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ARTICLE

Impact of N, P, K, Mg and S deficiency on physiological and growth aspects of the orchid *Dendrobium bigibbum*

Impactos da deficiência de N, P, K, Mg e S em aspectos fisiológicos e de crescimento da orquídea *Dendrobium bigibbum*

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Abstract: *Dendrobium bigibbum* is one of the main cultivated and commercialized orchids in the world. However, there is still lack of information on its nutritional requirements, plant response to macronutrient individual deficiency, and related biological harms. The objective of this study was to evaluate effects of N, P, K, Mg, and S deficiencies on physiological aspects, nutrient accumulation, dry matter production, and symptoms in *D. bigibbum* plants cultivated under nutrient solutions. Seven treatments were composed of a complete nutrient solution, solutions with individual omissions of N, P, K, Mg, and S, besides an only-water solution (control), organized in randomized blocks with 10 replications. Seedlings were planted in polyethylene pots of 1 dm^3 volume, filled with vermiculite, and acclimatized along 30 days. After that, nutrient solution applications started according to the treatments along 90 days. *D. bigibbum* plants, for an optimum growth, present the nutritional requirements according to the following descending order: K > N > Mg > P > S. However, the species is sensitive to N, P, K, Mg, and S deficiency, what impairs the photosynthetic rate, stomatal conductance, and transpiration rate; it similarly harms plant dry matter production, causing visual symptoms which are characteristic of each nutrient deficiency.
Keywords: nutrients, photosynthetic rate, stomatal conductance, transpiration rate.

Resumo: *Dendrobium bigibbum* é uma das principais orquídeas cultivadas e comercializadas no mundo. No entanto, ainda há escassez de informações acerca de suas necessidades nutricionais, resposta à deficiência individual de macronutrientes e os danos biológicos relacionados. O objetivo deste estudo foi avaliar os efeitos da deficiência de N, P, K, Mg e S nos aspectos fisiológicos, acúmulo de nutrientes, produção de matéria seca e sintomas em plantas de *D. bigibbum* cultivadas em soluções nutritivas. Sete tratamentos foram compostos por: uma solução nutritiva completa, e soluções com omissões individuais de N, P, K, Mg e S, além de uma solução somente de água (controle), organizados em blocos casualizados com 10 repetições. As mudas foram plantadas em vasos de polietileno de 1 dm^3 preenchidos com vermiculita, e aclimatadas por 30 dias. Após esse período, iniciaram-se as aplicações de solução nutritiva, de acordo com os tratamentos, ao longo de 90 dias. As plantas de *D. bigibbum*, para um ótimo crescimento, apresentam as necessidades nutricionais de acordo com a seguinte ordem decrescente: K > N > Mg > P > S. Entretanto, a espécie é sensível à deficiência de N, P, K, Mg e S, o que prejudica a taxa fotossintética, a condutância estomática e a taxa de transpiração; e prejudica igualmente a produção de matéria seca das plantas, causando sintomas visuais característicos de cada deficiência de nutrientes.
Palavras-chave: condutância estomática, nutrientes, taxa fotossintética, taxa de transpiração.

Introduction

Dendrobium species represent a prominent class of cultivated and commercialized orchids on a global scale. These organisms possess erect and slender pseudobulbs, as well as terminal inflorescences characterized by a profusion of flowers exhibiting a wide spectrum of colors (Lestari et al., 2023).

Optimal plant growth is contingent upon a comprehensive understanding of the nutritional requirements of each orchid species. A failure to adhere to these specific nutritional needs can result in a decline in quality and an escalation in production costs (Biswas et al., 2021; Jolman et al., 2022). The cultivation of orchids has gained significant momentum worldwide, with notable biotechnological interventions and commercial outcomes (Tiwari et al., 2024). However, for *Dendrobium bigibbum*, a prominent cultivated and commercialized orchid, the largely uncharacterized specific nutritional requirements present a significant challenge for tailored fertilization. This frequently leads to the application of general nutrient solutions, potentially causing nutritional deficiencies that negatively affect physiological processes and overall plant development (Biswas et al., 2021; Jolman et al., 2022).

A nutritional deficiency capable of inducing biological disturbances has been shown to impede plant growth (Kumari et al., 2022). This deficiency has been observed to restrict vital physiological processes, such as the photosynthetic rate (Didaran et al., 2024; Taiz et al., 2024). Consequently, ensuring adequate nutrient provision is imperative for fostering optimal growth in *Dendrobium nobile* orchids, underscoring the plant's responsiveness to nitrogen and phosphorus supply (Zhang et al., 2022).

Research on orchid nutritional requirements and deficiencies is limited to a few species. For instance, some studies have focused on the in vitro cultivation and roles of macronutrients in *Laelia cinnabarina* Bateman ex Lindl. (De and Biswas, 2022) and *Bletia catenulata* Ruiz & Pav. (Paiva Neto et al., 2022). Other research has investigated nitrogen in *Cattleya loddigesii* Lindl. (Oliveira et al., 2021) and potassium in *Phalaenopsis* sp. Blume (Cho et al., 2022). Furthermore, if the nutrients applied in the cultivation medium are insufficient to meet plant demand, nutritional disorders may occur. Generalizations of nutritional disorder symptoms in floriculture crops are complex because plant response to deficiencies is specific to plant genetics (Aiello et al., 2022; Frem et al., 2024).

However, the nutritional requirements of *D. bigibbum* for optimal growth remain to be elucidated, particularly regarding nitrogen, phosphorus, potassium, magnesium, and sulfur. Additionally, the existing literature does not provide a clear understanding of whether there is a difference among nutrients that act on growth limitation for this species. A comprehensive understanding of these nutritional requirements is essential for effective nutrient management, ensuring optimal growth and quality of the orchids.

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Given the paucity of knowledge regarding the nutritional requirements of *D. bigibbum* for optimal growth and the understanding of the differences in the role of nutrients as limiting factors, the hypothesis is advanced that the limitation of nutritional deficiencies in N, P, K, Mg, and S may have deleterious effects on physiological processes in different ways. However, given their critical roles in these processes, it is anticipated that the impact on the reduction in leaf and root dry matter production will be analogous, thereby influencing the growth of this species in a comparable manner.

Considering the aforementioned context, the aim of this study was to assess the repercussions of nitrogen, phosphorus, potassium, magnesium, and sulfur deficiencies on the cultivation of *Dendrobium bigibbum* orchid plants in nutrient solutions. This evaluation encompassed the consideration of physiological aspects, nutrient accumulation, dry matter production, and visual symptoms of deficiency.

Materials and Methods

The experiment was conducted in a greenhouse environment from January to June 2021 in Castanhal, Pará State, Brazil. The plants were covered with 150 µm thick polyethylene and shade cloth to maintain 50% of the external light. The local climate is classified as type Af, according to the Köppen classification. The light intensity was the sole variable that was actively controlled. Despite the absence of continuous temperature and relative humidity monitoring, the environmental conditions during the experimental period were consistent with the typical characteristics of the region during the study period.

Experimental Design and Treatments

The experimental design employed a randomized blocks configuration, encompassing seven distinct treatments and 10 replicates. The treatments consisted of variations of the Hoagland and Arnon (1938) nutrient solution, as follows:

1. Complete Solution: It is notable that the product contains all macronutrients.
2. Nitrogen Omission (-N): The solution is considered complete when the nitrogen is omitted individually.
3. Phosphorus Omission (-P): The solution is considered complete when the individual omission of P is taken into account.
4. Potassium Omission (-K): The solution is considered complete when the individual omission of K is taken into account.
5. Magnesium Omission (-Mg): The solution under consideration is considered complete when an individual omission of Mg is included.
6. Sulfur Omission (-S): The solution is considered complete when the individual omission of S is taken into account.
7. Control (Water Only): The solution is composed exclusively of deionized water.

Experiment Conduct

Plant Material: *Dendrobium bigibbum* orchid seedlings, with two to three pairs of expanded leaves, were individually transplanted into polyethylene pots with a volume of 1 dm^3. Each pot was filled with vermiculite, which served as an inert substrate.

Cultivation System: The pots were perforated at the base and placed on individual containers with a capacity of 0.5 dm^3, which were designed to collect the drained nutrient solution. A closed feedback system was implemented for each experimental unit, consisting of adapted hoses that collected the filtered solution from the pot and deposited it back into the 500 mL container. This ensured recirculation and minimized solution loss without mixing between treatments.

Acclimatization Period and Application of Treatments: The seedlings were subjected to a 30-day quarantine period, during which they were irrigated exclusively with deionized water. After this interval, the treatments were administered, employing the Hoagland and Arnon (1938) nutrient solution at a concentration that was half of its original value. A volume of 500 mL of solution was added to each pot on a daily basis, with replenishment based on evapotranspiration losses. Continuous monitoring of the pH or electrical conductivity of the substrate was not part of the experimental design. The application of the nutrient solutions was conducted over a period of 90 days, and the evaluations were conducted four months (approximately 120 days) after the commencement of the treatments.

Physiological and Growth Assessments

Physiological analyses: The net photosynthetic rate, stomatal conductance, and transpiration rate were evaluated on the second fully expanded leaves. The measurements were obtained between 5:00 a.m. and 7:00 a.m. The equipment utilized for the measurements was the LI-6400XT infrared gas analyzer (LI-COR). The controlled light conditions provided an intensity of 1,000 µmol m^{-2} s^{-1}, and the CO2 concentration was set at 400 µmol.

Visual Diagnosis: The visual diagnosis of the symptoms associated with macronutrient deficiency was conducted using systematic photographs, which were taken 10 days prior to the conclusion of the experimental period. The visual characteristics of the plants and leaves were meticulously observed for each treatment.

Dry Matter Production: At the conclusion of the experiment, the plants were extracted from their pots and categorized into their respective components: leaves, stems, and roots. The components were then separated, placed in paper bags, and dried in a forced-air oven at 70°C until a constant weight was achieved. The total dry matter of the aerial parts and roots was determined.

Foliar Chemical Analysis: The chemical analysis of the leaves was performed to determine the contents of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and sulfur (S), following the methodology of Bataglia et al. (1983). The calculation of nutrient accumulation in the leaves was performed by multiplying the content of each nutrient by the corresponding dry matter.

Statistical Analysis

The collected data were then subjected to analysis of variance (F test), with a probability level of 5%. In instances of significance, the Scott-Knott test was employed to compare means, also at a 5% probability level.

Results

Plants cultivated with no K, in comparison with those cultivated under the complete nutritive solution, had a decrease in the net photosynthetic rate; in turn, these plants differed from the others as the net photosynthetic rate was greater than in those submitted to omissions of the other treatments. Plants cultivated under the complete nutritive solution showed higher values of stomatal conductance and transpiration rate, differing from the other plants (Table 1).

Table 1. Net photosynthetic rate, stomatal conductance, and transpiration rate in leaves of *Dendrobium bigibbum* orchid plants cultivated under fertilization treatments.

Treatments	Net Photosynthetic Rate	Stomatal Conductance	Transpiration Rate
	μmol CO_2	mol H_2O m^{-2} s^{-1}	mmol H_2O
Complete	4.91 a	1.17 a	1.17 a
-N	3.15 c	0.52 b	0.52 b
-P	2.11 c	0.72 b	0.72 b
-K	3.78 b	0.67 b	0.67 b
-Mg	3.02 c	0.68 b	0.68 b
-S	2.16 c	0.79 b	0.79 b
Control	2.18 c	0.48 b	0.48 b
F test	13.05**	3.64*	3.64*
CV (%)	17.13	27.03	27.03
SD	0.53	0.19	0.19

Means followed by the same letter in the columns do not differ from each other by the Scott Knott test at **1% and *5% probability.

CV – coefficient of variation; SD – standard deviation.

In comparison with plants cultivated under the complete solution, those submitted to only-water solution and no N, P, K, Mg, and S, had a significant limited production, affecting total dry matter, and of aerial part and roots (Table 2). Therefore, nutrient omission reduced plant growth, as follows for aerial part, roots, and total plant, respectively: -N, in 37%, 25%, and 28%; -P, in 32%, 30%, and 32%; -K, in 25%, 27%, and 28%; -Mg, in 30%, 23%, and 20%; and -S, in 23%, 23%, and 23%.

Table 2. Dry matter (g $plant^{-1}$) of aerial part (DMAP) and roots (DMR), and total dry matter (TDM) of *Dendrobium bigibbum* orchid plants cultivated under fertilization treatments.

Treatment	DMAP	DMR	TDM
Complete	6.20 a	6.48 a	12.69 a
-N	4.24 b	4.87 b	9.11 b
-P	4.04 b	4.56 b	8.60 b
-K	4.37 b	4.76 b	9.13 b
-Mg	4.12 b	4.36 b	8.48 b
-S	4.76 b	5.02 b	9.78 b
Control	3.70 b	3.92 b	7.62 b
F Test	11.72**	22.96**	27.88**
CV (%)	9.23	5.99	5.67
SD	0.41	0.29	0.53

Means followed by the same letter in the columns do not differ from each other by the Scott Knott test at **1% probability.

CV – coefficient of variation; SD – standard deviation.

Leaf N contents reached greater values when the complete, -Mg, and -S solutions were applied, which did not differ among each other; -N, -P, -K, and only-water (control) solutions presented lower values (Table 3). Leaf P contents were not affected by the treatments. Leaf Mg contents were superior in plants cultivated under the complete solution but similar to plants submitted to the -Mg and -S solutions; -N, -P, -K, and only-water (control) solutions promoted lower Mg values. Leaf S contents were higher in plants cultivated under the complete and -P solutions.

Table 3. Contents and accumulation of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and sulfur (S) in leaves of *Dendrobium bigibbum* orchid plants cultivated under fertilization treatments.

Treatment	N	P	K	Mg	S
	Content (g kg^{-1})				
Complete	7.90 a	1.20 a	22.53 a	6.93 a	0.73 a
-N	5.33 b	1.06 a	15.10 b	4.03 b	0.53 b
-P	6.53 b	0.93 a	15.50 b	3.50 b	0.60 a
-K	5.73 b	0.93 a	13.00 b	3.36 b	0.50 b
-Mg	7.43 a	1.30 a	26.53 a	5.70 a	0.40 b
-S	8.70 a	1.33 a	22.60 a	5.93 a	0.50 b
Control	4.86 b	1.00 a	15.83 b	3.96 b	0.36 b
F Test	5.10**	2.78*	6.67**	2.94**	4.97**
CV (%)	15.45	28.98	17.92	27.35	17.59
SD	1.03	1.54	3.36	1.33	0.09
	Accumulation (mg plant^{-1})				
Complete	48.78 a	7.48 a	139.68 a	42.79 a	4.52 a
-N	22.30 b	4.54 b	64.27 b	17.03 c	2.27 b
-P	26.79 b	3.77 b	64.67 b	14.62 c	2.47 b
-K	25.92 b	4.24 b	58.98 b	15.37 c	2.26 b
-Mg	30.68 b	5.39 b	108.54 a	23.00 c	1.62 c
-S	41.83 a	6.36 b	109.11 a	28.44 b	2.38 b
Control	18.18 b	3.75 b	52.30 b	14.62 c	1.36 c
F Test	8.07**	2.78**	8.87**	7.50**	11.89**
CV (%)	20.22	28.98	21.22	27.00	19.74
SD	6.39	1.54	18.82	6.25	0.50

Means followed by the same letter in the columns do not differ from each other by the Scott Knott test at **1% probability.

CV – coefficient of variation; SD – standard deviation.

Nutrient accumulation in plants cultivated under the complete solution presented the following descending order: K > N > Mg > P > S. The greatest N accumulation was found in plants submitted to the complete solution, but it did not differ from plants cultivated under -S solution (Table 3). Higher P accumulation was also promoted by the complete solution. For Mg, the highest value was found in plants cultivated under both the complete and -S solutions. Superior S accumulation was achieved by plants submitted to the complete solution than those receiving -N, -P, -K, and -S solutions, which were similar among each other; on the other hand, these presented better results than the treatments of -Mg and only-water (control) solutions (Table 3).

Plant cultivation under a nutritive solution with nutrient omission causes nutritional deficiency, promoting plant disturbances that manifest visually. Visual symptoms in cultivated plants with individual omissions of N, P, K, Mg, and S are characteristic of each nutrient (Fig. 1). Therefore, plants cultivated under -N solution presented general chlorosis in the older leaves, resulting in decrease of growth, stem, and leaf number. Plants cultivated under P omission exhibited older leaves of opaque dark green color and minor width; furthermore, a reduced leaf number resulted in stunted plants. Plants cultivated under no K showed chlorosis in older leaves followed by growth reduction. Plants cultivated under Mg omission had a typical symptom of interveinal yellowing of old leaves. Under no S, new leaves had a lighter green color.

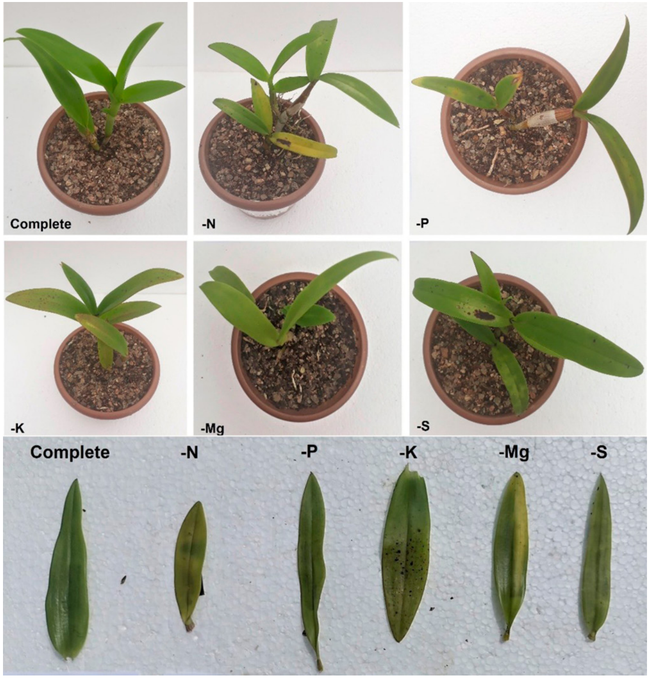

Fig. 1. Plants and leaf details of *Dendrobium bigibbum* orchid cultivated under a complete nutritive solution and deficiency of nitrogen (-N), phosphorus (-P), potassium (-K), magnesium (-Mg), and sulfur (-S).

Discussion

The assertion that epiphytic orchids possess minimal nutritional requirements and are capable of subsisting on the limited nutrients present in their host environment (Yudaputra et al., 2024) is a paradigm that this study seeks to re-evaluate. In contrast to this expectation, the *D. bigibbum* orchid, when cultivated in pots and supplied with a complete nutrient solution, exhibited significantly higher growth, suggesting that, in a controlled cultivation context, its nutritional demands are high. The concentrations that proved optimal for the development of *D. bigibbum* in this experiment are as follows: The nutrient composition of the medium is as follows: 7.5 mM N, 0.5 mM P, 3.0 mM K, 2.0 mM Ca, 1.0 mM Mg, 1.0 mM S, 23.0 µM B, 0.15 µM Cu, 45.0 µM Fe, 6.3 µM Mn, 0.05 µM Mo, and 0.6 µM Zn.

In the course of the investigation into the dynamics of nutrient accumulation in the leaves of *D. bigibbum,* a decreasing order of demand was identified: It has been established that the nutrients in question are most required (K and N) and least required (P and S). This hierarchy is corroborated by the findings of Menegusso et al. (2021), who observed a similar pattern in the development and accumulation of nutrients in *Dendrobium nobile*. The observed similarity between species of the same genus indicates the fundamental role of the genetic basis, which, through the regulation of transporters and gene expression, directly influences nutrient absorption processes and, consequently, the nutritional needs of the plant (Bhattacharya, 2021; Jalal et al., 2024).

The absence of essential macronutrients, including nitrogen, phosphorus, potassium, magnesium, and sulfur, in conjunction with the restriction of the water supply, resulted in substantial physiological impairment to *D. bigibbum* orchids. The results indicated a significant decline in net photosynthetic rate, stomatal conductance, and transpiration rate. This decline in physiological efficiency can be explained by the irreplaceable role of these nutrients in plant metabolism. Nitrogen, for instance, constitutes a structural element of chlorophyll and several essential proteins (Barhoumi, 2024; Taiz et al., 2024). Potassium functions as an activator of pivotal enzymes, including Rubisco (Hu et al., 2023; Prywes et al., 2023). Phosphorus is imperative in the formation of ATP, the predominant energy currency of the cell (Awad-Allah et al., 2023; Kabała and Janicka, 2023). Magnesium is a central component of chlorophyll and a cofactor in energy transfer reactions, and sulfur is indispensable for the synthesis of ferredoxin and coenzyme A (Sharma et al., 2024).

The deterioration of metabolic functions due to nutritional deficiency manifested itself in a significant reduction in dry matter production, both in the aerial parts and in the roots. It was observed that deficiency of each of the macronutrients (N, P, K, Mg, and S) resulted in comparable negative impacts on plant growth, demonstrating the low tolerance of *D. bigibbum* to any type of nutritional deficiency. This universal sensitivity is attributable to the fact that all these elements are essential and perform vital functions in physiological and biochemical processes that sustain the plant's entire life cycle (Kirkby et al., 2023). The observed limitation of growth, even subsequent to the mobilization of internal reserves, suggests that nutrient cycling is insufficient to compensate for a protracted deficiency (120 days) in an inadequate culture medium. Visually, nutritional deficiency in orchids is accompanied by disorders that progress from the molecular to the subcellular, cellular, and tissue levels, culminating in visible symptoms characteristic of each nutrient. This phenomenon has already been well described for various orchid species (Hoshino et al., 2023; Costa et al., 2024).

While the *D. bigibbum* orchid exhibited a higher demand for K, N, and Mg, contrasting with the S and P elements, this observation underscores the necessity for more precise fertilizer formulations. Notably, the species demonstrated equal susceptibility to deficiencies in all of these essential elements. This generalized sensitivity is exacerbated when the plant's nutrient reserves, which are maintained in structures such as the root velamen (which normally release water and nutrients gradually), are depleted. This phenomenon occurs, for example, during the initial quarantine period of the experiment.

This study contributes to a reevaluation of the notion that orchids are plants with minimal nutritional requirements. This misconception may stem from two sources: the nutrient reserve capacity in the roots, which can delay the onset of deficiency symptoms, and the sensitivity of orchids to high salt concentrations in the growing environment, which should not be interpreted as a low nutrient requirement (Balliu et al., 2021; Hailu and Mehari; Sogoni et al., 2021). Consequently, for cultivators of *D. bigibbum*, the implications are evident: orchids exhibit sensitivity to nutrient deficiencies once their reserves are depleted and when cultivated in an environment devoid of salt stress. In order to optimize cultivation, it is imperative that growers implement nutritional management strategies that meet the specific needs of *D. bigibbum*, ensuring a balanced and continuous supply of nutrients. A more profound comprehension of orchids' response to complete fertilization paves the way for the development of more efficient and sustainable cultivation practices, thereby maximizing plant quality and growth. It is imperative that further research be conducted, with a particular focus on the various nutrient concentrations present and the establishment of critical levels in leaves. Such efforts are essential for the advancement of nutritional monitoring and the resolution of problems in the field.

Conclusions

This study establishes the essential nutritional requirements for the optimal growth of the *Dendrobium bigibbum* orchid, identifying a descending order of demand: K > N > Mg > P > S. Furthermore, it was demonstrated that the species' sensitivity to N, P, K, Mg, and S deficiencies is a critical limiting factor, severely impacting overall plant development and biomass production, in addition to manifesting characteristic visual symptoms.

The obtained results confirm the hypothesis that the deficiency of each of these essential macronutrients similarly impairs the growth of *D. bigibbum*, even if their impacts on specific physiological processes may vary. This finding underscores the importance of a balanced supply of all these elements for maintaining plant health and vigor.

The significance of these findings lies in their capacity to transform *D. bigibbum* cultivation practices. Precise knowledge of the plant's nutritional needs is fundamental for optimizing fertilization programs, allowing growers to significantly enhance the health, vigor, and productivity of orchids.

To further refine the nutritional management of this valuable species, it is suggested that future research focus on determining specific doses for each nutrient and exploring their interactions. Such investigations will provide crucial data for formulating more efficient and sustainable fertilization strategies, ensuring the maximum growth potential and quality for the *Dendrobium bigibbum* orchid.

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Author Contribution

ROM: Conceptualization, Investigation, Methodology, Validation, Visualization, Writing – Original Draft. **RMP:** Investigation, Visualization, Writing – Original Draft. **RBMG:** Investigation, Visualization, Writing – Original Draft. **RINS:** Investigation, Visualization, Writing – Review & Editing. **RGV:** Writing – Review & Editing, Visualization. **VMM:** Data Curation, Investigation, Methodology, Visualization, Writing – Original Draft. **RNCCJ:** Visualization, Writing – Review & Editing. **KFLP:** Supervision, Writing – Review & Editing, Project Administration.

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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