Processamento e caracterização físico-química de um extrato solúvel em água com base na castanha do Pará (*Bertholletia excelsa*) e baru (*Dipteryx alata* Vogel)

Processing and physicochemical characterization of a water-soluble extract based on Pará nut (*Bertholletia excelsa*) and baru nut (*Dipteryx alata* Vogel)

Procesamiento y caracterización físicoquímica de un extracto soluble en agua a base de tuerca de Pará (*Bertholletia excelsa*) y tuerca de baru (*Dipteryx alata* Vogel)

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Resumo

Apesar das qualidades nutricionais e funcionais da Castanha-do-Pará (*Bertholletia excelsa*) e do Baru (*Dipteryx alata* Vogel), o aproveitamento industrial destas amêndoas

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ainda é escasso. Com isso, a elaboração do extrato hidrossolúvel a base de Castanha do Pará e Baru pode ser considerada uma alternativa para o consumo de alimentos à base desses vegetais que são pouco empregados industrialmente. Neste contexto, objetivou-se elaborar extratos hidrossolúveis vegetais à base de Castanha do Pará e Baru por meio de um delineamento de misturas do tipo simplex centroide, a fim de avaliar o comportamento da composição físico-química e física dos extratos vegetais processados. O modelo cúbico especial alcançou melhor ajuste às variáveis respostas, tanto para as caracterizações físico-químicas de umidade, lipídios, proteínas, cinzas, carboidratos, pH e acidez, quanto para as características físicas de luminosidade, cromaticidade e ângulo Hue, demonstrando este ser altamente preditivo (todos $R^2 > 97\%$). O teor de água influenciou diretamente os aspectos nutricionais dos extratos, onde uma diminuição na proporção de água na mistura proporcionou maiores conteúdos para a composição próximal. O comportamento dos parâmetros cor, previstos pelo modelo mostrou que variações nas proporções das concentrações das castanhas diferencia o comportamento dos índices de luminosidade. O pH teve maiores valores quando houve um aumento na concentração de castanha do Pará, já um aumento na proporção de castanha de baru diminuiu a acidez do extrato hidrossolúvel. Os modelos matemáticos obtidos permitiram avaliar os efeitos das interações entre as variáveis e as respostas, salientando sua aplicabilidade na indústria de alimentos.

Palavras-chave: Modelagem; Delineamento simplex centroide; Composição proximal; Leite vegetal.

Abstract

Despite the nutritional and functional qualities of Pará nut (*Bertholletia excelsa*) and of Baru nut (*Dipteryx alata* Vogel), the industrial exploitation of these two nuts is still scarce. With this, the elaboration of a water-soluble extract based on Pará and Baru nuts could be consider an alternative for the consumption of foods based on these vegetables, both little used industrially. Thus, by way of a simplex centroid experimental mixture design, this study aimed to elaborate water-soluble vegetable extracts based on Pará and Baru nuts. This study allowed evaluate the behavior of the physicochemical and physical characteristics of the processed vegetable extracts. The special cubic model obtained the best fit for the response variables, both for the physicochemical characterizations of moisture, lipid, protein, ash, carbohydrate, pH value and acidity, and for the physical characteristics of luminosity, chroma and hue angle. The results obtained showed that the model is highly predictive (all $R^2 > 97\%$). The water content directly influenced the nutritional aspects of the water-soluble

extracts, where a decrease in the proportion of water in the mixture provided greater content of proximate composition. The behavior of the color parameter predicted by the model showed that variations in the proportions of the nuts concentrations changes the behavior of the luminosity indexes. The pH had higher values when there was an increase in the concentration of Pará nuts, while an increase in the proportion of baru nuts decreased the acidity of the water-soluble extract. The mathematical models used allow to evaluate the effects of the interactions between variables and responses, highlighting their applicability in the food industry.

Keywords: Modelling; Simplex centroid design; Proximate composition; Non dairy milk.

Resumen

A pesar de las cualidades nutricionales y funcionales de las nueces de Pará (*Bertholletia excelsa*) y de Baru (*Dipteryx alata* Vogel), la explotación industrial de estas nueces aún es insuficiente. Siendo así, la elaboración de un extracto soluble en agua a base de nueces de Pará y Baru podría ser considerado una alternativa para el consumo de alimentos a base de estos vegetales, ambos poco utilizados industrialmente. Para ello fue usado un diseño experimental centroide simple da mezcla con el objetivo de elaborar extractos vegetales solubles en agua a base de nueces de Pará y Baru. Este estudio permitió evaluar el comportamiento de las características fisicoquímicas y físicas de los extractos vegetales procesados. El modelo de cúbico especial obtuvo el mejor ajuste para todas las variables de respuesta, tanto para la caracterización fisicoquímica de humedad, lípidos, proteínas, cenizas, carbohidratos, valor de pH y acidez, cuanto, para las características físicas de luminosidad, croma y ángulo de matiz. Os resultados obtenidos demostraron que el modelo es altamente predictivo (todos $R^2 > 97\%$). El contenido de agua influyó directamente en los aspectos nutricionales de los extractos, donde una disminución en la proporción de agua en la mezcla proporcionó un mayor contenido para la siguiente composición. El comportamiento del parámetro de color predicho por el modelo mostró que las variaciones en las proporciones de las concentraciones de nuez diferencian el comportamiento de los índices de luminosidad. El pH tuvo valores más altos cuando hubo un aumento en la concentración de nueces de Pará, mientras que un aumento en la proporción de nueces de baru disminuyó la acidez del extracto soluble en agua. Los modelos matemáticos utilizados permiten evaluar los efectos de las interacciones entre variables y respuestas, destacando su aplicabilidad en la industria alimentaria.

Palabras clave: Modelado; Diseño centroide simplex; Composición proximal; Leche vegetal.

1. Introduction

Water-soluble extracts appear as a plant-based beverage that have commercial and nutritional appeal and that also have been used as alternative to lactose-free diets (Silva et al. 2020). Nondairy beverages are processed by extracting plant material, such as nut, soy, rice, and so on in water. The plant materials are homogenized and thermally treated to enhance suspension of particles and to increase shelf life (Mäkinen, Wanhalinna, Zannini, & Arendt, 2016).

Water-soluble vegetable extracts are protein products of vegetable origin defined by Brazilian National Health Surveillance Agency - ANVISA - RDC nº 268 (Brasil, 2005) as "foods obtained from the protein parts of vegetable species, which can be presented in the granular, powdered, liquid or other forms, with the exception of those not conventionally used as food, to which other ingredients can be added, so long as this does not change the character of the product".

The use of soy milk was first reported about 2000 years ago in China. Soy milk was the first plant-based milk which serves the purpose of providing nutrients to the population where the milk supply was inadequate (Sethi, Tyagi & Anurag, 2016). However, it has limitation in consumer acceptance due to its undesirable aftertaste (Sebastian, Barus, Mulyono & Yanti, 2018).

Following the world tendency in the segment of water-soluble vegetable extracts, water-soluble extracts based on Pará and Baru nuts were obtain as a pioneer work on the subject, with the aim of developing a beverage of vegetable origin with commercial and nutritional appeal with respect to certain health aspects such as the lack of animal fat and high mineral contents. With this in view, it is essential to know the behavior of the ingredients, both individually and in combinations, since this knowledge is essential for their exploitation, favoring their development during the various phases of product development.-

Mixtures or blends are defined as a set of two or more components. When the properties of interest are basically a function of the mixture or of a combination of components, experimental mixture designs are used for product development in substitution of the development of the mixture formulation by trial and error. The Simplex-centroid mixture design makes it possible to obtain formulations with an exact number of experiments and one can choose the best condition for a given response through variations in the formulation of specific components (Barros Neto, Scarminio & Bruns, 2010; Moraes Filho, Busanello, Prudencio & Garcia, 2018).

In the development of new products, food developers must have knowledge about the quality and storage requirements of raw materials and final products, product, formulation and the processes needed to safely manufacture the final food product (Azanedo, Garcia-Garcia, Stone, & Rahimifard., 2020).

Considering that a water-soluble vegetable extract is a beverage with a high unsaturated fatty acid content, and thus a highly perishable food due to oxidative processes, which can result in the appearance of rancid odors and flavors, the elaboration of ternary mixtures of Pará nut, Baru nut and water was proposed by way of an experimental mixture design to determine the best possible formulation for this mixed beverage. Hence physical, physicochemical and microbiological determinations were carried out so as to verify the quality of the product. Due to the aforementioned, this study aimed to evaluate the behavior of the physicochemical and physical composition of water-soluble extracts based on Pará nuts and baru using a simplex centroid type design.

2. Material and methods

2.1 Raw materials

The Pará nuts used in this study were *in natura* and partially skinned. One part was donated by the company *Delta Castanhas do Brasil Ltda* (Iporá, GO, Brazil) and the other part acquired from the company *Naturalista Produtos Naturais Ltda* (Goiânia, GO, Brazil) together with the roasted, non-skinned Baru nuts.

2.2 Processing of the water-soluble extract based on Pará and Baru nuts

The methodology used for the production of the water-soluble extract based on Pará and Baru nuts was developed by Cardoso et al. (2020).

To obtain the water-soluble extract, the nuts were first sanitized using a 300 ppm chlorine solution, and then ground for 10 minutes in an industrial stainless steel blender (Skymsen model LSR 25, Metalúrgica Siemsen Ltda, Brusque, SC, Brazil) together with previously pasteurized water heated to 45 ºC, according to the proportions established by the proposed experimental mixture design. The entire homogeneous contents of the blender were then centrifuged (Vicini model VCC-7000, China), obtaining two co-products, the water-

soluble extract (liquid phase) and the moist residue of Pará and Baru nuts (solid phase). The liquid phase was heated to 85 ºC.

Carboxymethylcellulose (CMC) was added to the water-soluble extract in a proportion of 0.2% (w/v) in order to minimize separation of the oily and aqueous phases, together with the preservatives citric acid, sodium benzoate and potassium sorbate in the proportions of 0.05% (w/v), 0.15% (w/v) and 0.10% (w/v), respectively. The concentrations of each preservative used were established according to current legislation for coconut milk (Brasil 2013).

The water-soluble extracts were further homogenized for 5 minutes and then filled into glass bottles with crown-type metal caps. The bottled product was pasteurized in a jacketed stainless-steel tank using a binomial of 80 ºC for 25 minutes, then cooled and stored under refrigeration (4 ± 2ºC).

2.3 Physicochemical characterization and colorimetry

The percentages of moisture, ash and protein and the pH value were determined according to Association of Official Analytical Chemists - AOAC (2010), and the lipid content was determined using the methodology proposed by Bligh & Dyer (1959). The total titratable acidity was determined directly by titration and the result expressed in percent oleic acid, according to Analytical standards of the Adolfo Lutz Institute and the carbohydrate content was determined by difference by subtracting the sum of the moisture, protein, lipid and ash contents from 100. The instrumental color parameters (L*, a* and b*) were determined using a Hunterlab colorimeter model Colorquest II (Hunter Associates Laboratory Inc, Reston, Virginia, USA). The results were expressed as L* (Luminosity) which varies from 0 (black) to 100 (white); a* which varies from -a* (green) to +a* (red); and b* which varies from -b* (blue) to +b* (yellow). The values for chroma and the hue angle were calculated based on the coordinates determined (Arivalagan et al., 2018).

The statistical data analysis was carried out using the variance analysis (ANOVA) and Tukey's test at the 5% significance level ($p \leq 0.05$) with the aid of the Statistica 7.0 (Statsoft Inc, 2004).

2.4 Formulation and experimental design

The proportions of the mixtures were defined by employing a mixture design of the simplex-centroid type (Lima, Afonso, Costa, & Carvalho, 2019), with a view to evaluating the behavior of the interaction between the components.

The concentrations of water (x1), Pará nut (x2) and Baru nut (x3) were established as the independent variables, where the minimal amount of water was 65% (w/w) for each formulation, whereas the minimal amount of each of the nut components was 5% (w/w). The moisture, ash, lipid, carbohydrate and protein contents, plus the acidity, pH value, luminosity, chroma and hue angle were defined as the response variables. Table 1 shows the 7 different combinations used, both in terms of the original and pseudo-components

Table 1. Experimental design for the processing of the water-soluble extract based on Pará nut (*Bertholletia excelsa*) and Baru nut (*Dipteryx alata* Vogel).

Mixture design - Simplex-centroid						
Trial	Water (X_1)		Pará nut (X_2)		Baru nut (X_3)	
	Pseu	Real	*Pseud*	Real (%)	*Pseu*	Real
1	1	90.00	0	5.00	0	5.00
2	0	65.00	1	30.00	0	5.00
3	0	65.00	0	5.00	1	30.00
4	1/2	77.50	1/2	17.50	0	5.00
5	1/2	77.50	0	5.00	1/2	17.50
6	0	65.00	1/2	17.50	1/2	17.50
7	1/3	73.33	1/3	13.33	1/3	13.33

Source: Authors (2020).

The decoding of the pseudo-components into real concentrations was carried out using equations (1) to (3) since the restrictions for each component in the tertiary mixture had been established.

$$x_1 = 0.25x_1^{'} + 0.65 \quad \textbf{(1)} \qquad x_2 = 0.25x_2^{'} + 0.05 \quad \textbf{(2)} \qquad x_3 = 0.25x_3^{'} + 0.05$$

(3)

Where x_1, x_2 and x_3 represent the water, Pará nut and Baru nut concentrations, respectively, in terms of the real concentrations, and x'_1, x'_2 and x'_3 correspond to the contents of each component (water, Pará nut and Baru nut, respectively) in terms of pseudo-components.

3. Results and Discussion

Table 2 shows the results obtained for the determinations of moisture, protein, ash, lipid and carbohydrate.

Table 2. Physicochemical characterization of the water-soluble extract based on Pará nut (*Bertholletia excelsa*) and Baru nut (*Dipteryx alata* Vogel)

	Moisture	Protei	Ash	Lipid	Carbohydrat
(1; 0;	89.16[a] ±	3.17[d] ±	0.38[c] ±	6.76[g] ±	0.53[d] ± 0.28
(0; 1;	65.74[f] ±	6.50[b] ±	1.25[a] ±	23.34[a] ±	3.18[c] ± 0.29
(0; 0;	65.73[f] ±	8.63[a] ±	1.17[a] ±	16.57[c] ±	7.89[a] ± 0.74
(½;	79.90[b] ±	5.53[c] ±	0.70[b] ±	13.50[e] ±	0.38[d] ± 0.13
(½; 0;	79.51[c] ±	4.86[c] ±	0.73[b] ±	10.42[f] ±	4.49[b] ± 0.19
(0; ½;	66.46[e] ±	9.32[a] ±	1.20[a] ±	18.85[b] ±	4.18[bc] ± 0.16
(⅓;	75.05[d] ±	5.67[bc] ±	0.79[b] ±	14.41[d] ±	4.09[bc] ± 0.58

Means followed by different letters in the same column differed significantly at the 5% level, according to Tukey's test. Source: Authors (2020).

The changes in moisture content presented a direct relationship with the proportion of water established by the mixture design, the smaller the proportion of water the smaller the moisture content found in the vegetable extract (Trials 2, 3 and 6). Thus, this variable presented results that were inversely proportional when compared with the other response variables, that is, for the trials with a larger water composition and hence a higher moisture content, the other response variables showed their smallest values (Trial 1). Considering these results, note that the amount of water had a direct influence on the nutritional aspects of the water-soluble extract and Labuza & Altunakar (2020), considers that the amount of water is related to the stability, quality and composition of the food. Note also that the moisture content obtained a significant difference in almost all the trials ($p<0.05$), with the exception of trials 2 and 3, which showed no significant difference between them, it being evident that the interaction between the nuts did not cause changes in the variable of moisture content, that is, the contents and types of nut were not important, only the water content being important.

Diverse authors have reported in the literature a variety of values for the moisture contents of different water-soluble extracts, for example, 78% for coconut milk, 76.11% for the water-soluble extract from babassu, 85.89% for the water-soluble extract from Baru and 92.98% for the water-soluble extract from soybean (Carvalho et al., 2011; Carneiro, Arévalo-Pinedo, Azzini, Giraldo-Zuniga, & Pinedo, 2014; D' Oliveira, 2015).

Observing the variations in the lipid contents presented in Table 2, all the formulations proposed by the design presented significant differences. Both the proportion of nut added to the formulations and the type of nut directly influenced the lipid composition of the extracts. An observation of trials 2 and 3 shows that the greater the amount of nut added, the greater the lipid content and also that the type of nut directly interfered, such that the larger the amount of Pará nut added for the same amount of water, the greater the lipid content. This fact can be proven from an observation of Trials 2 and 3, which both had the same proportion of water (65%) and the same total proportion of nuts (35%), but the nuts in Trial 2 were composed of 30% Pará nut and 5% Baru nut, whilst the nuts in Trial 3 were composed of 30% Baru nut and 5% Pará nut. These trials presented lipid contents of 23.34% and 16.57%, respectively, since the lipid contents of the individual nuts were discrepant, being 66.20% for Pará nut and 35.72% for Baru nut, justifying this difference (Santos, Corrêa, & Lannes 2011; D'Oliveira, 2015).

Carneiro et al. (2014) reported that the amount of fat in commercial coconut milk varied from 20 to 22%, and hence to standardize the fat content it would be necessary to establish the amount of added water at about 65%. In the present study this suggests a variation in Pará nut greater than that in Trial 6 (17.5%) and lower than that in Trial 2 (30%).

When the sum of the Pará and Baru nut contents was equal to the maximum amount allowed of 35% (Trials 2, 3 and 6), note that the contents of all the responses presented their highest values, except for the moisture and carbohydrate contents. The protein content varied between 3.17 and 9.32%, these values varying in proportion to the amounts of nuts added to the formulation, that is, trials with 35% of nuts (2, 3 and 6) showed the highest protein contents, followed by Trial (7) with 22.66% of nuts, then Trials (4 and 5) with 22.5% of nuts and finally Trial (1) with 10% of nuts in its formulation, which showed the lowest protein content in the extract.

When water-soluble extracts containing the same proportion of water are compared (2, 3 and 6) and (4 and 5), the ash and protein contents of these trials did not show significant differences, except for the protein content of trial 2. The latter difference occurred because the formulation of trial 2 contained 30% of Pará nut but only 5% of Baru nut, resulting in a much smaller protein content as compared with trial 3, which contained the same total nut content of 35%, but was composed of 30% Baru nut and 5% of Pará nut. Baru nut contains almost twice the amount of protein as Pará nut (26.97% and 13.75%, respectively) (Lima, Freitas, Czeder, Fernandes, & Naves, 2010; Santos, 2015), explaining this difference in protein content between trials 2 and 3.

Felberg, Antoniassi, Deliza, Freitas, & Modesta (2009), studying mixed beverages of soybean extract with Pará nut extract (with a 40% content), found protein contents of 2.33%, whereas the beverage made only with whole Pará nut showed a reduced protein content of 1.75%.

The water-soluble extracts formulated in the present study conformed to the parameters described in the Brazilian legislation, which fixes the identity and minimum quality characteristics that protein products of vegetable origin should obey, and recommends a minimum protein content of 3% (Brasil, 2005).

In general, the extracts showed elevated protein contents, being notorious when compared with other results found in the literature, such as that described by Carvalho et al. (2011) working with extracts from broken rice grains, whole rice grains and soybeans, who found protein contents to the order of 0.73%, 0.84% and 2.51%, respectively. Carneiro et al. (2014) working with water-soluble babassu extracts, found protein contents between 2.45 and 2.70%.

The differences found in the chemical compositions of the water-soluble vegetable extracts prepared in the present study and others discussed in the literature may be explained by many factors, such as the composition of the raw materials, the mode of processing of the water-soluble extract as well as the analytical methodology applied.

Table 3 shows the results obtained for the determinations of pH value, acidity and the color variation of the samples produced.

Table 3. Evaluation of the chemical characteristics and color variation of the different formulations of water-soluble extract based on Pará nut (*Bertholletia excelsa*) and Baru nut (*Dipteryx alata* Vogel).

T	Mix	pH	Acidity	Luminos	Chroma		Hue
1	(1;	5.79^e ±	1.46^e ±	76.52^b ±	15.64^e	±	79.41^a
2	(0;	6.20^b ±	3.04^c ±	80.71^a ±	12.66^f	±	76.02^d
3	(0;	5.98^d ±	5.00^a ±	59.19^g ±	24.31^a	±	70.99^g
4	(½;	6.32^a ±	2.18^d ±	75.51^c ±	11.49^g	±	77.09^c ±
5	(½;	6.14^c ±	2.85^c ±	71.61^d ±	19.61^c	±	74.01^f ±
6	(0;	6.15^c ±	3.90^b ±	66.44^f ±	18.77^d	±	75.11^e
7	(⅓;	6.14^c ±	3.32^c ±	69.03^e ±	20.47^b	±	77.84^b

Means followed by different letters in the same column differed significantly at the 5% level, according to Tukey's test. Source: Authors (2020).

Table 3 shows that the water-soluble vegetable extracts based on Pará and Baru nuts presented pH values close to neutrality, hence these products were classified in the low acidity category (pH > 4.0). Note that maintaining the amount of water fixed and only varying the amounts of the nuts, Pará nut increased the pH value whereas Baru nut decreased it (trials 2;3 and 4;5), the contrary occurring with acidity.

Silva et al. (2020) studying water soluble baru extract, in proportions of 1:6 and 1:10 baru:water found values for pH at about 5.85 and 5.6, respectively. Carneiro et al. (2014) in a study of the shelf life of a mixed beverage of babassu and Pará nut extracts, found pH values similar to those found in the present study (6.14) whereas the acidity was 1.70. Thus, this occurred because the Baru nuts have a more acid pH value than the Pará nuts.

While evaluating the concentration of a water-soluble soybean extract, Barana, Oliveira, & Granato (2018), combined the nutritional advantages of whey and soybean by developing a type of chocolate beverage with water-soluble soybean and the pH values vary 6.5 to 6.6. Santos (2015), evaluating the stability of a water-soluble Pará nut extract, found an acidity of 0.30 and pH value of 6.34 for the treatment without preservatives and acidity of 0.53 and pH value of 5.87 with preservatives.

The elevated values for acidity found in the present study could be justified by differences in the raw materials used to elaborate the beverages and to differences in the processing procedure used, where some steps such as blanching and autoclaving were not applied in this study.

In general, the values found for Luminosity (L) varied between 59.19 and 80.71 distant from white. As the values become more distant from white, so the samples become

more saturated, that is, they gained chroma and showed shades of grey. Increases in Luminosity were observed in experiments with higher concentrations of Pará nut and minimum proportions of Baru nut (Trials 1, 2 and 4).

Carneiro et al. (2014) found a value of 73.35 for the attribute of Luminosity for a mixed beverage containing 60% of babassu and 40% of Pará nut, as chosen by the sensory evaluation. Silva, et al. (2020) studying water-soluble baru extract found values ranging from 67 to 70 for luminosity. These variations are mainly due to characteristics of the raw materials, since Pará nut shows higher values for luminosity than Baru nut (Santos, 2012).

The values for chroma define the color intensity, those closer to 0 being indicative of more neutral (greyer) colors and those closer to 60 indicating more vibrant and intense colors. The chroma values increased as the Baru nut content increased and the Pará nut content decreased, indicating more vibrant colours.

Considering the results shown in Table 3, the mean angle obtained for the hue angle between all the trials was 75.78, corresponding to a color varying between red and yellow. This property indicates the tonality and can vary from 0º to 360º, 0º corresponding to red, 90º to yellow, 180º to green and 270º to blue (Souza, 2010).Considering the values found for Luminosity, chroma and hue angle, the product obtained in the present study showed a yellowish white color with a reddish tendency.

With the aim of analyzing the fit of the experimental data obtained, the linear, quadratic and special cubic models were tested by applying the analysis of variance (ANOVA) at the 5% level of significance ($p \leq 0.05$). The experimental (R^2) and fitted (R^2fitted) determination coefficients and the p value were analyzed in order to choose the best-fitting model.

Table 4 shows the results obtained for the coefficients tested, for each response variable.

Table 4. The p-values and the experimental (R^2) and fitted (R^2_{fitted}) determination coefficients obtained for the models tested, for each response variable.

Response variable	Model	p-value	R^2	R^2_{fitted}
Moisture	Linear	0.0000	0.9872	0.9858
	Quadratic	0.0000	0.9991	0.9988
	Special cubic	0.0000	0.9999	0.9999
Protein	Linear	0.0000	0.8412	0.8236
	Quadratic	0.0002	0.9566	0.9421
	Special cubic	0.0009	0.9809	0.9727
Lipid	Linear	0.0000	0.9827	0.9808
	Quadratic	0.0000	0.9974	0.9966
	Special cubic	0.0035	0.9986	0.9981
Ash	Linear	0.0000	0.9481	0.9423
	Quadratic	0.0062	0.9670	0.9611
	Special cubic	0.0202	0.9767	0.9708
Carbohydrates	Linear	0.0000	0.9072	0.8969
	Quadratic	0.0200	0.9431	0.9289
	Special cubic	0.0001	0.9801	0.9735
pH-value	Linear	0.0071	0.4232	0.3591
	Quadratic	0.0000	0.9354	0.9138
	Special cubic	0.0000	0.9969	0.9956
Acidity	Linear	0.0000	0.9604	0.9560
	Quadratic	0.1133	0.9659	0.9599
	Special cubic	0.0102	0.9777	0.9722
Luminosity (L*)	Linear	0.0000	0.8672	0.8524
	Quadratic	0.0000	0.9750	0.9667
	Special cubic	0.0224	0.9830	0.9757
Chroma (C)	Linear	0.0000	0.8794	0.8660
	Quadratic	0.1505	0.9144	0.8859
	Special cubic	0.0000	0.9987	0.9982
Hue angle (H°)	Linear	0.0000	0.7812	0.7569
	Quadratic	0.0129	0.8911	0.8548
	Special cubic	0.0000	0.9979	0.9970

Source: Authors (2020).

A model is considered to fit the data satisfactorily if the fitted determination coefficients (R^2) show values above 0.85. All the models obtained fitted the data of the response variables except the quadratic model for the attributes of acidity and chroma, for

which the p values were not significant ($p > 0.05$). The values for R^2 and R^2_{fitted} were close to unity for all the models, confirming their good fit and good predictive capacity.

Although all the models showed a good fit, the special cubic model, in addition to being significant ($p < 0.05$) in all cases, presented the highest values for R^2 and R^2_{fitted}, and hence the special cubic was considered to be the most adequate for this study

D'Oliveira (2015), when developing a Baru nut-based beverage aromatized with chocolate, used response surface methodology to test the fit of the models to the sensory analysis attributes (color, aroma, flavor, texture, sweetness and global acceptance). The author found much lower values for the determination coefficients, varying between 0.71220 and 0.79257, than those found in the present study.

Hence the mathematical special cubic models constructed showed a good fit to the experimental data and high coefficients ($R^2 > 0.9767$) and the analysis of variance ($p < 2.02\%$) showed that these models could be used for predictive ends.

Table 5 shows the predictive equations generated by the special cubic model for the physicochemical analysis and color variation.

Table 5. Equations for the physicochemical characterization of the water-soluble extract based on Pará nut (*Bertholletia excelsa*) and Baru nut (*Dipteryx alata* Vogel).

| Response variable	Equation
Moisture	$y = 89.16x_1 + 65.74x_2 + 65.73x_3 + 9.78x_1x_2 + 8.24x_1x_3 + 2.89x_2x_3 - 22.09x_1x_2x_3$
Protein	$y = 3.17x_1 + 6.5x_2 + 8.63x_3 + 2.77x_1x_2 - 4.19x_1x_3 + 7.01x_2x_3 - 28.43x_1x_2x_3$
Lipids	$y = 6.76x_1 + 23.34x_2 + 16.57x_3 - 6.20x_1x_2 - 4.99x_1x_3 - 4.42x_2x_3 + 15.89x_1x_2x_3$
Ash	$y = 0.36x_1 + 1.24x_2 + 1.16x_3 - 0.40x_1x_2 - 2.43x_1x_2x_3$
Carbohydrates	$y = 0.63x_1 + 3.18x_2 + 7.98x_3 - 6.11x_1x_2 - 5.63x_2x_3 + 39.42x_1x_2x_3$
pH	$y = 5.79x_1 + 6.20x_2 + 5.98x_3 + 1.29x_1x_2 + 1.02x_1x_3 + 0.27x_2x_3 - 3.55x_1x_2x_3$
Acidity	$y = 1.44x_1 + 2.98x_2 + 4.96x_3 - 1.4x_1x_3 + 9.4x_1x_2x_3$
Luminosity	$y = 75.19x_1 + 80.71x_2 + 59.19x_3 - 9.77x_1x_2 + 17.67x_1x_3 - 14.02x_2x_3 - 53.52x_1x_2x_3$
Chroma	$y = 15.64x_1 + 12.66x_2 + 24.31x_3 - 10.65x_1x_2 - 1.45x_1x_3 + 1.14x_2x_3 + 111.55x_1x_2x_3$
Hue angle	$y = 79.41x_1 + 76.02x_2 + 70.99x_3 - 2.49x_1x_2 - 4.75x_1x_3 + 6.42x_2x_3 + 77.79x_1x_2x_3$

Where: x_1 = the proportion of water in the mixture, x_2 = the proportion of Pará nut in the mixture, x_3 = the proportion of Baru nut in the mixture, and y = the estimate of the response. Source: Authors (2020).

The high coefficients and ANOVA showed that the equations could be used for predictive ends.

The objective of analyzing the results was to numerically model the behavior of the mixtures of Pará nut and Baru nut in the elaboration of a mixed water-soluble extract. The region of combination between the three variables x_1, x_2 and x_3 can be seen in the contour curves obtained using the mathematical models and presented in Figure 1, corresponding to

moisture, protein, lipid, ash, carbohydrate, pH and acidity, respectively, and in Figure 2, corresponding to luminosity, chroma and the hue angle, in this order.

Figure 1. Contour curves for the models referring to the physicochemical attributes of the water-soluble extracts based on Pará nut (*Bertholletia excelsa*) and Baru nut (*Dipteryx alata* Vogel).
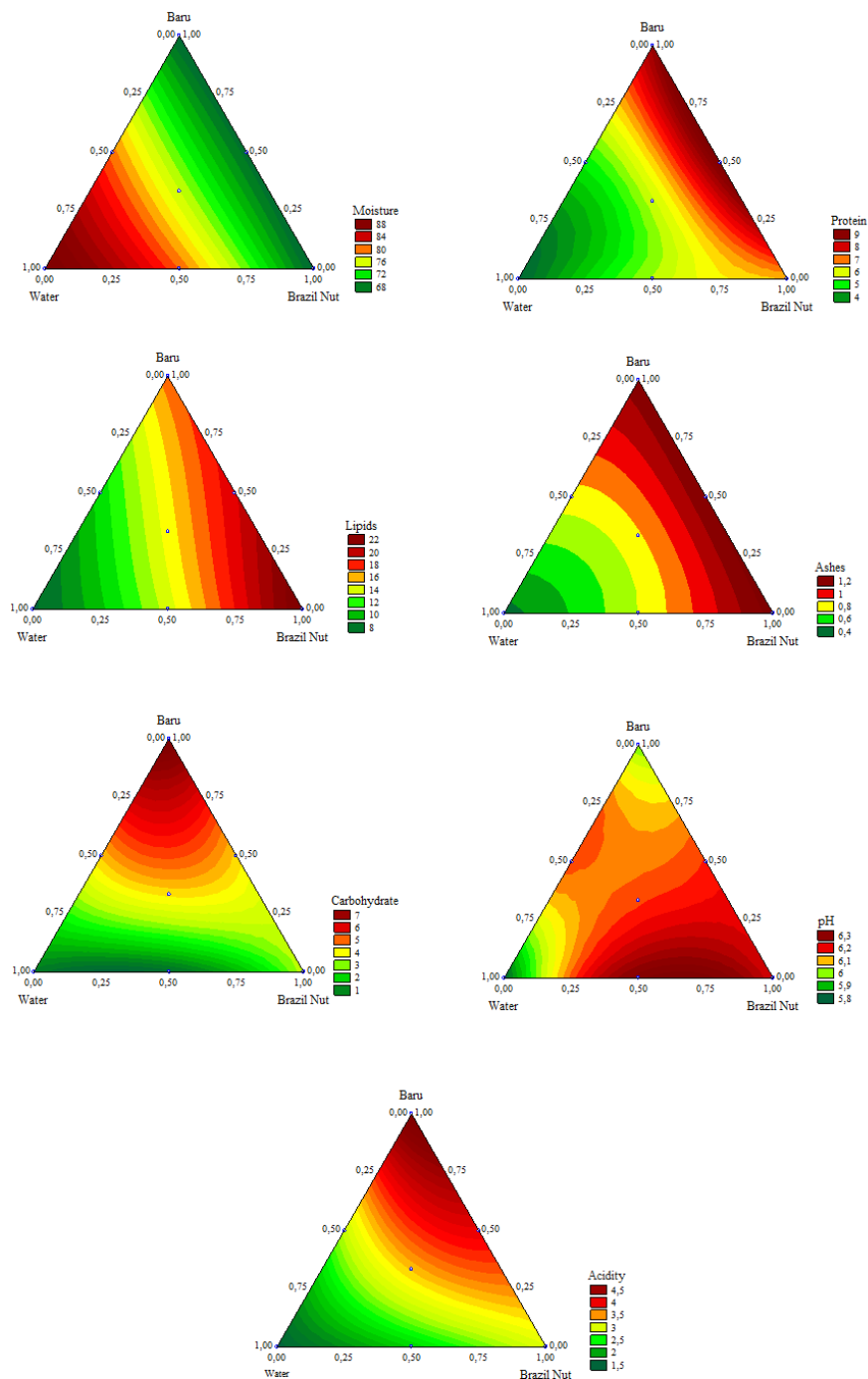
Source: Authors (2020).

All the contour curves showed that concentrations close to 100% water, green-colored regions, were less efficient with respect to the composition of the extracts studied, providing smaller indexes for the proximate composition except for moisture. To the contrary, on observing the contour curve for the variable of moisture content, the highest proportion was found on the vertexes (1, 0, 0), represented by the red-colored region, signifying that the greater the amount of water added in the trials, the greater the moisture content found. This was proven by the model in the predictive equation for moisture (Table 5) by way of the elevated coefficient for the proportion of water in the mixture (x_1) of 89.16.

Observing the contour curve for the variable lipid, it can be seen that the greatest levels for this variable were close to the variable Pará nut, as proven by the values obtained in Table 1 and by the equation (Table 5), where Trials 2 and 6 presented the largest values for this variable, presenting levels of 100% and 50% of Pará nut associated with the variable of water at its lowest level. This infers that the water acts as an ingredient that decreases the lipid content in the extract. The lowest levels for this variable can be found at the extremity for the totality of water and about 50% of the nut, as shown by the results obtained for trials 1 and 4.

The results showing greater efficiency for the contents of carbohydrate can be seen on the vertexes (0, 0, 1) with the greatest proportion of Baru nut (red region), since this parameter is calculated by difference (carbohydrates = 100 – moisture – protein – lipid – ash) and the extracts with a greater proportion of Baru nut (Trials 2;3 and 4;5) presented lower lipid contents and consequently higher values for carbohydrate.

The results with the greatest efficiency for the acidity contents can be observed on the vertexes (0, 0, 1) with the greatest proportion of Baru nut (red region) as proven in trial 3, which had the highest acidity content.

In a search for the highest indexes of protein and ash, it was shown from the response surfaces plotted, that the most efficient effects for these parameters were due to the combination between elevated Pará nut and Baru nut contents (red region) showing synergistic action between these components.

From the equations generated for the color variation (Luminosity, Chroma and hue angle) one can see that the combination of the coefficients for Pará nut and Baru nut (x_2x_3) showed a synergistic effect, that is, it contributed to increases in the chroma and hue angle (x_2 and $x_3 >$ zero) but not for luminosity, as shown by the contour curves presented in Figure 2.

An analysis of the contour curves shown in Figure 2 indicates that the luminosity (L*) decreased with increases in the quantity of Baru nut, as can be proven by trials 3 and 5. Thus formulations with greater Pará nut contents tend to white. Felberg et al. (2009) reported

values of 82.47 < L* < 87.64 in studies with a mixed beverage in which Pará nut extract (10, 20, 30, 40 and 50%) was added to a soybean beverage. The authors showed that the values for luminosity behaved in a manner similar to that found in the present study, in which the greater the amount of water-soluble Pará nut extract added to the beverage, the greater the values obtained for luminosity.

Figure 2. Contour curves for the models referring to the colorimetric attributes of the water-soluble extracts based on Pará nut (*Bertholletia excelsa*) and Baru nut (*Dipteryx alata* Vogel).
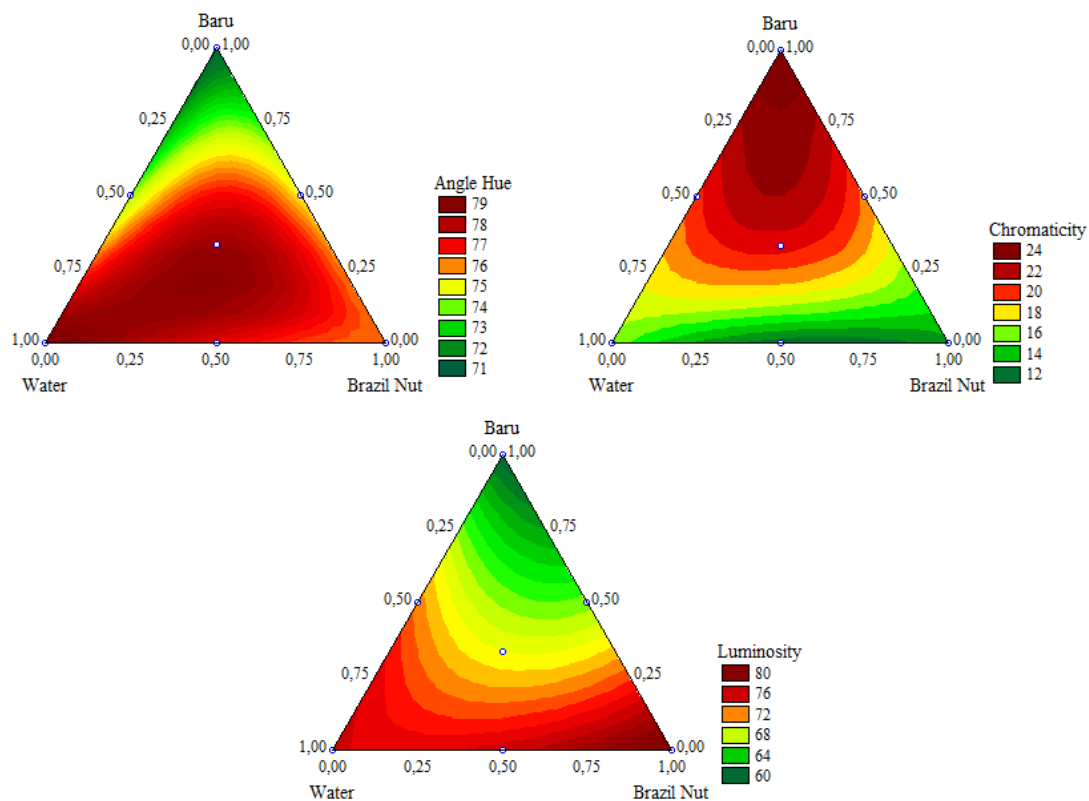
Source: Authors (2020).

The values for chroma presented an action to the contrary of that found for luminosity, since for this parameter, the greater the proportion of Baru nut the greater the value for chroma. Consequently, greater proportions of water and Pará nut lead to a beverage with a less intense color, as proven by trials 2 and 4.

With respect to the hue angle, the largest values for this parameter can be found in the dark red region, close to the centroid (⅓, ⅓, ⅓). Thus, greater proportions of Baru nut in the

extract formulations contribute to a decrease in tonality, and hence the extracts tend to a red color.

With the objective of proving the efficiency of the model, the models generated were validated, showing a great proximity between the observed and predicted values, confirming the good predictive capacity of the models tested from their experimental and fitted determination coefficients, for which the error obtained was lower than 0.1697% for all the response variables studied.

4. Conclusions

The elaboration of a mixed water-soluble extract based on Pará and Baru nuts can be considered an alternative for the consumption of foods based on these vegetables.

The cubic models fitted the experimental data best and were shown to be highly predictive, considering the high coefficients and analysis of variance. In general, the mathematical models allowed for the evaluation of the effects of the interactions between the variables and the responses, emphasizing their applicability for the food industry.

It was shown that the water content had a direct influence on the nutritional aspects of the water-soluble extracts based on Pará and Baru nuts, where a decrease in the proportion of water in the mixture provided larger contents for the proximate composition.

An increase in the concentration of Pará nut raised the pH values and an increase in the proportion of Baru nut contributed to a decrease in the acidity of the water-soluble extract.

The behavior of the color parameters predicted by the model, showed that an increase in concentration of Pará nut increased the indexes of luminosity, resulting in the water-soluble extracts tending to a white color. On the other hand, an increase in the proportion of Baru nut resulted in more intense colors, contributing to a decrease in tonality of the water-soluble extracts.

Carbohydrates were calculated by using an equation. Thus, analytical measure could be necessary in order to best determine the concentration. Desirability test can be executed to estimate the best formulation based on the physicochemical composition

Disclosure of conflict of interest

The authors have no conflicts of interest to declare.

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References

AOAC – *Association of Official Analytical Chemists*. (2010). Official methods of analysis of the Association of Official. Analytical Chemistry. 18. ed. Washington: AOAC, v. 1 e 2.

Azanedo, L., Garcia-Garcia, G., Stone, J., & Rahimifard, S. (2020). An Overview of Current Challenges in New Food Product Development. *Sustainability*, 12, 3364.

Arivalagan, M., Manikantan, M. R., Yasmeen, A. M., Sreejith, S., Balasubramanian, D., Hebbar, K. B., & Kanade, S. R. (2018). Physiochemical and nutritional characterization of coconut *(Cocos nucifera L.)* haustorium based extrudates. *Food Science and Technology*, 89, 171-178.

Barana, A. C., Oliveira, D. F., & Granato, D. (2018). Development and optimization of a mixed beverage made of whey and water-soluble soybean extract flavored with chocolate using a simplex-centroid design. *Food Science and Technology*. Vol.38 no.3 Campinas.
.
Barros Neto, B., Scarminio, B., & Bruns, R. E. (2010). *Como fazer experimentos: Pesquisa e desenvolvimento na ciência e na indústria.* Porto Alegre: Editora Bookman, (4ª Ed).

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, Toronto, v37, n.8, p.911-917.

Brasil, 2005. Anvisa - (2005). Ministério da Saúde. Agência Nacional de Vigilância Sanitária. Resolução. Legislação. Resolução nº 268, de 22 de setembro de 2005. Regulamento técnico para produtos protéicos de origem vegetal. Diário Oficial da União, Brasília, 23 de setembro de 2005.

Brasil, 2013. Anvisa -Agência Nacional de Vigilância Sanitária. Resolução RDC n. 8 de 06 de março de 2013. Dispõe sobre a aprovação de uso de aditivos alimentares para produtos de frutas e de vegetais e geleia de mocotó. Brasília, DF: ANVISA, 2013

Cardoso, C., Santos, M., Silva, Y., Canedo, M., Garcia, L., & Silva, F. (2020). Processing, characterization and stability of Brazil nut (*Bertholletia excelsa*) extract. *Research, Society and Development,* 9(5), e137953292.

Carneiro, B. L. A., Arévalo-Pinedo, A., Azzini, L. S., Giraldo-Zuniga, A. D., & Pinedo, R. A. (2014). Estudo da estabilidade do extrato hidrossolúvel "leite" de babaçu (*Orbygnia speciosa*) pasteurizado e armazenado sob refrigeração. *Revista Brasileira de Fruticultura,* Jaboticabal - SP, 36(1): 232-236.

Carvalho, W. T., Reis, R. C., Velasco, P., Soares Júnior, M. S., Bassinelo, P. Z., & Caliari, M. (2011). Características físico-químicas de extratos de arroz integral, quirera de arroz e soja. *Pesquisa Agropecuária Tropical*, Goiânia, 41(3): 422-429.

D'Oliveira, A. C. (2015). *Desenvolvimento de bebida aromatizada da Baru* (*Dipteryx alata* Vogel)**.** Dissertação (Mestrado em Saúde e Desenvolvimento na Região Centro-oeste) Universidade Federal do Mato Grosso do Sul. Campo Grande. 99p.

Felberg, I., Antoniassi, R., Deliza, R., Freitas, S. C., & Modesta, R. C. D. (2009). Soy and Brazil nut beverage: processing, composition, sensory, and color evaluation. *Ciência e Tecnologia de Alimentos*. Campinas, 29(3): 609-617.

Labuza, T. P. & Altunakar, B. (2020). Water Activity Prediction and Moisture Sorption Isotherms. *In Water Activity in Foods* (eds G.V. Barbosa-Cánovas, A.J. Fontana, S.J. Schmidt and T.P. Labuza).

Lima, N. D., Afonso, M. R. A., Costa, J. M. C., & Carvalho, J. D. G. (2019). Powdered beverage mix with acerola pulp, whey and maltodextrin. *Revista Ciência Agronômina*. V. 50, n.4.

Lima, J. C. R., Freitas, J. B., Czeder, L. P., Fernandes, D. C., & Naves, M. M. V. (2010). Qualidade microbiológica, aceitabilidade e valor nutricional de barras de cereais formuladas com polpa e amêndoa de Baru. *Boletim CEPPA*, Curitiba, 28(2): 331- 343.

Mäkinen, O. E., Wanhalinna, V., Zannini, E., & Arendt, E.K. (2016). Foods for Special Dietary Needs: Non-dairy Plant-based Milk Substitutes and Fermented Dairy-type Products. *Critical Reviews in Food Science and Nutrition*, 56(3), 339-349.

Moraes Filho, M. L., Busanello, M., Prudencio, S.H., & Garcia, S. (2018). Soymilk with okara flour fermented by Lactobacillus acidophilus: Simplex-centroid mixture design applied in the elaboration of probiotic creamy sauce and storage stability. *LWT - Food Science and Technology*, 93, 339-345.

Santos, O. V., Corrêa, N. C. F., & Lannes, S. C. S. (2011). Caracterização física, físico-química, microbiológica e micotoxicologica da Castanha-do-Pará *(Bertholletia excelsa H. B. K). Revista Iluminart*, Sertãozinho, 7, 48-59.

Santos, O. V. (2012). *Estudos das potencialidades da castanha-do-brasil: produtos e subprodutos.* Tese (doutorado) – Faculdade de Ciências Farmacêuticas da Universidade de São Paulo. Departamento de Tecnologia Bioquímico-Farmacêutica. São Paulo. 214p.

Santos, M. D. (2015). *Avaliação de estabilidade do extrato hidrossolúvel de castanha-do-brasil (Bertholletia excelsa)*. Dissertação (Mestrado em Ciência e Tecnologia de Alimentos) Universidade Federal de Goiás, Goiânia. 79p

Silva, A. T., Silva, F. T., Alves, J. S., Peres, D. S., Garcia, L.G.C., & Santos, P. A. (2020). Physical-chemical profile and bioactive compounds of water-soluble baru extract (*Dipteryx alata* Vogel). *Research, Society and Development*, v. 9, n. 5, e199953294.

Sethi, S., Tyagi, S. K., & Anurag, R. K. (2016).Plant-based Milk Alternatives an Emerging Segment of Functional Beverages: A Review. *Journal of Food Science and Technology*. Sep;53(9):3408-3423.

Sebastian, A., Barus, T., Mulyono, N., & Yanti. (2018). Effects of fermentation and sterilization on quality of soybean milk. *International Food Research Journal* 25(6): 2428-2434.

Souza, B. A. M. (2010). Indução floral do abacaxi ornamental Ananas Bracteatus no norte de Minas Gerais. Trabalho de Conclusão de Curso (Curso de Bacharelado em Engenharia Agronômica) – Universidade Estadual de Montes Claros, Janaúba, Minas Gerais. 42p.

StatSoft Inc. 2004. Statistica (data analysis software system), version 7.0.

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