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Chemical and physical variability of traditional varieties of corn (*Zea mays* L.) grown in the Juruá Valley, Acre, Brazil

Variabilidade nutricional e física de variedades tradicionais de milho (*Zea mays* L.) cultivados no vale do Juruá, Acre, Brasil

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Abstract

The traditional varieties of maize grown by family farmers are a source of genetic variability and are essential for food security. Thus, the present study aims to evaluate, based on physical and chemical components, the behavior of the genetic variability of traditional maize cultivated on non-flooded and floodplain areas, in the Juruá region, state of Acre. The characteristics consisted of the determination of dry matter, mineral material, crude protein, ether extract, gross energy, neutral detergent fiber, starch and *in vitro* digestibility of dry matter, vitreousness and grain density. Data were analyzed using descriptive statistics, associated with multivariate analysis of principal components (PCA), with the aid of the R software. By means of the PCA, the varieties grown on non-flooded and floodplain areas formed 3 distinct groups, in which the vitreosity in the grains ranged from 73.7% to 79.46%, so that the reddish grain varieties had a greater presence of endosperm vitreous and higher density, with a strong and positive correlation between these variables. The yellow and orange-yellow grain varieties showed greater adherence to energy, starch and greater digestibility. Therefore, the traditional varieties cultivated on non-flooded and floodplain areas, present variations in relation to the physical and chemical analyses.
Keywords: nutritional value; genetic resources; on-farm conservation.

Resumo

As variedades tradicionais de milho cultivados pelos agricultores familiares constituem-se em fonte de variabilidade genética e são fundamentais para segurança alimentar. Assim, o presente trabalho tem como objetivo, avaliar, com base em componentes físicos e químicos, o comportamento da variabilidade genética de milho tradicional cultivadas em terra firme e praia, na regional Vale do Juruá, estado do Acre. As características constaram da determinação de matéria seca, material mineral, proteína bruta, extrato etéreo, energia bruta, fibra em detergente neutro, amido e digestibilidade *in vitro* da matéria seca, vitreosidade e densidade dos grãos. Os dados foram analisados mediante estatística descritiva, associado à análise multivariada de componentes principais (PCA), com auxílio do *software* R. Por meio da PCA, as variedades cultivadas em terra firme e praia formaram 3 grupos distintos, na qual a vitreosidade nos grãos variou de 73,7% a 79,46%, de modo que, as variedades de grãos avermelhadas apresentaram maior presença de endosperma vítreo e maior densidade, havendo uma correlação forte e positiva entre essas variáveis. Já as variedades de grãos amarelas e amarelas-oranges apresentaram maior aderência a energia, amido e maior digestibilidade. Portanto, as variedades tradicionais cultivadas em terra firme e praia, apresentam variações em relação as análises físicas e químicas.
Palavras-chave: valor nutricional; recursos genéticos; conservação *on farm*.

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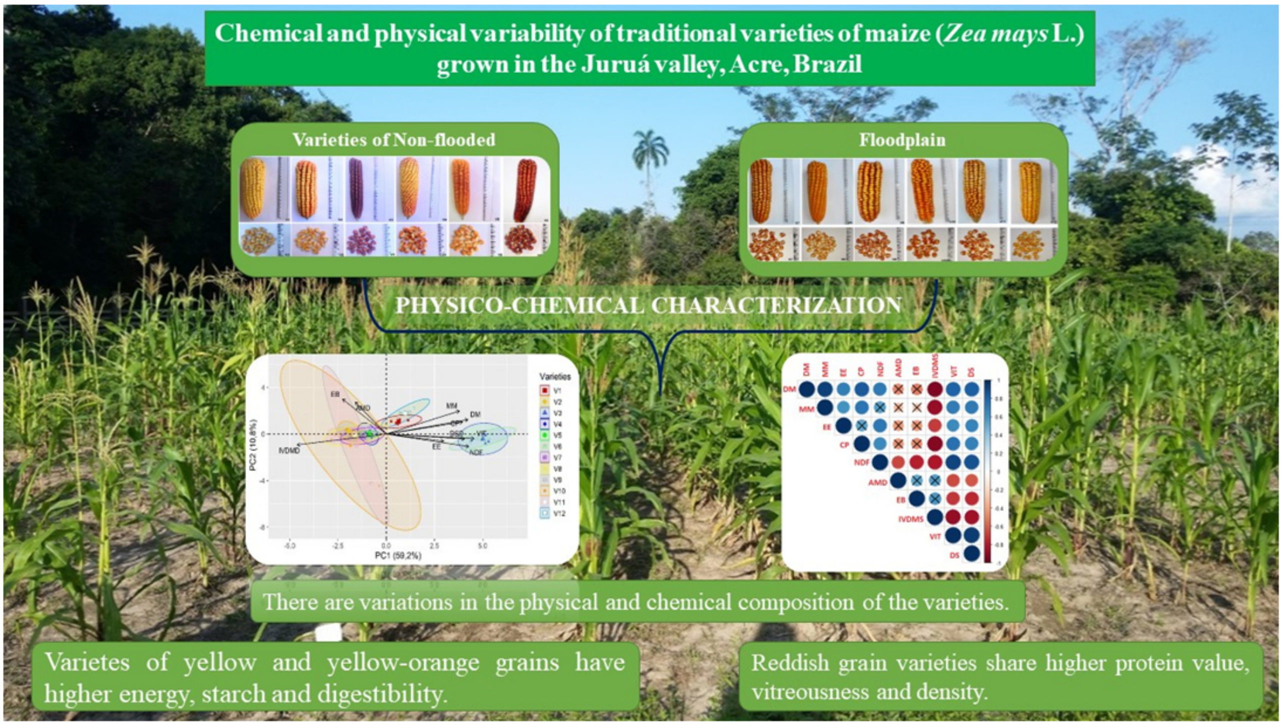

Graphical abstract - Chemical and physical variability of traditional varieties of corn (*Zea mays* L.) grown in the Juruá Valley, Acre, Brazil

1. Introduction

The world demand for maize has grown in recent years, driven by advances in the economy of Asian countries and the use of this cereal for ethanol production in the United States [1]. The growing demand, both internal and external, reinforces the great potential of the sector that, together with soybeans, is considered a basic input for poultry and pig farming, two extremely competitive markets internationally and revenue generators for Brazil [2].

The importance of maize in Brazil is wide, because its production occurs both in small typically family farms, whose purpose is subsistence, as well as in large tracts of land, in which the use of production technologies and skilled labor predominates [3]. In economically developed regions, crops are intended for the cultivation of hybrid and transgenic maize, while in regions where there is a predominance of family farming, the cultivated maize consists of local traditional varieties [4].

Traditional maize presents itself as a viable alternative of production for small farmers, because it needs low levels of investment in inputs to achieve satisfactory productivity [5]. In addition, these plant materials are a precious source of favorable alleles, useful to enrich the genetic basis of existing breeding programs [6]. However, the selection made by both farmers and environmental factors provided the existence of a great genetic variability for these varieties [7].

In the case of family farming, maize is of great importance for subsistence, because it has high energy value and is consumed directly as food, in the form of cooked maize or its derivatives such as pamonha, canjica, couscous and cakes [8]. Although maize grains are considered an indispensable food for the survival of these farmers, the amounts of some nutrients, present in unbalanced quantities or at levels inadequate for consumers who depend on maize as the main source of food [9].

It is therefore essential that studies in order to know the nutritional value and the characteristics of the grains of traditional varieties are developed, in order to make them available to current and future research programs aimed at obtaining plants with high quality protein source In maize grain, the protein and energy content is concentrated mostly in the endosperm, distributed in the farinaceous and vitreous regions, in which vitreousness refers to the amount of vitreous endosperm on the total endosperm [10].

Thus, the present work has as main objective to evaluate, based on physical and chemical components, the behavior of genetic variability of traditional varieties of maize grown on non-flooded and floodplain areas, in the regional Vale do Juruá, state of Acre.

2. Material and methods

The study was conducted in the western extremity of the state of Acre, regional Juruá Valley, which is formed by the municipalities of Cruzeiro do Sul, Mâncio Lima, Rodrigues Alves, Porto Walter and Marechal Thaumaturgo [11]. The region is composed of soils developed from sediments related to the Juruá river basin, with coarser texture (sandy), which gives them good drainage conditions, despite contributing to their dystrophism [12]. The predominant climate of this regional is the subtype Af, in which the annual rainfall varies between 2,000 mm and 2,500 mm, with the most rainfall areas of Acre, the average maximum temperature is 27.7 oC and the minimum is 22,2 ºC [13].

The study was conducted with 12 traditional varieties of maize (V1, V2, V3, V4, V5, V6, V7, V8, V9, V10, V11 and V12), harvested after drying in the field and from planting already installed in the region in non-flooded and floodplain areas (Table 1). Each variety was collected in different properties, where the producers themselves are the holders of the seeds that were passed from generation to generation. The varieties collected were classified based on grain color in yellowish, yellowish/orange and reddish according to the criteria of Mattar et al.[14] and Teixeira et al. [15].

For the characterization of the centesimal composition (chemical analysis), the samples were dried in an oven at 105 C for 24 hours and crushed in a Willey mill, in sieves with 1 mm screen. Then were analyzed to determine the composition in dry matter (DM, %), mineral matter (MM, %), crude protein (CP, %), ether extract (EE, %), crude energy (EB, kcal/ kg), according to procedures described by Silva and Queiroz [16]. Starch (AMD, %) was obtained by the sum of the carbohydrates amylose and amylopectin present in the product, and its measurement is expressed in grams of starch per 100 grams of product.

In vitro dry matter digestibility (IVDMD, %) was determined according to the two-step method proposed by Tilley and Terry [17]. While neutral detergent fiber (NDF, %) was calculated according to the methodology proposed by Van Soest et al. [18]. The physical characteristics analyzed were grain density (DSD, g/cm^3) according to Kniep and Mason [19]) and vitreousness (VIT, %), by the method of manual grain dissection [20], in which 100 grains of each cultivar were randomly selected and divided into 10 groups, visually homogeneous in grain size and shape. Vitreousness was determined on one from each randomly selected group. After immersion in distilled water for 3 minutes, the grains were dried with paper towel and the pericarp and germ, removed with scalpel leaving only the total endosperm, which was weighed. Then the farinaceous endosperm was removed and the weight of the remaining vitreous endosperm was expressed as a percentage of the total endosperm.

Tabela 1. Visual characteristics of traditional varieties of maize from planting in non-flooded and floodplain areas in the Juruá Valley region, Acre.

Cultivar	Place of cultivation	Grain color
V1	non-flooded	Yellowish
V2	non-flooded	Yellowish/Orange
V3	non-flooded	Reddish
V4	non-flooded	Yellowish/Orange
V5	non-flooded	Yellowish/Orange
V6	non-flooded	Reddish
V7	Floodplain	Yellowish/Orange
V8	Floodplain	Yellowish/Orange
V9	Floodplain	Orange
V10	Floodplain	Orange
V11	Floodplain	Orange
V12	Floodplain	Yellowish

For all characteristics evaluated, the analyzes were performed involving five replications, and each repetition was considered 5 grams of grain from the ears collections of each variety. Therefore, data were analyzed using descriptive statistics, associated with multivariate principal component analysis (PCA) to detect grouping among maize varieties. The data were analyzed using the software R version 4.1.1 [21], methodology described in the work of Schmitz et al. [22].

3. Results and discussion

Through principal component analysis (PCA) it was observed that there are strong relationships between the variables studied, because the first two axes were responsible for 70% of the total variation of the data (Figure 1a), in which the variability explained by these axes is therefore, highly significant, since most of the variation and patterns of the data are limited to PCA1 and PCA2, which can be summarized in biplot scatter charts [23].

Figure 1a shows the distribution of the varieties in 3 distinct groups that are to the right and left of the PCA1. In group 1 (lower right side of the graph) was composed of V3 and V6, which are characterized by presenting grains of reddish colors, while group 2, by varieties V2, V4, V5, V7, V8, V9, V10 and V11, with grains predominantly yellow-orange colors. Group 3 (upper right side of figure 1) is formed by V1 and V12 of yellowish grains, and is characterized by a transition between group 1 and 2, as it shares both high values of DM, MM, EB, DSD, AMD as well as low values for NDF, VIT, IVDMD and EE. With the exception of group 1, whose varieties are grown on dry land, groups 2 and 3 were represented by mixture of varieties collected on non-flooded and floodplain areas. Regarding the place of cultivation, the mixture of varieties occurs because

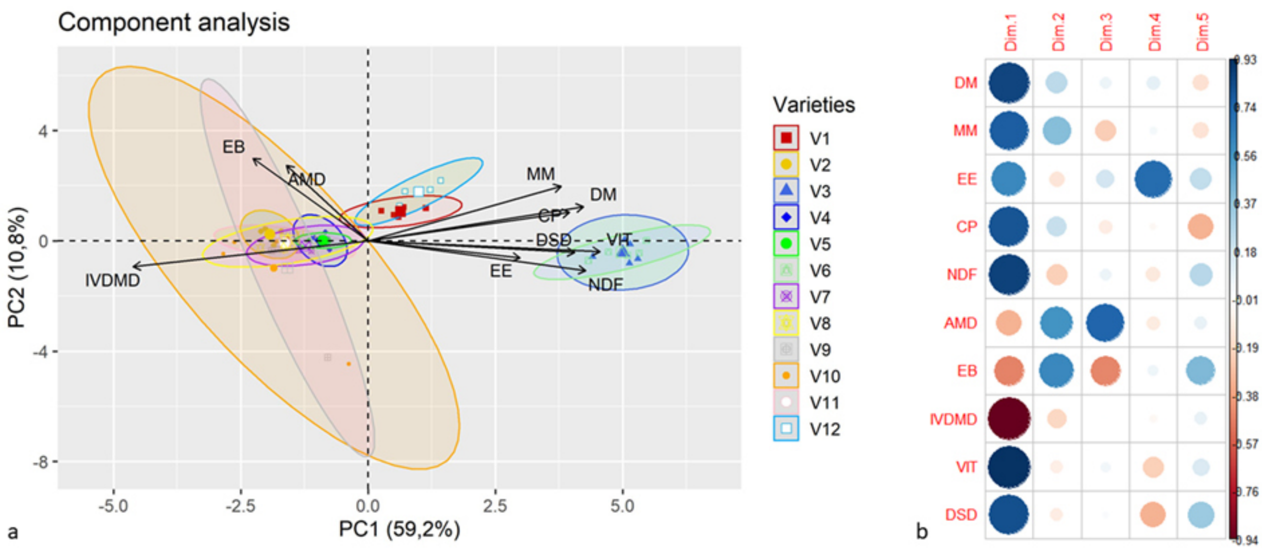

Figure 1: (a) Graphical dispersion (biplot) of 12 traditional varieties and physical and chemical characteristics of maize; (b) Correlations between the chemical and physical variables of grains with the five first principal components (PCA).

Table 2. Average values of the chemical and physical composition of the grains based on dry matter.

Varieties	Variables									
	DM %	MM %	EE %	CP %	NDF %	AMD %	IVDMS %	VIT %	EB kcal/kg	DSD g/cm³
	Non-flooded area									
V1	90,4	1,02	2,95	8,86	8,74	74,53	81,72	75,57	3.862,6	1,29
V2	89	0,96	2,90	8,48	8,77	75,08	83,30	73,7	3.866,4	1,28
V3	91	1,05	2,97	9,13	9,38	72,53	79,34	79,28	3.654,8	1,33
V4	88,7	0,94	2,89	8,77	8,77	74,54	82,46	75,3	3.839	1,29
V5	88,8	0,93	2,87	8,82	8,82	74,43	82,56	75,67	3.841	1,28
V6	91,2	1,05	2,95	9,12	9,53	72,52	79,65	79,46	3.662,2	1,32
Average	89,84	0,99	2,92	8,88	9,0	73,94	81,50	76,50	3787,67	1,30
CV%	1,25	5,62	1,67	2,82	3,66	1,48	1,90	2,85	2,60	1,54
	Floodplain area									
V7	88,61	0,97	2,91	8,33	8,83	75,07	83,32	75,65	3.869,4	1,29
V8	88,69	0,95	2,88	8,40	8,79	75,72	83,83	75,62	3.872,6	1,29
V9	88,72	0,93	2,87	8,4	8,77	71,97	83,82	75,49	3.849,2	1,29
V10	88,68	0,91	2,86	8,46	8,73	75,15	83,94	75,0	3.680,2	1,29
V11	88,95	0,93	2,90	8,56	8,72	75,32	84,04	74,96	3.860,6	1,29
V12	90,48	1,07	2,86	8,95	8,70	75,04	81,27	76,36	3.874,2	1,30
Média	89,02	0,96	2,88	8,52	8,76	74,71	83,37	75,51	3.834,37	1,29
CV%	0,90	6,18	1,44	2,54	0,67	4,70	1,27	0,85	4,70	0,39

Dry Matter=DM, Mineral Matter=MM, Ether Extract=EE, Crude Protein=CP, Neutral Detergent Fiber =NDF, Starch=AMD, Crude Energy=EB, In vitro dry matter digestibility=IVDMS, Vitreosidae=VIT, Density=DSD

farmers use the same seeds both for planting in dry land as well as in floodplain area, because the planting window in these environments in the regional Juruá occurs in different months. In addition, producers sell maize seeds in local markets, in which floodplain área maize seeds can be purchased and planted on dry land or the reverse may occur.

One of the characteristics that influenced the division was the grain texture, since the VIT values of 79.28% (V3) and 79.46% (V6) observed in Table 2, classifies the grains of this group in hard texture (Flint) presence of vitreous endosperm in relation to total endosperm. Hardness is a physical characteristic that influences the quality and processing of maize grains [24], and has a strong relationship with grain density and susceptibility to attack by pests and diseases [25]. Therefore, in Brazil, due to the origin of the germplasms used and the objectives of breeding programs, the cultivation of maize with hard texture endosperm predominates [26]. This affinity for hard grains implies directly in less action of digestive enzymes, and consequently can reduce the degradability of starch causing a lower digestibility [27]. However, hard grains have higher protein content compared to grains with pharyngeal consistency, that is, those with lower VIT and DSD [28].

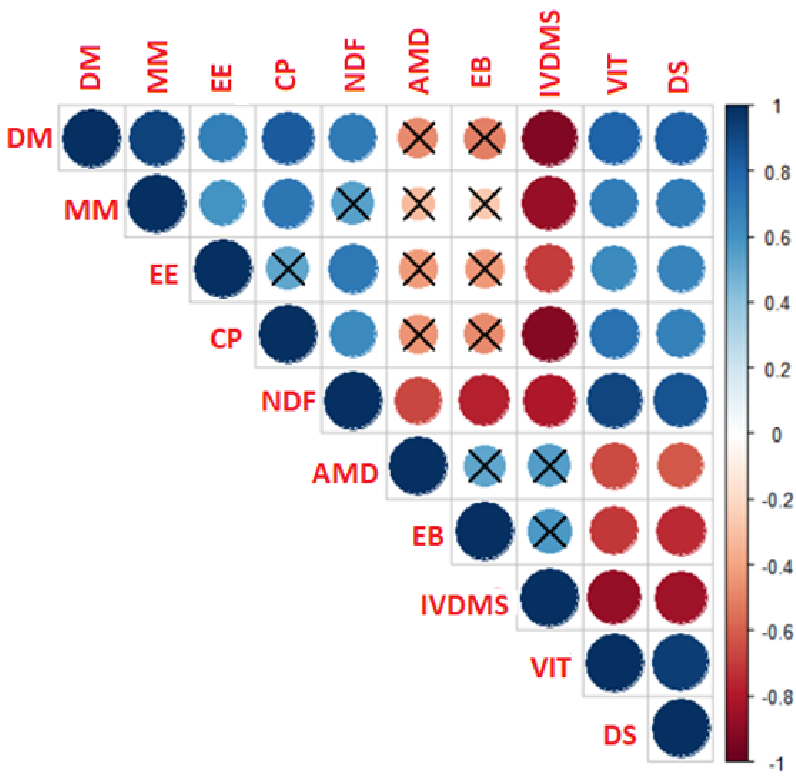

Figure 2. Pearson correlation between the chemical and physical variables of the grains.

Observing the results of Table 2, it is noticed that in group 2 and 3 the varieties presented lower values of VIT and DSD in relation to those of group 1, which had higher digestibility, higher proportions of starch and available energy, but lower contents of CP. Thus, the higher digestibility in the varieties of these groups can be derived from the reduced presence of a protein matrix that surrounds the starch granules, resulting in vague spaces between these structures within the cells in the endosperm, thus facilitating the enzymatic attack [29].

Considering the CP content, the values in this study ranged from 8.4 to 9.13%, denoting that the VIT correlated positively with the CP content (Figure 2), because the varieties with higher VIT also presented higher CP, the same trend observed by Rossi et al. [30]. The differences observed in the CP content may be related to differences in the nitrogen uptake efficiency available in the soil for the plant [31], since the tropical grasses have high response potential to nitrogen fertilization [32].

Regarding the average starch contents, the values ranged from 72.53 to 72.52% in group 1, 71.97% to 75.72% in group 2 and 74.53% to 75.04% in group 3, indicating an increase in starch content as the VIT decreases. This relationship is in agreement with the study of Pineda-Hidalgo et al. [33], in which it was highlighted that the starch content has a negative correlation with grain hardness. Starch is the main composition of cereal seeds [34], and in maize culture, for greater accessibility of microorganisms to the granules of this carbohydrate, has been used the ensiling technique, for favoring the partial solubilization of the protein matrix of the grains facilitating the access of microorganisms [35].

An important feature in the evaluation of silage quality is the percentage of NDF, which represents the fraction of structural carbohydrates contained in food and its composition is related to dry matter intake (DM) [36]. In this context, the NDF content varied from 9.38 to 9.53% in group 1, from 8.72 to 8.74% in group 2 and 8.74 to 8.70% in group 3 lower than those found by Zilic et al. [37], variation from 11.02 to 14.72% of NDF. This inferiority of NDF will provide a higher grain digestibility, due to the present fibrous content is much lower. In addition, the concentration of NDF in the diet is negatively correlated with the energy concentration, that is, the lower NDF, the higher the energy content of the food [38]. This correlation was observed in this study (Figure 2), in which the varieties of group 2 that presented lower NDF content obtained respectively higher EB values.

As for the dry mass of grains (DM), there was a trend of higher values in varieties 3 and 6 (91%) (Table 2). Overall, the mean DM ranged from 88.61 to 91.2% (V7 and V6, respectively), whose variation may be related to the physical characteristics of the grains, since grains with pharyngeal endosperm have a less compacted cell structure. With this, there are air gaps between starch granules which allows moisture to remain longer in the endosperm [29]. The moisture level in maize grains is considered an important parameter, because in conditions of high temperatures, long-term storage and high moisture contents potentiate contamination by fungi, which produce mycotoxins [39].

In the mean values of EE and MM, there was variation between varieties, in which the average values ranged from 2.86 to 2.97% for EE and 0.91% to 1.07% for MM. Vásquez-Carrillo et al. [40] in a study with 11 local varieties of Mexican maize, concluded that the average oil contents were 4.9% for local maize, 3.7% for white hybrids and 3.2% for yellow hybrids, values higher than those verified in this study. Although the total fat levels of the grains studied are relatively low, the presence of linolenic fatty acids makes maize oil extremely important in the diet for influencing the prevention of cardiovascular diseases and the fight against cholesterol [41]. However, these contents can be affected by environmental and genetic factors [42] and the form of processing, and lipid elimination may occur by oxidation [43].

Regarding the content of MM material in the grains, it is observed that they are close to those obtained by Pekel et al. [44] that evaluated the chemical composition of maize grains, the contents ranged from 0.8 to 1.3 %. In general, millet grains are rich in minerals magnesium, potassium and phosphorus and are mostly accumulated in the germ [9]. The MM content is considered as a legal quality measure and used as a criterion in food identification [45]. However, the percentages of MM from plant products provide little information about their composition, not being an indicator to distinguish the varieties [46]. In maize, the stress conditions represented by water deficit and nutritional deficiency affect the absorption of nutrients and influence the productivity and qualities of the grains, differences in MM levels observed in the present study may be associated with these factors.

4. Conclusion

The traditional varieties cultivated on non-flooded and floodplain areas, present variations in relation to the physical and chemical analyses. The varieties with yellow and orange-yellow grains were associated with greater presence of energy, starch and digestibility. However, the reddish ones are sharing higher protein value, vitreousness and density. Therefore, it is observed that in the Juruá region, the traditional maize varieties presented diversity in their composition and that future studies considering soil, plant and climate factors are necessary for a better understanding and use of these materials.

Conflict of interest

The authors declare that there is no conflict of interest.

Author contributions

Conceptualization: D.R. Araujo; *Data curation:* L.O. Nascimento, J.G.V. Moreira; *Formal analysis:* J.G.V. Moreira, C.S. Souza, J.B. Ferreira; *Funding acquisition*:: D.R. Araujo, F.A. Gomes; *Investigation:* D.R. Araujo; *Methodology*: F.A. Gomes, E.P.L. Matta; *Project management:* D.R. Araujo, F.A. Gomes, E.P.L. Matta; *Resources*: F.A. Gomes; *Supervision:* E.A. Araujo, J.B. Ferreira; *Writing (original draft)*: D.R. Araujo, C.S. Souza, J.G.V. Moreira.

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