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Açaí pulp dehydration by foam-mat drying to produces açaí powder

Desidratação de polpa de açaí pelo método da camada de espuma para obtenção de açaí em pó

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The foam-mat drying was used as a dehydration method for açaí pulp. The types of foaming agents, the influence of concentration and whipping time were evaluated for foam formation. After choosing the agent/additive a 2^2 Factorial Experimental Design, with three central points were realized to evaluated the influence of the drying process conditions. The optimized condition was verified by the desirability function and it was compared to the açaí pulp and açaí foam both freeze-dried. Emustab was identify as an appropriate foaming agent for açaí foam. The drying temperature showed significative effects on total anthocyanins and moisture, while the Concentration and the interaction Concentration and Temperature were significants for lightness. The açaí dehydrated by foam-mat was equal to the freeze-dried açaí pulp in terms of moisture and water activity results, as freeze-dried açaí foam showed divergent results for these parameters. All dehydrated products differed in terms of color parameters.
Keywords: *Euterpe oleracea*, emulsifier, vegetable product.

A secagem em camada de espuma foi utilizada como método de desidratação da polpa de açaí. Os tipos de aditivos, a influência da concentração e tempo de agitação foram avaliados para a formação de espuma. Após a escolha do aditivo, Planejamento Experimental Fatorial 2^2, com três pontos centrais foi realizado para avaliar a influência das condições de processo de secagem. A condição otimizada foi obtida utilizando a função desejabilidade e foram comparados com o açaí liofilizado e a espuma de açaí liofilizada. Emustab foi identificado como o aditivo adequado para a formação de espuma de açaí. A temperatura de secagem apresentou efeitos significativos sobre as respostas antocianinas totais e umidade, enquanto Concentração de aditivo e a interação Concentração e Temperatura foram significativos para luminosidade. O açaí desidratado por camada de espuma se equiparou ao açaí liofilizado quanto aos resultados de umidade e atividade de água, enquanto a espuma de açaí liofilizada apresentou resultados divergentes para estes parâmetros. Todos os produtos desidratados diferiram quanto aos parâmetros de cor.
Palavras-chave: *Euterpe oleracea*, emulsificante, produto vegetal.

1. INTRODUCTION

Drying is an important step in food preservation as it increases its shelf life, however, it involves high temperatures and/or high energy consumption During the food drying process it is necessary to maintain the product quality, in addition to the reduced drying cost. Freeze-drying is the best way to dehydrate most of the food products; however, it is associated with high cost [1].

Researches into the development of alternative drying processes are important for the industry, one of them being the foam-mat drying, which is a method that uses hot air and has advantages over traditional drying. The main advantage is the decrease in temperature, resulting in less drying time compared to non-foamed matrices under the same conditions, thus reducing the product thermal degradation. The reduction in drying time is due to the increase in the contact surface exposed to air and the foams heat and mass transfer specific characteristics [2, 3]

Foam-mat drying is a relatively simple method, being considered a lower cost process than freeze-drying and spray drying for the production of dehydrated foods in powder form. It is effective for thermosensitive, sticky, or viscous foods that are difficult to spray dry [2, 3].

Açaí, the fruit of the *Euterpe oleracea* palm tree, has crossed the Amazon region consumption frontiers. Currently, accepted as an energy drink and raw material for ice cream, sweets, cakes, and others, it is recognized as a pulp with high nutritional and antioxidant value [4].

Some alternative techniques for obtaining powdered açaí have already been evaluated, such as the use of a spouted bed dryer with inert particles [5], in place of spray drying, and *Refractance Window* [6], however, no previous work has evaluated the use of foam-mat drying in açaí. Thus, the objective of this study was to evaluate the obtainment of powdered açaí by the foam-mat drying method, examining the best foaming agent and drying condition.

2. MATERIAL AND METHODS

The experiments were carried out at the Laboratório de Operações de Separação (LAOS) and at the Laboratório de Produtos de Origem Animal (LAPOA) of the Federal University of Pará, campus Belém – Pará. The medium type açaí pulp used in the experiments was supplied by the ARGUS FRUITS industry, located in the municipality of Benevides-PA, kept frozen in a freezer until the experiments and analysis were carried out. Defrosting was carried out according to the supplier's consumption instructions, indicated on the product packaging, which consisted of defrosting 50% of the pulp and then processing in a blender.

2.1. Raw material characterization

Density analyzes were performed using the methodology proposed by Mounir (2018) [3]; moisture and dry solids content of açaí pulp, by evaporation in an infrared device (GEHAKA, model VI 2000); the water activity was measured in an Aqualab device (Decagon Devices - 4TE, Pullman, WA, E.U.A), at a temperature of 25 ºC; total soluble solids content (TSS) using a bench top Abbé refractometer (Quimis - Q767B, Diadema, SP, Brazil), according to official method nº 932.12 [8]; and pH was evaluated using digital bench top pHmeter (Akso – LineLab, São Leopoldo, RS, Brazil) [9]. The total titratable acidity (TTA) was performed using a digital pHmeter during the titration, in which 10 mL aliquots of the sample in 90 mL of distilled water were titrated with a standardized 0.1 N NaOH solution, until pH = 8.2, and the results were expressed in g of citric acid/100 g of açaí pulp [9]. The total anthocyanin content was determined by the differential pH method [7], using spectrophotometer UV/Vis (Thermo Scientific, model Genesys 10-S). The determination of color was performed with the aid of a colorimeter (Konica Minolta, CR 400, Osaka, Osaka, Japan). The parameters evaluated were L* (lightness), a* (red to green), b* (yellow to blue), h (hue angle) and C* (saturation).

2.2. Obtaining and characterization of the açaí pulp foam

2.2.1 Açaí pulp foaming test

Different additives were tested to assess the formation or non-formation of foam. Formulations that were not between 0.2 - 0.6 g/cm³ of density [3] were considered inadequate and discarded, and formulations that were within the stipulated range were evaluated for expansion and stability properties. The additives used for the açaí foaming test were: Guar Gum and Xantana Gum (Daxia Doce Aroma Industria e Comercio Ltda, Guarulhos, SP, Brazil), Whey (Firmino Vieira e Cia. Ltda., SP, São Paulo, Brazil), CMC (carboxymethylcellulose) (Arcólor®, São Lourenço, São Paulo, Brazil), Albumin (Naturovos, Salvador do Sul, RS, Brazil), emustab (water, monoglycerides of distilled fatty acids, salt of fatty acids, sorbitan monostearate, and polyoxyethylene sorbitan monostearate) (Duas Rodas Industrial Ltda., Jaraguá do Sul, SC, Brazil), Neutral Alloy and Emulsifier Marvi Gel Plus (Marvi Ltda., Rodovia Mello Peixoto SP-PR Km 376, Brazil). These additives were added to the açaí pulp, in different proportions (ranging from 0.5% to 10% w/w) and each mixture was whipped (whipping times varied from 3 to 11 minutes) by a kitchen mixer (Arnor Agili, SX10, 200 W, 1100 rpm) at speed 2. In this

preliminare test, the proportions of additives, the mixture of them, and whipping time were based on previous studies of foam-mat drying, recorded in literature.

2.2.2. Evaluating the density, expansion, and stability of açaí foam

After selecting the most appropriate additive, the influence of different additive concentrations and whipping times on foam density, expansion, and stability properties was evaluated. The procedure performed was the same used in item 2.2.1, with the whipping times evaluated of 3, 5, 7, 9, and 11 minutes and the additive concentration of 5 and 10%. Foam densities were calculated as described by Mounir (2018) [3]. The foam expansion, which indicates the ability of the foam to incorporate air into its structure, was determined from Equation 1:

$$\text{Expansion (\%)} = \frac{{}^{1}/_{\rho_{efoam}} - {}^{1}/_{\rho_{pulp}}}{{}^{1}/_{\rho_{foam}}} \times 100 \quad (1)$$

where ρ represents density in g/cm^3.

To assess the foam stability, the method proposed by Muthukumaran et al. (2008) [10] was used, with some modifications. A Buchner funnel was filled with 50 mL of foam and the liquid drained by gravity was collected in a 50 mL beaker. The volume V (mL) of the drained liquid was measured directly in the beaker, as a function of time, during 120 minutes. The percentage of coalesced foam in relation to the initial volume was evaluated.

2.3. Study of foam-mat drying of açaí

After verified in previous tests, the processing time was kept constant (three hours, on average) in order that the powders obtained were preferably in the water activity range of 0.3 - 0.4. The foams (approximately 300 g) were distributed in stainless steel trays measuring 0.5 x 30 x 40 cm (height x width x length) (Figure 1a), forming a layer 0.5 cm of thickness, and subjected to drying in a oven (Quimis, model Q314M242, Diadema, SP, Brazil) with forced air circulation. At the end of drying, the trays were scraped and the dehydrated foam powder disintegrated (Figure 1 b), to carry out the necessary analyses.

(a) **(b)**

Figure 1. Açaí foam (a) distributed in the tray and (b) açaí turned to powded after drying.

The drying experiments followed a Factorial Experimental Design 2², with three central points, totaling seven tests. The aim of this experimental design was to evaluate the influence of the following variables: Additive concentration (C) and Drying temperature (T), on the responses: Total Anthocyanins (TA), Moisture (U), Water activity (Aw), and Lightness (L*) color parameter.

Table 1 shows the variables and design levels used to study the dehydration of açaí in a foam-mat drying.

Table 1. Variables and levels used for dehydration of açaí in a foam-mat drying.

Variables	Levels		
	-1	0	+1
C (%)	5.0	7.5	10.0
T (ºC)	50	60	70

Through the Desirability Function, the best drying condition, within the studied limit, for the Total Anthocyanins (TA), Moisture (U), and Lightness (L*) responses was determined. For comparative purposes, a part of the açaí used as raw material for the foams elaboration and also the foam produced in the additive concentration of the best drying condition chosen were lyophilized. The process was carried out in an LS6000 lyophilizer (TERRONI EC, SP, Brazil) for 48 hours. Analysis performed for comparison were TA, color (L*, a*, b*, C, h), U, and Aw.

2.4. Statistical treatment of experimental data

To evaluate the influence of whipping time and additive concentration on the density, expansion, and foam stability responses (made in triplicate), analysis of variance (ANOVA) with Tukey's test at 5% probability was used to compare the averages, using Statistica® software version 7.0 (StatSoft, Inc., USA) and Microsoft Office Excel 2010. In the factorial design, the results were evaluated through ANOVA procedure and F test. The regression coefficients determination and desirability function application were performed with the aid of the Statistica® software. For the analysis and interpretation of the effects of all response variables, the 95% confidence level was considered.

3. RESULTS AND DISCUSSION

3.1. Characterization of açaí pulp

The açaí pulp presented 13.55% solids (moisture = 86.45%), being considered medium type açaí, as indicated by the supplier's label and by the legislation [11]. The pH and titratable acidity values found were 5.01 ± 0.00 and 0.1707g/100 g ± 0.02, respectively, being within the range established by legislation [11]. Current legislation does not have a standard for the soluble solids content, being the value found in this work 3.25 ± 0.35 °Brix. Pereira et al. (2002) [12] determined the densities of thick, medium, and popular açaí types and their experimental results were in the range of 1.007 to 1.025 g/cm³, differently from what was determined in the present work, of 0.8381 g/cm³. It is likely that this difference in density occurred since the measurements were taken right after the açaí homogenization in a blender, resulting in the incorporation of air during this step and consequent reduction in density.

The determined lightness indicated a darker color than expected (L* = 18.7 ± 0.46), being close to the value found by Canuto et al. (2010) [13] of L*=16.6. This work presented a value of a* = 6.66 ± 1.50 and b* = 5.62 ± 0.79, indicating a reddish-yellow hue, corroborating with the h value found (40.39 ± 0.46), while C* = 8.72 ± 1.65, indicates less intense coloration. The total anthocyanins content had an average of 345.42 ± 25.87 mgC3G/100g d.b. (dry basis), in accordance with the values recorded by Rogez (2000) [14] for açaí pulp obtained during the harvest and off-season which it was between 357 to 926 mg/100g in dry basis.

3.2. Result of açaí foam tests

3.2.1. Determination of the best additive for the açaí foam formation

The preliminary tests results for foam formation showed that in none of the studied concentrations and whipping times, the additives Guar Gum, Xanthan Gum, Carboxymethylcellulose (CMC), Whey, Albumin, Neutral Alloy, and Marvi Gel Plus Emulsifier used were able to reduce sufficiently the açaí density to less than 0.6 g/cm³.

When used in the proportion of 0.5% plus 4.5% of Emustab, albumin and CMC produced foams with 0.4330 and 0.5072 g/cm³ densities, respectively. Probably the density reduction is associated with a higher concentration of Emustab added to the formulations, since this additive alone at 5% concentration was able to produce foam with 0.3750 g/cm³ density.

3.2.2. Evaluation of density, expansion, and stability of açaí foam

Emustab was the most suitable additive for evaluating the influence of whipping time and additive concentration. Thus, the condition that promoted the best characteristics in density, expansion, and stability parameters of the foam was evaluated (Table 2). Density is one of the main parameters to assess foam quality, especially during whipping. The greater the amount of air incorporated during whipping, the lower the foam density. Also, the more air in the foam, greater the capillarity. In contrast, higher densities result in a longer drying time, leading to low product quality caused by thermal degradation [3].

Table 2. Results of açaí pulp foam by differents concentration of Emustab and differents whipping times.

Parameter	Concentration of Emustab (%)	Whipping time (min.)				
		3	**5**	**7**	**9**	**11**
Density (g/cm³)	5	0.4653± 0.00 ^{Aa}	0.3542± 0.00 ^{Ba}	0.3401± 0.00 ^{Ba}	0.3643± 0.00 ^{ABb}	0.3856± 0.00 ^{ABb}
	10	0.4071± 0.00 ^{Aa}	0.4068± 0.00^{Aa}	0.3837± 0.00 ^{Aa}	0.4489± 0.00 ^{Aa}	0.4353± 0.00 ^{Aa}
Expansion (%)	5	44.64± 0.00 ^{Ba}	57.86± 0.00 ^{Aa}	59.54± 0.00 ^{Aa}	56.66± 0.00 ^{Aba}	54.12± 0.00 ^{Ba}
	10	51.56± 0.00 ^{Aa}	51.60± 0.00 ^{Aa}	54.34± 0.00 ^{Aa}	46.59± 0.00 ^{Ab}	48.20± 0.00 ^{Ab}
Stability (%)	5	95.0± 0.00 ^{Aa}	96.8± 0.00 ^{Aa}	100.0± 0.00 ^{Aa}	99.5± 0.00 ^{Aa}	100.0± 0.00 ^{Aa}
	10	100.0± 0.00 ^{Aa}	100.0± 0.00 ^{Aa}	100.0± 0.00 ^{Aa}	100.0± 0.00 ^{Aa}	100.0± 0.00 ^{Aa}

Mean ± standard deviation. Equal letter in the same column and equal letter in the same line did not differ by Tukey's test ($P<0.05$).

At all concentrations and whipping times evaluated, the açaí foam density was in the range of 0.2 to 0.6 suggested by Mounir (2018) [3], with the lowest density (0.3401 g/cm³) being obtained with 5% Emustab for 7 minutes of whipping. The highest density (0.4653 g/cm³) was observed at the same concentration, at 3 minutes of whipping. This condition was also the one that presented the smallest foam expansion.

Bag et al. (2011) [15] and Kandasamy et al. (2012) [16] observed a gradual increase in foam expansion with increasing whipping time, until reaching a time limit in which there was no further expansion. The increase in additive concentration used by these authors also collaborated to reduce the foams densities up to a limit in which they started to have an increase in densities. For the açaí foams there was no significant difference ($p>0.05$) between the additive concentrations up to 7 minutes of whipping, for the decrease in density, after this time, the 10% foams started to have higher density values compared to the 5%.

During the analyses, although the whipping times of 5 and 7 minutes did not differ statistically from each other at the 5% concentration, the foam coalescence obtained in the shortest time was observed a behavior that would make it difficult to transfer the foam from the kitchen mixer bowl to the drying tray. Thus, it was opted for a 7 minutes whipping time, in order to guarantee the foam stability for the drying process. The stable foam structure is desirable for quick drying and easy removal of dry material from the tray. If foam breaks or drains excessively, drying time is increased, reducing product quality [15].

3.2.3. Dehydration of açaí pulp in a foam-mat drying

The drying time of three hours was established based on previous studies, in order to reach water activities in the range of 0.3 to 0.4. As can be seen in Table 3, in tests 2 and 4 the Aw values were greater than 0.4. Since Aw is related to product stability, the products of these two tests are considered unstable and more susceptible to degradation, due to the high availability of existing water.

Table 3. Experimental designs for the foam-mat drying tests of açaí pulp powder and analyses data. TA: Total Anthocyanins, U: Moisture, L: Lightnes, Aw: Water Activity.*

Test	C (%)	T (ºC)	TA (C3G mg/100g d.b.)	U (%)	L*	Aw
1	10.00	70	93.81	3.5	21.69	0.351/0
2	10.00	50	67.83	15.0	18.33	0.8712
3	5.00	70	105.52	5.5	23.15	0.4436
4	5.00	50	57.47	10.0	31.33	0.5024
5	7.50	60	73.36	3.5	25.93	0.4421
6	7.50	60	71.90	5.7	24.99	0.3151
7	7.50	60	83.90	4.9	23.81	0.4723

Table 4 shows the results of the statistical analysis, applied to the experimental data obtained from drying açaí pulp in a foam-mat drying. Factor and interaction effects in which there is an asterisk are significant at a 95% confidence interval ($p \leq 0.05$).

None of the variables had significant effect on Aw. Although temperature was not significant ($p > 0.05$), it is observed that temperature had a negative effect on the Aw response. This is desirable to obtain powders with low Aw values, which was not possible in tests 2 and 4, probably because the minimum temperature used in the design was not enough to reduce it to adequate values.

Table 4. Estimation of effects for the response variable Water activity, Total Anthocyanins, Moisture and Lightness.

Water activity (Aw)				
Variables	**Estimated effect**	**Pure error**	***t*(2)**	**Statistical significance (*p*)**
Mean	0.485*	0.031	15.394	0.0041
Concentration	0.138	0.083	1.655	0.2396
Temperature	-0.289	0.083	-3.470	0.0739
Concentration x Temperature	-0.231	0.083	-2.765	0.1096
Total Anthocyanins (TA)				
Variables	**Estimated effect**	**Pure error**	***t*(2)**	**Statistical significance (*p*)**
Mean	79.112*	2.474	31.968	0.000
Concentration	-0.675	6.547	-0.103	0.927
Temperature	37.015*	6.547	5.653	0.029
Concentration x Temperature	-11.035	6.547	-1.685	0.233
Moisture (U)				
Variables	**Estimated effect**	**Pure error**	***t*(2)**	**Statistical significance (*p*)**
Mean	6.871*	0.420	16.326	0.003
Concentration	1.500	1.113	1.347	0.310
Temperature	-8.000*	1.113	-7.184	0.018
Concentration x Temperature	-3.500	1.113	-3.143	0.088
Lightness (L*)				
Variables	**Estimated effect**	**Pure error**	***t*(2)**	**Statistical significance (*p*)**
Mean	24.175*	0.401	60.213	0.000
Concentration	-7.230*	1.062	-6.806	0.020
Temperature	-2.410	1.062	-2.268	0.151
Concentration x Temperature	5.770*	1.062	5.431	0.032

Total anthocyanins content was between 57.47 to 105.52 mg/100g d.b. (Table 3) is lower than that found by Costa et al. (2015) [5] in a fluidized bed with values ranging from 81.07 to 269.82 mg/100g (d.b.).

Temperature (T) was the only variable with a statistically significant effect ($p \leq 0.05$) for total anthocyanin (TA) responses, showing a positive effect with increasing temperature. For Tonon et al. (2010) [17] and Costa et al. (2015) [5] the drying temperature was also significant in total anthocyanins content in dehydrated açaí, however, with negative effects on the responses. It is estimated that this contradiction observed in the drying açaí in a foam-mat drying in relation to these authors is related to the enzyme peroxidase inactivation, in the range of temperature and processing time evaluated in the present study. Peroxidase is heat resistant, due to its inactivation starting at 70 ºC. In general, it is assumed that when peroxidase is inactivated, all other enzymes are also inactivated [14], and in açaí this would be the case of the polyphenoloxidase enzyme, which together with peroxidase, catalyze the anthocyanins oxidation reaction.

The T effect for moisture (U) response was statistically significant ($p \leq 0.05$), being negative with increasing temperature, which is desirable to obtain lower moisture content. The same behavior was observed by Costa et al. (2015) [5] in fluidized bed and Tonon et al. (2010) [17] in the spray drying, both with açaí.

For L* responses, the additive concentration was significant, as also observed by Chaux-Gutiérrez et al. (2017) [18], and showed a negative effect, that is, higher concentrations would result in lower L* powders. The C x T interaction was also significant, however with a positive effect, indicating higher L* values. By eliminating the non-significant factors, the regression significance and the lack of fit in relation to 95% confidence ($p \leq 0.05$) was verified, using the F test in the variance analysis (Table 5).

Table 5. Variance Analysis (ANOVA) for Total Anthocyanins (TA), Moisture (U), and Lightness (L).*

TA						
Factors	**Quadratic sum**	**Degree of freedom**	**Mean square**	**F_{calc}**	**F_{tab*}**	**R^2**
Regression	1370.11	1	1370.11	27.74	6.60	0.8472
Residue	246.98	5	49.39			
Lack of fitt	161.24	3	53.74	1.25	19.16	
Pure error	85.74	2	42.87			
Total	1617.09	6				
U						
Regression	101.00	3	33.66	21.35	9.277	0.955
Residue	4.73	3	1.57			
Lack of fit	2.25	1	2.25	1.81	18.513	
Pure error	2.48	2	1.24			
Total	105.73	6				
L*						
Regression	85.56	2	42.78	15.71	6.94	0.8870
Residue	10.89	4	2.72			
Lack of fit	8.63	2	4.31	3.83	19	
Pure error	2.25	2	1.12			
Total	96.46	6				

In general, more than 80% of the responses variability can be explained by the three models generated (regression coefficients of 0.8472, 0.9550, and 0.8870 for total anthocyanins, moisture, and L*, respectively), represented by the equations 2, 3, and 4.

$$TA\ (mg/100g\ C3G) = 79.11 + 18.50\ T \quad (2)$$

$$U\ (\%) = 6.87 - 4.00\ T \quad (3)$$

$$L^* = 24.17 - 3.61\ C + 2.88\ CT \quad (4)$$

The models also presented significant regressions at the 95% confidence level (F calc higher than the F tab) and non-significant lack of fit at the same confidence level (F calc lower than the F tab), thus becoming useful models. According to Box and Wetz (1973) [19], for a model to be considered not only useful, but also predictive, the F calc value must be greater three or four times than the F tab value. Therefore, only the model for total anthocyanins (Equation 2) meets this criterion and can be considered predictive.

3.2.4. Optimization of drying conditions: desirability function

The estimation of the optimal drying conditions in açaí foam-mat drying was performed using the Desirability Function, shown in Figure 3.

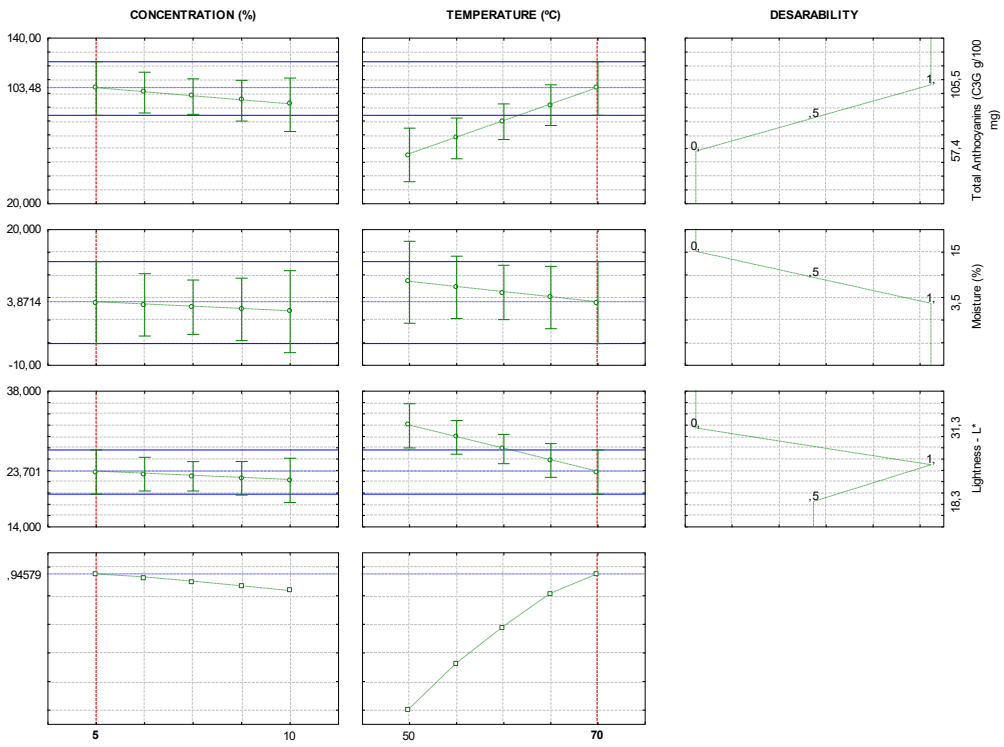

Figure 2. Desirability profile for optimizing açaí in foam-mat drying.

The desirable characteristics were established as: higher concentration of total anthocyanins (1.0), low moisture (0.0), and moderate lightness (0.5). The vertical dashed lines (in red) indicate the concentration and temperature conditions of maximum global desirability, which reaches the value of 0.9457, considered acceptable and excellent, according to Akhnazarova and Kafarov (1982) [20] classification.

Therefore, the powder produced with a 5% concentration followed by drying at 70 ºC, may present average values of 103.48 mgC3G/100g d.b. for total anthocyanins, 3.87% moisture, and 23.7% lightness.

3.3. Characterization of dehydrated açaí in the optimized condition

The açaí obtained in the optimum drying condition in a foam-mat drying was compared to freeze-dried foam (containing the same concentration of Emustab) and with freeze-dried açaí pulp, whose results are shown in Table 6. Taking into account the dehydrated açaí moisture, the freeze-dried açaí foam (FF) had the highest average and statistical difference ($p \leq 0.05$) in relation to the freeze-dried açaí pulp (FA) and the açaí obtained in the foam-mat drying (FM) optimal condition, which did not differ from each other ($p > 0.05$). The water activity was also higher for FF, showing a statistical difference ($p \leq 0.05$) among the others. This factor may be related to water retention by the additive, which when drying at low temperatures did not reach low values for water activity.

Table 6. Characteristics of products obtained in the optimized condition. FA: freeze-dried açaí pulp, FF: freeze-dried açaí foam, FM: açaí obtained in the optimal condition of foam-mat drying.

	FA	FF	FM
Moisture (%)	6.65 ± 0.35 b	9.1 ± 0.28 a	6.35 ± 0.63 b
Aw	0.4871 ± 0.04 b	0.7077 ± 0.00 a	0.3798 ± 0.37 b
L*	27.43 ± 0.02 a	20.31 ± 0.26 c	23.48 ± 0.46 b
a*	9.17 ± 0.17 a	4.20 ± 0.30 c	8.05 ± 0.18 b
b*	5.18 ± 0.05 b	2.83 ± 0.24 c	9.29 ± 0.02 a
C*	10.31 ± 0.14 b	5.18 ± 0.03 c	12.30 ± 0.10 a
h	29.23 ± 0.48 b	30.98 ± 0.13 b	49.10 ± 0.70 a

Mean ± standard deviation. Equal letter in the same line did not differ by Tukey's test (P<0.05).

All dehydrated açaís differed in terms of color parameters L*, a*, b*, and C*. Only FA and FF did not differ (p>0.05) in relation to hue (h). These differences in color can be seen in Figure 4. Low L* values indicate that the powders are dark. Positive a* values demonstrate the predominance of red coloring over green (a* negative), while b* values are also positive, indicating the predominance of yellow coloring over blue (negative b*). Color intensity indicated by C* was low in all samples, showing a grayish, weak, or diluted color. The color hue (h) in all dehydrated açaís was between 0º (referring to red + a*) and 90º (referring to yellow + b*).

Figure 3. Açaí powder obtained by the optimal condition of foam-mat drying, freeze-dried açaí foam and freeze-dried açaí pulp, respectively.

Table 7 shows total anthocyanins values found under different raw material conditions: unprocessed, foamed, and dried in a foam-mat drying. Açaí stability regarding to color, antioxidants, and polyphenols is influenced by processing, storage, and temperature, in addition to depending on the interactions between the matrix components [21]. Therefore, the total anthocyanins content becomes an important criterion in the evaluation of the açaí foam-mat drying process.

Table 7. Results of Total Anthocyanin. TA: Total Anthocyanins A: açaí pulp, FA – freeze-dried açaí pulp, E: 5% Emustab foam, FF: freeze-dried açaí foam, FM: oven dried foam-mat at 70 °C.

Sample	TA (mgC3G/100g d.b.)
A	345.42 ± 25.87 [a]
FA	404.56 ± 46.96 [a]
E	331.23 ± 5.05 [a]
FF	376.10 ± 4.79 [a]
FM	92.29 ± 8.16 [b]

Mean ± standard deviation. Equal letter in the same line did not differ by Tukey's test (P<0.05).

There was no significant difference ($p>0.05$) between the transformation process of açaí pulp into foam (A and FA) for total anthocyanins concentration. Anthocyanins concentration was higher in dehydrated by lyophilization samples compared to dehydrated in a foam-mat at 70 ºC samples, with a significant difference ($p\leq0.05$) between the two processes. Carvalho et al. (2017) [22] evaluated the qualitative and quantitative changes of anthocyanins present in jambolão juice dehydrated by foam-mat drying and by lyophilization; as a result, the two drying processes did not statistically differ in total anthocyanin responses. Through the results, the authors reinforce how the structure of anthocyanins can influence their stability; 3-glycosidic anthocyanins were more unstable and more reactive than those derived from 3,5-diglycosidic anthocyanins, especially cyanidin-3-glycoside. In other words, normally, diglycosidic anthocyanins are more stable than monoglycosidic ones.

Açaí pulp dehydrated in a foam-mat visually showed a brown color, this may be related to the loss of anthocyanins and enzymatic browning during the drying process. Some studies on drying in a foam-mat relate the darkening of final products to high temperatures [16, 23, 24]. Franco et al. (2015) [24] attribute a series of factors that may be related to the accentuated browning, among them, the enzymatic activity, also very present in yacon juice, which, during drying, due to the temperature, stimulates the activity of peroxidase (POD) and polyphenol oxidase (PPO) enzymes, promoting phenolic compounds degradation and generating black or brown pigments. Açaí naturally has POD and PPO enzymes, responsible for enzymatic browning; the açaí pasteurization with the addition of citric acid allows the inactivation of these enzymes and partial anthocyanins protection [14]. In pasteurized açaí pulp, anthocyanins decrease linearly and follow first-order kinetics, while in unpasteurized pulp, the degradation of anthocyanins follows second-order kinetics and they decrease exponentially [25].

Dehydrated açaí pulp is a good option to guarantee the fruit availability during off-season periods, facilitating transport and storage. Therefore, foam-mat drying can be used as a simpler drying technique.

4. CONCLUSION

Among the tested additives, Emustab was the most suitable for the açaí pulp foam formation. The chosen ranges of Emustab concentration (5 to 10%) and whipping time (3 to 11 min.) for foam formation allowed obtaining the adequate density for the drying process in a foam-mat. In both responses, total anthocyanins and moisture, the variable Temperature showed statistical influence. Regarding the lightness response, the Concentration and Temperature interaction, as well as the Emustab Concentration response had statistical influence. Dehydrated açaí pulp by foam-mat drying matched freeze-dried açaí pulp in terms of moisture and water activity results, by Tukey's test, while freeze-dried açaí pulp foam showed divergent results for these parameters. All dehydrated açai pulps differed in terms of color parameters L*, a*, b*, and C*, which could also be seen visually. Generally speaking, dehydration of açaí pulp in a foam-mat drying can be used as a simpler drying alternative for obtaining dehydrated açaí pulp.

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