Microencapsulation of babassu coconut milk

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Abstract

The objective of this study was to obtain babassu coconut milk powder microencapsulated by spray drying process using gum Arabic as wall material. Coconut milk was extracted by babassu peeling, grinding (with two parts of water), and vacuum filtration. The milk was pasteurized at 85 °C for 15 minutes and homogenized to break up the fat globules, rendering the milk a uniform consistency. A central composite rotatable design with a range of independent variables was used: inlet air temperature in the dryer (170-220 °C) and gum Arabic concentration (10-20%, w/w) on the responses: moisture content (0.52-2.39%), hygroscopicity (6.98-9.86 g adsorbed water/100g solids), water activity (0.14-0.58), lipid oxidation (0.012-0.064 meq peroxide/kg oil), and process yield (20.33-30.19%). All variables influenced significantly the responses evaluated. Microencapsulation was optimized for maximum process yield and minimal lipid oxidation. The coconut milk powder obtained at optimum conditions was characterized in terms of morphology, particle size distribution, bulk and absolute density, porosity, and wettability.

Keywords: *Orbignya phalerata* Mart.; spray drying; lipid oxidation; response surface; scanning electron microscopy.

1 Introdution

Babassu (*Orbignya phalerata* Mart.) is one of the most important representatives of Brazilian palms, and it is spread along the Southern limits of the Amazon basin; the states of Maranhão, Piauí, and Tocantins have the largest babassu fields (CARRAZA; SILVA; ÁVILA, 2012). The babassu coconut almond is of great economic importance in rural Brazil since a considerable number of families collect and process it for their economic survival. According to Carraza, Silva and Ávila (2012), Brazilian production is close to 120 million ton/year, corresponding to trade values of almost R$ 150 million. There are several uses for babassu coconut; however, its potential remains unexploited due to the lack of scale and production structure. So far, practically only oil and press cake extracted from its almonds are industrially produced. However, due to its nice flavor and nutritional value, babassu almond can be incorporated in other food products.

One of the products derived from this palm, babassu coconut milk has been handmade for use in regional cuisine. However, the launch of this product into the market depends on the development of processing technologies and conservation. Amongst the several methods employed for preservation, drying is a process in which the water activity of the food is removed by vaporization or sublimation. Therefore, using drying to obtain babassu milk powder is one of the various technologies used for its processing.

Spray drying is a process that changes liquid food into a powder form. Due to short contact time between hot air and the droplets inside the drying chamber, spray drying is suitable for heat-sensitive products promoting a higher retention of flavor, color, and nutrients. Moreover, this technique has been widely used in the microencapsulation of food ingredients susceptible to deterioration by external agents. Microencapsulation consists of entrapping an active agent in a polymeric matrix in order to protect it from adverse conditions (RÉ, 1998). Since babassu coconut milk is composed by a major lipid fraction (around 80%, dry basis) (ARÉVALO-PINEDO et al., 2005), it is susceptible to lipid oxidation during processing and storage, resulting in the formation of unpleasant flavor. Therefore, microencapsulation of this product has been proposed as an alternative to minimize such degradation reaction.

Gum Arabic is a natural hydrocolloid, which consists of a complex mixture of glycoproteins and polysaccharides. It has been recognized as an effective encapsulating agent due to its ability to stabilize emulsions and facilitate good volatile retention; in addition, it has high water solubility and low solution viscosity (THEVENET, 1995). Since babassu coconut milk is composed of high content of fat acids and low molecular weight sugars, its powder form presents low glass transition temperature (T_g). This can lead to adhesion of powder to the dryer wall and difficult handling thus making its storage and use substantially more difficult. To overcome these problems, the use of wall material with high molecular weight during spray drying, such as gum Arabic, is necessary to increase the T_g of the product preventing stickiness and reducing powder hygroscopicity.

The physicochemical properties of spray-dried microcapsules depend on the characteristics of the feed solution (e.g., viscosity, flow rate), the drying air (e.g., temperature,

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pressure, air flow), contact between the hot air and droplets in the drying chamber (cocurrent or countercurrent flow), and the type of atomizer used (MASTERS, 1991). According to Barbosa-Cánovas and Juliano (2005), the knowledge and understanding of powder properties is essential to optimize processes, functionality, and reduce costs.

The objective of this study was to study the influence of inlet air temperature and wall material (gum Arabic) concentration on process yield, lipid oxidation, and physicochemical properties of the powder (moisture content, hygroscopicity, and water activity) during spray drying of babassu coconut milk. Moreover, in the present study, the spray drying condition was optimized in order to obtain the maximum process yield and minimum lipid oxidation; and the microcapsules obtained under the optimized condition was characterized for bulk density, absolute density, porosity, wettability, particle size distribution, and morphology.

2 Materials and methods

2.1 Materials

Babassu coconut almonds were provided by Monte Alegre farm (Governador Eugênio Barros, MA, Brazil). The material was wrapped in a thermal container and forwarded via air transport to the city of Campinas, SP, Brazil. The almonds were acquired from a single batch in order to use the same raw material during all analyses Gum Arabic Instantgum® (Colloides Naturels, São Paulo, Brazil) was used as wall material in the drying process.

2.2 Preparation of babassu coconut milk

The babassu coconut milk processing comprised of the following steps: selecting; peeling with stainless steel knives to remove the brown film; maintaining in hot water (85-90 °C, 15 minutes) to inactivate lipases; and homogenization blending with hot water (2:1 water:coconuts ratio, w/w) (80 °C, 15 minutes) to obtain a homogeneous consistency. The mixture was vacuum filtered through a porous material to remove suspended solids. The resulting milk was heated (90 °C, 15 minutes) under stirring to coagulate proteins and homogenized for 5 minutes using an industrial blender to break up the fat globules, rendering the milk a uniform consistency.

2.3 Spray drying

Before the spray drying process, gum Arabic was added directly to the babassu coconut milk (10-20 g gum Arabic/100 g feed solution). The mixture dissolution was performed using a Turrax high shear mixer (Extratur Disperser, Quimis, Brazil) at room temperature and 16,000 rpm for 15 minutes and kept under magnetic agitation during the spray drying process.

The tests were conducted using a laboratory spray dryer (model B191, Büchi, Flawil, Switzerland). The equipment was operated using a 0.7 mm diameter double fluid atomizer nozzle. The drying chamber dimensions are: diameter of 110 mm and a height of 435 mm. The drying process was accomplished by passing constant compressed air stream of 0.6 m^3/h and airflow of 19 m^3/h. A fixed feed flow of 0.2 kg/h was used. The experiments were performed under different conditions regarding the inlet air temperature (T_{in}, 170-220 °C) and the gum Arabic concentration (C_{GA}, 10-20%, w/w), as shown in Table 1.

2.4 Experimental design

The spray drying tests were carried out according to a rotational central composite design (Table 1). The independent variables were: inlet air temperature in the dryer and gum Arabic concentration. The evaluated responses were: yield process, powder physicochemical properties of powder (moisture content (X), hygroscopicity (H), water activity (A_w)), and lipid oxidation (LO). A polynomial equation was used for fitting the experimental data (Equation 1). Analysis of variance (ANOVA), lack of fit test (test F), determination of regression coefficients, and generation of response surfaces were carried out with Statistica *software* 9.0 (Statsoft, Tulsa, USA). Only the variables with a confidence level above 90% ($p \le 0.1$) were considered significant.

$$Y = \beta_0 + \beta_1 T_{\text{in}} + \beta_2 C_{\text{GA}} + \beta_{11} T_{in}^2 + \beta_{22} C_{GA}^2 + \beta_{12} T_{\text{in}} C_{\text{GA}} \quad (1)$$

where Y is the response (dependent variable); β_0 is the constant regression coefficient; β_1, and β_2 are the linear regression coefficients; β_{11}, and β_{22} are the quadratic regression coefficients; β_{12} is the interaction regression coefficients; and T_{in} and C_{GA} are the coded values of variables.

Response surface methodology was used to optimize the microencapsulation of babassu coconut milk in order to obtain maximum process yield and minimum lipid oxidation, water content, and hygroscopicity. The microcapsules obtained under the optimized conditions were characterized for bulk and absolute densities, porosity, wettability, particles size, and morphology.

2.5 Characterization of the microcapsules

Process yield: It was determined as the ratio of mass of total solids in the powder and the mass of total solids in the feed solution.

Moisture content: It was determined gravimetrically using a vacuum oven at 70 °C until sample constant weight. Moisture content of feed solutions was determined using a forced circulation oven (60 °C, 24 hours) and a vacuum oven (70 °C until constant weight) (ASSOCIATION..., 2006). This analysis was performed in quintuplicate.

Hygroscopicity: Quintuplicate samples (approximately 1 g) were placed in a container at 25 °C with a saturated NaCl solution (75.29% relative humidity). The samples were weighed after one week, and the hygroscopicity value was expressed as g adsorbed moisture/100g of dry matter (Cai and Corke (2000), with some modifications).

Water activity (A_w): It was determined in quintuplicate using a Decagon (model Pawkit, Aqualab, USA), at 25 °C.

Peroxide index – Lipid oxidation: The oxidation of microcapsules was monitored by the determination of peroxide index, in triplicate (PARTANEN et al., 2008). The oil fraction was extracted from the powder samples with iso-octane/isopropanol, and it was homogenized with a chloroform/methanol (7:3) mixture, iron chloride, and an ammonium thiocyanate solution. The mixture was incubated for 5 minutes in dark and absorbance was read at 500 nm (spectrophotometer DU-7-B340, Beckman, Krefeld, Germany). The peroxide index was quantified based on a standard curve of several dilutions of hydrogen peroxide and expressed as milliequivalents (meq) of hydroperoxide per kg of oil (BAE; LEE, 2008).

Bulk density (ρ_b)*:* Approximately 2 g of powder were introduced into a 10 mL glass graduated cylinder (readable to 1 mL) and compacted by gently tapping the graduated cylinder on the counter (50 times), in quintuplicate. The ρ_b was calculated by dividing the mass of the powder by the volume occupied in the cylinder.

Absolute density (ρ_a)*:* It was determined at 25 °C using a helium pycnometer (Micromeritics AccuPyc 1330, Norcross, USA). The analysis was performed in triplicate.

Porosity (ε)*:* It was calculated by Equation 2 (KROKIDA; MAROULIS, 1997):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_a}\right) \times 100 \quad (2)$$

Particle size distribution: It was measured using a laser light diffraction system (Mastersizer S, Malvern Instruments, Malvern, UK). A small amount of the powder was suspended in isopropanol, and the particle size distribution was monitored until successive readings became constant; particle size (*D[4,3]*) was expressed as the mean of ten repetitions.

Wettability: About 1 g of the powder samples was sprinkled over the surface of 400 mL of distilled water at 25 °C without agitation. The time it took until the last powder particles submerge was recorded and used for a relative comparison of the extent of wettability between the samples (HLA; HOGEKAMP, 1999). The results were expressed as the mean of eight repetitions.

Particles morphology: The microstructure of the powder particles was evaluated using scanning electron microscopy (SEM). The powders were attached to SEM stubs using a double-sided adhesive tape coated with gold/palladium under vacuum in a sputter coater (model SC7620, VG Microtech, Ringmer, UK) at a coating rate of 0.51A°/s, 3-5 mA, 1 V, and 0.08-0.09 mbar for 180 s. The coated samples were observed in a scanning electron microscope (LEO440i model, Leica Electron Microscopy Ltd., Oxford, England). The SEM was operated at 20 kV and 150 pA with a magnification of 3,000× and 5,000×.

3 Results and discussion

The composition of the babassu coconut milk (in wet basis), obtained according to AOAC (ASSOCIATION..., 2006), was: moisture content of 78.3±0.001 g/100 g, protein of 2.0±0.02 g/100 g, fat of 19.0±0.05 g/100 g, ash content of 0.3±0.0001 g/100 g, total sugar of 3.7±0.3 g/100 g, and reducing sugar of 2.6±0.1 g/100 g; titratable acidity was 0.6±0.1 g/100 g, pH 6.60.2, and total soluble solids 4.1±0.2 °Brix.

3.1 Response surface analysis

Process yield, powder physicochemical properties (moisture content, hygroscopicity and water activity), and lipid oxidation were obtained using 17 combinations of the independent variables: inlet air temperature and gum Arabic concentration, as shown in Table 1.

Table 2 shows the coded regression coefficients for polynomial equations, the respective F and p values, and coefficients of determination R^2. Neglecting the non-significant terms, the resulting equations were tested by analysis of variance. Only the models predicted moisture content, hygroscopicity, and process yield adequately, showing significant regression, low residual values, and lack of fit and satisfactory R^2.

Powder moisture content and hygroscopicity

The moisture contents (Table 1) are lower than 3.5%, value considered standard for powder products (GUERRA; NEVES; PENA, 2005). This could be due to the high T_{in} used in this study (170-220 °C). At higher T_{in}, there is a larger temperature gradient between the atomized feed and the air drying, resulting in a greater heat transfer into the particles and, thus, higher evaporation rate. Laksono and Kumalaningsih (2000) found higher moisture content (4.8 to 5.8%) of coconut milk powder dehydrated by oven drying. However, the moisture contents of the spray-dried products obtained in this study are similar to those obtained by Tonon et al. (2009), Ferrari, Germer and Aguirre (2012) and Enríquez-Fernández, Camarillo-Rojas and Vélez-Ruiz (2013) on studies on spray drying of açai, blackberry and concentrated milk, respectively. Figure 1a shows the response surface generated by the proposed model. According to this figure, C_{GA} was the variable that most influenced powder moisture content. The lowest values were obtained when higher C_{GA} was used. According to Quek, Chok and Swedlund (2007), the addition of gum Arabic in the mixture before spray drying increases the amount of total solids and reduces the amount of water to be evaporated, resulting in a decrease in the powder moisture content.

The hygroscopicity values (Table 1) were lower than those of other spray-dried products such as pequi pulp with Tween 80 and gum Arabic (10.7-14.3 g/100 g), açai pulp with maltodextrin (12.5-15.8 g/100 g), propolis extract with gum Arabic/starch (13.8-29.3 g/100 g), and betacyanin pigments (44.6-49.5 g/100 g) (SANTANA et al., 2013; TONON; BRABET; HUBINGER, 2008; SILVA et al., 2013; CAI; CORKE, 2000), showing the high physical stability of babassu coconut milk powder. As can be seen in Figure 1b, lower hygroscopicity values are obtained at low C_{GA}. Comparing Figures 1a and 1b, it can be observed that hygroscopicity values were inversely proportional to the powder moisture content, i.e., products with lower moisture were more hygroscopic. This same behavior was reported by Tonon, Brabet and Hubinger, (2008) and Ferrari et al. (2012)

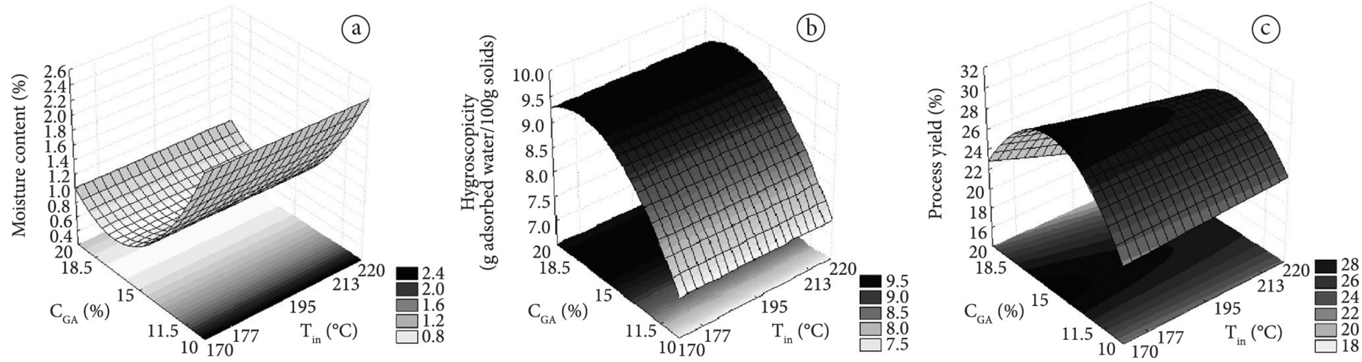

Figure 1. Response surfaces: (a) moisture content, (b) hygroscopicity, and (c) process yield.

Table 1. Experimental design for spray drying of babassu coconut milk.

Test	Independent variables (Coded value)		Dependent variables					
	T_{in} (°C)	C_{GA} (%)	X	H	A_w	Y	LO	T_{out}
1	177 (–1)	11.5 (–1)	1.78±0.03	8.31±0.01	0.23±0.02	25.83	0.022±0.006	130±0.5
2	213 (1)	11.5 (–1)	1.69±0.01	8.37±0.02	0.17±0.04	26.16	0.028±0.013	152±0.5
3	177 (–1)	18.5 (1)	0.52±0.02	8.94±0.01	0.21±0.01	25.00	0.020±0.048	127±0.1
4	213 (1)	18.5 (1)	0.62±0.04	9.86±0.01	0.15±0.01	22.35	0.053±0.006	154±0.3
5	170 (–1.41)	15 (0)	0.92±0.03	9.62±0.01	0.15±0.03	30.19	0.012±0.003	123±0.5
6	220 (1.41)	15 (0)	0.72±0.02	9.46±0.04	0.14±0.02	27.01	0.064±0.043	155±0.1
7	195 (0)	10 (–1.41)	2.39±0.06	6.98±0.01	0.58±0.02	21.67	0.043±0.009	143±0.3
8	195 (0)	20 (1.41)	1.25±0.01	9.45±0.01	0.25±0.03	20.33	0.049±0.028	135±0.2
9	195 (0)	15 (0)	0.85±0.01	9.00±0.01	0.20±0.01	27.82	0.048±0.005	132±0.2
10	195 (0)	15 (0)	0.93±0.01	9.10±0.01	0.20±0.01	28.01	0.047±0.036	127±0.1
11	195 (0)	15 (0)	0.85±0.01	9.06±0.02	0.21±0.02	28.32	0.051±0.009	128±0.4

X = moisture content (%); H = hygroscopicity (g adsorbed water/100g dry matter); A_w = water activity; Y = process yield (%); LO = lipid oxidation (meq peroxide/kg of oil); T_{out} = outlet air temperature (°C).

for spray-dried açai and blackberry, respectively. According to these authors, powders with low moisture content have a great capacity to absorb humidity from the environment, which is related to the high water concentration gradient between the product and the surrounding air.

Process yield

Process yield corresponds to the amount of product recovered. Material loss in a spray-drying system is mostly due to the attachment of powder to the wall of the dryer and to cyclones with poor efficiency (WANG; LANGRISH, 2009). Retention of products in the dryer is undesirable because it is not cost effective and affects product quality; accumulated product subjected to more intense heat treatment may have different properties. Process yield values of spray drying of babassu coconut milk (Table 1) were lower than those of spray drying of açai (34.3-55.7%), oregano essential oil (59.7%), and pequi (29.6-56.1%) (TONON; BRABET; HUBINGER, 2008; BOTREL et al., 2012; SANTANA et al., 2013). Higher values were obtained around the midpoint of the C_{GA} studied range and at low T_{in}. Lower T_{in} resulted in lower T_{out} (Table 1). Consequently, there is a decrease in the temperature difference between T_{out} and glass transition temperature ($\Delta T = T_{out} - T_g$), and the product become less sticky increasing the process yield. A quadratic trend can be seen between C_{GA} and the process yield (Figure 1c), with an increase in the response up to approximately 15%. This fact occurs due to the increase in the powder T_g, which decreases powder stickiness and increases product recovery during spray drying. On the other hand, at C_{GA} above 15%, slight decreases in the process yield are observed, probably due to the increase in feed viscosity, which can cause more solids to paste in the dryer chamber wall, thus reducing the process yield. In addition, the higher the solids content in the mixture, the higher the amount of solids available to be in contact with the chamber wall and to paste in it (TONON; BRABET; HUBINGER, 2008).

Water activity (A_w) and lipid oxidation

Water activity values for all experimental tests ranged from 0.14 to 0.58 (Table 1). Only the result of test 7 is above the limit of 0.30. When A_w is below 0.3, there is a reduction in the reaction rate, and the food product can be considered stable (FENNEMA, 1996), except in terms of lipid oxidation. Since most of the babassu milk spray-dried samples had very low A_w (0.14-0.23), lipid oxidation could occur during storage, leading to the formation of volatile secondary oxidation products. These products are generally considered responsible for the undesirable off-flavour in oxidized products.

Tonon, Grosso and Hubinger (2011) found lipid oxidation values ranging from 0.017 to 0.106 meq peroxide/kg oil for linseed oil drying encapsulated with gum Arabic, which were very similar to those of babassu coconut milk powder (Table 1). This response was influenced only by positive linear term T_{in}, indicating that at the highest T_{in}, higher values of lipid oxidation of powders were obtained (Table 2). The use of higher T_{in} supplies more available energy for lipid oxidation, which occurs more intensely, favoring the formation of peroxide (TONON; GROSSO; HUBINGER, 2011). Since R^2 of the adjusted models for water activity responses and lipid oxidation were very low (Table 2), the predictive models and their respective response surfaces were not obtained.

3.2 Characterization of the spray-dried babassu coconut milk obtained under the optimum condition

Optimization of the spray drying of babassu coconut milk was carried out to obtain the maximum values of process yield and minimum lipid oxidation. Analyzing Figure 1 and Table 2, the values T_{in} 170 °C and C_{GA} 15% can be recommended as the optimized condition. The babassu coconut milk obtained under the optimized condition was characterized for bulk and absolute density, porosity, wettability, particle size, and morphology.

Bulk density, absolute density, and porosity

The knowledge of product density is important since it indicates the weight of a material in a given volume. Low bulk density of a product results in a bulk package, and therefore it is not desirable. In addition, there is a greater amount of air between the microcapsules and a greater possibility of food undergo oxidation decreasing its stability (BARBOSA-CÁNOVAS; JULIANO, 2005). The bulk density of spray-dried babassu milk was 0.39±0.003 g/mL. This value was similar to that of the microcapsules of vegetable oil (TURCHIULI, 2005), oregano essential oil (BOTREL et al., 2012), rosemary essential oil (FERNANDES; BORGES; BOTREL, 2013), and soy milk powder (JINAPONG; SUPHANTHARIKA; JAMNONG, 2008). On the other hand, higher values of bulk density (0.46-0.56 g/mL) were obtained for spray-dried milk (ENRÍQUEZ-FERNÁNDEZ; CAMARILLO-ROJAS; VÉLEZ-RUIZ, 2013). Absolute density corresponds to the real solid density and does not consider the spaces between the particles, in contrast to the bulk density, which takes into account all of these spaces. The absolute density of babassu coconut milk powder was 1.16±0.01 g/mL. Similar values were obtained by Ferrari et al. (2012) and Santana et al. (2013).

Another property of fundamental importance in food processing operations is porosity. It plays an important role in the reconstitution of dry products and control of the rehydration rate (KROKIDA; ZOGZAS; MAROULIS, 1997). Moreover, powders with lower porosity have fewer amounts of empty spaces between particles, preventing the oxidation of pigments and, consequently, increasing powder stability. The porosity of babassu coconut milk powder was calculated as 66%.

Wettability and particle size

Wettability can be defined as the ability of a powder bulk to be penetrated by a liquid due to capillary forces (HOGEKAMP; SCHUBERT, 2003). It is inversed related to the particle size because larger particles show more spaces between them, being more easily penetrated by water. A particulate system with small particles is less porous and, thus, the liquid penetration into this system is more difficult resulting in poor reconstitution properties. The wettability of babassu coconut milk powder was 12.2 minutes. Jinapong, Suphantharika and Jamnong (2008). Based on the properties of spray-dried soybean milk, it was verified that the wetting time was very much smaller (1-5 minutes) than that of babassu milk powder. Therefore, since the microcapsules of babassu milk showed a very high wettability time, this product had bad reconstitution property. Powders with good reconstitution property have wetting time of few seconds.

According to Gong et al. (2007), spray-dried powders often have a small particle size (<50 μm) with poor handling and reconstitution properties. Figure 2 shows the particle

Table 2. Regression coefficients for experimental design responses.

Coefficients	Moisture	Hygroscopicity	A_w	Yield	Lipid oxidation
β_0	0.88	9.05	0.20	28.05	0.05
β_1	ns	ns	ns	−1.63	0.03
β_{11}	ns	ns	ns	ns	ns
β_2	−0.99	1.40	ns	−1.56	ns
β_{22}	0.86	−0.84	0.17	−7.07	ns
β_{12}	ns	ns	ns	−1.64	ns
R^2	0.95	0.84	0.61	0.98	0.58
F_c	70.39	21.57	6.38	68.74	12.43
F_t	3.11	3.11	3.11	3.18	3.36
p-value	<0.001	0.001	0.020	<0.001	0.010

ns: Non-significant (p>0.10); R^2: coefficient of determination; F_c, F_t: calculated and tabulated F values (p≤0.10).

size distribution of babassu coconut milk powder. A bimodal distribution was observed, indicating two predominant sizes: one with lower volume (<1%) and smaller particle diameters (0.3-0.5 μm); and another with larger volume (7-8%) and particle size (1-400 μm). According to Tonon et al. (2009), in a particulate system with bimodal distribution, the smaller particles can penetrate into the spaces between the larger ones and occupy less space. The presence of larger particles may be attributed to the beginning of the agglomeration process. The mean diameter *D[4,3]* was 10.7±0.2 μm.

3.3 Scanning electron microscopy

The morphological characteristics of the spray dried babassu coconut milk powders are shown in Figure 3. In general, spherical particles and absence of cavities are observed, which indicate the formation of a continuous film on the outer wall of the microparticles and may suggest higher encapsulation efficiency. This is an advantage since it implies that the capsules have lower permeability to gases, increasing the protection and retention of the active material (CARNEIRO et al., 2013).

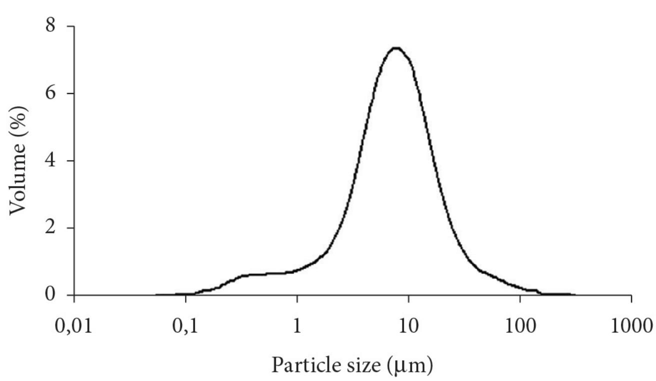

Figure 2. Particle size distribution of spray-dried babassu coconut milk powders produced at inlet air temperature of 170 °C and with 15% gum Arabic.

According to Figure 3, it was observed the presence of particles of irregular shapes and different sizes, while the smaller particles adhere to the surfaces of larger ones. Barbosa-Canovas, Rufner and Peleg (2005) define these particle types as "partially random mixture", and they are characterized by the partial interaction between particles of different sizes. According to Cano-Chauca et al. (2005), adhesion of smaller particles around the larger ones indicates the absence of crystalline surfaces, which is an amorphous compound characteristic. The presence of these amorphous surfaces implies high solubility of the powder in water (CANO-CHAUCA et al., 2005; YU, 2001) and higher dissolution rate as compared to compounds in crystalline state (YU, 2001).

4 Conclusions

Independent variables (inlet air temperature in the dryer and gum Arabic concentration) influenced significantly ($p<0.1$) the moisture content, hygroscopicity, and yield of the process. The T_{in} of 170 °C and C_{AG} of 15% can be recommended as the optimized condition to obtain a powder product with maximum process yield and minimum lipid oxidation. The particle size distribution presented a bimodal behavior. As for morphology, the samples exhibited a large number of regular and spherical particles. The results obtained in this study indicate that high quality powders with low moisture content, hygroscopicity, and lipid oxidation can be produced by spray drying. The obtained products can be used as novel and inexpensive food sources of natural flavorings in the production of dry mixes, beverages, desserts, and other products.

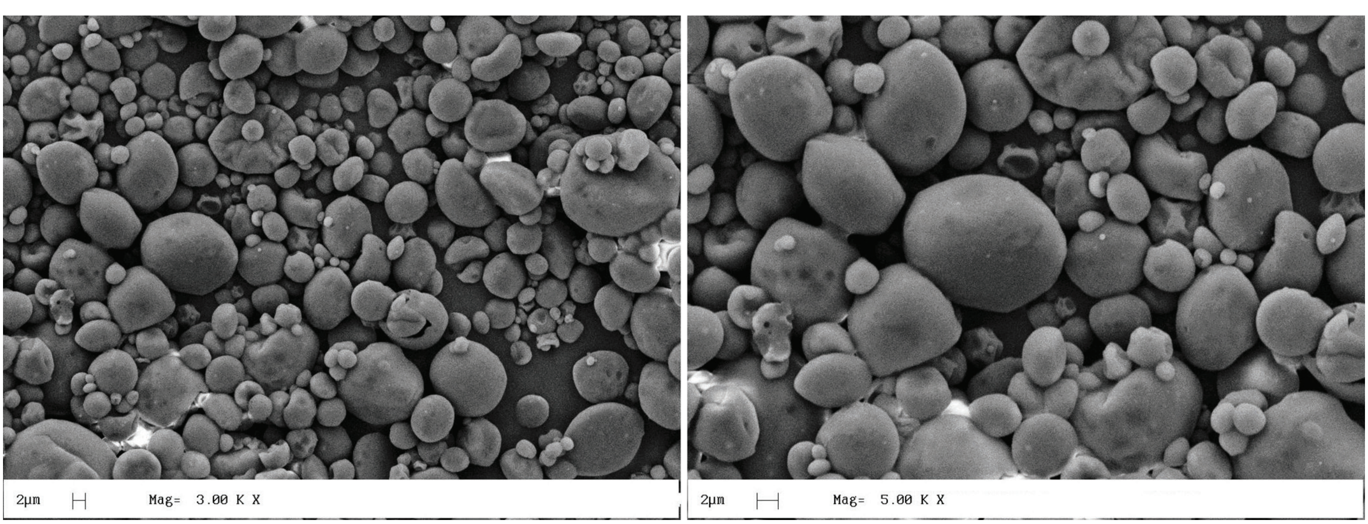

Figure 3. Micrographs of spray-dried babassu coconut milk formulated with 15% Arabic gum. Images with magnifications of 3,000× (left figure) and 5,000× (right figure).

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