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Camu-Camu Flour Processed in Conventional Oven and Solar Dryer: Quality Product and Accessible Low Technology Products as an Opportunity to Family Agriculture

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Abstract

The culture of camu-camu fruit is one of the most promising in the Amazon region; with proper industrialization the fruit could contribute to local food security, which raises excellent opportunities to further elaborate products with higher aggregate value to introduce to population living in natural producing areas. The aim of this research was to carry out a comparison of the agro-industrial and nutritional quality of fruit flour prototypes and residues from the processing of camu-camu dehydrated in a conventional electric oven and an alternative solar dryer, verifying the possibility of obtaining a standardized flour product with the techniques used. The camu-camu fruits was harvested in March of 2018 at Morena Lake, Boa Vista municipality, Roraima State, Brazil and, processed into flour at Embrapa Laboratories. Furthermore, an analysis of moisture, soluble solids, titratable acidity, pH, color and N, P, K, Ca, Mg, S, Cu, Zn, Mn, Fe and B contents of the flour, were carried out and evaluated. The experimental design was completely randomized in a factorial scheme, evaluating three raw materials by two drying methods. The data was statistically validated using an analysis of variance, when there was statistical difference, the means of agroindustrial and elemental characteristics were compared by the T (0.05) and Tukey (0.05) tests. The main quality differences in the interaction between raw materials and drying methods are in moisture, soluble solids, titratable acidity, color and P, K and Ca contents. In general, the macro and microelement contents of the camu-camu flour dehydrated in a hot air oven with forced ventilation, and in a low-cost convection solar dehydrator presented the following order N > K > P > Ca > S > Mg > Mn > Fe > B > Zn > Cu. The evaluated camu-camu flours are presented as alternatives for the integral use of the fruit and processing residues, having satisfactory qualities, with the possibility of being used in agro-industrial products.

Keywords: agroindustrial quality, agroindustrial waste, alternative dryer, macroelements, microelements, *Myrciaria dubia* (Kunth) McVaugh

1. Introduction

Brazil has biodiversity capable of guaranteeing the security and food sovereignty of its population. The camu-camu [*Myrciaria dubia* (Kunth) McVaugh] is a wild species with considerable economic potential, capable of placing it at the same level of importance as other traditional Amazon native fruits, such as açaí (*Euterpe oleracea* Mart.) and cupuaçu [*Theobroma grandiflorum* (Willd. ex Spreng.) K.Schum.] (Brazil, 2015). Among the vast possibilities of using camu-camu daily, the juice stands out for its convenience, which has considerable antioxidant and anti-inflammatory properties, when compared with vitamin C (ascorbic acid) tablets containing the equivalent concentration; consequently, it could be used as a dietary supplement with the potential to prevent atherosclerosis (Inoue et al., 2008).

In addition to ascorbic acid, other properties relevant to biotechnology are found in the camu-camu fruit. Kaneshima et al. (2017) discovered several antimicrobial constituents of biotechnological interest in the vegetal components of camu-camu, suggesting that the bark (epicarp) and the seeds can be used for therapeutic applications. Montero et al. (2018) pointed out that bark, pulp and seeds of fruits, such as camu-camu and acerola (*Malpighia emarginata* DC.), present good contribution of phenolic compounds and high antiradical activity, which indicates the presence of bioactive compounds and encourages the elaboration of phytotherapeutic and commercial food products. Additionally, research has shown that camu-camu products can contribute to the management of inflammatory conditions affecting a wide range of illnesses, and overall promoting good-health (Langley et al., 2015).

Despite all the benefits of camu-camu, waste is an issue due to lack of information on the socioeconomic, agroindustrial and biotechnological potential of the fruit, in its naturally producing regions. When processed, the residues from the extraction of the pulps are normally disposed of inappropriately in the environment. Over the years, considerable amounts of residue have been wasted, with high nutritional and functional potential that could have been introduced in new products, as raw material complementation or supplementation, provided that the processing is viable for the region, and the final product meets standards set by regulatory authorities.

In the food industry, waste residues are defined as raw material not used in the processing of the main product (Evangelista, 2008). According to the current Brazilian legislation (Brazil, 2010), the camu-camu waste is classed as origin and hazard as industrial and non-hazardous waste, respectively. According to Evangelista (2008), the increase in the use of residual raw materials, primarily bark, seeds, branches and bagasse; has given rise to new sources income, making possible the existence of low-cost and varied byproducts in the market. Using technological methods, domestic fruit waste generated from processing of camu-camu pulp and juice can become profitable by-products.

In order to increase stability and reduce post-harvest losses, industrialization of camu-camu residues to produce flour can yield very satisfactory results, when methods comparable to the drying processes of acerola and taperebá (*Spondias mombin* L.) are applied; serving as an alternative to diversify the commercialization possibilities of the camu-camu fruit. Such industrialized products, allows the storage and consumption of camu-camu, after harvest periods (Freitas et al., 2016; Reis et al., 2017), which has long been one of main objectives in food conservation.

Drying is a widely used post-harvest technology, that reduces the moisture content of the fruit to a level that prevents growth of fungi, minimizing microbial degradation of the products; this method aids in overcoming problems that arise from overproduction, oversupply, post-harvest handling, insect pests, pathogens and short shelf-life (Chong & Law, 2010). Besides, for and Shahidi (2013), dried fruits with their unique combination of flavor, aroma, essential elements, fiber, phytochemicals and bioactive compounds, are convenient step for healthy eating and a means of bridging the gap between recommended and actual consumption.

The most common heat sources used for drying agricultural products are fossil fuels, electricity and solar energy (Ekechukwu, 1999). According to Sharma, Chen, and Lan (2009), even low-cost food drying equipment can help reduce deterioration, improve product quality and hygiene standards of processing. The use of this technology could have a significant impact on rural and riparian communities. Around the world, there has been collaboration on the benefits of food drying, and evidently the use of alternative methods for processing has gained traction. Almuhanna (2012) obtained good results with the use of a forced-air solar oven as a solar dryer, under the climatic conditions of the Eastern Province of Saudi Arabia. Alternativelly, a low-cost solar that functions efficiently, with reduced maintenance needs can be a substitute for expensive conventional dryers, as reported by Basumatary et al. (2013) in Assam, northeastern India.

In the Amazon region, production systems found in small farms and businesses are commonly low budget technology, such as blenders or mixers, with few establishments having access to industrial pulpers. Flour presents a flexible alternative to small farms and businesses, increasing the likelihood of implementing this type of camu-camu residue. Furthermore, a combination of low budget agricultural conditions and high levels of solar radiation flux, these alternative methods of food processing are attractive options to optimize the use of native fruits, resulting in an enhanced production in low-income communities with limited technological access, Junior et al. (2012).

As emphasized by Sharma et al. (2009), the desired result when applying drying methods is to significantly improve agricultural returns to farmers in recognition of their dedication to growing crops. In the case of tucumã (*Astrocaryum aculeatum* G. Mey.), another fruit native to the Amazon region, one of the viable alternatives of sustainable use was the dehydration of fruit pulp, followed by spraying. It is a relatively simple technology in which the fruit can be processed with the use of equipment accessible to small farmers, increasing shelf-life and reducing costs (Yuyama et al., 2008).

The objective of this research was to carry out a comparison of the agro-industrial and nutritional quality of fruit flour prototypes and residues from the processing of camu-camu dehydrated in a conventional electric oven and an alternative solar dryer, verifying the possibility of obtaining a standardized flour product with the techniques used.

2. Method

2.1 Plant Material Used

The fruits samples were collected manually in March 2018, from adult native plants, in good physiological conditions, in an area on the shores of Lake Morena (Figure 1), in the municipality of Boa Vista, Roraima (reference geographic coordinates of reference 02°27′45″N and 60°50′14″W, with 60 m of altitude).

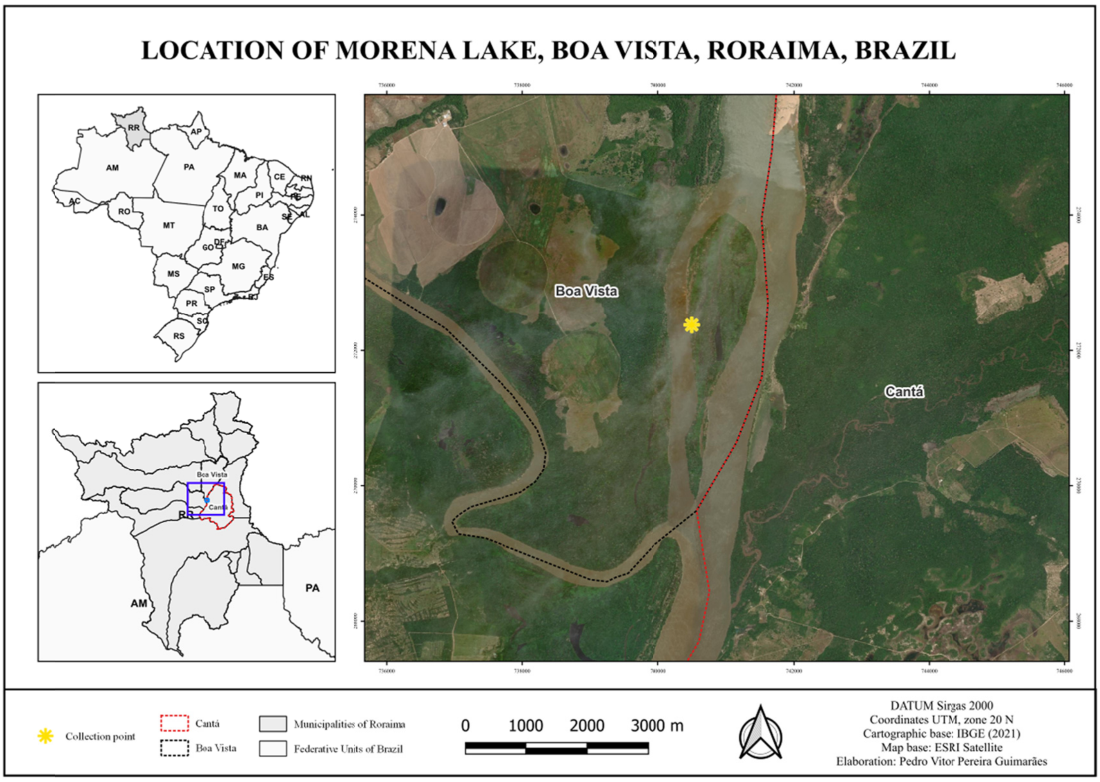

Figure 1. Georeferenced location of sampling point of camu-camu (02°27′45″N and 60°50′14″W) Morena Lake population in Boa Vista, Roraima, Brazil

2.2 Fruit Sampling and Preparation

After collection, the fruit samples were packed in small plastic bags and placed in ice filled styrofoam boxes, further transported 70 km to the Post-Harvest and Agroindustrialization Laboratory of Embrapa Roraima, in Boa Vista. The samples were handled in a controlled ambient room (25±1 °C; 60±5% R.U.), where sorting and elimination of soil and fruits with mechanical injuries was carried out.

Subsequently, in accordance with recommendations by National Sanitary Surveillance Agency (ANVISA, 2004), sanitation was carried out using a solution of tap water and 0.02% sodium hypochlorite ($NaClO$) for 10 minutes.

After rinsing, the fruits were processed by separating the liquid fom pulp, to obtain raw materials used in the production of the flour prototypes. Sub-samples of the fresh fruits were reserved for biometric characterization.

2.3 Whole Fruit (WF) Processing to Obtain Pulp Production Residue (PPR) and Juice Production Residue (JPR)

Two methods of fruit processing were tested to obtain the residue: the pulp production using a industrial vertical fruit pulper, and production of homemade juice using a blender, being the latter commonly found in small farms and homes throughout the region.

To prevent shaving the integument of seeds, which can release astringent substances, in the pulp using the vertical fruit pulper a 1mm sieve was used (compact model, with 1 cv of power, brand Bonina). The production of homemade juice was carried out in an electric blender (model optimix plus, with 550 W of power, brand Arno), using the pulse function for five times, to prevent crusing of the seeds, after which the juice was filtered in a 1 mm plastic sieve.

2.4 Characterization of Whole Fruits, Pulp Production Residue and Juice Production Residue in Natura

The moisture or water content was determined by gravimetric method, in circulating hot air oven, set around the 105 ºC range, with results expressed as a percentage. The determination of moisture, soluble solids titratable acidity and pH were performed in a controlled temperature room (25±1 °C), using the methods of the Adolf Lutz Institute (IAL, 2008), correcting the data at 25 °C, accordingly.

Soluble solids of the samples were determined using a digital refractometer, with results expressed in °Brix, previously calibrated with deionized water (0.0 °Brix). The titratable acidity of the frozen samples was determined by volumetry using 0.1 N NaOH solution as titrant and 1% phenolphthalein as indicator. The titratable acidity of the flours was determined by potentiometry, using 0.1 N NaOH solutions as titrant until pH in the range of 8.2-8.4. Each titratable acidity analyzes had values expressed in grams (g) of citric acid 100 g^{-1} samples. The ratio was obtained by the relationship between soluble solids and titratable acidity.

For determination of pH a digital potentiometer was used, where the measurements were performed in a homogeneous extract diluting of 10 g of the sample in 100 mL of deionized water (1:10 w/v). The samples were homogenized in a mixer for approximately 60 seconds per sample. To calibrate the potentiometer, buffer solutions of pH 4.0 and 7.0 were used. Colorimeter calibrated on a standard plate (Y = 87.2; x = 0.3167; y = 0.3237) was used to determine the color (luminosity, chromaticity and *hue* angle), with the results expressed in the CIE L*C*h system. The samples were extracted using 0.5% oxalic acid and tritated with 2,6dichlorophenolindophenol (Ranganna, 1986). Results were expressed in mg of ascorbic acid 100 g^{-1} sample.

2.5 Drying of Fruits and Waste From Professional Pulp and Juice Production

The fruit and the two different residues obtained were dried using two methods classed hereby as traditional and alternative. As a traditional method, the drying oven with forced air circulation and renewal was adopted. The alternative method consisted of using a solar dryer adapted for the experiment, with natural air circulation and renewal.

2.5.1 Conventional Dryer Oven

For the conventional drying of whole fruits and camu-camu processing residues, an electric oven was used with forced air circulation and hot air renewal, set in the range of 60±5 ºC, in accordance to the methods described by Adolf Lutz Institute (2008).

The samples were placed in aluminium containers and added to the electric oven with forced air circulation and hot air renewal. The process was carried out in a controlled environment (25±1 ºC; 60±5% R.U.), until the display showed a constant mass, after approximately 96 hours.

2.5.2 Alternative Solar Dryer

The solar drier used in the experiment is a 80 cm × 30 cm × 30 cm prototype made out of marine grade plywood. The samples separated for drying were accommodated in roasting trays of 27 cm by 12 cm, with 3 cm of height, arranged in a support, made with galvanized screen, and a 0.2 cm thick glass cap was used. To optimize the solar incidence radiation the dryer has a slope (Figure 2).

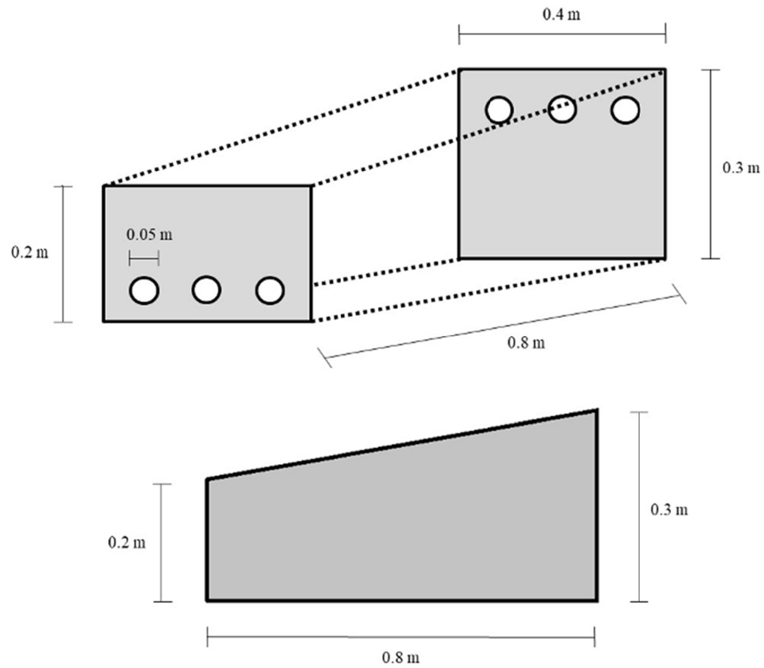

Figure 2. Design of the solar food dryer prototype scheme, adapted for camu-camu drying

The sides of the cabinet were painted in matte black color for wood conservation and absorption of solar radiation transmitted through the glass cover. Six holes (5 cm diameter) were drilled for ventilation on the front and back of the dryer cabinet;a screen was placed in the airing holes to protect against dust, insects and birds. It is classified as a cabinet dryer, with direct sunlight exposure and natural air circulation, where the solar radiation passes through the glass, to be incident on the samples placed for drying. The glass cover reduces direct convective losses to the environment and increases the temperature inside the dryer. This solar dryer prototype was based on the model developed by Jairaj, Singh, and Srikant (2009).

The samples were arranged in aluminium containers and added to the alternative solar dryer. During the drying process, the samples were exposed daily to temperatures ranging between 45 to 63 °C (average 53±6.45 °C), from 8:00 am to 5:00 pm, until it presented a constant mass rate, after approximately 120 hours.

2.6 Grinding/Milling

After completely drying, the fruit samples and residues were processed in blender (Arno brand, model optimix plus, with 550 W power) for 5 minutes, aiming to obtain a homogenous material with flour texture.

2.7 Characterization of Dried Fruit Flours and Dried Camu-Camu Waste

2.7.1 Agroindustrial Quality

The humidity was determined by gravimetric method, in an air oven with circulation, graduated in the range of 105 ºC, with values expressed as a percentage. Moisture, soluble solids, titratable acidity and pH were determined in an air-conditioned room (25±1 °C), using the methods of the Adolf Lutz Institute (IAL, 2008) and the data, when necessary, corrected at 25 °C.

The soluble solids of the samples were determined using a digital refractometer, previously calibrated with deionized water (0.0 °Brix). The titratable acidity of the frozen samples was determined by volumetry using 0.1 N NaOH solution as titrant and 1% phenolphthalein as indicator. The titratable acidity of the flours was determined by potentiometry, using 0.1 N NaOH solution as titrant until pH in the range of 8.2-8.4. Both titratable acidity analyzes had values expressed in g of citric acid. Soluble solids ratio was obtained: acidity titrable by the algebraic operation of dividing values found for soluble solids and titratable acidity. The samples were extracted using 0.5% oxalic acid and tritated with 2,6dichlorophenolindophenol (Ranganna, 1986). Results were expressed in mg of ascorbic acid 100 g^{-1} sample.

For determination of pH, a digital potentiometer was used, the measurements were performed in a homogeneous extract of the dilution of 10 g of the sample in 100 mL of deionized water (1:10 w/v). The samples were homogenized in a mixer for approximately 60 seconds per sample. For calibration of the potentiometer, buffer solutions of pH 4.0 and 7.0 were used. Colorimeter calibrated on a standard plate (Y = 87.2; x = 0.3167; y = 0.3237) was used to determine the color (luminosity, chromaticity and *hue* angle), with the results expressed in the CIE L*C*h system.

2.7.2 Nutritional Quality

Flour prototype samples stored in paper bags, underwent a macro and microelement analysis using sulfuric acid digestion to determine contents for nitrogen (N); and nitric-perchloric acid digestion to determine P, K, Ca, Mg, S, Cu, Fe, Mn and Zn contents. Colorimetry was used for analysis of P, S and B; atomic absorption spectrophotometry was used for Ca, Mg, Cu, Fe, Mn and Zn analysis, and for K, flame photometry emission was used.

2.8 Experimental Design and Statistical Analysis

The experimental design used was the completely randomized, in a factorial scheme (3 × 2). One of the factors studied was the raw material, containing three levels [whole fruit (WF), pulp residue production (PPR) and juice residue production (JPR)]. On the other hand, the second factor analysed was the drying method by conventional dryer oven or alternative solar dryer, being all analysis performed with four replicates. The data was submitted to the normality test (Shapiro-Wilk) and homogeneity test (Levene), were statistically validated by analysis of variance and, if found to be significant (0.05), compared by Tukey test (raw material) and test F (drying method factor), both to 5% probability. Analysis and plots of the figures were performed in the R 4. 2. 2. Environment (R Core Team, 2023), using the Rcmdr package (Fox & Bouchet-Valat, 2019).

3. Results and Discussion

The whole fruit and waste juice used as raw materials in the production of camu-camu flour, are acidic, high in water content and reddish-purple colour. Table 1 shows the results of the physio-chemical analysis obtained for the frozen raw materials at the time of the start of the experiment.

Table 1. Mean values of quality characters measured in whole fruits, pulp production residue and camu-camu juice production residue *in natura*

Parameters measured	WF	PPR	JPR
Moisture (%)	80.13±0.95	88.28±0.51	75.30±1.70
Total solids (%)	19.87±0.95	11.72±0.51	24.70±1.70
Soluble solids (°Brix)	7.08±0.17	6.45±0.13	6.80±0.25
Titratable acidity (g citric acid 100 g^{-1})	4.28±0.11	2.82±0.15	2.23±0.10
Solid soluble: titratable acidity	1.65±0.01	2.29±0.09	3.05±0.08
pH	2.99±0.05	3.37±0.05	3.46±0.06
Luminosity	25.52±0.71	28.63±1.51	36.28±1.37
Chromaticity	28.65±2.52	30.01±1.90	24.61±2.05
Angle *hue* (°)	16.86±2.41	19.61±2.89	20.19±1.02
Acid ascorbic (mg ascorbic acid 100 g^{-1})	2203.19±200.72	1449.16±40.10	1034.00±41.97

Note. WF = whole fruit; PPR = pulp production residue; JPR = juice production residue.

During the analysis, a significant difference (0.05) was verified in the interaction of the treatments tested for the majority of the variables, being necessary to perform the unfolding of treatments. The prototypes of camu-camu flour presented satisfactory low moisture values, since water content is a parameter that must be maintained at a low percentage to avoid growth of microorganisms (Reis et al., 2017). Flours elaborated with raw materials processed in the solar dryer showed the higher moisture values (from 1.22 to 2.04%), compared to those processed in the conventional oven (from 0.20 to 0.37%), worth noting that the moisture widely range depending on the equipment used (Table 2).

Table 2. Average moisture values of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
	---------------------------------- %	----------------------------------
Whole fruit	0.25±0.01 aB	1.42±0.17 bA
Pulp production residue	0.37±0.15 aB	2.04±0.16 aA
Juice production residue	0.20±0.01 aB	1.22±0.17 bA
C.V. (%)	14.51	
Overall mean	0.91	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also do not diverge when applying F test at 5%.

The flour evaluated in this experiment presented less moisture than the camu-camu flour analysed by Azevêdo et al. (2014) in hot air oven experiments at two temperatures (50 and 80 °C) and lyophilizer, yielding values ranging from 5.90±0.90 to 5.90±1.20%. The prototype camu-camu flours tested here also present lower moisture than those studied by Chagas, Vanin, and Carvalho (2016) in a dehydration experiment at temperatures of 40 and 60 °C, with values between 10.55±0.15% and 7.26± 0.06%, respectively.

Analysis of the flour processed in the alternative solar dryer presented soluble solids values of up to 2.43±0.13 °Brix, above the average found in flour dried in a conventional oven, up to 1.78±0.10 °Brix (Table 3). Soluble solids are the portions of the total solids that are dissolved in the vacuolar sap, in fruits especially it corresponds primarily to sugars, minerals and pectin (M. I. Chitarra & A. B. Chitarra, 2006). Considering that solar drying methods preserves sugar content better than conventional ovens, the higher soluble solid content found in this study can be anticipated.

Table 3. Mean values of soluble solids of flours derived from dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
	--------------------------------- °Brix	----------------------------------
Whole fruit	1.78±0.10 aB	2.43±0.13 aA
Pulp production residue	0.95±0.13 cB	1.48±0.10 bA
Juice production residue	1.15±0.06 bB	1.30±0.08 bA
C.V. (%)	6.66	
Overall mean	1.51	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also does not diverge when applying F test at 5%.

It was observed that, in the two types of drying, the flours elaborated with whole fruits of camu-camu had the highest soluble solids contents, consequently, were the sweetest samples. Prototypes of camu-camu flour have similar soluble solids values under pasteurization and dehydration in a forced circulation oven (50 °C) of acerola juice production (1.07 and 1.23 °Brix) and grape (0.20 and 2.33 °Brix), as recorded by Storck et al. (2015). However, these values are lower than residual values of soluble solids found in flour made of oranges (3.50 and 3.77 °Brix) and apple (3.47 to 5.10 °Brix), manufactured by using residual byproducts of juice.

It was verified that the prototype of camu-camu flour, elaborated with raw materials processed in conventional greenhouse, are statistically more acid than the prototypes of flour elaborated with raw materials processed in the solar dryer. Analysis of both drying methods yielded the highest results, greater than 4 g of citric acid 100 g^{-1}, when flour made of whole fruit was tested (Table 4).

Table 4. Mean values of titratable acidity of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
	------------------------ g of citric acid 100 g^{-1}	------------------------
Whole fruit	4.19±0.04 aA	4.04±0.07 aB
Pulp production residue	2.38±0.06 bA	1.59±0.08 cB
Juice production residue	2.64±0.14 bA	2.32±0.07 bB
C.V. (%)	2.93	
Overall mean	2.86	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also do not diverge when applying F test at 5%.

The average concentration of citric acid (titratable acidity) present in the flours studied is close to the values reported by Juliano et al. (2014) in a preservation experiment of lyophilized camu-camu pulp, with averages of 2.32 to 3.1 g of citric acid 100 g^{-1}. For M. I. Chitarra and A. B. Chitarra (2006) citric acid is an organic tricarboxylic acid, used as a respiratory substrate for carbon supply, and energy production in the different phases of vegetables life cycles, which can prevent enzymatic browning and potentiate other antioxidants like ascorbic acid, highly present in the camu-camu fruit.

Corroborating the titratable acidity data, mean values of pH 3.04 indicated that the camu-camu evaluated were acidic (Table 5), being the nuts the most acidic among the evaluated raw materials. The flour dried in a conventional oven presented more acidity than those processed in a solar dryer. The pH measurements of camu-camu flour, based on pulp and juice production residues, are within the range found by Azevêdo et al. (2014), in which dehydration of camu-camu waste was evaluated in different methods, with values varying between 3.30±0.10 and 3.80±0.10.

Table 5. Mean values of pH of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
Whole fruit	2.71±0.03 cA	2.74±0.06 cA
Pulp production residue	3.43±0.02 aA	3.26±0.06 aB
Juice production residue	3.10±0.03 bA	3.01±0.03 bB
C.V. (%)	1.20	
Overall mean	3.04	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also do not diverge when applying F test at 5%.

Colour determined by measurement of luminosity, chromaticity and *hue* angle, of the camu-camu flour was influenced by not only the raw materials or the drying methods, but an interaction of both factors; with colour and appearance being fundamental, if not the most important attributes of food quality (Toci & Zanoni, 2016). The luminosity, a light indicator, ranged from 23.12±1.24 to 51.56±1.29, which represents low and medium values (Table 6). It has been observed that the residue-based flours of home-made juice are the clearest, with the whole-fruit at the opposite end of the spectrum.

Table 6. Mean values of luminosity of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
Whole fruit	23.12±1.24 cB	35.98±1.14 cA
Pulp production residue	37.14±1.57 bB	40.59±0.86 bA
Juice production residue	43.40±1.61 aB	51.56±1.29 aA
C.V. (%)	3.39	
Overall mean	38.63	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also do not diverge when applying F test at 5%.

The prototype solar dryer yielded better results at reducing enzymatic browning, when compared to the flour processed using the conventional oven, as evidenced by lower luminosity values. Another influencing factor was the drying temperature as evidenced by Azevêdo et al. (2014), where higher temperatures provided flour of darker colouring, and low luminosity values of 58.90±1.10. The intensity of the color tone of the flour was more significant when drying the raw materials in the solar dryer, indicating that the prototypes of camu-camu flour processed in the solar dryer have a more vibrant color (Table 7).

Table 7. Mean values of chromaticity of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
Whole fruit	14.46±0.44 bB	22.74±0.40 cA
Pulp production residue	22.85±0.39 aB	26.50±0.81 aA
Juice production residue	23.70±0.62 aA	24.40±0.18 bA
C.V. (%)	2.28	
Overall mean	22.44	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also do not diverge when applying F test at 5%.

Among the samples evaluated, those made with pulp residue presented more chromaticity with values between 22.85±0.39 and 26.50±0.81. The chromaticity values recorded in the camu-camu flour prototypes are considered low, indicating low intensity of the tonality. However, they are close to the results of Azevêdo et al. (2014), with a variation of 26.00±0.20 and 27.20±0.20. The prototypes of flour evaluated have an orange-red *hue*, not so evident, due to the low values of chromaticity, being the camu-camu flour processed in the solar dryer with the highest values of *hue* angle (Table 8).

Table 8. Mean values of *hue* angle of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
	------------------------------------ °	------------------------------------
Whole fruit	52.15±0.66 cB	55.04±0.23 bA
Pulp production residue	53.00±0.50 bB	54.71±0.40 cA
Juice production residue	56.45±0.34 aA	57.02±0.26 aA
C.V. (%)	0.78	
Overall mean	54.73	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also do not diverge when applying F test at 5%.

For Evangelista (2008), residues of pigmented vegetables can be used in food products and culinary preparations, acquiring sophisticated characteristics such a colour. In this experiment, it was observed that the camu-camu flours evaluated have the potential to be used as food colouring adding pigmentation to homemade recipes. According to Toci and Zanoni (2016) this type of food additive is classed as natural organic, if principles such as chlorophyll, carotenoids, anthocyanins, tannins and betalains are isolated using technological processes. Like this, in addition of having functionality when applied to food, it has a significant nutritional value.

When comparing camu-camu flours dried a conventional oven with circulation and hot air renewal at 60±5 °C, with the prototypes processed in a solar dryer, the latter presented optimal values in all three aspects of the colorimetric analysis, that being luminosity, chromacity and *hue* angle. This experimental result is justifiable since natural heat sources, such as direct sunlight, result in processed food with higher qualities. Although, dehydrated foods can incur higher costs at production, the improvement of such qualities increase commercial value of the product (Evangelista, 2008).

Analysis of the concentration of asorbic acid, yielded a significant effect (0.05) in the interactions between raw materials and types of drying (Table 9). The flours produced in the alternative dryer had more ascorbic acid content. The whole fruit being the raw material provided the highest values of ascorbic acid, followed by the pulp production residue and the juice production residue, in either type of drying. The camu-camu flour prototypes tested here present ascorbic acid values like those found in the literature.

Table 9. Mean values of ascorbic acid of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
	------------------------------ mg 100 g^{-1} ------------------------------	
Whole fruit	556.74±aB	650.33±aA
Pulp production residue	393.11±bB	436.67±bA
Juice production residue	188.33±cB	211.67±cA
C.V. (%)	3.12	
Overall mean	406.14	

Note. Means followed by the same lowercase letter in the column and upper case in the row do not differ statistically from each other at the 5% probability level by the Tukey test. C.V. = coefficient of variation.

In addition to ascorbic acid, an essential nutrient, the flour prototypes made of fruit and residues of camu-camu presented significant levels of macro and microelements. In general, microelement of dehydrated camu-camu flour in either a conventional or a low-cost solar convection dryer, presented the following content order N > K > P > Ca > S > Mg. The relation K > Ca recorded here is further corroborated in several articles in the scientific literature with camu-camu results being like fruits and squash (Zapata & Dufuor, 1993; Justi et al., 2000; Yuyama et al., 2003; Aguiar & Souza, 2015; Freitas et al., 2016; Ribeiro et al., 2016; Sousa, 2016; Abanto-Rodriguez et al., 2018). The results suggest that there is a correlation between macroelements mentioned above.

The statistical difference of 5% in the nitrogen concentration among the evaluated flours prototypes was observed only in the raw materials (Figure 3). With the highest mean values of 0.86±0.09 g 100 g^{-1}, from flour elaborated with homemade juice. The nitrogen values of camu-camu flours were higher than the results of Zapata and Dufuor (1993) analyzing pulps, with a concentration varying from 0.57 to 0.74g of 100 g^{-1} sample.

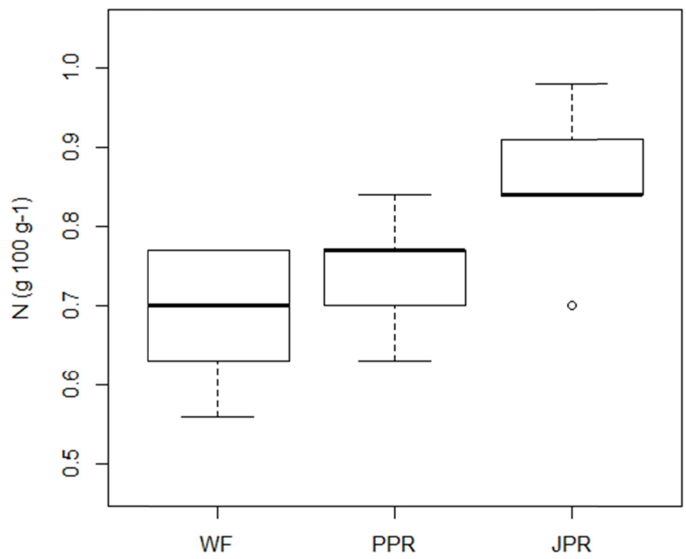

Figure 3. Mean concentrations of nitrogen of whole fruit flours (WF), pulp production residue (PPR) and juice production residue (JPR) camu-camu

According to Troeh and Thompson (2007), organic components essential to plants for example amino acids like enzymes and energy transfer materials such as chlorophyll, adenosine diphosphate and adenosine triphosphate, contain nitrogen in their composition. Higher values of nitrogen found in the manufactured with homemade juice are a result of lower water content, in relation to other raw materials. that, by processing the fruits in the blender using a "pulse" function, could have caused mechanical injuries in the seed coatings releasing, for example, chlorophyll a pigment that gives green color to the vegetables. Mahan and Raymond (2018) state that nitrogen is an essential element in the human body, corresponding to about 3% of body mass, being present in nucleic acids, amino acids and proteins.

The prototypes of camu-camu flour with higher values of phosphorus were based on the pulp production residue, with averages of 0.09±0.01 and 0.10±0.01 g 100 g^{-1}. Remarkably, the conventional oven yielded a higher concentration of phosporus in flour than in a solar dryer, when whole fruits and pulp residue was used (Table 10).

Table 10. Mean values of phosphorus of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
	------------------------------- g 100 g^{-1}	---------------------------------
Whole fruit	0.09±0.01 bA	0.07±0.01 cB
Pulp production residue	0.10±0.01 aA	0.09±0.01 aB
Juice production residue	0.08±0.01 cA	0.08±0.01 bA
C.V. (%)	3.40	
Overall mean	0.09	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also does not diverge when applying F test at 5%.

The phosphorus values of the flours recorded here are higher than the frozen pulps evaluated by Zapata and Dufuor (1993), with an average of 0.03 g 100 g^{-1} of sample. Taiz et al. (2017) state that phosphorus plays a central role in reactions involving adenosine triphosphate, being a component of sugars-phosphate, nucleic acids, nucleotides, coenzymes, phospholipids, phytic acid and others. According to Whitney and Rolfes (2008), phosphorus is the second most abundant mineral in the human body, and not only found in bones and teeth, but in all cells of the body as part of a main buffer system composed of phosphoric acid and their salts.

Similarly, interations between drying methods and raw materials also influenced potassium content of the flour prototypes. Flour based on whole fruits showed the highest concentration of potassium, mainly when processed in the conventional oven, with a mean of 0.84±0.08 g 100 g^{-1} (Table 11).

Table 11. Mean values of potassium of flours of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
	-------------------------------- g 100 g^{-1}	--------------------------------
Whole fruit	0.84±0.08 aA	0.64±0.01 aB
Pulp production residue	0.69±0.03 bA	0.71±0.01 aA
Juice production residue	0.53±0.03 cA	0.53±0.03 bA
C.V. (%)	6.01	
Overall mean	0.66	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also do not diverge when applying F test at 5%.

It is worth noting that the whole fruit processed in a conventional oven presented higher values of potassium than those reported by Aguiar and Souza (2015), with 0.80 g 100 g^{-1} of camu-camu pulp dehydrated by lyophilization, which is considered the best method of food processing available today. Zapata and Dufuor (1993) reported that potassium was the most abundant mineral in their studies, with values of up to 0.07 g 100 g^{-1} in frozen pulp, which is considered nutritionally significant and may be related to high vitamin content C. The flours tested here were richer in potassium than the *in natura* pulps evaluated by Justi et al. (2000), with mean values of 0.08 g of K 100 g^{-1}.

Troeh and Thompson (2007) point out that the plants absorb potassium in the form of K^+ ions, which help to maintain the osmotic concentration necessary to maintain cellular turgidity, being essential for the formation of sugars in leaves and for their transport to other plant organs such as roots, tubers, stems, and fruits. According to Mahan and Raymond (2018), potassium is the main electrolyte within the cells of the body acting in close association with other elements in the maintenance of bodily fluids, as well as in the production of electrical impulses in the nerves, muscles and heart. As a result, cases of loss of potassium element in skeletal muscle tissue can result in fatigue.

Calcium was another element that showed significant influences (0.05) when interactions of drying methods and ras material was analysed. Being the main statistical difference observed in the process of solar drying the juice and pulp residues, with an average value of 0.06±0.01 and 0.09±0.01 g of Ca 100 g^{-1}, respectively (Table 12).

Table 12. Mean values of calcium of dried camu-camu raw materials in a conventional drying oven and in an alternative solar dryer

Camu-camu flours	Conventional dryer oven	Alternative solar dryer
	------------------------------- g 100 g^{-1}	--------------------------------
Whole fruit	0.08±0.01 aA	0.07±0.02 abA
Pulp production residue	0.07±0.01 aA	0.09±0.01 aA
Juice production residue	0.08±0.01 aA	0.06±0.01 bB
C.V. (%)	13.08	
Overall mean	0.07	

Note. Averages of the same lowercase letters in the columns do not differ statistically when analysed by Tukey test at 5% probability. Similarly, the averages represented by the same uppercase letter in the rows also do not diverge when applying F test at 5%.

The dry camu-camu prototypes evaluated a satisfactory average calcium concentration, with values higher than those found in the frozen pulps evaluated by Zapata and Dufuor (1993), the pulps *in natura* by Justi et al. (2000) and pulps lyophilized by Aguiar and Souza (2015), with recorded values between 0.01 and 0.02 g of calcium 100

g^{-1}. According to Taiz et al. (2017), calcium occurs in plants as a bivalent Ca^{2+} cation and is a constituent of the middle lamella of cell walls. Calcium is required as a cofactor by some enzymes involved in the hydrolysis of ATP and phospholipids acting as a secondary messenger in the metabolic regulation. According to Silva, Pires, and Cozzolino (2016), calcium is the most abundant mineral in the human body responsible for up to 2% of body weight and has structural and functional roles ranging from skeletal formation and maintenance to the regulation of spatial neuronal function.

In this experiment, no significant differences (0.05) were observed in the macroelement concentration of magnesium and sulfur, in relation to drying methods and raw material of the samples. Literature reported for for *in natura*, frozen and lyophilized pulp by several authors such as Zapata and Dufuor (1993), Justi et al. (2000), Aguiar and Souza (2015), provided results similar to those observed in this study using the conventional oven drying method (Figure 4).

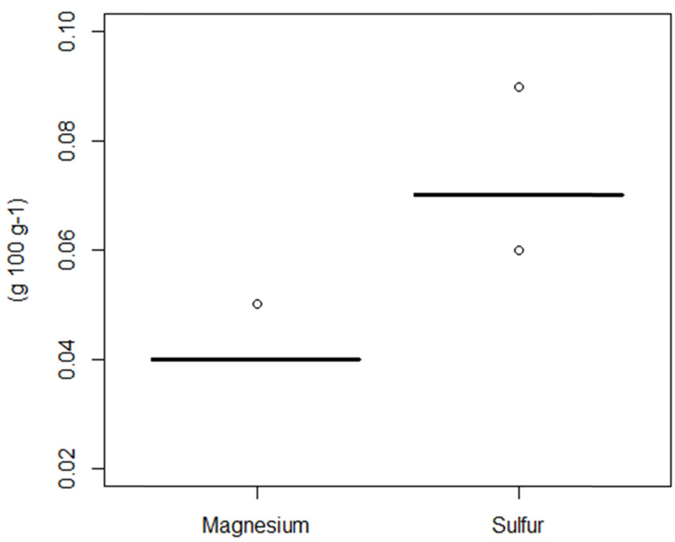

Figure 4. Mean magnesium and sulfur concentrations of whole fruit based flours, pulp production residue and camu-camu juice production residue

It is important to note that magnesium is present in plants in the form of Mg^{2+} ion, and is vital for photosynthesis, since every chlorophyll molecule contains Mg^{2+} at the core of its complex structure, as well as being a substrate to many enzymes (Troeh & Thompson, 2007). Magnesium is an essential mineral that assists in more than 300 enzymatic reactions, including glycolysis, lipid and protein metabolism, and the hydrolysis of adenosine triphosphate. In addition, it is a regulator of neuromuscular, immunological and hormonal function (Mahan & Raymond, 2018).

Plants absorb soil sulfur as sulfate ions (SO_4^{2-}) or sulfur dioxide (SO_2) from the air, aiding in the composition of certain amino acids, such as cystine, cysteine and methionine, and as a constituent of several coenzymes and vitamins, such as coenzyme A, biotin, vitamin B1 and pantothenic acid (Taiz et al., 2017). According to Whitney and Rolfes (2008), sulfur appears in vitamin B, thiamine and the amino acids methionine and cysteine, being mainly required for the composition proteins of the skin, hair and nails.

In this study, the micronutrient contents of camu-camu flour processed in a hot air oven with forced ventilation and low-cost convection dryer were as follows Mn > Fe > B > Zn > Cu. In the analysis of fruits of Zapata and Dufuor (1993) of the Nanay River, Iquitos-Peru, de Justi et al. (2000) from the Morretes Experimental Station of the Agronomic Institute of Paraná, Paraná-Brazil and Sousa (2016) with fruits collected manually in Roraima regions, the Mn > Fe > Zn > Cu ratio was also observed in pulps, and seeds bio-processed from camu-camu, indicating the possibility of a strong correlation between these microelements.

The significant difference (0.05) in the copper concentration among the flour prototypes evaluated was observed only in the raw materials (Figure 5), mainly between whole fruit flours ranging between 0.65±0.09 mg 100 g^{-1} and 0.95±0.09 mg 100 g^{-1}, the latter being higher than those found by Aguiar and Souza (2015) in lyophilized pulps, of an average of 0.84 mg of Cu 100 g^{-1}, and similar to the data presented by Sousa (2016) with bio-processed seeds (1.00 mg Cu 100 g^{-1}).

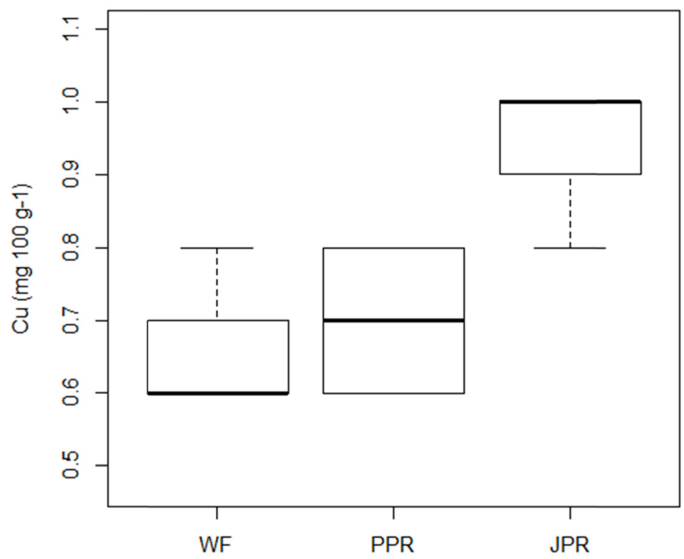

Figure 5. Mean concentrations of copper of whole fruit flour (WF), pulp production residue (PPR) and juice production residue (JPR) camu-camu

According to Dechen, Haag, and Carmello (1991), copper controls the production of DNA and RNA in plants, influencing the permeability of xylem vessels to water, and participating in physiological processes such as photosynthesis, respiration, carbohydrate distribution, nitrogen fixation, protein and cell wall metabolism. Copper and other heavy metals are essential for the proper formation of hemoglobin, and it is a cofactor in several enzymes that can potentially affect health, including antioxidant defense, oxygen transport and utilization, immune function, and synthesis of catecholamines and connective tissue (Mahan & Raymond, 2018).

Similar to that observed in nitrogen and copper concentrations, the significant difference (0.05) in the manganese concentration among the flour prototypes evaluated was found only in the raw materials, mainly among the flour made with pulp production residue (2.73±0.30 mg 100 g^{-1}) and residue of homemade juice (3.28±0.30 mg 100 g^{-1}). Flour samples elaborated with whole fruits presented the highest amplitudes in the concentration of manganese (Figure 6).

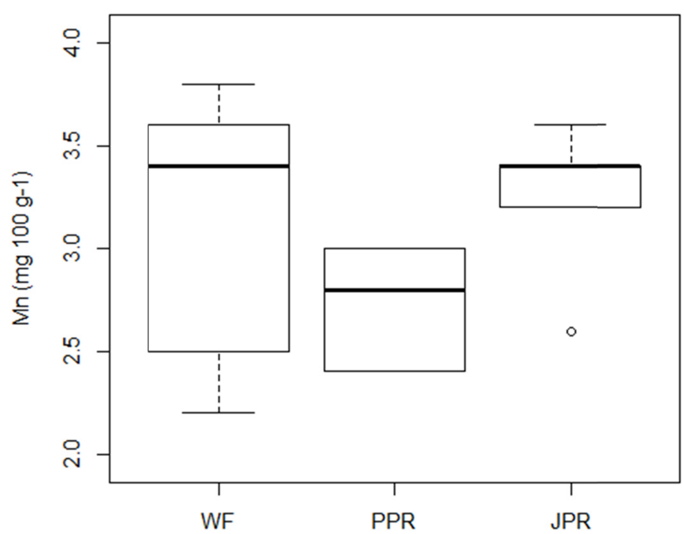

Figure 6. Mean concentrations of manganese of whole fruit flours (WF), pulp production residue (PPR) and juice production residue (JPR) camu-camu

The average manganese values of the flours tested are lower than Mn values of bioavailable sourced seeds used by Sousa (2016), with averages of 7.50 and 9.40 mg of Mn 100 g^{-1}. However, it was observed that whole-fruit flour and dried camu-camu residues, independently of the drying method used, presented manganese values higher than those found by Aguiar and Souza (2015) in lyophilized pulps, with an average of 1.29 mg Mn 100 g^{-1}.

Assuring foods with considerable microelement values such as manganese is a necessity, as it is a crucial component the composition of human bones and metabolically activates organs such as the liver, kidneys and pancreas (Whitney & Rolfes, 2008). In plants, manganese in its ionic form (Mn^{2+}) is required for the activity of some dehydrogenases, decarboxylases, kinases, oxidases and peroxidases. Furthermore, it is involved with other enzymatic reactions activated by cations and in photosynthetic evolution of O_2 (Taiz et al., 2017).

Under the conditions established in this experiment, the drying methods and the raw materials evaluated did not influence the concentrations of iron, zinc and boron microelements, presenting no significant differences (0.05) in the evaluated samples, being boron and iron the elements with the greatest amplitudes. The evaluated flour prototypes had in the general an average content concentration of 2.57±1.31 mg of Fe 100 g^{-1}, 1.06±0.18 mg of Zn 100 g^{-1} and 1.18±0.68 mg of B 100 g^{-1} (Figure 7).

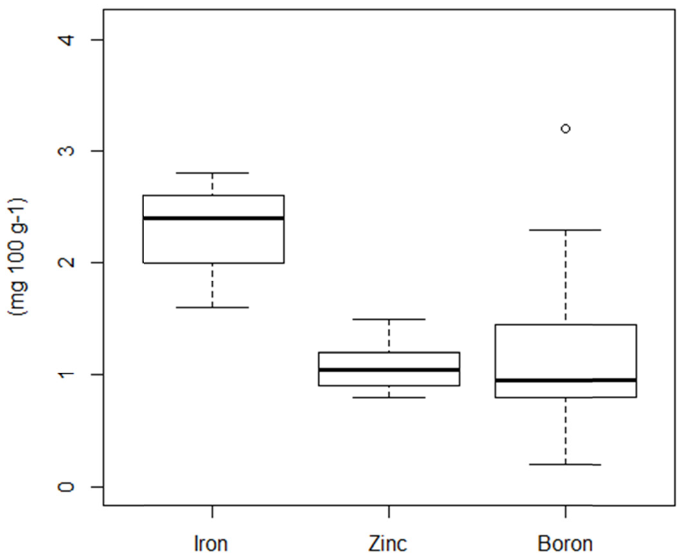

Figure 7. Mean iron, zinc and boron concentrations of whole fruit flours (WF), pulp production residue (PPR) and juice production residue (JPR) camu-camu

Noteworthy, flour prototypes evaluated had higher iron values than those found in the scientific literature of frozen and freeze-dried pulps, where mean values varied from 0.18 to 2.23 mg of Fe 100 g^{-1} (Zapata & Dufuor, 1993; Aguiar et al., 2000). According to Dechen et al. (1991) iron is considered a key metal for energy transformations needed for synthesis and other vital processes of cells, including the development and reduction of chloroplasts, mitochondria and perixomes. Iron is an essential component of hemoglobin, hence critical for the transport of oxygen from the lungs to tissues. It plays a similar role in myoglobin, which acts on the muscle as an oxygen receptor to maintain an oxygen supply readily available for mitochondria (Mahan & Raymond, 2018).

In the present study, the average zinc concentration was higher than values found in the scientific literature for *in natura* pulps (Justi et al., 2000), average values of 0.36 mg of Zn 100 g^{-1} and frozen (Zapata & Dufuor, 1993), with 0.13 mg Zn 100 g^{-1}. However, for lyophilized pulp and bioprocessed seeds zinc values are lower than those reported by Aguiar and Souza (2015) and Sousa (2016), with a average of 1.26 mg of Zn 100 g^{-1} and 3.10 mg of Zn 100 g^{-1}, respectively.

Many enzymes require zinc ions (Zn^{2+}) for their activities, and for some plants, zinc for chlorophyll biosynthesis (Taiz et al., 2017). Dehydrogenases, proteinases, peptidases and phosphohydrolases are among the many enzymes that require zinc (Dechen et al., 1991). According to the results of Mahan and Raymond (2018), in the human body zinc is the primary cofactor of more than 300 enzymes, many of which participate in inflammatory responses. Besides being necessary for wound healing, zinc aids in maintaining the taste and olfact, supporting normal growth and development during various life stages, including gestation, childhood and adolescence.

The values of boron in the types of flour tested present satisfactory results, in accordance with an average of 1.00 mg of B 100 g^{-1} of bio-processed seeds reported by Sousa (2016); and, well above the low average of 0.05 mg of B 100 g^{-1} in frozen pulps published by Zapata and Dufuor (1993). According to Dechen et al. (1991) the main functions attributed to boron are the metabolism of carbohydrates and sugar transportation through membranes, synthesis of nucleic acids and phytohormones, formation of cell walls and cell division. According to Whitney and Rolfes (2008), boron is an element that strengthens bones and plays a key role in brain activities.

The experimental data indicates that dried fruits and residues of the camu-camu, processed under the conditions tested could lead to alternative products for farmers and familiar agroindustries, with solid agroindustrial and nutritional quality. Evangelista (2008) emphasizes that institutions responsible for processing residues, from varied and distant origins, could establish a largar variety of subproducts with greater technical and economical yield, especially when it comes to producers specializing in certain by-products, which often, cannot consume all the surplus raw material.

4. Conclusion

The evaluated fruits of camu-camu have desirable quality characteristics, similar to the results found in the technical-scientific literature. Under the conditions tested, there is statistical difference (0.05) in the agroindustrial and nutritional quality of camu-camu flours prototypes, depending on the raw material used and the drying method. Flours elaborated with whole fruits and camu-camu processing residues present satisfactory macro and microelement concentration, often surpassing some elements, including comparations to results obtained in literature referent to frozen and *in natura* pulps, bio-processed seed powder and whole-fruit camu-camu.

A standardized farinaceous product was obtained from the drying processes tested, presenting desirable characteristics for the national and international market. Solar drying can be a technical-economical alternative for drying camu-camu fruits and residues generated in processing due to their low cost and high quality, mainly in areas with availability of sun throughout the year, such as camu-camu producing regions.

The flour processing methods based on whole fruits and residues from camu-camu is an adequate alternative for the industrialization of this fruit, especially in its naturally producing regions, being a viable use of its agroindustrial and nutritional qualities.

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