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Freeze-dried bacuri pulp powder: the effect of adjuvants[1]

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ABSTRACT - The aim of this study was to evaluate the effect of the drying adjuvants maltodextrin, gum Arabic and albumin on the physical and physicochemical characteristics of freeze-dried bacuri pulp powder. The adjuvants were added to the pulp at a concentration of 20% (w/w), giving three samples that were dehydrated in a freeze-dryer. The samples were analysed for moisture content, colour using the CIELab scale, phenolic compounds, hygroscopicity, particle morphology and density. The fluidity of the powders was evaluated using the Carr index and Hausner ratio. The moisture ranged from 2.33% to 2.76%, the powder containing albumin having the lowest moisture content ($p < 0.05$). A difference ($p < 0.05$) was seen in the colour parameters of the samples, except for luminosity in the samples containing maltodextrin or albumin. The level of phenolic compounds ranged from 183.22 to 386.90 mg GAE/100 g of solids, with the sample containing albumin again showing the lowest value ($p < 0.05$). The hygroscopicity of the powders ranged from 6.22% to 6.92%, the densities ranged from 287.9 to 433.1 kg/m³, and the wall friction angle from 12.2° to 13.55°. The Carr index and Hausner ratio varied from 23.21% to 25.80% and 1.30 to 1.34, respectively. The bacuri pulp powder was classified as having acceptable fluidity regardless of the adjuvant; however, the adjuvants had an effect on particle morphology and on the composition of the powder.

Key words: Maltodextrin. GumArabic. Albumin. Amazon.

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INTRODUCTION

Due to the diversity and potential of fruits from the Amazon, together with the attention given to exotic tropical fruit, their prospective commercialisation and industrial use is important. From the northeast of the Amazon to the state of Piauí, one fruit species has shown growth both on the market and in the production systems of local communities: *Platonia insignis* Mart., popularly known as 'bacuri' (LUSTOSA *et al*., 2016). As it is a regional fruit, with a lack of incentives for its agricultural production and a lack of innovative technological solutions for its exploitation, only a portion of the Brazilian population knows about and consumes bacuri.

The development of bacuri pulp powder can promote its consumption in the different regions of Brazil as either reconstituted juice or an ingredient, and is an effective way of guaranteeing supply of the product despite its being both regional and seasonal.

Drying technologies are important for reducing the moisture content of foods as well as extending their shelf life. Among these technologies, freeze-drying is the most suitable for bacuri, as the fruit is viscous and rich in fibre, which makes it difficult to dry using other equipment such as a spray-dryer (SABAREZ, 2021).

Considering that most fruit pulps have high levels of sugar, the addition of adjuvants during the drying process is considered essential for producing a less hygroscopic powder of better fluidity. These drying agents form a thin layer on the surface of the dry particles, protecting the food components from oxygen, light and moisture, preventing chemical and enzyme reactions, and contributing to the fluidity of the powdered product, as well as its storage (TONON; BRABET; HUBINGER, 2009).

The study and evaluation of fruit powders allows a better understanding of their characteristics. The aim of this study was therefore to evaluate the effect of the drying adjuvants maltodextrin, gum Arabic and albumin on the physical and physicochemical characteristics of freeze-dried bacuri pulp powder.

MATERIAL AND METHODS

Preparing and drying the samples

The bacuri pulp was purchased from a fruit processing company in the north of the state of Piauí and stored in the refrigeration laboratory of the Federal University of Ceará in a vertical freezer at -18 °C. Before the drying process, the pulp was thawed and the drying adjuvants maltodextrin, gum Arabic and albumin added at a ratio of 20% (m/m) to give three different samples. The samples were then homogenised using the Mondial Versatile Black Blender with a power of 200 W.

The samples were frozen at -38 °C for 24 hours in the CL90-40V ultra-low-temperature freezer (Terroni). After freezing, the samples were transferred to the LS 3000 freeze-dryer (Terroni), where they remained for 24 hours, reaching a final pressure of between 20 and 30 Pa. After drying, the samples were ground in a blender for one minute. The drying process was carried out twice for each sample. The physical and physicochemical analyses were carried out in triplicate.

Physicochemical analysis

The moisture content of the powdered samples of freeze-dried bacuri pulp was determined as per the Instituto Adolfo Lutz (2008); the colour was evaluated based on the CIELab scale, with the L*, a* and b* parameters determined using the CR410 colorimetric spectrophotometer (Konica Minolta). The level of phenolic compounds was determined based on Larrauri, Rupérez and Saura-Calixto (1997), and the hygroscopicity as per Goula and Adamopoulos (2008).

Physical analysis

The particles of each powder were evaluated from micrographs obtained using the Quanta FEG 540 scanning electron microscope (FEI). The powder samples were deposited on double-sided adhesive tape and affixed to a metal support. The metal plate with the powders was then covered in platinum and gold using a model Q1550TES coater (Quorum), and micrographs were captured at a resolution of 500x and 2000x.

To evaluate powder flow in the samples, the wall friction angle and the apparent and compaction densities were determined. These parameters were obtained using the Powder Flow Test equipment from Brookfield Engineering Laboratories. From the densities, the Carr index (Equation 1) and the Hausner relationship (Equation 2) were determined. The samples were then classified according to their fluidity (Table 1) as per Aziz *et al*. (2018).

$$CI = \frac{\propto_c - \propto_a}{\propto_c} \times 100 \quad (1)$$

$$HR = \frac{\propto_c}{\propto_a} \quad (2)$$

where:

CI - Carr index (%)

HR - Hausner ratio

α_c - compaction density (kg/m³)

α_a - apparent density (kg/m³)

Analysis of Variance (ANOVA) and Tukey's test were used to analyse the results considering a confidence interval of 95% ($p < 0.05$).

Table 1 - Classification of powder fluidity (AZIZ *et al*., 2018)

Fluidity	Carr index (%)	Hausner Ratio
Excellent	< 10	1.00-1.11
Good	11-15	1.12-1.18
Moderate	16-20	1.19-1.25
Acceptable	21-25	1.26-1.34
Difficult	26-31	1.35-1.45
Very difficult	32-37	1.46-1.59
Overly difficult	> 38	> 1.60

RESULTS AND DISCUSSION

The results for the moisture, phenolic compounds and hygroscopicity of the powder samples are shown in Table 2. To be considered a microbiologically safe food, a powdered product must contain up to 5% moisture; in the case of powders, low humidity influences their fluidity and stability in addition to making the powder less sticky (FAZAELI *et al*., 2012).

The moisture content of the samples varied from 2.33% to 2.76%, with the powder containing albumin having the lowest value, and differing from the other powders ($p < 0.05$). Kandasamy *et al*. (2019) found moisture levels between 4.36% and 6.38% in papaya powder containing 15% (m/m) albumin, while Krumreich *et al.* (2016) obtained values of 6.03% and 7.18% moisture in freeze-dried uvaia (Eugenia pyriformis) powder containing 10% (m/m) maltodrextrin and gum Arabic, respectively. The moisture content of the powders can vary due to the type of fruit and type and concentration of the adjuvant, in addition to the drying conditions.

For colour (Table 2), only the sample containing gum Arabic differed from the other samples ($p < 0.05$) in the L* coordinate (luminosity,) presenting the lowest value. The colour parameter is usually decisive in consumer purchasing, with the adjuvants favouring luminosity in the bacuri pulp powder. Krumreich *et al.* (2016) found that uvaia powder became lighter with the addition of maltodextrin and gum Arabic, increasing the L* value from 89.19 to 101.66 and 94.88, respectively, in relation to the pulp.

Each of the samples differed ($p < 0.05$) in green and red (a*), and blue and yellow (b*) chromaticity. The a* coordinate showed mostly negative results (Table 2), with a predominance of green, whereas Sample 2 showed a positive value, indicative of a reddish colour. In the b* coordinate, yellow was more predominant.

The levels of phenolic compounds varied (Table 2), with the sample containing albumin presenting the lowest value and differing ($p < 0.05$) from the others. The adjuvants maltodextrin and gum Arabic were better able to preserve bioactive compounds in the bacuri pulp powder. Asquieri *et al*. (2020), evaluating the effect of maltodextrin, aerosil and starch on the retention of phenolic compounds in yacon root powder, found that maltodxtrin and starch helped preserve these compounds. For Espinoza, Martínez and Navarrete (2021), the phenolic compounds in freeze-dried orange powder were better preserved by gum Arabic, with values of 703.02 mg GAE/100 g of solids. Kuck and Noreña, (2016), when encapsulating the phenolic extract of grape skin with gum Arabic, polydextrose and guar gum, obtained the highest value for phenolic compounds in the sample containing gum Arabic (250.3 mg GAE/ 100 g of solids). Asquieri *et al*. (2020) state that an increase in adjuvant, as well as milder temperatures during drying, helps to retain more phenolic compounds in the powder.

Bacuri pulp powder showed low hygroscopicity, with values less than 7% (Table 2). The sample containing maltodextrin had the lowest hygroscopicity and differed ($p < 0.05$) from that containing albumin. A similar result to that found by Alves, Afonso and Costa (2020), who studied the effect of different adjuvants on the hygroscopicity of dragon fruit powder and found the lowest values in samples containing maltodextrin (6.83%). Maciel *et al*. (2020b) found that an increase in the concentration of maltodextrin in cupuassu powder resulted in a reduction in hygroscopicity that ranged from 3.89% to 4.09%. According to Alves, Afonso and Costa (2020), differences in hygroscopicity can be explained by the type and concentration of adjuvant used and by the characteristics of the powder itself, such as the moisture and sugar content. Fernandes *et al*. (2014) found that in tomato powder with added albumin the presence of adjuvants reduces the action of the sugars and organic acids responsible for absorbing moisture.

Table 2 - Mean values for the physicochemical characterisation of freeze-dried bacuri pulp powder containing 20% (m/m) maltodextrin, gum Arabic or albumin

Analysis		Powder samples containing adjuvant[1]		
		maltodextrin	gum Arabic	albumin
Moisture (%)		2.76 ± 0.11 a	2.58 ± 0.07 a	2.33 ± 0.12 b
Colour	L*	77.83 ± 0.25 a	67.77 ± 5.0 b	74.14 ± 0.10 a
	a*	-1.21 ± 0.01 c	0.50 ± 0.14 a	-1.03 ± 0.07 b
	b*	8.18 ± 0.24 c	10.49 ± 0.14 b	20.02 ± 0.11 a
Phenolic compounds (mg AGE/100 g solids)		386.90 ± 19.17 a	377.18 ± 19.30 a	183.22 ± 26.85 b
Hygroscopicity (%)		6.22 ± 0.24 b	6.79 ± 0.37 ab	6.92 ± 0.23 a

[1]containing 20% (m/m); mean values followed by the same letters on the same line do not differ by Tukey's test at 5% probability

The micrographs of the powders containing 20% (m/m) drying adjuvant are shown in Figure 1. In general, the three samples showed non-spherical and irregular shapes. The same behaviour was found by Kuck and Noreña (2016) when evaluating the effect of spray drying and freeze-drying on the particles of grape skin extract. The same authors reported that with spray drying the powder presented spherical particles with surface concavities, while in the freeze-dried powders the particles were irregular, porous and brittle, similar to those in Figure 1.

It was found that powder containing gum Arabic (Figure 1C and D) has smaller particles compared to samples containing maltodextrin (Figure 1A and B) or albumin (Figure 1E and F). In the sample containing maltodextrin (Figure 1A and B), more agglomerated particles with sharper edges can be seen compared to the samples containing gum Arabic or albumin, where the shape is more curved. Shaaruddin *et al.* (2017) report that particle agglomeration is typical of polysaccharide-rich powder. The sample containing gum arabic (Figure 1C and D) showed more dispersed particles, therefore fewer agglomerates.

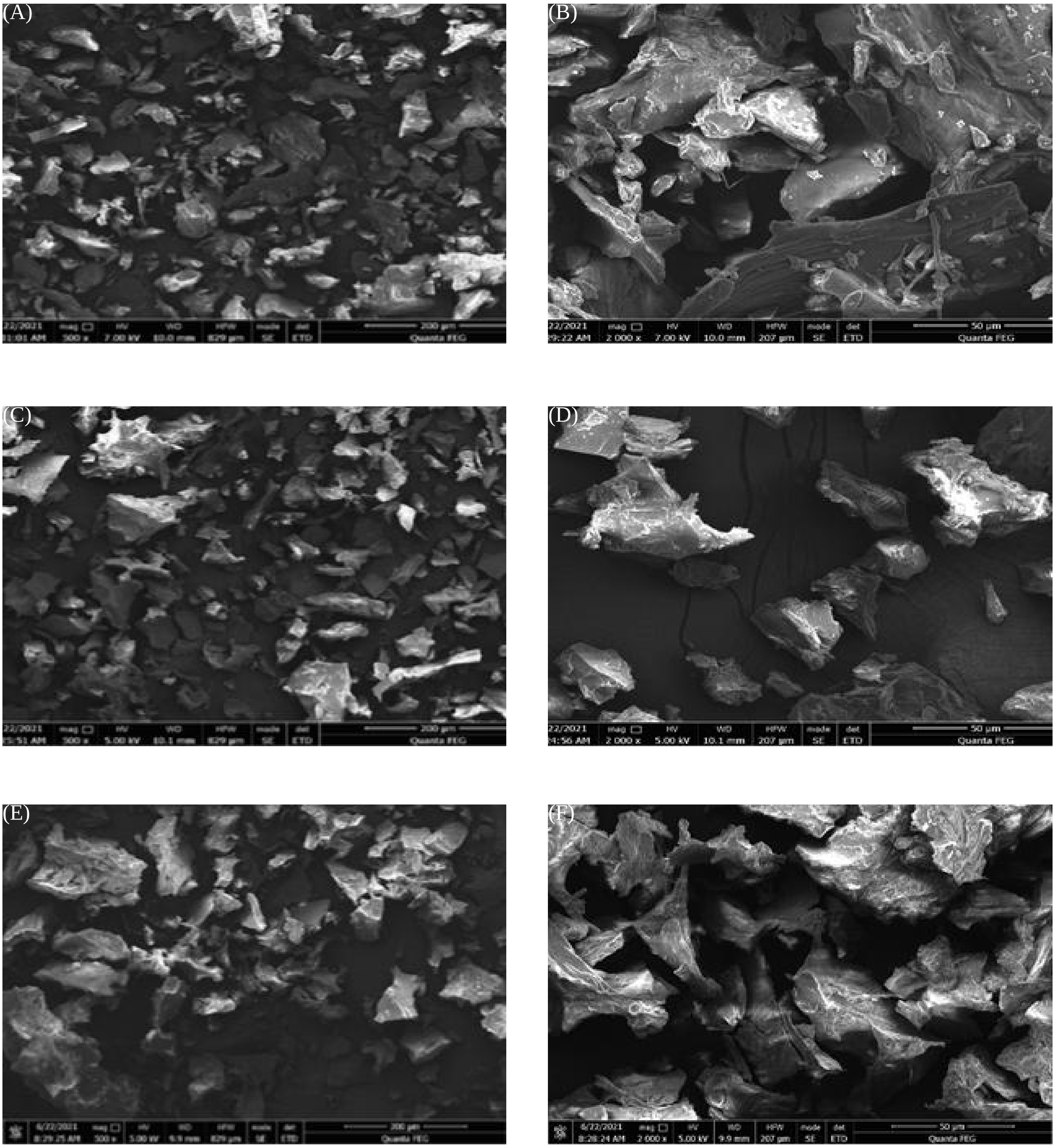
Note that the particles (Figure 1) have indentations or pores, typical of freeze-dried products. Araújo *et al*. (2020), and Melo, Cavalcante and Amante (2020) reported the presence of pores when evaluating the morphology of coconut powder containing maltodextrin and of red araçá powder, respectively. For Ezhilarasi *et al.* (2013), the porous structure of freeze-dried products is directly related to sublimation of the ice during the drying process. The particles of red araçá powder (MELO; CAVALCANTE; AMANTE, 2020) were larger and had rougher surfaces than those in this study, which can be explained by the lack of drying adjuvants. The size and shape of the particles affect the flow behaviour of the powders. The more symmetrical the particles, the better their fluidity; on the other hand, irregular shapes and sharp edges result in a less fluid powder. Fruit-based powders mostly tend to have asymmetric shapes, as they generally contain large amounts of fibre and sugars among other constituents, which enables powders with more complex and agglomerated particles to be formed (ZEA *et al*., 2013).

Table 3 shows values for density (kg/m³) in the samples of bacuri pulp powder. The sample containing maltodextrin, although not statistically different from the other samples shows higher densities. According to Tkacz *et al*. (2020), the differences in density can be explained by the polymeric interactions between the adjuvant and the carbohydrates in the fruit. Rocha *et al* (2017) found differences in the density of mango powder as a function of the addition of adjuvants due to changes in the shapes and surfaces of the particles. Ribeiro, Costa and Afonso (2020) determined apparent densities between 304.4 and 366.9 kg/m³ and compaction densities between 418.2 and 493.4 kg/m³ when evaluating cocoa powder containing 15% and 30% maltodextrin, and reported that increasing the concentration of the adjuvant resulted in higher densities.

According to Campos and Ferreira (2013), increases in the density of a powder is the result of applied tension, where powders that show a greater difference between the apparent and compaction density show less fluidity and greater particle cohesion. It was found that the sample containing albumin presented the smallest difference in compaction density, 87.1 kg/m³, while the sample containing maltodextrin presented the greatest difference, 116.6 kg/m³.

The values for friction angle in the three samples (Table 3) were close, with no difference between them. The smaller the angle, the more easily the powder will flow (DORNELAS *et al*., 2021). Afonso *et al*. (2019), observed maximum values for the wall friction angle ranging from 18.9° to 23.9° in mango powders with different concentrations of maltodextrin, where increasing the concentration of the adjuvant reduced the angle. Maciel *et al*. (2020a) report that increasing the concentration of albumin in guava powder reduced the wall friction angle, reporting values of 20.4° and 13.6° for the maximum and minimum values, respectively. The wall friction angle represents the resistance between the powder and the wall of the storage environment, where the greater the angle, the more difficult it will be for the dust to flow along the wall (FITZPATRICK *et al*., 2004).

Figure 1 - Micrographs of particles of freeze-dried bacuri pulp powder containing 20% (w/w): maltodextrin 2000x (A) and 500x (B); gum Arabic 2000x (C) and 500x (D); albumin 2000x (E) and 500x (F)



¹containing 20% (m/m); mean values followed by the same letters on the same line do not differ by Tukey's test at 5% probability

Table 3 - Density, wall friction angle, CI and HR in freeze-dried bacuri pulp powder containing 20% (m/m) maltodextrin, gum Arabic or albumin

Analysis		Powder samples containing adjuvant[1]		
		maltodextrin	gum Arabic	albumin
Density (kg/m^3)	apparent	321.5 ± 19.3a	301.2 ± 10.5a	287.9 ± 35.9a
	compaction	433.1 ± 14.8a	392.2 ± 1.13a	375.0 ± 22.1b
Wall friction angle (°)	minimum	12.20 ± 1.41a	12.55 ± 0.21a	12.70 ± 0.28a
	maximum	12.60 ± 0.85a	13.00 ± 0.57a	13.55 ± 0.92a
Carr Index (%)		25.80 ± 1.37a	23.21 ± 1.74a	23.37 ± 3.58a
Hausner Ratio		1.34 ± 0.025a	1.30 ± 0.030a	1.31 ± 0.060a

[1]containing 20% (m/m); mean values followed by the same letters on the same line do not differ by Tukey's test at 5% probability

The Carr index and the Hausner ratio are two parameters used in the food industry to evaluate and compare the fluidity and compressibility of a product, as well as whether the food will require mechanical force to move it in silos or in other equipment during processing (AZIZ *et al*., 2018).

Based on the values for the Carr index (CI) and Hausner ratio (HR) shown in Table 3, the powders under analysis are classified as having acceptable fluidity according to Table 1. Alves, Afonso and Costa (2020) evaluated freeze-dried dragon fruit powder containing maltodextrin, and obtained a CI of 22.6%, classifying the powder as having acceptable fluidity. In the study by Zea *et al*. (2013) on guava powder containing 10% maltodextrin, the CI and HR values were 27.2% and 1.37, respectively. For dragon fruit powder containing 10% maltodextrin, the same authors found a CI of 34.9% and HR of 1.53. According to Aziz *et al*. (2018), in addition to the drying method, the type of adjuvant and its concentration will influence the fluidity of the powders.

Bhusari, Muzzafar and Kumar (2014) found CI values between 19.34% and 34.16%, and HR values between 1.27 and 1.52 for tamarind powder with added maltodextrin, gum Arabic and whey-protein concentrate. The authors concluded that in addition to the type of adjuvant, increasing the moisture content of the powder increases cohesion between the particles, making it difficult for the powder to flow. In the present study, it was found that the sample containing maltodextrin presented the highest moisture content among the samples, with the highest CI and HR values (Table 3) and, therefore, showed greater difficulty in flowing. The Wan der Waals forces and electrostatic forces are also factors that hamper the fluidity of powders. Electrostatic forces often cause cohesion in powders and the initial formation of agglomerates; however, the Wan der Waals forces are almost four times greater than are the electrostatic forces. This effect generally occurs when moisture is adsorbed by the particles, the small amount of moisture being responsible for the cohesion of slightly moist powders (AZIZ *et al*., 2018).

CONCLUSIONS

1. The type of drying adjuvant affects the physical-chemical characteristics and morphology of bacuri pulp powder;
2. Maltodextrin and gum Arabic were the best adjuvants for maintaining the phenolic compounds in bacuri pulp, whereas albumin resulted in a powder with a lower moisture content;
3. The bacuri pulp powders were classified as having acceptable fluidity regardless of the adjuvant used.

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