetative growth, root elongation, and biomass accumulation, whereas the medium supplemented with 'Nanica' banana peel (BNC) promoted greater root emission. For pseudobulb and leaf emission, MS medium under 3,000 K LED proved to be more efficient.

Thus, MS media supplemented with banana pulp and peel, used as organic supplements with biostimulant potential and associated with 3,000 K LED lighting, represent a promising strategy for the micropropagation of *L. gloriosa*, potentially improving plantlet performance and contributing to more efficient and sustainable practices.

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Author Contribution

ALXA: Conceptualization, Data Curation, Investigation, Methodology, Writing – Original Draft. **MVBMQ:** Data Curation, Investigation, Formal Analysis, Visualization, Writing – Review & Editing. **LMR:** Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Writing – Original Draft. **RBP:** Data Curation, Investigation, Validation, Visualization, Writing – Review & Editing. **FOF:** Data Curation, Investigation, Validation, Visualization, Writing – Review & Editing. **FS:** Data Curation, Investigation, Validation, Visualization, Writing – Review & Editing. **JSS:** Conceptualization, Formal Analysis, Methodology, Supervision, Writing – Review & Editing. **JCS:** Conceptualization, Formal Analysis, Methodology, Supervision, Writing – Review & Editing.

Conflict of Interest

The authors declare that they have no conflicts of interest that may have inappropriately influenced the conduct of the research or the preparation of the present manuscript. All experimental procedures, data analyses, and interpretations were conducted with technical rigor and scientific impartiality, ensuring the integrity, transparency, and credibility of the results presented.

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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