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MULTIVARIATE ANALYSIS OF EXPORT OF LIMITING NUTRIENTS IN HELICONIA CULTIVARS

ANÁLISE MULTIVARIADA DA EXPORTAÇÃO DE NUTRIENTES LIMITADORES EM CULTIVARES DE HELICONIA

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ABSTRACT
The basic understanding of the export of nutrients by tropical flowers is of fundamental importance for fertilization programs, constituting a prerequisite for product quality and commercialization success. Thus, this study aimed to identify the export of limiting macro and micronutrients in Heliconia cultivars. The experiment was conducted in Benevides, state of Pará, Brazil. Randomized complete design blocks, distributed in five replicates were used in the study. The treatments consisted of three Heliconia cultivars (*Red gold*, *Golden torch* and *Golden adrian*), in which leaves, stems and flowers were analyzed. The experimental data were subjected to the Multivariate Factorial Analysis (MFA) statistical technique, using SPSS Statistics 17.0 Software. It was verified that Heliconia cultivars showed differences in the development, especially *Golden torch*, which presented the highest plant height (113.6 cm) and flower weight (0.052 g) and the lowest leaf area (590.63 cm^2). The *Red gold* cultivar showed greater development in stem diameter (2.82 cm), leaf area (899.30 cm^2), and stem (0.166 g) and leaves (0.106 g) weights, with lower plant height (84.5 cm) when compared with the other studied cultivars. From MFA, it was observed that the different Heliconia cultivars presented high similarity regarding nutrients and total contents, in which *Red gold* explained 95.00% and 44.62% of the total variance, respectively. Moreover, MFA identified the formation of five groups for nutrient contents and two for export of macro and micronutrients in leaves.
Keywords: tropical flowers, plant nutrition, cluster analysis.

RESUMO
O entendimento básico da exportação de nutrientes por flores tropicais é de fundamental importância para os programas de fertilização, constituindo um pré-requisito para a qualidade do produto e o sucesso da comercialização. Assim, este estudo teve como objetivo identificar a exportação de macro e micronutrientes limitantes em cultivares Heliconia. O experimento foi realizado em Benevides, estado do Pará, Brasil. Foram utilizados blocos de estudo completos ao acaso, distribuídos em cinco repetições. Os tratamentos consistiram em três cultivares Heliconia (ouro vermelho, tocha dourada e adriiana dourada), nas quais foram analisadas folhas, caules e flores. Os dados experimentais foram submetidos à técnica estatística de Análise Fatorial Multivariada (AMF), utilizando o software SPSS Statistics 17.0. Verificou-se que as cultivares Heliconia apresentaram diferenças no desenvolvimento, principalmente a tocha dourada, que apresentou a maior altura de planta (113,6 cm) e peso de flor (0,052 g) e a menor área foliar (590,63 cm2). A cultivar Ouro Vermelho apresentou maior desenvolvimento nos pesos de diâmetro do caule (2,82 cm), área foliar (899,30 cm2) e peso do caule (0,166 g) e folhas (0,106 g), com menor altura da planta (84,5 cm) quando comparado com os demais estudados. cultivares. A partir da MFA, observou-se que as diferentes cultivares Heliconia apresentaram alta similaridade em relação aos nutrientes e teores totais, nas quais o ouro vermelho explicou 95,00% e 44,62% da variância total, respectivamente. Além disso, a AMF identificou a formação de cinco grupos para o conteúdo de nutrientes e dois para exportação de macro e micronutrientes nas folhas.
Palavras-chave: flores tropicais, nutrição de plantas, análise de agrupamentos.

1. INTRODUCTION

The world activity of flowers and ornamental plants has increased, occupying an estimated area of 609 thousand hectares [1], with world flower production estimated at US $

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55 billion [2]. Thus, there have been advances in the market structure, diversification of species and varieties, diffusion of new production technologies, efficient distribution and marketing system, and integration with social inclusion programs [3].

Among the cultivated ornamental plants, Heliconia have been widely commercialized in the international market, with increase of the production area in countries of Central America and South America [4]. Heliconia presents exotic inflorescence appearance in a variety of colors and shapes, with continuous and large flower production, post-harvest durability and lower acquisition cost [5].

Although floriculture is one of the segments of agriculture with the highest profitability per unit area and fast return on applied investments, the sector is highly competitive, requiring the use of advanced technologies [6]. Field management plays an important role on floriculture due to low fertility of soils, associated with the lack of knowledge about the nutritional needs of the export of nutrients by Heliconia [7].

Important characteristics for post-harvesting and commercialization of Heliconia, such as stem length and diameter, length of inflorescence [8], number of tillers and leaves, leaf area, leaf dry mass production [9], post-harvest durability [10] and carbohydrate content of floral stems are compromised by nutritional deficiencies [11]. In order to analyze the nutritional status of the plants, a quantitative evaluation of the nutrients is required, in which using only univariate statistical methods could compromise the proper interpretation of the results [12]. One option for analyzing the results is the use of Principal Components Analysis (PCA), which allows the dimensional reduction of the problem, besides increasing the efficiency of its interpretation and the choice of the solution to be further adopted [13].

The PCA method, which consists of rewriting the coordinates of the samples in another system that is more convenient for data analysis, allows the reduction of the number of evaluated variables and can be used to judge the importance of the original variables. The variables that present greater weight and are more important from the statistical point of view [14] can assist better in studies on vegetative development [15], soil fertility [16] and plant mineral nutrition [17].

Thus, this study aimed to identify the export of limiting macro and micronutrients in different plant parts of Heliconia cultivars using Multivariate Factorial Analysis.

2. MATERIAL AND METHODS

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The study was carried out in an agricultural field area located in Benevides, state of Pará, Brazil (23º 25' S and 51º 57' W), which presents a commercial plantation history of Heliconia, cultivated in 4x4-m spacing, arranged in clumps shaded by Azadirachta.

The soil of the experimental area is classified as Yellow Oxisol with medium texture [18]. Soil samples were collected from the 0-0.20 mm depth, in areas cultivated with Heliconia. Upon collection, soil samples were characterized for their chemical attributes (Table 1), following the methodology described by [19].

Table 1 - Results of the chemical analysis of the soil of the study area.

Attribute	Unit	Heliconia cultivars (analysis by planting area)		
		Red Gold	*Golden Torch*	*Golden adrian*
pH in H_2O		5.7	4.7	5.0
N	%	0.17	0.30	0.25
MO	$g\ kg^{-1}$	14.33	21.95	17.38
P	$mg\ dm^{-3}$	46	43	47
K	$mg\ dm^{-3}$	36	43	47
Na	$mg\ dm^{-3}$	15	21	18
Ca	$cmol_c\ dm^{-3}$	3.1	2.2	2.4
Ca+Mg	$cmol_c\ dm^{-3}$	5.1	4.1	3.5
Al	$cmol_c\ dm^{-3}$	0.2	0.7	0.7
H+Al	$cmol_c\ dm^{-3}$	3.63	7.2	5.7

Three Heliconia cultivars were randomly selected: *Golden torch*, *Golden adrian* and *Red gold* (Figure 1). The collected plant material was separated into leaves, stems and flowers, and weighed to determine the fresh weight. The material was further dried in a forced-air circulation oven at 60 °C, until constant weight to obtain the dry weight (g).

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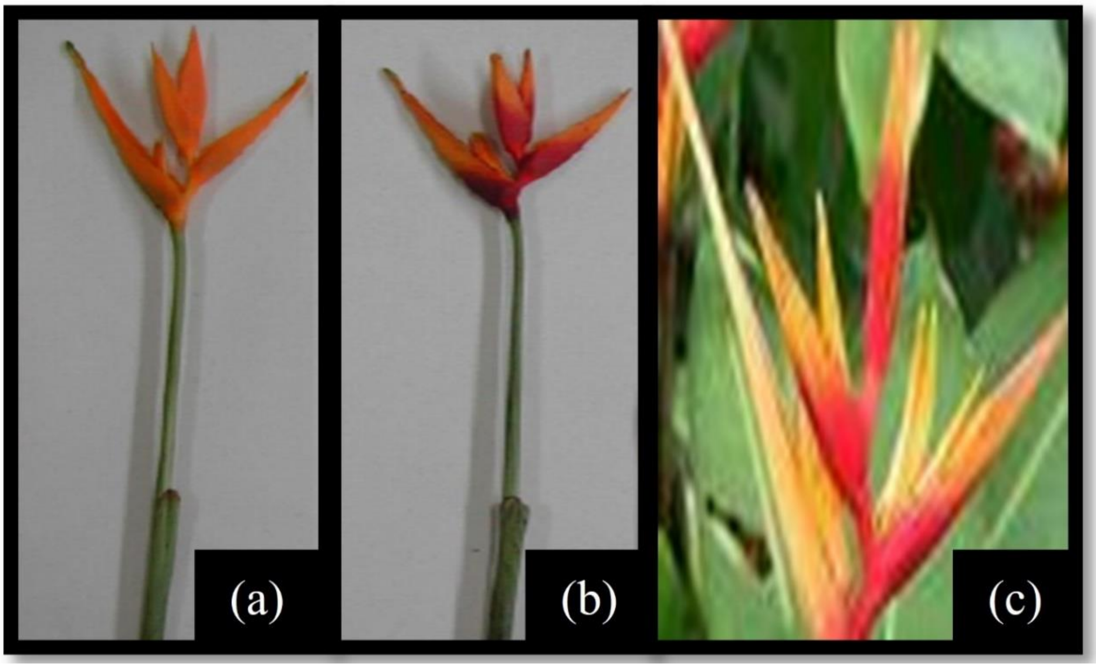

Figure 1. Heliconia flower stems of the cultivars *Golden torch* (a), *Golden adrian* (b) and *Red gold* (c).

The plant tissues were analyzed for their macro and micronutrient contents. Nitrogen levels were determined by titration, while phosphorus was determined by colorimetry, and potassium, calcium, magnesium, copper, iron, manganese and zinc levels were by atomic absorption spectrophotometry after sample digestion [20]. The contents of macronutrients (g kg^{-1}) and micronutrients (mg kg^{-1}) levels were calculated according to the equation below:

$$Content_{(nutrients)} = Level_{(nutrientes)} \times Dry\ mass_{(Leaves,stem\ and\ flowers)}$$

Data adjustment analysis and Principal Component Analysis (PCA) were performed based on the correlation matrix between the components and the attributes, in order to identify new variables that explain most of the variability, generating new values for each sampling point corresponding to the main components, using SPSS Statistics Software 17.0.

A cluster analysis was used, using the Ward method, with the purpose of classifying the chemical attributes of leaf tissue (nutrient contents) in plant parts of the three studied Heliconia cultivars and the components in homogeneous groups. The multivariate analysis method does not consider the distribution of the data. Thus, grouping was based on the measures of similarity between the variables [21].

The selection of the number of principal components was based on the criterion of analysis of the approximation quality of the correlation matrix, using the components associated

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with eigenvalues greater than [21]. In the case of the correlation of the components with the chemical attributes (nutrient contents), values higher than 0.7 were considered significant [22]. The other factorial analyzes (cluster and scree plot) were tested to perform grouping of cases (*Red gold* leaf – RGF; *Red gold* stem – RGH; *Red gold* flower – RGF; *Golden torch* leaf – GTF; *Golden torch* stem – GTH; *Golden torch* flower – GTFL; *Golden adrian* leaf – GAF; *Golden adrian* stem – GAH; *Golden adrian* flower – GAFL), correlating them with the macro and micronutrient contents in each part and total plant [23].

3. RESULTS AND DISCUSSION

The stem diameters (Figure 2a) of the three different Heliconia cultivars were: 2.32 cm (*Golden adrian*), 2.82 cm (*Red gold*) and 1.93 cm (*Golden torch*). As for plant height (Figure 2b), *Golden torch* presented the highest value (113.60 cm), which was 39.73% higher than *Golden adrian* (97.81 cm) and *Red gold* (84.50 cm). The values of plant height obtained in the present study were superior to that described by [24], who verified plant heights of up to 60 cm in Alpine plants.

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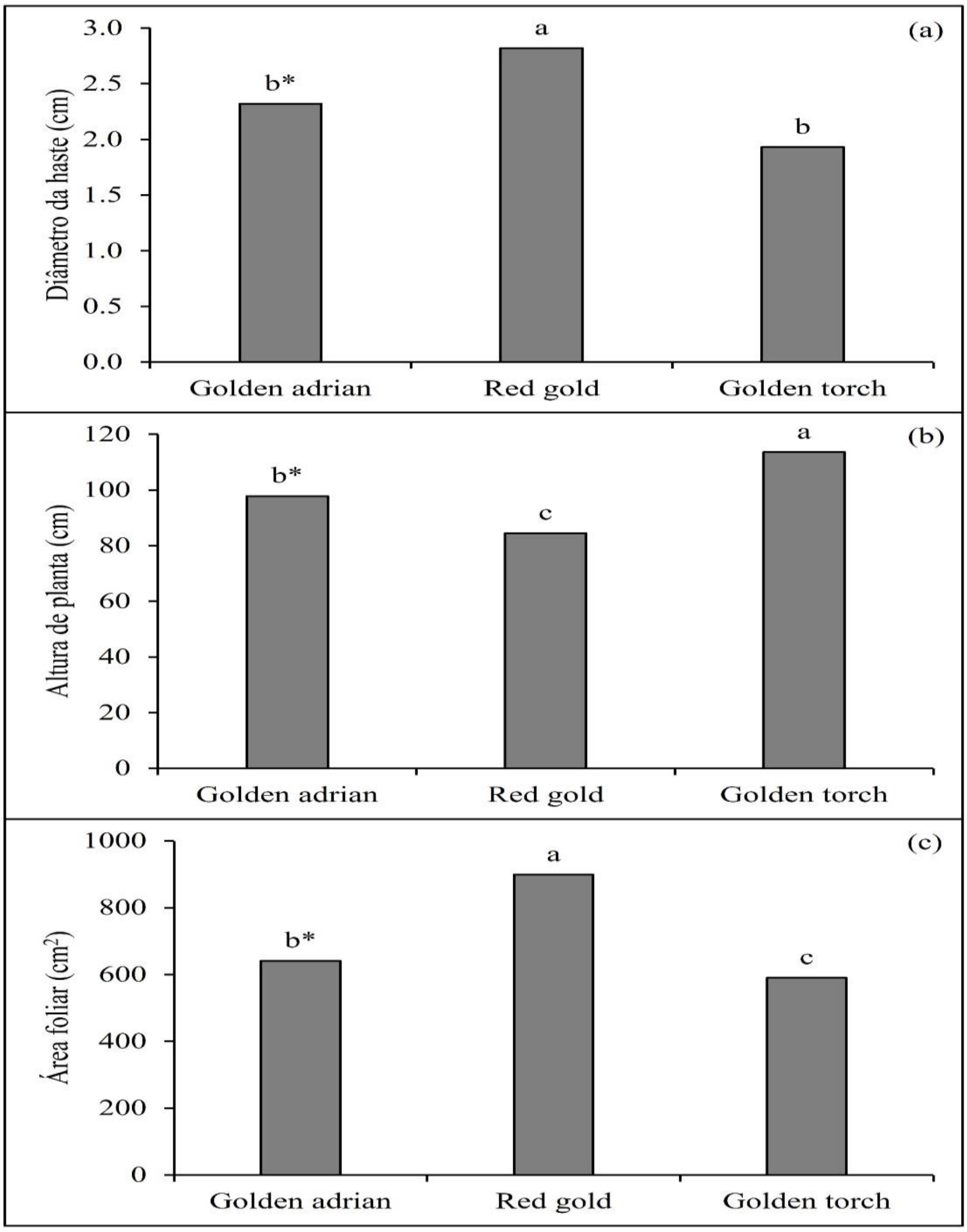

Figure 2 - Plant height (a), stem diameter (b) and leaf area (c) of Heliconia cultivars (*Golden adrian*, *Red gold* and *Golden torch*) cultivated in Benevides, state of Para, Brazil (2011).
* Averages followed by the same capital letter do not differ significantly from each other at 5% probability level by the Tukey test.

The highest leaf area was obtained for *Red gold* (899.30 cm^2), followed by *Golden adrian* (640.99 cm^2) and Golden torch (590.63 cm^2) (Figure 2c). [25] related changes in the leaf area to the photosynthetic capacity, which justifies the higher plant height obtained for *Red gold*, since the increase of the leaf area might reflect on the higher biomass investment in the photosynthetic surface growth [26], provided by greater interception of light energy and CO_2 [27].

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Leaf area values were higher than those reported by [11]. This difference can be attributed to the soil correction procedure performed by the authors prior to fertilization, promoting soil pH elevation and reduction of the exchangeable aluminum content, elevation of available calcium and magnesium contents, and increased availability of phosphorus to the plants [28, 29], supplying the nutritional need of the plant.

Red god showed higher leaf (Figure 4a) and stem (Figure 4b) weights, with values of 0.106 and 0.166 g, respectively. The highest flower weight (0.052 g) was obtained for *Golden torch* (Figure 4c). According to [30], the highest weight of stems occurs because *Heliconia psittacorum* reproduced more than the large Heliconia species.

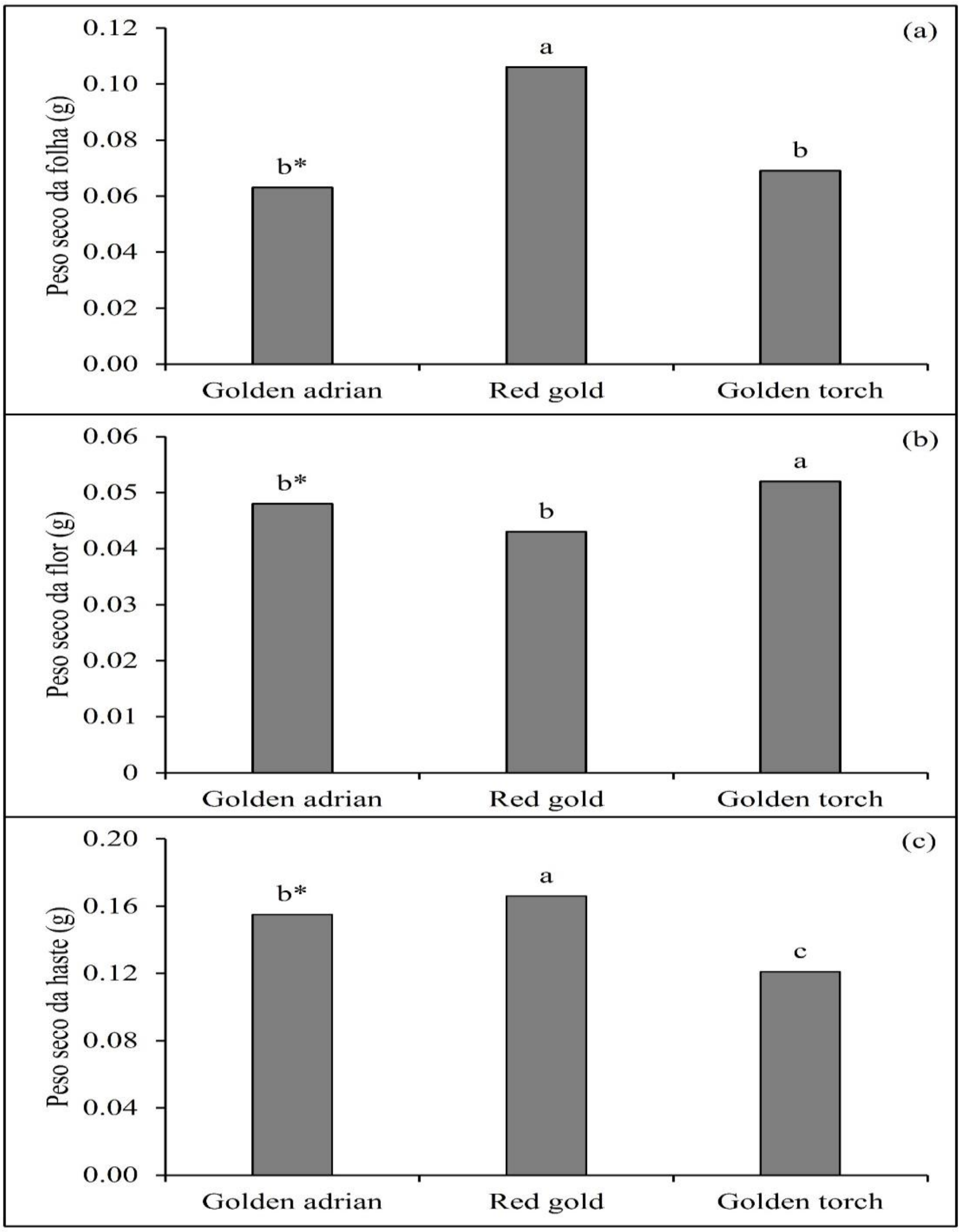

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Figure 3 - Dry weight of leaf (a), flower (b) and stem (c) of three heliconia cultivars (*Golden adrian, Red gold* and *Golden torch*), cultivated in Benevides, PA (2011).
* Averages followed by the same capital letter do not differ significantly from each other at 5% probability level by the Tukey test.

In the principal component analysis, four components were extracted, which, cumulatively, explained 93.49% of the total variability of the experimental data (Table 2). The first principal component, which was named *Red Gold* Leaf (RGF), presented 44.62% of the total data variability and correlated with nine chemical attributes (N, P, K, Ca, Mg, Cu, Mn, Fe and Zn), with a high negative correlation (> 0.70) between Zn, Cu, Mn, P and Ca. The component was negatively influenced by the total nutrient content related to the export of nutrient, since this attribute represents the nutritional portion that should be at the appropriate levels if there is no nutrient exportation by the plant. Furthermore, it would be necessary to presume future fertilization techniques to meet the needs of the plants.

Table 2 - Total explained variation of factors related to nutrient contents obtained through the factorial analysis of three Heliconia cultivars.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
RGF	8,580	95,339	95,339	8,580	95,339	95,339
RGH	,327	3,633	98,972			
RGFL	,049	,541	99,513			
GTF	,017	,192	99,705			
GTH	,015	,166	99,871			
GTFL	,009	,104	99,975			
GAF	,002	,024	99,999			
GAH	7,593E-5	,001	100,000			
GAFL	-1,960E-16	-2,178E-15	100,000			

Extraction Method: Principal Component Analysis.

The second principal component, which was named *Red gold* stem (RGH), explained 21.29% of the total variability of the data. Only the N and Fe attributes showed a significant correlation, verifying that the component was related to the plant leaf tissue, since the correlation with the stem and the export of nutrients (N and Fe) was high, which in turn was influenced by the first principal component (RGF). The significant and positive correlation value was expected for N and Fe because of the export of nutrients by Heliconia stems, reinforcing the nitrogen requirement information of the plant [31].

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For the principal component analysis, only one component was extracted, which, in a cumulative form, explained 95.34% of the total variability of the data (Table 3). The first and only main component, called *Red Gold* Leaf (RGF), presented 95.34% total data variability and high positive correlation (>0.70) with nine chemical attributes (total contents of N, P, K, Ca, Mg, Cu, Mn, Fe and Zn). The components had a positive influence on the total nutrient content related to the export of nutrients by another organ of the plant (leaf) (Table 3), since this attribute represents the nutritional portion in which the plant presents the level, making the heliconia species less susceptible to nutrient loss.

Table 3 - Total explained variation of factors related to total nutrient contents obtained through the factorial analysis of three Heliconia cultivars.

Attribute	Unit	Heliconia cultivars (analysis by planting area)		
		Red Gold	*Golden Torch*	*Golden adrian*
pH in H_2O		5.7	4.7	5.0
N	%	0.17	0.30	0.25
MO	g kg^{-1}	14.33	21.95	17.38
P	mg dm^{-3}	46	43	47
K	mg dm^{-3}	36	43	47
Na	mg dm^{-3}	15	21	18
Ca	$cmol_c$ dm^{-3}	3.1	2.2	2.4
Ca+Mg	$cmol_c$ dm^{-3}	5.1	4.1	3.5
Al	$cmol_c$ dm^{-3}	0.2	0.7	0.7
H+Al	$cmol_c$ dm^{-3}	3.63	7.2	5.7

By comparing the nutrient contents presented in Tables 2 and 3, where they express the total of the explained variance, there was a significant reduction in the number of factors between the two tests, identifying in the first four factors and in the second only one factor. Thus, with the use of factorial analysis in order to correlate the data, it was verified that *Red gold* leaf best explained the high amounts of export of macro and micronutrients by the leaves. It presented the largest leaf area, being the species more suitable for expansion of large areas of plantation, followed by the cultivar *Golden torch*. Nevertheless, *Golden adrian* was not expressive for amounts of export of macro and micronutrients, since the eigenvalues of Tables 2 and 3 were equal to 1.0. It means high significance, and that the factor can explain the factor-related autovariance of the data, showing contents of highly significant nutrients for Heliconia with larger numbers of leaf area, constituting a nutrient reserve for the plant.

The cluster analysis technique complemented the results obtained with the use of principal components analysis in an efficient way. It was used the nine original attributes, adopting the Ward method with the measure of the similarity given by the Euclidean distance,

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with the purpose of grouping them, defining the cut distance equal to 0.3 cm, thus forming groups homogeneous, in the grouping with four principal components (Figure 4).

```
                    Rescaled Distance Cluster Combine

  C A S E      0         5        10        15        20        25
Label     Num  +---------+---------+---------+---------+---------+

Cu          6   -+
Zn          9   -+
Mn          7   -+
N           1   -+
K           3   -+
Fe          8   -+
Ca          4   -+
Mg          5   -+
P           2   -+
```

Figure 4 - Dendogram of the macro and micronutrients contents obtained on the basis of the raw data matrix, using Ward's method of connection with "Fenon Line" separating the respective groups of the three Heliconia cultivars.

There was a similarity between the actual set of evaluated attributes (macronutrients and micronutrients) and the four main components (*Red gold* leaf, *Red gold* stem, *Red gold* flower and *Golden Torch* leaf) (Figure 4). It facilitated the interpretation by reducing the complexity of interpretation of the chemical attributes of the plant tissue (nutrient contents) [32]. From the results, it was observed that macro and micronutrients were exported to the different vegetation organs of Heliconia, mainly Cu and N. Thus, it is necessary the replacement through fertilization so that the plants do not present symptoms of deficiency [33]. [31] and [9] verified that N was the nutrient that most limited the growth of Heliconia, with 60-80% reduction in the number of shoots, 66-74% in the average dry leaf mass and 50% in the underground dry mass, 35% in the number of leaves and 27% in the leaf area. Similar results of growth reduction were observed for other ornamental plants, such as *Zingiber spectabilis* [34, *Aechmea fasciata* [35] and *Lilium longiflorum* [36].

Heliconia cultivars that limited the group showed a similarity with the neighboring group, especially Group 1 (6, 9, 7, 1, 3, 8, 4, 5 and 2) (Figure 4). Thus, Heliconia plants presented export of macro and micronutrients, requiring future fertilization recommendations in the areas of flower production.

There was greater similarity of plants from Group 1 (1, 7 and 9) with Group 2 (2, 4 and 5), and smaller with Group 3 (7, 1, 3, 4, 5 and 8). Group 1 showed a higher accumulation of export of nutrients (N, Mn and Zn) in the different vegetative parts of the plants, showing the need for replacement fertilization in the production areas of ornamental plants of *Red gold* leaf.

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Group 2 (*Red gold* stem) exported more accumulated amount of P, Ca and Mg. Group 3 (Red gold flower) presented higher accumulated contents of Mn, N, K, Ca and Fe.

```
                    Rescaled Distance Cluster Combine

  C A S E      0         5        10        15        20        25
Label     Num  +---------+---------+---------+---------+---------+

Cu          6   -+
Zn          9   -+---+
Mn          7   -+   +-----------------------------------------+
N           1   -----+                                          |
K           3   -+-+                                            |
Fe          8   -+ +---+                                        |
Ca          4   ---+   |                                        |
Mg          5   -------+-----------------------------------------+
P           2   -------+
```

Figure 5 - Dendogram of the total macro and micronutrient contents obtained on the basis of the raw data matrix, using Ward's method of connection with "Fenon Line" separating the respective groups of the three Heliconia cultivars.

The graphical form of factor definition indicated that the variance was explained by the first factors, with significant differences, and later smoothing of the curve, in which point 2 determined the number of factors to be considered. The total contents of N, P, K, Ca and Mg are considered to be the most exported by heliconia (Figure 6a). The nutrient contents accumulated by the plants presented smaller differences, with point 2 allowing the determination of the formation of two expressive factors in the analysis, characterized by accumulated N and P contents (Figure 6b).

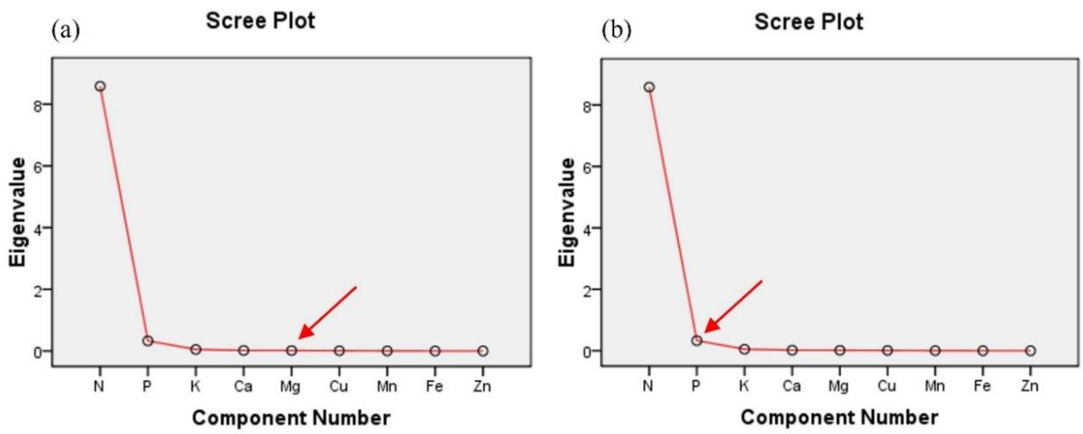

Figure 6 - Difference of factor definition by the eigenvalue and the slope graph for nutrient (a) and (b) total nutrient contents.

3. CONCLUSIONS

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Heliconia cultivars presented differences in the vegetative development with higher heights and numbers of flowers found for the *Golden torch* cultivar. As for stem diameter, leaf area and stem weight, the *Red gold* cultivar presented the highest values.

The multivariate analysis identified that Heliconia cultivars present medium similarity to contents and high similarity to export of total nutrients, with the formation of five and two groups for export macro and micronutrient contents and total contents in leaves, respectively. The highest variability occurred for the *Red gold* cultivar in the leaf, with explanation of the total variance of 44.62% for macronutrient contents and 95.00% for total macronutrient contents.

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