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Scientific article

Development and nutritional status of calla lily submitted to nutrient deficiency

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Abstract

Knowledge about the nutritional aspects of calla lily, an important species for the floriculture industry, is essential for quality on cultivation. As there are variations in the symptoms of nutritional deficiencies among species, it is necessary to study the development of plants and their nutritional status when grown under nutrient omission. Thus, the aim was to evaluate the development of calla lily plants and identify the levels of nutrients and their interactions in cultivation conditions under nutritional deficiency. The treatments consisted in the use of the complete nutrition solution and the omission of N, P, K, Ca, Mg, S, Fe, B, and Mn, separately. The experimental design was in randomized block design with four replications. The omissions of P, S, Ca, K, N, and B have influenced the plant development providing lower production of leaves and in small size, reduction on shoots production and less leaves emitted by the shoots, besides a lower values of dry matter. Among these nutrients, the deficiencies that most affected the growth and quality of calla lily plants development were N, B and Ca. The B and N deficiency inhibited the flowering and the absence of S and K provided inflorescences production with lower quality, besides malformation. The main interactions that occurred were increasing in the content of K (leaves), Fe (leaves) and Mn (leaves and inflorescences) in the absence of Ca. In the absence of Mg there was an increase in Ca (leaves, rhizomes, and inflorescences), Zn (leaves and roots) and Fe (rhizomes). It can be concluded that the nutritional deficiencies that most affected the production of inflorescences in calla lily were those of B, N, P, K, Ca, and S and the main nutritional interactions occurred in the absence of Ca with an increase in K, Fe and Mn and an increase in Ca, Fe and Zn in the absence of Mg.
Keywords: cut flower, floriculture, mineral nutrition, nutrient content, ornamental plant, *Zantedeschia aethiopica*.

Resumo

Desenvolvimento e estado nutricional de copo-de-leite submetido à deficiência de nutrientes

O copo-de-leite é uma importante espécie para o setor de floricultura e o conhecimento acerca dos aspectos nutricionais da cultura são imprescindíveis para o seu cultivo comercial. Como ocorrem variações nos sintomas de deficiências nutricionais entre as espécies, torna-se necessário o estudo do desenvolvimento das plantas e do seu estado nutricional quando cultivadas com a omissão dos nutrientes. Dessa forma, este trabalho teve como objetivo avaliar o desenvolvimento das plantas e identificar os teores de nutrientes e as interações entre os mesmos em condições de cultivo sob deficiência nutricional Mudas micropropagadas de copo-de-leite foram submetidas a dez tratamentos que consistiram no uso da solução nutritiva completa e na omissão de N, P, K, Ca, Mg, S, Fe, B e Mn. O delineamento experimental utilizado foi o de blocos ao acaso com quatro repetições. Observou-se que as omissões de P, S, Ca, K, N e B influenciaram no desenvolvimento da planta, com menor produção de folhas que se apresentaram de tamanho reduzido, com redução no número de brotos e emissão de novas folhas nos brotos, além de menores valores de massa seca. Dentre essas, as deficiências nutricionais que mais prejudicaram o crescimento e a qualidade das plantas de copo-de-leite foram as de N, B, e Ca. Os tratamentos com deficiência de B e N impediram o florescimento de copo-de-leite e a ausência de S e K proporcionaram a produção de inflorescências de menor qualidade e com malformação. As principais interações que ocorreram foram o aumento do teor de K (folhas), Fe (folhas) e Mn (folhas e inflorescências) na ausência de Ca. Na ausência de Mg houve aumento de Ca (folhas, rizomas e inflorescências), Zn (folhas e raízes) e Fe (rizomas). Pode-se concluir que as deficiências nutricionais que mais afetaram a produção de inflorescências foram de B, N, P, K, Ca e S, e que as principais interações nutricionais ocorreram na ausência de Ca com aumento de K, Fe e Mn e aumento de Ca, Fe e Zn na ausência de Mg.
Palavras-chave: flor de corte, floricultura, nutrição mineral, planta ornamental, teor de nutrientes, *Zantedeschia aethiopica.*

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Introduction

Calla lily (*Zantedeschia aethiopica* (L.) Spreng.), Araceae, has been widely used as ornamental plant due to its unique inflorescences shape (Kumar and Dogra, 2020). This species may be cultivated in gardens as well as in commercial scale for cut flower production (Reis et al., 2019). It is one of the most important species for smallholder farmers since may be cultivated in small areas and the initial investment is not expensive with a fast economic return of the investment. In addition, besides the floral stems, the seedlings can be commercialized, making the activity profitable (Almeida et al., 2012b).

Despite the calla lily being one of the most important species cultivated for cutting, many aspects of the culture have not been clarified. One of the limitations in production is a lack of information on the nutritional aspects of this species. There are some results showing plant response to specific fertilization and discussion on aspects of the mineral nutrition. In general, calla lily plants are responsive to different sources of organic and mineral fertilization, but nutrient deficiency can limit the development as occurred in other species (Almeida et al., 2015; Boldrin et al., 2019). In plants grown in the field, high doses of NPK 10:10:10 (350 kg 1000 m^{-2}) and manure (40 L m^{-2}) provided better calla lily plant development (Almeida et al., 2012a). Studies on nutrients absorption by calla lily showed that the plant has a great requirement for fertilization in the pre-flowering stage, being potassium the element required in higher volume (Carneiro et al., 2015). For calla lily growing under optimal conditions with correct supply of macro and micronutrients, plant development is constant over time. Under these conditions, the production of inflorescences already occurs 30 days after planting with optimal biometric characteristics related to the length of the stem and the size of the spathe, compatible with the age of the plant (Carneiro et al., 2011).

Nutrient deficiency in calla lily compromises plant quality and inflorescences production, besides the visual symptoms have been observed such as reduction on development, necrosis, and anomalies (Fernandes et al., 2012; Almeida et al., 2015). Besides the characterization of the visual symptoms, it is necessary to perform chemical analyses to confirm the nutritional deficiency. In addition, it is important to consider the nutrients, since in the absorption process, an antagonism, inhibition, or even synergism, might occur (Marschner, 2012; René et al., 2017).

Considering the economic importance of calla lily as cut flower and the lack of knowledge of nutrition for this species, the aimed was to evaluate the development and identify the levels of nutrients in different parts of the plant and the interactions between them in conditions of cultivation under nutritional deficiency.

Material and Methods

For the experiment, 7 cm micropropagated seedlings of calla lily were used. After acclimatization performed on commercial substrate based on pine bark plantlets were kept for 48 days in a plastic tray for adaptation, in a modified 25% strength Hoagland solution (Hoagland and Aron, 1950). Then, plants were transferred to pots (1.9 L) containing the treatments prepared with 30% ionic strength Hoagland solution. The experiment consisted of ten treatments, which comprised a complete solution and solutions with individual omission of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg), sulfur (S), boron (B), manganese (Mn), zinc (Zn), and iron (Fe) (Table 1). The solutions were prepared by eliminating a specific element without modifying the concentration of the remaining nutrients.

Table 1. Chemical composition of nutrient solutions (mL stock solution per liter of solution)[1].

Stock solution	Molarity	Complete	-N	-P	-K	-Ca	-Mg	-S	-B	-Mn	-Fe	-Cu	-Zn
$NH_4H_2PO_4$	1 M	1	0,1	0,1	1	1	1	1	1	1	1	1	1
KNO_3	1 M	6	0,6	6	0,6	6	6	5	6	6	6	6	6
$Ca(NO_3)_2.4\ H_2O$	1M	4	0,4	3	4	0,4	4	3	4	4	4	4	4
$MgSO_4.7H_2O$	1M	2	2	2	2	2	0,1	-	2	2	2	2	2
K_2SO_4	0,5 M	-	3	-	-	-	1	-	-	-	-	-	-
$Ca(H_2PO_4).H_2O$	0,05 M	-	10	-	-	-	-	-	-	-	-	-	-
$CaSO_4.2H_2O$	0,01 M	-	200	-	-	-	-	-	-	-	-	-	-
$Mg(NO_3).6H_2O$	1 M	-	-	-	-	-	-	2	-	-	-	-	-
NH_4NO_3	1 M	-	-	1	3	4	-	-	-	-	-	-	-
*Solução A		1	1	1	1	1	1	1	-	-	1	-	-
*Solução A –B		-	-	-	-	-	-	-	1	-	-	-	-
*Solução A –Mn		-	-	-	-	-	-	-	-	1	-	-	-
*Solução A –Cu		-	-	-	-	-	-	-	-	-	-	1	-
*Solução A –Zn		-	-	-	-	-	-	-	-	-	-	-	1
**Fe-EDTA		1	1	1	1	1	1	1	1	1	-	1	1

[1] According to Hoagland & Arnon (1939), solution number 2.

*Composition: H_3BO_3 2.86 g L^{-1}; $MnCl_2.4H_2O$ 1.81 g L^{-1}; $ZnSO_4.7H_2O$ 0.44 g L^{-1}; $CuSO_4.5H_2O$ 0.08 g L^{-1}; $H_2MoO_4.H_2O$ 0.02 g L^{-1}.

**Fe-EDTA (Jacobson, 1951).

The experimental design was the randomized block with four replications and one plant per plot.

Daily, after checked the water consumption, the content was replaced whenever it was necessary to complete volume demarcated in each pot. Every 15 days, the solutions were exchanged. The plants were cultivated inside a greenhouse under 50% shade provided by black polypropylene shade cloth. The temperature in average varied from 15.3 °C to 27.6 °C (night and day), and the average relative air moisture was 71.3%.

The complete experimental period in which all plants were evaluated was 12 months. Flower onset was variable among treatments, and the first harvest occurred between 3 to 9 months after planting according to the treatments. The quality was evaluated by observing the length and the diameter of the stem, width, length of the spathe. By the time of visible symptoms manifested, the plants were harvested and taken to the laboratory to perform agronomical analyses as number, width and length of the leaves, plant height, and stem diameter. For the analysis, plants were separated in leaves, rhizomes, and roots. All samples, including the inflorescences previously harvested, were kept in a forced circulation oven at temperatures between 65 °C to 70 °C, until reach constant weight, to the measurement of dry matter. The chemical analyses aimed to determine the content of N, P, K, Ca, Mg, S, B, Cu, Fe, Zn, and Mn (According to Malavolta et al. (1997) methodology). The extract was obtained by nitroperchloric digestion and, after that; the nutrients were determined by Kjeldahl (N), Colorimetry (P), Atomic Absorption Spectrophotometry (Ca, Mg, Cu, Fe, Mn, and Zn), and Turbidimetry (S).

Data were submitted to analysis of variance and averages were compared by Tukey-Kramer test at 5% significance.

Results

Vegetative growth

The number of leaves formed in the plants cultivated in solution with omission of Fe, S, N, K, and Mn was not modified, comparing to those cultivated in a complete solution. The omission of Ca, P, and B affected the number of leaves. In the absence of S, N, P, and B the leaves presented smaller width and the absence of N, P, Ca, S, and B plants induced smaller high (Table 2).

Table 2. Number, length and width of leaves, height, number of buds, and number of leaves per shoot in calla lily plants cultivated in complete solution and under nutrient omission.

Treatment	Number of leaves	Leave length (cm)	Leave width (cm)	Height (cm)	Number of buds*	Number of leaves per bud
Complete	5.50 a	16.78 a	11.25 abcd	17.88 ab	13.60 abc	54.25 a
-N	3.75 abc	11.95 ab	8.40 cde	7.63 f	7.54 c	1.50 g
-P	1.30 cd	11.82 ab	7.70 de	13.61bcdef	13.20 abc	27.19 bcdef
-K	3.50 abcd	14,.8 ab	10.48 abcd	18.85 ab	8.58 bc	25.00 def
-Ca	1.00 d	-	-	11.00 cdef	12.68 abc	17.75 ef
-Mg	5.00 ab	16.73 a	13.03 a	22.70 a	12.81 abc	42.25 ab
-S	6.00 a	10.00 b	5.28 e	10.63 def	13.87 ab	25.00 cdef
-B	2.75 bcd	13,90 ab	9.25 bcd	8.38 ef	19.11 a	12.25 fg
-Fe	5.75 a	17.33 a	12.40 ab	20.95 ab	14.01 b	50.25 a
-Mn	5.00 ab	15.08 ab	11.10 abcd	19.23 ab	12.55 abc	46.50 a

Means followed by the same letter (column) do not differ according to the Tukey-Kramer test ($P \leq 0.05$)

*Despite the data transformation, real data were presented regarding the number of buds.

Plants cultivated in the absence of B presented lack of apical dominance, slower growth and reduced on leaves. However, the number of buds was similar to the reference plant (Table 2). In consequence of the absence of apical dominance, an increase in the development of buds occurred, resulting in over sprouting. Plants grown in the omission of N, K, and Fe had lower number of shoots. In exception for the treatments with Fe, Mg, and Mn omission, all the other provide shoots with few leaves in comparison to plants grown in complete nutrient solution (Table 2).

A significant difference ocurred among the treatments regarding plant dry matter. Excepting for Mg, Mn, and Fe omission, in all other treatments, the dry matter reduced in comparison to plants grown in a complete solution. The nutritional deficiencies that most affected the plant dry matter were the omission of N, B, Ca, and S (Table 3).

Table 3. Dry matter of calla lily plants cultivated in complete solution and under nutrient omission.

Treatment	Dry matter (g)		
	Leaves	Rhizomes	Roots
Complete	31.48 a	34.31 abc	10.34 a
-N	3.68 g	6.36 i	2.61 gh
-P	20.61 bcd	23.02 cdefgh	7.87 bcdef
-K	19.56 cd	16.34 fghi	5.94 ef
-Ca	17.64 de	15.53 hi	7.20 cdef
-Mg	28.99 ab	19.62 efgh	6.83 def
-S	9.53 efg	19.92 defgh	5.36 f
-B	5.60 fg	16.02 ghi	1.32 h
-Fe	35.14 a	27.35 bcde	11.16 a
-Mn	31.19 a	38.24 a	10.69 a

Means followed by the same letter (column) do not differ according to Tukey-Kramer test ($P \leq 0.05$)

Quantity and quality of inflorescences produced

The main nutrients that affected calla lily flowering were N, B, K, S, Ca, and P. The absence of N and B prevented blooming in calla lily and the absence of S and K provided low quality of inflorescences besides malformation. The number of inflorescences was hardly reduced in plants cultivated in solution with omission of S, P, or Ca. Cultivation of plants in solutions lacking Mn, Fe or Mg did not affect blooming, and the inflorescences presented the same number as for plant cultivated in complete solution (Table 4).

Table 4. Number and characteristic of calla lily inflorescences cultivated in complete solution and under nutrient omission.

Treatment	Number of inflorescences	Stem length (cm)	Stem diameter (cm)	Spathe width (cm)	Spathe length (cm)	Dry matter (g)
Complete	3.00 abc	21.24 b	0.83 abc	9.35 a	9.79 a	1.55 a
-P	1.75 cd	21.33 b	0.92 a	8.48 a	9.33 ab	1.36 a
-K	3.00 abc	19.50 b	0.70 bc	6.97 a	7.43 b	0.83 b
-Ca	2.00 bcd	26.58 a	0.79 abc	8.55 a	8.76 ab	1.25 a
-Mg	3.00 abc	20.25 b	0.85 abc	8.31 a	8.85 ab	1.24 a
-S	1.25 d	12.01 c	0.68 c	3.44 b	4.54 c	0.65 b
-Fe	3.50 ab	22.05 b	0.88 ab	8.55 a	9.20 ab	1.54 a
-Mn	4.00 a	25.68 a	0.85 abc	9.36 a	9.76 a	1.56 a

Means followed by the same letter (column) do not differ according to Tukey-Kramer test ($P \leq 0.05$)

Plants cultivated in solutions without Ca and Mn showed inflorescence stems with longer length, in average 26.56 cm and 25.68 cm, respectively. These values are higher than the observed in stems from plants cultivated in complete solution. Plants cultivated in solution with Mn omission produced higher number of inflorescences with longer-length stems and higher spathe dimensions, like the ones obtained in the complete solution (Table 4).

Nutrient contents

For most treatments in which one of the nutrients was omitted, changes were observed in the contents of other nutrients in different parts as in leaves, rhizomes, roots, and inflorescences (Tables 5 and 6). Furthermore, it was possible to detect some interactions between nutrients through the increase or decrease of one of the elements in the absence of other (Tables 5 and 6).

Table 5. Average content of macronutrients (g kg^{-1}) in leaves, rhizomes, roots and inflorescences of calla lily cultivated in complete solution and under nutrient omission.

Treatment	N	P	K	Ca	Mg	S
Leaves						
Complete	32.91 b	3.67 b	25.65 b	22.02 ab **	3.84 bc	2.89 b
- N	50.41 ab	4.91 ab	25.80 b	8.29 b**	6.82 a	2.80 bc
-P	32.30 b	1.45 b	102.49 a	15.54 b**	1.87 c	2.75 bc
- K	44.09 ab	5.95 ab	9.60 b	21.94 ab**	5.20 ab	2.81 b
- Ca	30.05 b	4.15 b	100.75 a	7.90 b**	6.93 a	4.58 a
- Mg	33.89 b	6.43 a	23.70 b	27.58 a**	1.30 c	2.06 c
- S	57.52 a	5.46 ab	25.80 b	17.85 b**	2.63 bc	0.78 d
- B	40.10 b	4.60 ab	25.65 b	21.89 ab**	1.88 b	3.31 b
- Fe	27.88 b	3.58 b	26.40 b	25.61 ab**	4.38 b	3.15 b
- Mn	27.42 b	3.68 b	25.80 b	24.24 ab**	4.05 b	2.76 bc
Rhizomes						
Complete	37.03 c	4.52 b	5.40 c	7.64 bc	1.70 a	2.00 b
- N	35.63 c	4.58 b	7.20 bc	0.65 d	1.99 a	1.35 c
-P	41.94 bc	0.79 c	6.48 bc	4.86 cd	0.86 a	2.13 b
- K	73.02 a	8.24 a	1.05 d	5.20 c	2.05 a	2.82 ab
- Ca	54.57 b	8.59 a	9.14 bc	0.05 d	2.60 a	2.99 a
- Mg	45.34 bc	4.22 b	40.80 a	22.27 a	0.81 a	1.76 bc
- S	44.96 bc	6.82 ab	3.75 cd	3.68 cd	1.34 a	0.77 c
- B	41.12 bc	6.91 ab	9.15 b	1.86 d	1.18 a	2.20 b
- Fe	41.02 bc	5.07 b	6.15 c	10.07 b	1.97 a	1.97 bc
- Mn	32.83 c	5.27 b	40.20 a	9.41 b	2.20 a	1.70 bc
Roots						
Complete	30.26 c	1.25 b**	2.92 b**	2.72 ab**	7.47 ab	2.40 b
- N	38.52 b	1.79 a**	6.49 a**	1.13 c**	6.31 b	2.38 b
-P	29.02 c	1.15 b**	6.75 a**	2.23 b**	7.43 ab	2.91 ab
- K	49.31 a	1.82 a**	1.34 c**	1.92 b**	7.44 ab	3.61 a
- Ca	38.11 bc	1.58 ab**	2.92 b**	0.95 b**	2.25 c	3.87 a
- Mg	36.66 bc	1.57 ab**	2.51 b**	2.69 ab**	2.59 c	0.83 c
- S	41.15 b	1.99 a**	7.54 a**	2.03 b**	6.29 b	1.34 c
- B	38.04 bc	1.68 ab**	5.70 a**	2.18 b**	5.04 bc	2.64 b
- Fe	29.76 c	1.11 b**	2.27 bc**	3.00 a**	9.83 a	1.30 c
- Mn	27.51 c	1.70 ab**	2.92 b**	2.97 a**	10.14 a	0.93 c
Inflorescences						
Complete	31.64 b	4.24 c	4.35 ab**	8.70 c	2.11 c	1.90 ab
- P	32.20 b	2.77 d	5.05 a**	7.84 cd	1.82 c	1.99 ab
- K	49.64 a	6.07 a	3.71 b**	5.59 d	2.39 c	2.37 a
- Ca	33.12 b	5.20 b	4.81 ab**	1.75 e	3.91 a	2.20 a
- Mg	31.31 b	1.22 e	2.36 c**	16.19 a	1.16 d	1.37 b
- S*	59.23	5.43	74.40**	11.57	2.17	1.87
- Fe	33.32 b	4.39 bc	4.90 a**	8.69 c	2.18 c	2.03 a
- Mn	30.27 b	1.10 e	1.92 c**	13.25 b	3.25 b	1.40 b

Means followed by the same letter in each column do not differ according to Tukey-Kramer test (P. 0.05)

*Mean of a single sample

** Original data (despite the transformation)

Table 6. Average content of micronutrients (mg Kg^{-1}) in leaves, rhizomes, roots, and inflorescences of calla lily cultivated in complete solution and under omission of nutrients.

Treatment	B	Fe	Mn	Zn	Cu
Leaves					
Complete	41.57 bc	122.84 b	129.25 b	210.61 ab **	10.19 ab
- N	46.90 bc	96.88 b	177.15 ab	104.58 bc**	10.86 ab
-P	61.75 ab	185.20 ab	251.30 a	177.68 ab**	11.92 ab
- K	66.26 ab	112.97 b	166.95 ab	270.43 a**	14.06 a
- Ca	81.33 a	249.92 a	244.12 a	134.29 b**	8.81 b
- Mg	42.55 bc	153.69 b	157.54 ab	284.29 a**	11.48 ab
- S	57.13 b	94.94 b	181.13 ab	67.36 c**	8.83b
- B	27.60 c	91.80 b	83.94 bc	56.26 c**	8.39 ab
- Fe	49.68 bc	120.27 b	154.14 b	212.72 ab**	10.72 ab
- Mn	40.78 c	126.41 b	30.80 c	217.02 ab**	9.48 b
Rhizomes					
Complete	12.91 ab	144.86 cd	46.62 bc	89.69 c	11.18 b
- N	7.35 b	83.42 d	62.09 b	101.26 bc	8.66 b
-P	15.50 a	147.83 cd	58.42 b	74.75 cd	12.05 ab
- K	9.44 b	175.85 c	46.87 bc	133.04 a	16.10 a
- Ca	11.09 ab	158.93 cd	86.87 a	118.25 ab	11.71 b
- Mg	11.75 ab	425.30 a	59.07 b	123.17 ab	8.93 b
- S	6.92 b	87.44 d	50.53 bc	42.45 e	10.87 b
- B	5.36 b	90.80 d	30.62 c	68.20 d	9.86 b
- Fe	12.43 ab	77.21 d	51.17 b	109.66 b	13.82 ab
- Mn	9.46 b	329.05 b	14.19 d	89.24 c	9.55 b
Roots					
Complete	31.59 b	980.44 b	7.32 b**	141.81 b	23.00 b
- N	45.25 a	1629.38 ab	12.18 a**	51.23 c	21.56 b
-P	44.20 ab	436.60 b	5.70 b**	108.52 bc	31.98 ab
- K	36.15 ab	2253.75 a	9.58 ab**	178.58 ab	49.37 a
- Ca	40.41 ab	1214.83 b	5.58 b**	107.52 bc	48.25 a
- Mg	30.80 b	1548.75 ab	5.99 b**	189.81 a	23.57 b
- S	46.40 a	1442.81 ab	9.30 ab**	36.70 c	10.02 b
- B	38.72 ab	979.50 b	11.59 a**	62.69 c	10.17 b
- Fe	29.18 b	471.44 b	7.03 b**	135.40 b	21.32 b
- Mn	26.15 b	1183.13 b	3.42 c**	151.07 ab	14.12 b
Inflorescences					
Complete	59.37 a	51.31 b	77.82 bc	51.82 b	5.88 b
- P	53.24 a	76.98 a	104.78 a	66.01 b	8.65 b
- K	59.54 a	75.89 a	62.72 c	97.83 a	16.65 a
- Ca	63.33 a	64.24 ab	112.40 a	62.57 b	8.04 b
- Mg	55.31 a	75.95 a	73.14 bc	58.22 b	8.40 b
- S*	64.43	58.53	152.37	51.45	8.70
- Fe	58.44 a	62.85 ab	94.45 ab	62.53 b	7.86 b
- Mn	59.36 a	67.55 ab	17.12 d	60.45 b	8.69 b

Means followed by the same letter in each column do not differ according to Tukey-Kramer test (P. 0.05)

*Mean of a single sample

** Original data (despite the transformation)

Nitrogen deficiency

Plants cultivated with N omission showed no significant difference in the levels of this element in any part of the plant, compared to those grown in complete solution. Possibly, this occurred due to the concentration of nutrients, since plants presented low dry matter (Table 5).

Concerning other macronutrients, N deficiency resulted in a significant increase in the Mg content of the leaves, besides a reduction in S and Ca contents of the rhizomes, and an increase in the P and K and reduction in Ca contents in roots (Table 5).

Analyzing micronutrients, in calla lily cultivated with N omission, the roots contents of B and Mn showed to be significantly higher than the other treatments. In addition, a lower Zn content ocurred in roots (Table 6).

Phosphorus deficiency

In P omission, the content of this nutrient in rhizomes and inflorescence reduced, besides no significant difference occurred in leaves (Table 5). Observing other macronutrients, there was a significant increase of K in leaves, roots and inflorescences. Concerning micronutrient levels, a reduction in Mn content occurred, both in leaves and in inflorescences (Table 6).

Potassium deficiency

As can be observed in Table 4, the omission of K provided a reduction in the levels of this nutrient in rhizomes and roots. The K contents in the leaves and inflorescences did not differ from the plants grown in the complete solution. In relation to other macronutrients, P and N levels increased in rhizomes, roots, and leaves. Furthermore, there was an increase in the S content in the rhizome and Ca content reduction in inflorescences. An increase in Zn and Cu levels was observed in rhizomes and inflorescences of calla lily. The levels of Cu and Fe also increased in the roots of the plants grown in K absence (Table 6).

Calcium deficiency

Ca absence on nutritional solution provided a significant reduction in this element levels in rhizomes, roots, leaves, and inflorescences (Table 5). Otherwise, the omission of Ca provided an increase in the Mg content in leaves and inflorescences, S content in leaves, rhizomes, and roots, K in leaves, and P content on rhizomes (Table 5).

For micronutrients, the omission of Ca resulted in an increase in Fe and B contents in leaves, an increase in Mn in leaves, rhizomes and inflorescences (Table 6).

Magnesium deficiency

Plants of calla lily cultivated submitted to Mg omission showed a reduction in the content of this nutrient in the roots and inflorescences. In leaves, the content of this element did not differ from those plants grown in complete solution (Table 5).

Analyzing other nutrients, P content had arisen in leaves but decreased in inflorescences. An increase in S content ocurred in leaves and roots, and in Ca in leaves, rhizomes, and inflorescences (Table 5). Concerning the micronutrients, the omission of Mg significantly increased the content of Zn and Fe in the rhizomes and Zn in roots (Table 6).

Sulfur deficiency

The omission of S resulted in reduction in the content of this nutrient on leaves, rhizomes, and roots (Table 5). It was not possible to carry out a statistical analysis of the sulfur content in the inflorescences, since presented very small size, resulting in only one useful sample for the average of all repetitions (Table 5). Data was just displayed. In S absence, calla lily plants showed an increase in the content of N in leaves, and P and K in roots (Table 5).

Plants grown in S absence showed reduction in Zn content, both in roots and inflorescences, but there was an increase in B content in roots (Table 6).

Boron deficiency

B contents in the leaves and rhizomes of calla lily plants grown in this nutrient omission were significantly reduced as demonstrated by the chemical analysis, although this difference was not detected by the statistical analysis. However, the B content in the root was very similar to the content observed in the complete solution (Table 6). In the absence of B, there was a reduction in Ca content in rhizomes and an increase of K in the roots (Table 5). For micronutrients, the B omission influenced Zn contents, being reduced in the leaves, rhizomes, and roots. There was also an increase in the Mn content in roots (Table 6).

Iron deficiency

Chemical analysis of leaves and inflorescences showed Fe levels similar to those from plants grown in complete solution (Table 6). Fe deficiency resulted in increased K content in the rhizome and inflorescences. In addition, there was a reduction in the S content in the root (Table 5). Among other micronutrients, there was only a significant increase in the Zn content in rhizomes.

Manganese deficiency

Plants cultivated in Mn omission showed an increase in the rhizome K content, besides of an increase of Mg and Ca content in roots, and a reduction in the P content in inflorescences and S in roots (Table 5). A significantly reduction in Mn levels was observed in all parts of the plant (Table 6).

Discussion

Results showed that there is a strong interaction between different nutrients and nutrient-nutrient, influencing ion accumulation (Bouain et al., 2019). The stress caused by the omission of nutrients resulted in changes in the absorption of different elements (Buet et al., 2019). In addition, the statements of nutritional deficiency and common components are involved through signaling mechanisms may be confirmed (Buet et al., 2019).

Our results demonstrate that omissions of N, P, Ca, K, S, and B were the ones that most influenced calla lily development, reducing shoots number, inducing lower leaves production and in small size, besides lower dry matter values. In *Strelitzia augusta,* the omission of N and Ca also affected dry matter production (Coelho et al., 2020a).

The main product resulting from calla lily cultivation is the inflorescence, which affected by the omission of N, P, K, Ca, S, and B. In addition, it was observed that plants cultivated under the omission of N did not flower, demonstrating the importance of nitrogen fertilization for these plants. Even though K deficiency did not influence the qualitative characteristics of the inflorescences, the dry

matter production was affected. Similar results had been observed for heliconia (Castro et al., 2007) and tagetes (Coelho et al., 2011). Furthermore, K omission induced malformation on inflorescences.

Calcium omission influence blooming since this nutrient affect cell differentiation and elongation, being necessary for cell division and formation of cell wall cannot be substituted in their function by other ions (Costa et al., 2017; González-Fontes et al., 2018; Kirchhelle et al., 2019). For marigold, Ca omission also affected blooming (Coelho et al., 2011) but not in *Etlingera elatior* (Frazão et al., 2010), showing some antagonistic results.

Absence of S in the nutrition solution induced also malformation in inflorescences, presenting reduction on size, with thinner stems as well as smaller spathes. Plants deficient in S are small and spindly with short and slender stalks (TSI, 2021), agreeing with results obtained for calla lily. Similarly, as observed in plants grown in N omission, the omission of B also did not allow inflorescences formation. In general, B deficiency affects plant blooming, causing floral abortion. In addition, in plants that present some flowers, the absence of this nutrient affects formation and development of reproductive organs (Marschner, 2012). In anthurium, B omission hardly affected inflorescences development (Pinho et al., 2020), demonstrating the essentiality of this nutrient.

Some nutrients did not influence plant development, indicating that calla lily plants may have a show low demand of these nutrients, or the reserves stored are enough to plant metabolism.

An interesting observation is that in the absence of Ca, there was an increase in the content of K (leaves), Fe (leaves), Mn (leaves and inflorescences). In addition, in the absence of Mg there was an increase Ca (leaves, rhizomes, and inflorescences), Zn (leaves and roots) and Fe (rhizomes).

The increase of K content in plants occurred due to the effect of competitive inhibition between this element and Ca (Malavolta, 2006), meaning that higher concentrations of Ca inhibit K absorption. In this study, there was no competitive inhibition, since in nutrient solution with Ca omission, an increase on K absorption occurred. In *Strelitzia augusta*, the omission of Ca also influenced the increase in K content (Coelho et al., 2020b).

No competitive inhibition may have occurred between Ca and Mg, Ca and Mn, and Mn and Mg (Malavolta, 2006). This explains the founded of highest Ca and Mg contents in calla lily's roots in absence of Mn, higher levels of Mg in leaves and inflorescences in the treatment with Ca omission, and higher levels of Ca in leaves, rhizomes and inflorescences in the treatment with Mg omission. In *Strelitzia augusta* the absence of competitive inhibition between Ca and Mg was also observed (Coelho et al., 2020b). Ca and Mg have similar chemical characteristic such as ionic radius, valence, hydration degree and close mobility, which justifies the proximity between these nutrients and causing competition for absorption sites. In consequence of this proximity, the presence of one of these elements can affect the other absorption processes (Malavolta, 2006).

Concerning other nutrients, an elevated content of Fe ocurred in leaves under Ca omission, probably due to the absence of an intervention in the Fe absorption caused by Ca (Dechen et al., 2018). The absence of Mg was also increase of Fe content in calla lily rhizomes, as it was also observed for *Strelitzia augusta* (Coelho et al., 2020b). An increase in Zn content on calla lily leaves and roots can be due to the competitive inhibition between Mg and Zn (Malavolta et al., 1997). Thus, in the absence of Mg, Zn absorption was facilitated, providing an increase on this element content in plants.

There was an increase or decrease of several elements in the different parts of the plant that were not discussed due to the absence of similar results or justifications for these interactions in the literature. However, this information is important for further considerations on the nutritional aspects of calla lily.

Conclusions

The nutritional deficiencies that most affected the growth and quality of calla lily plants were N, B, and Ca. The nutritional deficiencies that most affected the production of inflorescences were those of B, N, P, K, and Ca. Blooming is inhibit by B and N deficiencies. The omission of P and Ca reduce the number of inflorescences, and S and K omission induced malformation. The nutritional deficiencies modify the nutritional contents in different parts of the plant, with possible effects on absence of competitive inhibition. The main interactions occurred with the increase in the content of K (leaves), Fe (leaves) and Mn (leaves and inflorescences) in the absence of Ca and in the absence of Mg there was an increase in Ca (leaves, rhizomes, and inflorescences), Zn (leaves and roots) and Fe (rhizomes).

Author Contribution

EFAA: Research conduction, data entry, manuscript writing and review. **PDOP:** Research idea and planning, manuscript writing and review. **JEMF:** Research planning and conduction, data entry. **MNOR:** Manuscript writing and review. **NPO:** Research conduction and data entry.

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