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Drying in foam mat of mixed pulp of jambolan (*Syzygium cumini* L.) and acerola (*Malpighia emarginata* D. C.): effect of additives and temperature

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Abstract

While acerola is a source of minerals and vitamins, jambolan has a high content of phenolic compounds. The objective of this work was to evaluate the quality of the mixed jambolan, and acerola pulp obtained by drying them in a foam mat. Three foams were produced, composed of mixed pulp + 1% albumin and 0.5% additives (F1: xanthan gum; F2: carboxymethylcellulose; and F3: guar gum), subjected to agitation to form the foam and distributed in trays with 0.5 cm thick and dehydrated at 50, 60, 70 and 80 °C. The experimental design was completely randomized in a 3 x 4 factorial scheme (3 formulations and 4 drying temperatures) with three replications for the analyses. All powders showed low water content and water activity. All dry samples showed high levels of ascorbic acid and bioactive compounds. However, the increase in drying temperatures resulted in a reduction in acidity. The powders with xanthan gum (F1) generated higher levels of proteins and flavonoids, while the samples with guar gum (F3) had higher levels of solubility and; powders with carboxymethylcellulose (F2) had higher contents of anthocyanins and phenolic compounds, standing in nutritional and functional components among the formulations for drying in a foam mat.

Keywords: albumina.; carboxymethylcellulose.; dehydration.; guar gum.; xanthan gum.

Introduction

Mixed fruit pulps are products commonly elaborated to obtain new flavors. With the growing knowledge about the role of micronutrients and bioactive compounds, there is a new line of studies, in which the elaboration of mixed pulps has as main purpose the obtainment of compounds with higher bioactive potential.

Among the fruits that stand out for having a special nutritional and bioactive characteristic, acerola (*Malpighia emarginata* D. C.) had its consumption boosted by its high ascorbic acid content (Cruz et al., 2019).

Jambolan (*Syzygium cumini* (L.) Skeells) is known for its purplish pigment that gives color to the fruit directly related to the high content of phenolic compounds. Its flavor is predominantly sweet and astringent (Brandão et al., 2019).

The perishability and seasonality of fruits are the reason for the necessity of fast consumption and/or post-harvest processing. For these reasons, preservation methods such as drying are of great relevance to increase the shelf life and commercial value of plant products (Sousa et al., 2019). In foam mat drying, a liquid product is converted into a stable foam by the addition of foaming agents and mechanical agitation, placed to dry in a thin, porous layer at relatively low temperatures and for short periods of time (Tavares et al., 2017).

Foam mat drying is a drying technique used on heat-sensitive, sticky, and high-sugar foods such as fruit pulps and juices. The efficiency of this method is explained by the fact that air bubbles increase the internal surface area, creating a structure less resistant to the transport of water vapor mass, which provides a reduction in temperature and dehydration time (Freitas et al., 2018).

This work was carried out with the aim of evaluating the physical, bioactives and physicochemical quality of mixed jambolan and acerola pulp powders, produced by foam-mat drying method at temperatures from 50 to 80 ºC.

Results and discussion

Physicochemical analysis

Table 1 shows the average values of water content, water activity, pH, soluble solids and acidity of the blended pulp powder formulations resulting from the application of the foam-mat drying method.

Water content in the mixed pulp powder formulations varied from 7.59 to 16.76 g 100 g^{-1}, statistically reducing with each 10 ºC increase in drying temperature. Among formulations, sample F1 maintained the highest water content at all drying temperatures. The differences in water content among the formulations of mixed powdered pulp may be related to the drying temperature and the volumetric expansion of the foam that depending on its values allows the incorporation of more air into the pulp.

Thus, heat can be transferred more efficiently and when there is an increase in temperature there is an increase in the temperature gradient between the environment and the drying air, resulting in an increase in the driving force of water evaporation (Thuwapanichayanan et al., 2008).

Silva et al. (2019) studied the drying of acerola (*Malpighia emarginata* D.C.) residues and verified that when drying the samples at a temperature of 150 °C water content of 6.7 g 100 g^{-1}. Almeida et al. (2020), when producing flour from jabuticaba (*Myrciaria cauliflora*) peel by convective drying at 50 °C, found that the samples reached a water content of 14.90 g 100 g^{-1}.

The water activity of the mixed powder pulps also suffered significant reductions statistically with the increases in drying temperature, probably due to the lower moisture content of the samples at higher temperatures. Among formulations, F1 showed the highest values in most cases, while F2 and F3 alternated as having the lowest ones.

The reductions in water activity from 50 to 80 °C, for F1, F2 and F3, were 23.46; 31.40 and 21.40%, respectively. Gomes et al. (2017) studying the drying of acerola pulp, reported a reduction in a_w from 0.330 to 0.276 between temperatures of 60 and 80 °C.

The powders presented very acidic pH values (< 4.5), an important characteristic to avoid the development of microorganisms. The values obtained in the drying temperatures were similar among the formulations, being equal between F2 and F3 at 60 and 80 °C, indicating that the additives did not exert a buffering action on the samples. The F1 presented the highest pH values in the temperature ranges used. The xanthan gum present in F1 is able to stabilize emulsions in a wide range of pHs and temperatures (Luvielmo and Scamparini, 2009).

In F2 the lowest pH averages were determined, explained by the pH range of carboxymethylcellulose (4.5-6.0) being lower compared to that of guar gum (5.5-6.2) (Gil, 2007). Rigueto et al. (2020), determined pH in the range of 3.5 to 3.47 in jambo (*Syzygium malaccense*) powders dehydrated by foam mat drying at temperatures from 50 to 70 °C.

The highest contents of soluble solids (SS) alternated between formulations F1 and F3, depending on the drying temperature. With the increase of temperature, formulations F2 and F3 had their contents reduced, contrary to F1, whose SS increased between 50 and 80 ºC.

Silva et al. (2019), evaluated the effect of drying baru (*Dipteryx alata* Vogel) and observed that the soluble solids content decreased with increasing drying temperature between 40 and 100 °C, ranging from 2.65 to 2.57 °Brix.

The acidity had alternately higher values in samples F3 and F1. With increasing drying temperatures, the acidity was reduced in a statistically significant way inversely to the pH. The decrease in citric acid content is due to its low stability at high temperatures (Podsedek, 2007). Freitas et al. (2018) reported acidity reduction in drying cashew (Spondias mombin L.) pulp from 1.2 g 100 g^{-1} in drying at 50 °C to 0.6 g 100 g^{-1} at 80 °C.

Table 2 shows the average values of protein content, total sugars, reducing and nonreducing sugars of the mixed pulp powder formulations obtained by foam mat drying.

The protein contents were statistically higher in sample F1, followed by F3 and, with the lowest values, by sample F2 at all drying temperatures. With increasing drying temperatures, samples F2 and F3 showed a tendency to reduce protein, contrary to sample F1. Crocetti et al. (2016) verified protein contents of 16.92 g 100 g^{-1} in beet powders (*Beta vulgaris* L.) obtained in oven drying and 14.58 g 100 g^{-1} in freeze-drying.

The total sugars were higher in formula F3 at lower temperatures. At 70 and 80 ºC the values were reduced, being exceeded by the contents of sample F2. In sample F1, the values were significantly lower than the others, reaching only 45% of the value of F3 at 50 ºC. As the drying temperature increased, the contents of samples F2 and F1 increased, and those of F3 decreased. Seraglio et al. (2018) reported values of 52.88 g 100 g^{-1} for guabiju (*Myrcianthes pungens*) pulp and 54.53 g 100 g^{-1} in jambolan (*Syzygium cumini*) pulp.

In general, the mixed pulp powder formulations showed low levels of reducing sugars, and the levels remained approximate among the three formulations and showed no trend of behavior with increasing drying temperature. Orqueda et al. (2016) similarly found low reducing sugars, 0.40 g 100 g^{-1}, in tamarillo (*Solanum betaceum*) powder.

Among the sugars present, there was a predominance of nonreducing sugars. Nonreducing sugars showed similar behavior to total sugars, with higher values alternating between F2 and F3, with increasing contents in F2 and F1 and decreasing in F3, with increasing drying temperature. Chahdoura et al. (2019), evaluating *Opuntia microdasys* powder, determined a value of 50 g 100 g^{-1} for the content of nonreducing sugars.

Bioactives analysis

Table 3 shows the mean values of ascorbic acid, flavonoids, anthocyanins and total phenolic compounds of the mixed pulp powder formulations obtained by foam mat drying.

It is observed, except at a temperature of 60 ºC, higher values of ascorbic acid in the F1 formulation, and the lowest in F2, at all drying temperatures. As the temperature increased, the ascorbic acid contents progressively reduced, with final reductions between 50 and 80 ºC of about 26%.

Nogueira et al. (2019) reported that acerola waste powders, dried by the system consisting of a compacted bed dryer assisted by infrared radiation (IR), had the ascorbic acid contents reduced by about 20% compared to the fresh product.

The flavonoid contents were higher in formulation F1 at all drying temperatures, followed by formulation F2 as of 60 °C. As temperature increased, statistically significant and progressive reductions were observed at each increase of 10 ºC. Despite this, samples F1 and F2, dried at 80 ºC still retained 95.43 and 86.64% of the flavonoid content determined at 50 ºC, respectively.

Tavares et al. (2019), studying foam mat drying of BRS Violeta grapes (BRS Rúbea x IAC 1398-21) at 60, 70 and 80 °C, observed a reduction in flavonoid content from 11.28 to 8.25 mg 100 g^{-1}.

Anthocyanins were best preserved in formulation F2 at all drying temperatures, followed by formulation F1. With the increase of the drying temperature the contents were reduced in statistically significant values in the three formulations. Between 50 and 80 ºC formulations F1, F2 and F3 preserved 56, 61 and 59% of anthocyanins contents, respectively.

Vimercati et al. (2019) verified anthocyanin contents in the range of 90 to 130 mg 100 g^{-1} in dehydrated strawberry (*Fragaria* sp.) pulp. Braga et al. (2019) presented results for anthocyanin content of 199.72 mg 100 g^{-1} in blackberry (*Rubus* spp.) powder.

Table 1. Physicochemical parameters of powdered mixed pulp formulations obtained by foam mat drying, dry mass.

Parameters		Temperature (°C)			
		50	60	70	80
Water contente (g 100 g^{-1})	F1	16.76 ±0.06^{aA}	14.27±0.17^{aB}	13.61±0.07^{aC}	13.54±0.15^{aC}
	F2	15.36±0.12^{bA}	11.45±0.13^{bB}	8.55±0.08^{bC}	7.60±0.05^{bD}
	F3	15.20 ±0.12^{bA}	14.27±0.13^{aB}	7.95 ±0.16^{cC}	7.59 ±0.05^{bD}
a_w	F1	0.243±0.002^{aA}	0.215±0.002^{aB}	0.196±0.002^{aC}	0.186±0.002^{bD}
	F2	0.242±0.002^{aA}	0.207±0.002^{bB}	0.189±0.002^{bC}	0.166±0.001^{cD}
	F3	0.243±0.002^{aA}	0.203±0.001^{cB}	0.194±0.001^{aC}	0.191±0.001^{aD}
pH	F1	3.85±0.01^{aC}	3.87±0.00^{aB}	3.83±0.01^{aC}	3.89±0.01^{aA}
	F2	3.58±0.01^{cD}	3.67±0.00^{bC}	3.73±0.00^{cB}	3.80±0.00^{bA}
	F3	3.66±0.01^{bD}	3.67±0.01^{bC}	3.78±0.01^{bB}	3.80±0.01^{bA}
Soluble solids (°Brix)	F1	5.20±0.00^{cD}	5.22±0.00^{cC}	5.62±0.00^{aB}	5.82±0.00^{aA}
	F2	5.80±0.00^{bA}	5.60±0.00^{bB}	5.60±0.00^{cB}	5.20±0.00^{cC}
	F3	6.00±0.00^{aA}	5.80±0.00^{aB}	5.60±0.00^{bC}	5.80±0.00^{bB}
Acidity (g citric acid 100 g^{-1})	F1	5.39±0.04^{cA}	5.24±0.06^{bB}	5.18±0.03^{aB}	4.97±0.03^{aC}
	F2	5.65±0.03^{bA}	5.25±0.03^{bB}	5.09±0.04^{bC}	4.63±0.03^{cD}
	F3	5.84±0.02^{aA}	5.38±0.06^{aB}	4.98±0.06^{cC}	4.88±0.03^{bC}

Means followed by the same lower case letter in the columns and capital in the lines, do not differ statistically by Tukey test at 5% probability ($p<0.05$).

Table 2. Physicochemical parameters of powdered mixed pulp formulations obtained by foam mat drying, dry mass.

Parameters		Temperature (°C)			
		50	60	70	80
Protein (g 100 g^{-1})	F1	14.64±0.15^{aB}	14.80±0.17^{aAB}	14.80±0.14^{aAB}	14.93±0.03^{aA}
	F2	13.63±0.05^{cA}	13.30±0.05^{cB}	13.08±0.26^{cB}	13.14±0.11^{cB}
	F3	14.12±0.13^{bA}	14.28±0.15^{bA}	13.53±0.15^{bB}	13.54±0.21^{bB}
Total sugars (g 100 g^{-1})	F1	33.85±0.09^{cD}	38.90±0.13^{cC}	39.85±0.08^{cB}	40.91±0.08^{cA}
	F2	54.68±0.20^{bD}	56.23±0.24^{bC}	59.14±0.11^{aB}	61.31±0.23^{aA}
	F3	61.10±0.14^{aB}	61.48±0.14^{aA}	58.64±0.14^{bD}	59.66±0.11^{bC}
Reducing sugars (g 100 g^{-1})	F1	0.29±0.30^{bD}	0.32±0.32^{aB}	0.33±0.33^{aA}	0.31±0.31^{aC}
	F2	0.31±0.00^{aA}	0.31±0.00^{bA}	0.25±0.00^{cC}	0.28±0.00^{bB}
	F3	0.29±0.00^{bB}	0.30±0.00^{bA}	0.28±0.00^{bC}	0.26±0.00^{cD}
Non-reducing sugars (g 100 g^{-1})	F1	31.88±0.08^{cD}	36.66±0.13^{cC}	37.55±0.08^{cB}	38.65±0.08^{cA}
	F2	51.92±0.00^{bD}	53.38±0.00^{bC}	55.93±0.00^{aB}	57.99±0.00^{aA}
	F3	57.93±0.00^{aB}	58.28±0.00^{aA}	55.44±0.00^{bD}	56.43±0.00^{bC}

Means followed by the same lower case letter in the columns and capital in the lines, do not differ statistically by Tukey test at 5% probability ($p<0.05$).

Table 3. Bioactive compounds from powdered mixed pulp formulations obtained by foam mat drying, dry mass.

Parâmetros		Temperatura (°C)			
		50	60	70	80
Ascorbic acid (mg 100 g^{-1})	F1	800.58±0.00^{aA}	652.35±0.00^{bB}	633.93±0.00^{aC}	601.18±0.00^{aD}
	F2	713.84±0.00^{cA}	617.75±0.00^{cB}	549.32±0.00^{bC}	518.97±0.00^{cD}
	F3	750.33±0.00^{bA}	680.68±0.00^{aB}	548.06±0.00^{bC}	543.28±0.00^{bD}
Total flavonoids (mg 100 g^{-1})	F1	82.34±0.10^{aA}	80.32±0.00^{aB}	79.30±0.13^{aC}	78.57±0.00^{aD}
	F2	81.86±0.05^{cA}	78.69±0.05^{bB}	75.08±0.05^{bC}	70.92±0.05^{bD}
	F3	82.24±0.06^{bA}	78.60±0.05^{cB}	69.40±0.06^{cC}	68.55±0.04^{cD}
Anthocyanins*	F1	180.29±1.39^{bA}	165.94±1.25^{bB}	144.55±0.63^{bC}	100.86±0.97^{bD}
	F2	207.92±1.36^{aA}	197.14±1.21^{aB}	178.96±1.31^{aC}	126.03±0.60^{aD}
	F3	136.98±0.39^{cA}	127.71±0.08^{cB}	93.80±1.19^{cC}	80.13±0.31^{cD}
Phenolic compounds**	F1	6552.96±0.00^{bA}	5874.97±0.00^{bB}	5455.45±0.00^{bC}	5159.65±0.00^{bD}
	F2	6999.34±0.00^{aA}	6593.02±0.00^{aB}	6053.36±0.00^{aC}	5537.12±0.00^{aD}
	F3	5902.37±0.00^{cA}	5633.94±0.00^{cB}	5324.73±0.00^{cC}	5144.35±0.00^{cD}

*mg cyanidin-3-glycoside equivalente 100 g^{-1}; **mg gallic acid equivalente 100 g^{-1}. Means followed by the same lower case letter in the columns and capital in the lines, do not differ statistically by Tukey test at 5% probability ($p<0.05$).

Table 4. Physical parameters of powdered mixed pulp formulations obtained by foam mat drying, dry mass.

Parameters		Temperature (°C)			
		50	60	70	80
Angle of repose (°)	F1	35.64±0.37^{bA}	35.04±0.26^{bB}	34.38±0.26^{bC}	34.36±0.16^{bC}
	F2	37.94±0.44^{aA}	36.19±0.52^{aB}	36.12±0.73^{aB}	36.09±0.74^{aB}
	F3	35.05±0.76^{cA}	34.13±0.46^{cAB}	33.55±0.40^{cBC}	32.77±0.45^{cC}
Absolute Density (g cm^{-3})	F1	0.98±0.01^{cB}	0.91±0.01^{cC}	1.15±0.01^{aA}	1.15±0.01^{aA}
	F2	1.11±0.01^{bB}	1.14±0.01^{aA}	1.09±0.01^{bC}	1.06±0.01^{bD}
	F3	1.24±0.01^{aA}	1.09±0.01^{bB}	1.05±0.01^{cC}	0.89±0.01^{cD}
Apparent Density (g cm^{-3})	F1	0.42±0.00^{bC}	0.46±0.00^{bB}	0.51±0.00^{bA}	0.46±0.00^{bB}
	F2	0.38±0.00^{cD}	0.39±0.00^{cC}	0.40±0.01^{cB}	0.40±0.00^{cA}
	F3	0.49±0.00^{aD}	0.51±0.00^{aC}	0.55±0.01^{aB}	0.56±0.00^{aA}
Density compressed (g cm^{-3})	F1	0.50±0.00^{bC}	0.53±0.00^{bB}	0.57±0.00^{bA}	0.53±0.00^{bB}
	F2	0.50±0.00^{bB}	0.51±0.00^{cA}	0.51±0.00^{cA}	0.51±0.00^{cA}
	F3	0.57±0.00^{aD}	0.60±0.01^{aC}	0.65±0.01^{aB}	0.68±0.00^{aA}
Fator de Hausner	F1	1.22±0.03^{bA}	1.16±0.00^{cB}	1.13±0.02^{cC}	1.16±0.01^{cB}
	F2	1.31±0.03^{aA}	1.30±0.00^{aA}	1.26±0.02^{aB}	1.25±0.01^{aB}
	F3	1.17±0.00^{cB}	1.17±0.02^{bB}	1.19±0.00^{bB}	1.20±0.00^{bA}
Índice de Carr (%)	F1	16.66±0.00^{bA}	13.65±0.00^{cB}	10.01±0.00^{cC}	13.64±0.00^{cB}
	F2	23.49±1.57^{aA}	23.07±0.00^{aA}	20.52±1.00^{aB}	19.82±0.38^{aB}
	F3	14.29±0.00^{cB}	14.39±1.25^{bB}	15.79±0.00^{bA}	16.66±0.00^{bA}
Solubilidade (%)	F1	40.87±0.66^{cD}	42.22±0.57^{cC}	44.07±0.17^{bB}	45.11±0.14^{bA}
	F2	44.70±0.94^{bC}	46.52±0.36^{aB}	47.46±0.58^{aA}	47.53±0.47^{aA}
	F3	46.32±1.07^{aA}	45.17±0.64^{bAB}	44.13±0.51^{bB}	43.17±0.74^{cC}

Means followed by the same lower case letter in the columns and capital in the lines, do not differ statistically by Tukey test at 5% probability ($p<0.05$).

The total phenolic compounds showed higher values in samples F2, followed by F1, at all drying temperatures. The retention of phenolics in these two formulations between the temperatures of 50 and 80 ºC were 79.11 and 78.74%, respectively. The drying temperature affected all formulations equally, with progressive reductions in the contents as temperature raised. During drying processes, the activation of oxidative enzymes, such as polyphenoloxidase and peroxidase, can lead to the loss of phenolic compounds (Valadez-Carmona et al., 2017).

Nemzer et al. (2018), studying powders of blueberry (*Vaccinium myrtillus*), sour cherry (*Prunus cerasus*), strawberry (*Fragaria×ananassa*) and cranberry (*Vaccinium macrocarpon*) reported total phenolic values of 1920 mg 100 g^{-1}, 1330 mg 100 g^{-1}, 3730 mg 100 g^{-1} and 1690 mg 100 g^{-1}, respectively.

Physical analysis

Table 4 shows the average values of the physical parameters of the mixed pulp powder formulations obtained by foam mat drying. The angle of repose resulted higher in formulation F2, followed by formulation F1, at all drying temperatures. With increases in temperature, the angles tended to reduce in all samples, which is an advantage in material handling as it indicates better fluidity. Huang et al. (2018) studying beet (*Beta vulgaris*) powder reported angles of repose of 33.59°.

The different additives did not interfere in the absolute density of the formulations, with higher and lower values alternating between the samples. Similarly, it is not possible to identify consistent effect of the different drying temperatures, since the densities showed divergent effects reducing in F2 and F3 and increasing in F1. Silva et al. (2019) also observed this behavior in drying acerola (*Malpighia emarginata* D.C.) pulp residue, reporting absolute density of 1.48 g cm^{-3}.

The bulk densities showed consistent behavior, with higher values in formulation F3, followed by formulation F1, in all drying temperatures. Similarly, the increase in temperature led to increases in the apparent densities of the three formulations. The increase in bulk density occurs due to the reduction of interstitial air among the particles, which is desirable because it reduces the costs of transport and packaging (Zhao et al., 2009). A powdered product with high bulk density can be stored in smaller spaces and be viable for long-distance shipments. Gagneten et al. (2018) determined in currant (*Ribes nigrum*), raspberry (*Rubus idaeus* L.) and elderberry (*Sambucus nigra*) powders apparent density values in the range of 0.38 to 0.42 g cm^{-3}. The behavior of the compacted densities followed that of the bulk densities, presenting higher values in the F3 samples, followed by F1, and increases following the higher temperatures. The optimization of its value can be useful in terms of weight and quantity of material to be transported (Fernandes et al., 2014). Varhan et al. (2019) studying fig (*Ficus carica* L.) pulp powders produced at drying temperatures of 60, 70 and 80 °C found an increase in bulk density values from 0.36 to 0.50 g cm^{-3} and compressed density values from 0.57 to 70 g cm^{-3} with increasing temperature. Formulation F2 presented the highest values of the Hausner Factor and Carr's Index in all drying temperatures. At a temperature of 50 ºC it was followed by sample F1, and from 60 ºC on, by sample F3. In both indices there are increases and decreases with the increase of temperature, preventing the establishment of a relationship with these variables.

In the Hausner factor, values lower than 1.25 indicate good flow; higher than 1.5, bad flow and values between 1.25 and 1.5 require the incorporation of additives to improve flow (Wells, 1988). The F3 and F1 powders, according to this classification, present good fluidity, with F1 standing out, with the lowest values and, therefore, the highest fluidity among the samples.

Powder F2 resulted in the highest Hausner factors, with no statistical difference between temperatures of 50 and 60 °C, as well as, between 70 and 80 °C. Dehghannya et al. (2019), studying lemon (*Citrus latifolia*) juice powder, reported Hausner factor of 1.47 and Carr's index of 32.05%.

The Carr Index expresses the compressibility of a powder, where values < 15% indicate excellent flow; 15-20% good flow; 20-35% reasonable flow; 35-45% bad flow; > 45% very bad flow (Jinapong et al., 2008). According to this classification, F1 powders from 60 °C fall in the very good flow range (10.01 to 13.65%) and at 50 ºC good flow (16.66%); F2 powders have good flow at 80 ºC and reasonable for 50, 60 and 70 ºC (20.52-23.49%); and F3 samples evidence very good flow (14.29-14.39%) in the 50-60 ºC range and good (15.79-16.66%) from 70 to 80 ºC.

Regarding the solubility analysis, all powders showed results below 50% solubility, this fact may be linked to the hydration of additives, which is faster between pH 7.5 and 9. The solubility showed a tendency to increase at 80 °C, showing that shorter drying time entails greater stability in the structure of air bubbles during drying. The powder produced in this condition presents lower water content and higher porosity, which leads to a larger surface area of the powder for binding with water (Abbasi and Azizpour, 2016).

At 50 ºC, sample F3 presented the highest solubility among the formulations. From 60 ºC on, sample F2 outperformed the others, and remained so at drying temperatures up to 80 ºC. With the increase in temperature, samples F2 and F1 were benefited with increases in solubility, a behavior contrary to the formulation F3.

The guar gum used in formulation F3 is formed of branched galactose chains, which provide greater solubility at low temperatures and require longer hydration time than the other thickeners. Although albumin provides good stability to the dry powder, the formation of agglomerates caused by the content of carbohydrates and organic acids present in the formulation can contribute to a reduction of the product dispersion in water (Fernandes et al., 2014).

Shaari et al. (2017) determined solubility between 54.10 and 64.05% in pineapple (*Ananas comosus*) powder by varying egg albumin concentration by 5, 10 and 20%, finding that foam with higher expansion elevated the solubility of the powder. According to the authors, during rehydration a soluble powder should get wet instantly, submerge rather than float.

Materials and methods

Jambolan (*Syzygium cumini* L.) and acerola (*Malpighia emarginata* D.C.) specimens from the city of Macaíba, state of Rio Grande do Norte, Brazil (latitude: 5° 51' 36'' S, longitude 35° 20' 59'' W, altitude 15 m) were used as raw material.

Obtaining the mixed pulp

The fruits were selected, washed in running water and sanitized by immersion in chlorinated water (50 ppm) for 15 minutes. Then, they were pulped in a semi-industrial horizontal pulping machine (Itametal®, compact model, Itabuna, BA, Brazil). The pulps were packed in polyethylene containers and stored in freezers (-18±2 °C) until used in the experiments. The mixed pulp was prepared by previously thawing the jambolan and acerola pulp under refrigeration (4±1 °C) and homogenizing them (1:1 ratio) in a domestic blender for 1 minute.

Foam-mat drying

Three formulations were prepared for the foam mat drying process, as follows: F1 [mixed pulp + 1% albumin (Infinity Pharma®, Campinas, SP, Brazil) + 0.5% xanthan gum (GastronomyLab®, Brasilia, DF, Brazil)]; F2 [mixed pulp + 1.0% albumin + 0.5% carboxymethylcellulose - CMC (Neon®, Suzano, SP, Brazil)]; F3 [(mixed pulp + 1.0% albumin + 0.5% guar gum (GastronomyLab®, Brasilia, DF, Brazil)]. The foams were prepared by blending the mixed pulp of jambolan and acerola with additives in a planetary mixer at maximum speed (Arno®, Deluxe model, 300 W, Itatiaia, RJ, Brazil) at appropriate times for each formulation, being F1 for 30 minutes, F2 for 20 minutes, and F3 for 5 minutes.

Each foam produced was spread on stainless steel trays, making a mat 0.5 cm thick, measured with digital caliper (Onebycitess, 0-6"/150 mm). The samples in the trays were taken for drying in an oven with forced air circulation (FANEM 320E, São Paulo, SP, Brazil) at an air speed of 1.0 m s^{-1} and temperatures of 50; 60; 70 and 80 °C, which were weighed during drying at regular time intervals until constant mass (variation of 0.01 g). The dried material was removed with a plastic spatula, and then ground in a mini processor (Mallory Oggi+, Maranguape, CE, Brazil) obtaining the mixed pulp powders of the different formulations.

Physicochemical analysis

The physicochemical analysis determined in the pulp powder recorded in dry mass (dm) were: pH by potentiometric process in pHmeter (Tecnal, model TEC-2, Piracicaba, SP, Brazil); total titratable acidity (ATT), by potentiometric titration with standardized NaOH 0.1 M (g citric acid 100 g^{-1}); water content (g 100 g^{-1}) using conventional oven at 105 °C until constant mass; soluble solids - SS (°Brix) in portable refractometer (Instrutherm, RT - 30 ATC, São Paulo, SP, Brazil); and protein content (g 100 g^{-1}) by micro Kjeldahl method, according to methodologies recommended by AOAC (2016).

Water activity (a_w) measurements were determined by direct reading at 25 °C in an Aqualab 3TE hygrometer (Decagon Devices, Washington, USA).

The total content of soluble sugars was measured by the anthrone method (Yemm and Willis, 1954). The absorbance readings were obtained at 620 nm in a spectrophotometer (Coleman, 35 D, Santo André, SP, Brazil). The results were expressed in g 100 g^{-1}. The standard curve was prepared using glucose as standard at a concentration of 100 µg mL^{-1}.

The content of reducing sugars was quantified by the colorimetric method using 3,5-dinitrosalicylic acid (Miller, 1959). The absorbance readings performed at 540 nm in a spectrophotometer and the results expressed as g 100 g^{-1}. The standard curve was prepared using glucose as standard at a concentration of 2.5 µM mL^{-1}.

Bioactives analysis

The determination of ascorbic acid was performed according to the protocol of Oliveira et al. (2010), by titration with DCFI. The result was expressed in mg 100 g^{-1}.

The total phenolic content in the extracts was quantified by the spectrophotometric method with Folin-Ciocalteu (Waterhouse, 2006) and the results expressed as mg GAE (gallic acid equivalent) 100 g^{-1}. The standard curve was prepared using gallic acid as standard at a concentration of 100 µg mL^{-1}.

The pH differential method was used to measure the total content of anthocyanins (COHEN et al., 2006). The extract

was produced with ethanol (95%) - HCl (1.5 N) solution at a ratio of 85:15 and the results expressed as mg cyanidin-3-glucoside equivalent 100 g^{-1}.

Total flavonoids were determined according to the method described by Francis (1982), having the extract being produced with ethanol (95%) - HCl (1.5 N) solution in an 85:15 ratio. The concentration of flavonoids was expressed in mg 100 g^{-1}.

Total carotenoids were estimated according to the methodology described by Lichtenthaler (1987), using acetone as extractant and the results were expressed in mg 100 g^{-1}.

Physical analysis

For determination of bulk density, a known mass of powder was used. The calculation of bulk density was given by the ratio of mass to occupied volume (g cm^{-3}), according to (Goula and Adamopoulos, 2004). To determine the compacted density, the methodology of Tonon et al. (2013) was used, calculated by the ratio between the mass and the volume occupied by the compacted sample (g cm^{-3}).

The Hausner factor was calculated by the ratio of compacted density to bulk density (Hausner, 1967). The Carr's index was calculated according to Bhusari et al. (2014).

The absolute density of the powders was determined by the pycnometric method using hexane as immiscible liquid at a temperature of 25 °C, which consists of measuring the mass in relation to the volume of the sample. Solubility was determined by the method of Eastman and Moore (1984), modified by Cano-Chauca et al. (2005).

For the evaluation of the angle of repose, the methodology described by Aulton (2005) was used, in which the powder is drained through a funnel, supported by a universal support. The analyses were performed in quadruplicate and the results presented are averages.

Statistical analysis

The experimental design was completely randomized in a 3 x 4 factorial scheme (3 formulations and 4 drying temperatures) with three replications for the analyses. Data were submitted to analysis of variance (ANOVA) by the F test and means were compared by Tukey's test at 5% ($p< 0.05$), with the aid of the Assistat software 7.7 (Silva and Azevedo, 2016).

Conclusions

All formulations provided efficient drying of the mixed pulp of jambolan and acerola, with low values of water content and water activity. It also generated samples with good flow properties.

The formulation including xanthan gum resulted in powders with higher protein content, higher flavonoid content and, at most temperatures, higher ascorbic acid content; it also resulted in samples with better Hausner Factor and Carr's Index.

The mixed pulp in powder form is a source of nutrients and functional compounds important for human nutrition, with emphasis on formulations containing CMC with higher contents of anthocyanins and phenolic compounds and; at some temperatures, it also generated samples with lower values of water activity.

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