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Drying of butiá pulp by the foam-layer method and characterization of the obtained powder

Abstract – The objective of this work was to develop a drying process using the foam-layer method to obtain the powder from butiá (*Butia* spp.) pulp, as well as to characterize this powder according to its yield and physicochemical and technological characteristics. The foam was optimized for density and stability by varying whipping times and albumin and xanthan gum concentrations. Foam drying was optimized for vitamin C retention and yield using different foam thicknesses and drying temperatures. The optimized foam showed a density of 0.25 g cm^{-3} and a high stability, being suitable for subsequent drying. The lowest foam thickness (0.50 cm) and the highest drying temperature (80°C) resulted in the highest retention of vitamin C, whereas the increase in drying temperature improved yield. The butiá pulp powder obtained under the optimized condition presented an acid pH of 3.25, a low humidity of 7.97%, a water activity of 0.206, a water retention capacity of 4.90 g H_2O per gram of powder, a solubility of 74.40%, a soluble solids content of 61°Brix, and a predominantly yellow color. The foam-layer drying method can be used to obtain butiá pulp powder.

Index terms: *Butia*, albumin, density, stability, whipping times, xanthan gum.

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Secagem da polpa de butiá pelo método de camada de espuma e caracterização do pó obtido

Resumo – O objetivo deste trabalho foi desenvolver um processo de secagem, com o método de camada de espuma, para obter o pó da polpa de butiá (*Butia* spp.), bem como caracterizar esse pó de acordo sua produtividade e características físico-químicas e tecnológicas. A espuma foi otimizada quanto à sua densidade e estabilidade, tendo-se variado os tempos de batimento e as concentrações de albumina e goma xantana. Já a secagem da espuma foi otimizada em relação à retenção de vitamina C e à produtividade, com uso de diferentes espessuras da camada de espuma e temperaturas de secagem. A espuma otimizada apresentou densidade de 0,25 g cm^{-3} e alta estabilidade, sendo adequada para posterior secagem. A menor espessura de espuma (0,50 cm) e a maior temperatura de secagem (80°C) resultaram na maior retenção de vitamina C, enquanto o aumento da temperatura de secagem melhorou a produtividade. O pó de polpa de butiá obtido na condição otimizada apresentou pH ácido de 3,25, baixa umidade de 7,97%, atividade de água de 0,206, capacidade de retenção de água de 4,90 g de H_2O por grama de pó, solubilidade de 74,40%, teor de sólidos solúveis de 61°Brix e cor predominantemente com tonalidade amarela. O método de secagem por camada de espuma pode ser utilizado para obter o pó de polpa de butiá.

Termos para indexação: *Butia*, albumina, densidade, estabilidade, tempo de batimento, goma xantana.

Introduction

Butiá (*Butia* spp.) is the fruit of a palm tree of the genus Butia, of the Arecaceae family, which occurs naturally in South America and is on the list of endangered species in Brazil, where it shows potential for income generation (Hoffmann et al., 2014). The pulp of this fruit is rich in bioactive compounds with antioxidant activity, such as *β*-carotene and vitamin E, and has a high concentration of vitamin C (Barbosa et al., 2021). However, the widespread consumption of the fresh fruit is hindered by its high acidity, fibrous texture, and low sugar content, requiring processing to enhance its quality for a higher consumer acceptance and, consequently, to improve its shelf life throughout the year, which is important since this is a highly perishable seasonal fruit (Hoffmann et al., 2017).

Different methods, such as pasteurization (Hoffmann et al., 2017) and hot-air drying and microwave radiation (Ferrão et al., 2017; Macedo et al., 2020), have been used in recent studies for the preservation of fruit properties. However, further scientific efforts are necessary to find a technology for enhancing fruit shelf-life that is cheaper and easier to use, especially since most of the processing in Brazil is currently carried out by small farmers (Büttow et al., 2009).

The foam-layer drying method is a simple and accessible process, with lower equipment costs than the other methods (de Cól et al., 2021). The quality of the final product is affected by the additives used for foam formation, whipping time, drying temperature, and foam-layer thickness, which shows the importance of determining the ideal conditions for the entire process (Reis et al., 2021). Up to date, there are no known scientific studies on the drying of butiá pulp using this method.

The objective of this work was to develop a drying process using the foam-layer method to obtain the powder from butiá pulp, as well as to characterize this powder according to its yield and physicochemical and technological characteristics.

Materials and Methods

The butiá fruits used in the study were harvested in January 2021 in Vale do Taquari, a region of the state of Rio Grande do Sul, Brazil (29º28'01"S, 51º57'41"W, at 21 m of altitude). Clusters of three palm trees were collected when most of the fruits showed a yellow-orange color. When the fruits were considered mature, i.e., detached from the bunch after a light manual pressure, they were selected for sanity and integrity, sanitized, and stored at -18ºC. To obtain the pulp, the fruits were thawed under refrigeration and pulped using the DPT-75 pulp extractor, with a 1.0-mm sieve (Tomasi, Caxias do Sul, RS, Brazil); the pulp was kept at -18°C until use.

To produce the foam, the pulp was thawed under refrigeration and heated in a water bath, at 40°C, until reaching a temperature of 23°C. Albumin (Naturovos, Salvador do Sul, RS, Brazil) and xanthan gum (Foco Alternativo, Santa Cruz do Sul, RS, Brazil) were mixed into the pulp, and, then, the mixture was stirred using the 12-speed Oster Power 750 W household mixer (Newell Brands, Atlanta, GA, USA), at full speed, as described by Pandith & Srivastava (2018).

To evaluate the effect of different albumin (2.0 to 10% w/w) and xanthan gum (0 to 0.5% w/w) concentrations, as well as of whipping times (10 to 20 min), on foam density and stability, 19 assays were performed using a complete 2^3 factorial design (Table 1). Density was calculated by the ratio between foam weight and volume (Ratti & Kudra, 2006). Foam stability was determined by measuring the liquid drained from a 15 g foam sample – placed in a filter paper over a glass funnel – after 120 min at room temperature (Raharitsifa et al., 2006); the greater the amount of liquid drained, the less stable the foam.

Optimal foaming conditions were obtained using a full factorial design through the response surface methodology (RSM) (Pandith & Srivastava, 2018). The following equation was fitted to the experimental data of density and stability (means of triplicates): $Y_i = X_0 + X_1G + X_2A + X_3T + X_{11}G^2 + X_{22}A^2 + X_{33}T^2 + X_{12}G\times A + X_{13}G\times T + X_{23}A\times T$, where Y_i is the predicted response (Y_1 is density and Y_2 is stability); X_0 is the independent value; X_1, X_2, and X_3 are the linear coefficients; X_{11}, X_{22}, and X_{33} are the squared coefficients; X_{12}, X_{13}, and X_{23} are the interaction coefficients; G is xanthan gum; A is albumin; and T is whipping time.

For the drying process, the foams were placed in a single layer in 16x12 cm stainless steel trays and then dried in the SL-101 and SL 100 static-air ovens (Solab: Equipamentos para Laboratórios, Piracicaba, SP, Brazil). The mass of the samples was recorded every

30 min until no weight changes were detected in three subsequent weighing.

To evaluate the effect of different temperatures (60–80°C) and foam-layer thicknesses (0.50–1.50 cm) on vitamin C retention and yield, 11 assays were carried out in a full 2^2 factorial design (Table 2). Each drying assay was performed in a duplicate of two independent experiments, consisting of two trays with the same foam-layer thickness at the same temperature. Vitamin C content was determined by titration with sodium 2,6-dichloroindophenolate salt (Sigma-Aldrich, São Paulo, SP, Brazil) using method 967.21 of Official Methods of Analysis of AOAC International (Horwitz, 1980). Yield was calculated as the ratio between the dry material weight and time required for a complete drying, in grams per hour (Anesiadis et al., 2008).

To obtain the optimized drying conditions, the RSM was used (Pandith & Srivastava, 2018). For this, the following equation was fitted to the experimental data of vitamin C and yield: $Y_i = X_0 + X_1T + X_2E + X_{11}T^2 + X_{22}E^2 + X_{12}T\times E$, where Y_i is the predicted response (Y_1 is vitamin C and Y_2 is yield), X_0 is the independent value, X_1 and X_2 are the linear coefficients, X_{11} and X_{22} are the quadratic coefficients, X_{12} is the interaction coefficient, T is temperature, and E is foam-layer thickness.

For the characterization of butiá powder, humidity was measured by keeping 3.0 g of the sample, at 105ºC, in a static-air oven until reaching a constant mass (Horwitz, 1980), with results expressed in grams of water per 100 g of sample, on a wet basis. Water activity was determined using the LabSwift-aw water activity meter (Novasina AG, Lachen, Switzerland) at room temperature. The pH and total soluble solids (°Brix) of the pulp, foam, and powder were also obtained. Briefly, 5.0 g of the samples were diluted in 50 mL of distilled water and filtered through an 80 g m^{-2} filter paper, and, then, the pH and total soluble solids were measured, respectively, using the P1000 benchtop pHmeter (PHOX Suprimentos Científicos, Colombo, PR, Brazil) and the 32ATC portable refractometer (Homis do Brasil: Equipamentos Industriais Ltda, São

Table 1. Real and coded values[(1)] for the concentration of xanthan gum and albumin, as well as for whipping time, in the 2^3 factorial experiment, affecting the results obtained for butiá (*Butia* spp.) foam density and stability.

Assay[(2)]	Xanthan gum (% w/w)	Albumin (%)	Whipping time (min)	Density[(3)] (g mL^{-1})	Stability[(3)] (g of liquid drained in 120 min)
1	0.1 (-1)	3.6 (-1)	12 (-1)	0.56±0.02	0.62±0.04
2	0.4 (+1)	3.6 (-1)	12 (-1)	0.58±0.01	0.18±0.15
3	0.1 (-1)	8.4 (+1)	12 (-1)	0.22±0.01	0.00±0.00
4	0.4 (+1)	8.4 (+1)	12 (-1)	0.30±0.01	0.00±0.00
5	0.1 (-1)	3.6 (-1)	18 (+1)	0.46±0.01	0.32±0.14
6	0.4 (+1)	3.6 (-1)	18 (+1)	0.53±0.02	0.11±0.04
7	0.1 (-1)	8.4 (+1)	18 (+1)	0.31±0.01	0.00±0.00
8	0.4 (+1)	8.4 (+1)	18 (+1)	0.39±0.01	0.00±0.00
9	0.0 (-1.68)	6.0 (0)	15 (0)	0.27±0.01	0.04±0.07
10	0.5 (+1.68)	6.0 (0)	15 (0)	0.33±0.01	0.00±0.00
11	0.25 (0)	2.0 (-1.68)	15 (0)	0.81±0.01	0.18±0.10
12	0.25 (0)	10.0 (+1.68)	15 (0)	0.31±0.01	0.00±0.00
13	0.25 (0)	6.0 (0)	10 (-1.68)	0.29±0.01	0.00±0.00
14	0.25 (0)	6.0 (0)	20 (+1.68)	0.37±0.01	0.00±0.00
15	0.25 (0)	6.0 (0)	15 (0)	0.33±0.01	0.00±0.00
16	0.25 (0)	6.0 (0)	15 (0)	0.30±0.01	0.00±0.00
17	0.25 (0)	6.0 (0)	15 (0)	0.31±0.01	0.00±0.00
18	0.25 (0)	6.0 (0)	15 (0)	0.29±0.01	0.00±0.00
19	0.25 (0)	6.0 (0)	15 (0)	0.30±0.01	0.00±0.00

[(1)]Encoded values are in parentheses. [(2)]Assays to evaluate the effect of different concentrations of albumin (2.0–10% w/w), xanthan gum (0.0–0.5% w/w), and whipping times (10–20 min) on the foam density and stability of butiá pulp. [(3)]Means of triplicates.

Paulo, SP, Brazil). The solubility of butiá pulp powder was calculated by the ratio between the supernatant mass and the dry solid mass obtained after drying as described by Eastman & Moore (1984) – i.e., 1.0 g of powder was mixed with 100 mL of distilled water, kept under magnetic stirring for 5 min, and then centrifuged at 4,000 rpm for 5 min, after which 10 mL of the supernatant was transferred to a glass Petri dish that had been previously dried. In the present study, the samples were dried in the SL-100 oven (Solab: Equipamentos para Laboratórios, Piracicaba, SP, Brazil), at 105°C, until constant weight.

Water-holding capacity was determined according to Rosell et al. (2009). In this case, samples of 0.5 g of the powder were mixed with 10 mL of distilled water. The mixture was left to stand for 24 hours and, then, was centrifuged at 4,000 rpm for 3 min, and the supernatant was filtered through an 80 g m^{-2} filter paper. The water retained in the filter and the water collected during filtration were weighed, and the obtained amount was subtracted from the initial weight of water, showing the weight of water per gram of powder.

The color of the pulp, foam, and powder was measured with the CR-400 portable colorimeter (Konica Minolta Sensing Americas, Inc, Ramsey, NJ, USA) using the lightness (L*), red (a*), and blue (b*) coordinates. Hue angle (H^o) and chroma intensity (C*) were calculated through classical equations (McGuire, 1992).

For the statistical analysis, RSM data were analyzed by the Experimental Design module of the Statistica, version 10.0, software (TIBCO Software Inc., Palo Alto, CA, USA) and the analysis of variance (Anova). Three-dimensional surface plots were designed to illustrate the main and interactive effects of the independent variables on the dependent variables. Pulp, foam, and powder characteristics were compared through duplicates of two independent experiments by the Anova and, subsequently, Tukey's test, also using the Statistica, version 10.0, software (TIBCO Software Inc., Palo Alto, CA, USA), with differences considered significant at a 95% confidence level ($p<0.05$).

Results and Discussion

The results of the RSM for albumin concentration, xanthan gum concentration, and whipping times showed that xanthan gum (linear effect), albumin (linear and quadratic effect), and the interaction between albumin and whipping times significantly affected ($r^2=0.98$; $p<0.05$) foam density (Figure 1). The calculated F-value of 45.91 was higher than the critical F-value of 3.18, indicating the significance of the following model: $Y_1 = 0.31 + 0.026G - 0.13A + 0.094A^2 + 0.041A \times T$, where G is xanthan gum, A is albumin, and T are whipping times.

Density showed a concave response to increased changes in the dependent variable due to the linear

Table 2. Real and coded values[(1)] for drying temperature and foam-thickness layer in the 2^2 factorial experiments, affecting the results obtained for the yield and vitamin C retention of butiá (*Butia* spp.) dried foam and pulp.

Assay[(2)]	Temperature (ºC)	Thickness (cm)	Yield[(3)] (g per hour)	Vitamin C[(3)] (mg per 100 g)
1	63 (-1)	0.65 (-1)	1.81±0.01	4.14±0.00
2	77 (+1)	0.65 (-1)	2.96±0.32	12.35±0.00
3	63 (-1)	1.35 (+1)	1.68±0.12	4.16±0.00
4	77 (+1)	1.35 (+1)	3.36±0.37	6.12±0.02
5	70 (0)	1.00 (0)	2.52±0.36	8.15±0.00
6	70 (0)	1.00 (0)	2.12±0.17	8.26±0.00
7	70 (0)	1.00 (0)	2.56±0.33	6.05±0.02
8	60 (-1.41)	1.00 (0)	1.68±0.02	4.11±0.00
9	70 (0)	0.50 (-1.41)	2.39±0.30	8.13±0.00
10	80 (+1.41)	1.00 (0)	2.72±0.47	8.14±0.00
11	70 (0)	1.50 (+1.41)	2.32±0.19	4.10±0.00
Pulp	-	-	-	56.03±0.00

[(1)]Encoded values are in parentheses. [(2)]Assays to evaluate the effect of different temperatures (60–80°C) and foam-layer thicknesses (0.50–1.50 cm) on vitamin C retention and yield. Each drying assay was performed in a duplicate of two independent experiments, consisting of two trays with the same foam-layer thickness at the same temperature. [(3)]Means of duplicates from the two independent experiments.

and quadratic effect of albumin concentration. Although foam density was lower at a higher albumin concentration, the opposite occurred at concentrations above 9.0% (Figure 1 A), which may be explained by the saturation of albumin solubility (Rajkumar et al., 2007). In general, foam density was higher at 2.0–3.6% and lower at 6.0–10% albumin concentration. The lowest density was related to the highest concentrations of albumin and the shortest whipping time. Longer whipping times lead to an excessive protein denaturation, which is usually associated with the formation of insoluble aggregates that present a low water-retention capacity, causing foam to collapse and its density to increase (Raikos et al., 2007).

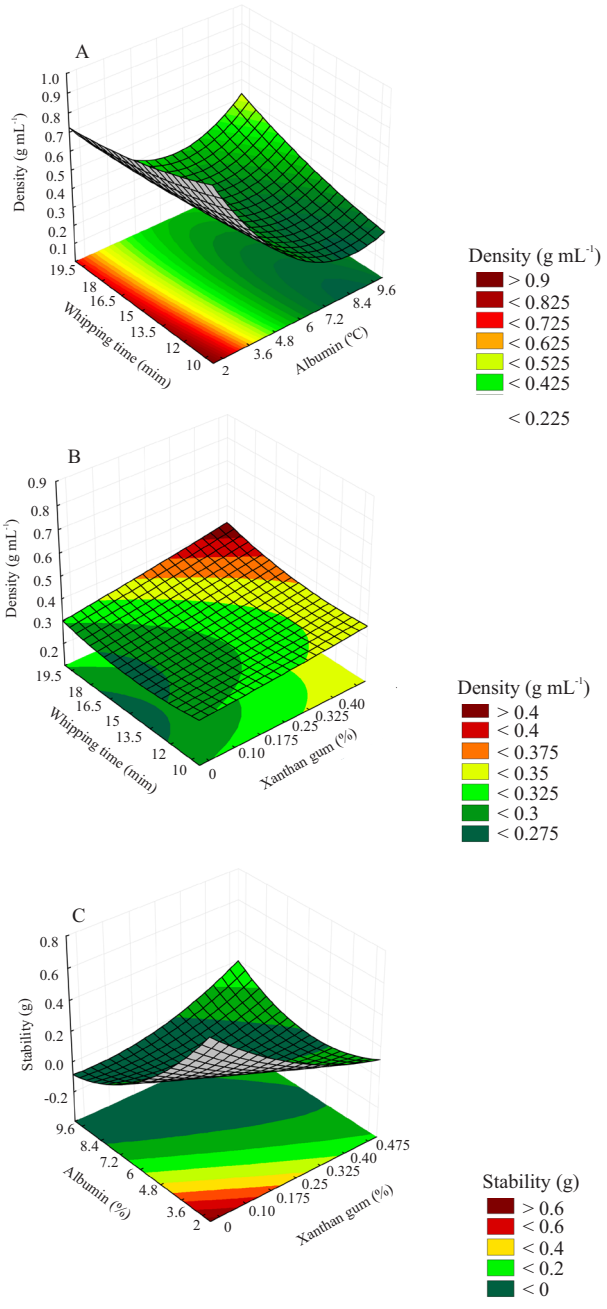

Figure 1. Butiá (*Butia* spp.) foam density response surface as a function of whipping time and albumin concentration (A), foam density as a function of whipping time and xanthan gum concentration (B), and foam stability as a function of albumin and xanthan gum concentrations (C).

For the foam-layer method, densities from 0.3 to 0.6 g mL^{-1} are indicated since foams with a low density dry faster, resulting in a lower thermal degradation and a higher general quality (Ratti & Kudra, 2006). Other studies presented similar results, with a reduction in density with the addition of albumin to plum (*Prunus domestica* L.) foam (Sifat et al., 2021) and an increase in density with the addition of xanthan gum to egg white-based protein foam (Zmudziński et al., 2014). In the present study, the increase in foam density due to the addition of xanthan gum (Figure 1 B) is attributed to the ability of this hydrocolloid to increase viscosity even at low concentrations, causing resistance to air incorporation during whipping (Dabestani & Yeganehzad, 2019).

The linear and quadratic effect of albumin concentration and the interaction of albumin concentration and xanthan gum played a significant role (r^2=0.77; $p<0.10$) on foam stability (Y_2), whereas whipping time did not ($p>0.10$). The calculated F-value of 3.45 was higher than the tabulated F-value of 3.18, showing the significance of the following model: $Y_2 = -0.11A - 0.056A^2 + 0.0811G \times A$, where A is albumin and G is xanthan gum.

A greater foam stability was obtained with higher amounts of albumin (Figure 1 C); however, when 0.25% (w/w) xanthan gum was added, a smaller amount of albumin was required to reach the desired stability. Susanti et al. (2021) highlighted that xanthan gum increased the viscosity of the continuous phase and that its interaction with protein led to a more rigid foam microstructure, whereas Dabestani & Yeganehzad (2019) found that xanthan gum increased the stability of pasteurized fresh egg-white foams, with no liquid drainage at the highest concentrations.

Vitamin C preservation was significantly affected by the linear effect of temperature and layer thickness, as well as by their interaction (r^2=0.91; $p<0.05$)

(Figure 2). The calculated F-value of 9.92 was higher than the tabulated F-value of 5.050, showing the significance of the following model: Y = 7.48 + 1.99T - 1.49E - 1.56T×E, where T is temperature and E is foam-layer thickness.

The amount of ascorbic acid was 56.03 mg 100 g^{-1} in in natura pulp and between 4.10 and 12.35 mg 100 g^{-1} in the powders, indicating a reduction of 92.68 to 77.96%. In the analyzed intervals, higher drying temperatures and a thinner foam-layer thickness provided a greater retention of vitamin C (Figure 2 A). It has been reported that vitamin C is more susceptible to degradation when exposed to longer drying times and low temperatures than to shorter times and high temperatures (Pandith & Srivastava, 2018). The smaller losses of vitamin C in the shortest drying time may be related to the lowest exposure of the vitamin to factors such as moisture, light, and oxygen, which contribute to its degradation (Freitas et al., 2018). According to Lee & Labuza (1975), the reduction of moisture increases the viscosity of the medium and reduces the mobility of reaction factors, helping to preserve vitamin C.

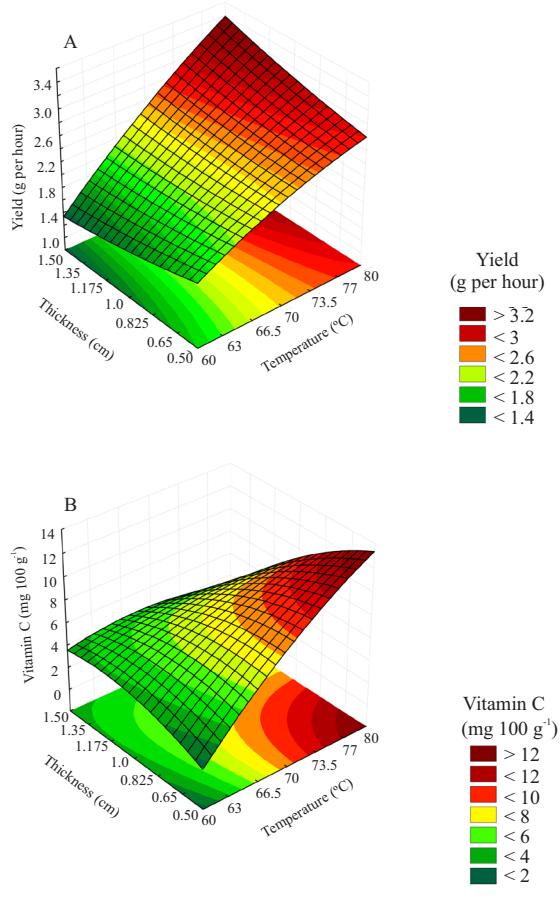

Figure 2. Vitamin C content (A) and yield (B) of butiá (*Butia* spp.) as a function of drying temperature and foam-layer thickness.

For yield, only the linear effect of temperature was significant (r^2=0.85; $p<0.05$) and foam-layer thickness did not cause significant changes ($p>0.05$) in the dependent variable. The calculated F-value of 5.66 was higher than the tabulated F-value of 5.050, showing the significance of the following model: Y = 2.40 + 0.54T, where T is temperature. Therefore, increasing the drying temperature increases yield (Figure 2 B), whereas increasing the thickness of the foam layer does not compensate for the time required for drying. Since food drying is characterized by a high consumption of energy (Qu et al., 2022), the conditions that promote a faster and more efficient removal of moisture are those that result in a higher yield. Using the foam-layer drying method, Araújo et al. (2017) found that the increase in temperature reduced the drying time of acerola (*Malpighia emarginata* DC.) pulp.

The curves obtained for drying (Figure 3), built from the moisture data on a wet basis and the drying rate as a function of time, were influenced by temperature and by the thickness of the foam layer, showing an exponential decay of moisture over time. When only temperature varied, the data from the drying curves of the first (63°C, 0.65 cm) and second (77°C, 0.65 cm) assays showed a strong drop in humidity at the highest temperature due to the increased heat transferred from the heating air to the foam (Araújo et al., 2017). When only the thickness of the foam layer varied, the data of the second (77°C, 0.65 cm) and fourth (77°C, 1.35 cm) assays indicated a more accentuated drop in moisture at the thinnest thickness, which is explained by the shortest path traveled by water and water vapor from the interior to the surface layer.

The foam showed a lighter color than the pulp, with an increase in luminosity and a decrease in a* and b*, which is attributed to the addition of albumin and the air contained in the foam (Shaari et al., 2018). However, drying had a darkening effect (Table 3) due to the heating of fruit sugars and the agents used for foam formation and stability (Quek et al., 2007), as well as to the degradation and/or transformation of phenolic compounds, vitamin C, and carotenoids (Sant'Anna et

al., 2013). The H° values of the pulp, foam, and powder indicate a predominantly yellow tone, and the C* values, that the pulp and powder have a more intense yellow color than the foam.

The foam had a higher pH than the pulp due to the addition of albumin, whose pH is between 7.0 and 8.0 (Mine, 1995). However, although still considered acid (<5.0), the powder had a higher pH than the foam, which is related to the destruction of acids by heat and drying time (Pandith & Srivastava, 2018).

The increase in the total soluble solids content is attributed to the concentrations of albumin and xanthan gum, as well as to the loss of water during drying. Likewise, Freitas et al. (2018) found that the addition of the foaming agent and drying increased the total soluble solids in cajá (*Spondias mombin* L.) powder, compared with the pulp.

The results obtained for moisture indicate that the applied drying conditions are sufficient for water removal. Foods presenting a water activity lower than 0.6 are considered microbiologically stable, and any deterioration that occurs is induced by chemical reactions and not by microorganisms (Quek et al., 2007).

The water-holding capacity of the powder of butiá can be explained by the fruit's fiber content, which varies from 0.84 to 4.89% (Hoffmann et al., 2014), whereas solubility is related to the solubility of albumin and the foam structure, resulting in a more porous powder and a greater surface area for the interaction with water (Shaari et al., 2018).

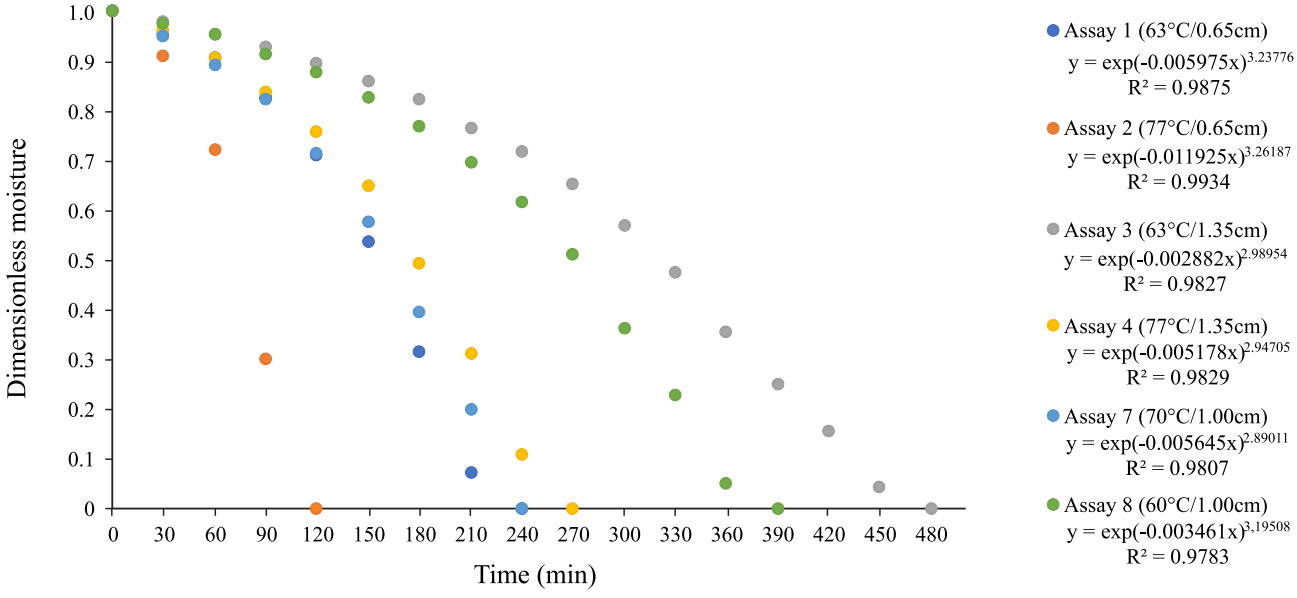

Figure 3. Drying curves of butiá (*Butia* spp.) pulp in the first, second, third, fourth, seventh, and eighth assays as a function of different temperatures and foam-layer thicknesses.

Table 3. Values obtained for color, pH, °Brix, humidity, water activity (Aw), water-holding capacity (WHC), and solubility of the butiá (*Butia* spp.) pulp powder[(1)].

Sample	Color[(2)]					pH	°Brix	Humidity (%)	Aw	WHC g H_2O per g powder	Solubility (%)
	L*	a*	b*	C	H°						
Pulp	67.30±0.62c	8.94±0.79a	58.92±2.57a	59.59	81.41	2.65±0.01c	6±0.01c	-	-	-	-
Foam	87.01±0.21a	0.22±0.15c	39.43±0.51c	39.43	89.71	3.21±0.01b	18±0.01b	-	-	-	-
Powder	72.25±1.06b	7.23±0.09b	53.99±0.26b	54.47	82.41	3.25±0.00a	61±0.00a	7.97±0.71	0.206±0.004	4.90±0.08	74.40±0.30

[(1)]Means followed by different letters, in the columns, differ significantly by Tukey's test, at 5% probability. [(2)]Chroma (C) and hue (H°) were calculated from the means of the lightness (L*), red (a*), and blue (b*) coordinates.

Conclusions

1. The foam-layer drying method is a viable alternative for obtaining the powder from butiá (*Butia* spp.) pulp.

2. Albumin (7.0% w/w), xanthan gum (0.25% w/w), and 10 min of whipping time are the optimized conditions to form foam using butiá pulp suitable for drying.

3. A thinner foam thicknesses of 0.50 cm and a higher drying temperature of 80°C retain more vitamin C, whereas only the use of higher temperature results in a higher yield.

4. The butiá pulp powder presents a low humidity and water activity, an acid pH, and a predominantly yellow color.

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References

ANESIADIS, N.; CLUETT, W.R.; MAHADEVAN, R. Dynamic metabolic engineering for increasing bioprocess productivity. **Metabolic Engineering**, v.10, p.255-266, 2008. DOI: https://doi.org/10.1016/j.ymben.2008.06.004.

ARAÚJO, C. da S.; MACEDO, L.L.; VIMERCATI, W.C.; SARAIVA, S.H.; OLIVEIRA, A. do N.; TEIXEIRA, L.J.Q. Cinética de secagem de acerola em leito de espuma e ajuste de modelos matemáticos. **Brazilian Journal of Food Technology**, v.20, e2016152, 2017. DOI: https://doi.org/10.1590/1981-6723.15216.

BARBOSA, M.C. de A.; ROSA, Q. da S.; CARDOSO, L. de M.; GOMIDES, A.F. de F.; BARBOSA, L.C. de A.; SANT'ANNA, H.M.P.; PINHEIRO, S.S.; PELUZIO, M. do C.G.; TEIXEIRA, R.D.B.L.; VALENTE, M.A.S. Composition proximate, bioactive compounds and antioxidant capacity of *Butia capitata*. **Food Science and Technology**, v.41, p.763-768, 2021. Suppl.2. DOI: https://doi.org/10.1590/fst.26720.

BÜTTOW, M.V.; BARBIERI, R.L.; NEITZKE, R.S.; HEIDEN, G. Conhecimento tradicional associado ao uso de butiás (*Butia* spp., Arecaceae) no Sul do Brasil. **Revista Brasileira de Fruticultura**, v.31, p.1069-1075, 2009. DOI: https://doi.org/10.1590/s0100-29452009000400021.

DABESTANI, M.; YEGANEHZAD, S. Effect of Persian gum and xanthan gum on foaming properties and stability of pasteurized fresh egg white foam. **Food Hydrocolloids**, v.87, p.550-560, 2019. DOI: https://doi.org/10.1016/j.foodhyd.2018.08.030.

DE CÓL, C.D.; TISCHER, B.; FLÔRES, S.H.; RECH, R. Foam-mat drying of bacaba (*Oenocarpus bacaba*): process characterization, physicochemical properties, and antioxidant activity. **Food and Bioproducts Processing**, v.126, p.23-31, 2021. DOI: https://doi.org/10.1016/j.fbp.2020.12.004.

EASTMAN, J.E.; MOORE, C.O. **Cold-water-soluble granular starch for gelled food compositions**. Int. Cl A23L 1/195; A23L 1/187. US n. 4,465,702, 1 Nov. 1982, Aug. 14 1984.

FERRÃO, T.S.; TISCHER, B.; MENEZES, M.F.S.C.; HECKTHEUER, L.H.R.; MENEZES, C.R.; BARIN, J.S.; MICHELS, L.; WAGNER, R. Effect of microwave and hot air drying on the physicochemical characteristics and quality of jelly palm pulp. **Food Science and Technology Research**, v.23, p.835-843, 2017. DOI: https://doi.org/10.3136/fstr.23.835.

FREITAS, B.S.M. de; CAVALCANTE, M.D.; CAGNIN, C.; SILVA, R.M. da; PLÁCIDO, G.R.; OLIVEIRA, D.E.C. de. Physical-chemical characterization of yellow mombin (*Spondias mombin* L.) foam-mat drying at different temperatures. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.22, p.430-435, 2018. DOI: https://doi.org/10.1590/1807-1929/agriambi.v22n6p430-435.

HOFFMANN, J.F.; BARBIERI, R.L.; ROMBALDI, C.V.; CHAVES, F.C. *Butia* spp. (Arecaceae): an overview. **Scientia Horticulturae**, v.179, p.122-131, 2014. DOI: https://doi.org/10.1016/j.scienta.2014.08.011.

HOFFMANN, J.F.; ZANDONÁ, G.P.; SANTOS, P.S. dos; DALLMANN, C.M.; MADRUGA, F.B.; ROMBALDI, C.V.; CHAVES, F.C. Stability of bioactive compounds in butiá (*Butia odorata*) fruit pulp and nectar. **Food Chemistry**, v.237, p.638-644, 2017. DOI: https://doi.org/10.1016/j.foodchem.2017.05.154.

HORWITZ, W. (Ed.). **Official Methods of Analysis of Association of Official Analytical Chemists**. 13th ed. Washington: AOAC, 1980. Official Method 967.21.

LEE, S.H.; LABUZA, T.P. Destruction of ascorbic acid as a function of water activity. **Journal of Food Science**, v.40, p.370-373, 1975. DOI: https://doi.org/10.1111/j.1365-2621.1975.tb02204.x.

MACEDO, L.L.; CORRÊA, J.L.G.; FONSECA, H.C.; ARAÚJO, C. da S.; VIMERCATI, W.C.; GANDIA, R.M. Convective drying of *Butia capitata* pulp: effect of air temperature on kinetic and quality parameters. **Research, Society and Development**, v.9, e73791110583, 2020. DOI: https://doi.org/10.33448/rsd-v9i11.10583.

MCGUIRE, R.G. Reporting of objective color measurements. **HortScience**, v.27, p.1254-1255, 1992. DOI: https://doi.org/10.21273/hortsci.27.12.1254.

MINE, Y. Recent advances in the understanding of egg white protein functionality. **Trends in Food Science & Technology**, v.6, p.225-232, 1995. DOI: https://doi.org/10.1016/S0924-2244(00)89083-4.

PANDITH, J.A.; SRIVASTAVA, A.K. Induction heating assisted foam mat drying of papaya pulp: drying kinetics, drying modeling, and effects on quality attributes. **Agricultural Engineering International: CIGR Journal**, v.20, p.206-215, 2018.

QU, H.; MASUD, M.H.; ISLAM, M.; KHAN, M.I.H.; ANANNO, A.A.; KARIM, A. Sustainable food drying technologies based on renewable energy sources. **Critical Reviews in Food Science and Nutrition**, v.62, p.6872-6886, 2022. DOI: https://doi.org/10.1080/10408398.2021.1907529.

QUEK, S.Y.; CHOK, N.K.; SWEDLUND, P. The physicochemical properties of spray-dried watermelon powders. **Chemical Engineering and Processing**, v.46, p.386-392, 2007. DOI: https://doi.org/10.1016/j.cep.2006.06.020.

RAHARITSIFA, N.; GENOVESE, D.B.; RATTI, C. Characterization of apple juice foams for foam-mat drying prepared with egg white protein and methylcellulose. **Journal of Food Science**, v.71, p.E142-E151, 2006. DOI: https://doi.org/10.1111/j.1365-2621.2006.tb15627.x.

RAIKOS, V.; CAMPBELL, L.; EUSTON, S.R. Effects of sucrose and sodium chloride on foaming properties of egg white proteins. **Food Research International**, v.40, p.347-355, 2007. DOI: https://doi.org/10.1016/j.foodres.2006.10.008.

RAJKUMAR, P.; KAILAPPAN, R.; VISWANATHAN, R.; PARVATHI, K.; RAGHAVAN, G.S.V; ORSAT, V. Thin layer drying study on foamed mango pulp. **Agricultural Engineering International: the CIGR Ejournal Manuscript**. FP 06 024, v.9, p.1-14, 2007.

RATTI, C.; KUDRA, T. Drying of foamed biological materials: opportunities and challenges. **Drying Technology**, v.24, p.1101-1108, 2006. DOI: https://doi.org/10.1080/07373930600778213.

REIS, F.R.; MORAES, A.C.S. de; MASSON, M.L. Impact of foam-mat drying on plant-based foods bioactive compounds: a review. **Plant Foods for Human Nutrition**, v.76, p.153-160, 2021. DOI: https://doi.org/10.1007/s11130-021-00899-3.

ROSELL, C.M.; SANTOS, E.; COLLAR, C. Physico-chemical properties of commercial fibres from different sources: a comparative approach. **Food Research International**, v.42, p.176-184, 2009. DOI: https://doi.org/10.1016/j.foodres.2008.10.003.

SANT'ANNA, V.; GURAK, P.D.; MARCZAK, L.D.F.; TESSARO, I.C. Tracking bioactive compounds with colour changes in foods – a review. **Dyes and Pigments**, v.98, p.601-608, 2013. DOI: https://doi.org/10.1016/j.dyepig.2013.04.011.

SHAARI, N.A.; SULAIMAN, R.; RAHMAN, R.A.; BAKAR, J. Production of pineapple fruit (*Ananas comosus*) powder using foam mat drying: effect of whipping time and egg albumen concentration. **Journal of Food Processing and Preservation**, v.42, e13467, 2018. DOI: https://doi.org/10.1111/jfpp.13467.

SIFAT, S.A.D.; TRISHA, A.T.; HUDA, N.; ZZAMAN, W.; JULMOHAMMAD, N. Response surface approach to optimize the conditions of foam mat drying of plum in relation to the physical-chemical and antioxidant properties of plum powder. **International Journal of Food Science**, v.2021, art.ID3681807, 2021. DOI: https://doi.org/10.1155/2021/3681807.

SUSANTI, D.Y.; SEDIAWAN, W.B.; FAHRURROZI, M.; HIDAYAT, M. Foam-mat drying in the encapsulation of red sorghum extract: effects of xanthan gum addition on foam properties and drying kinetics. **Journal of the Saudi Society of Agricultural Sciences**, v.20, p.270-279, 2021. DOI: https://doi.org/10.1016/j.jssas.2021.02.007.

ZMUDZIŃSKI, D.; PTASZEK, P.; KRUK, J.; KACZMARCZYK, K.; ROZNOWSKI, W.; BERSKI, W.; PTASZEK, A.; GRZESIK, M. The role of hydrocolloids in mechanical properties of fresh foams based on egg white proteins. **Journal of Food Engineering**, v.121, p.128-134, 2014. DOI: https://doi.org/10.1016/j.jfoodeng.2013.08.020.