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RESEARCH ARTICLE

Mixed pulp formulations of Jambolan (*Syzygium cumini* L.) and Acerola (*Malpighia emarginata* D.C.) for the foam-mat drying process

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ABSTRACT

Jambolan is a fruit with a sweet taste, slightly bitter and astringent, with a purple color. Acerola is a popular fruit in Brazil, rich in vitamin C. Both stand out for the high content of antioxidant compounds, whose importance has generated growing interest. In view of this, the present work was carried out with the objective of elaborating formulations with the mixed pulp of jambolan and acerola, incorporating foam promoting additives for drying by the foam-mat drying method and evaluating them for the beat time, density, volumetric expansion (overrun) and foam stability according to the beat time and physicochemical characteristics. Three formulations were made with the mixed pulp, all containing 1% albumin combined with 0.5% xanthan gum, 0.5% carboxymethylcellulose and 0.5% guar gum. The formulations were analyzed for stability, density, volumetric expansion, beating time, between 5 and 30 minutes, layer thickness, water content and volume drained at temperatures of 50 to 80 °C. All the elaborated foams were suitable for drying by the foam-mat process; the best results of density, beating time, overrun, stability (volume drained), drying time and yield were obtained with the albumin/guar gum combination, followed by albumin/CMC; the incorporation of additives and the foaming mixture changed the composition of the formulations in relation to the mixed pulp (control), increasing the TSS/TTA ratio, the protein content and reducing the levels of ascorbic acid, phenolic compounds, tannins, flavonoids and carotenoids, yield, shorter drying time, water content in dry base and wet base.

Keywords: *Syzygium cumini; Malpighia emarginata*; Foam-Mat; Carboxymethylcellulose; Guar Gum; Xanthan Gum

INTRODUCTION

Consumer demand for healthy food has led the fruit agribusiness to expand its offer in order to serve this new market, which requires, in addition to palatability, the ability of products to meet nutritional requirements. The class of bioactive principles, characteristic of fruit pulps, has, according to Chhikara et al. (2019) the ability to scavenge oxygen free radicals, and thus protect cells from oxidative stress.

Jambolan (*Syzygium cumini* L.) is a tree that had its origin in tropical Asia, specifically in India, East Africa and South America (Seraglio et al., 2018). The fruit, when ripe, has a brilliant purple color, a combination of sweet, mildly bitter and aromatic flavor (BALIGA et al., 2011).

Acerola (*Malpighia emarginata* D.C.) is a tropical fruit originating in Central and South America, also known as Barbados cherry, rich in vitamin C and bioactive compounds (Nogueira et al., 2019). Brazil is considered a major producer of acerola in South America, favored by its edaphoclimatic characteristics (Malegori et al., 2017).

Both jambolan and acerola are highly perishable fruits, with thin and delicate peels, which break easily and need to be subjected to a conservation process to obtain products with a good commercial reach. The processing of fruits that transform them into dry products is a strategy that allows them to be made available throughout the year, to preserve them for long periods, as well as to reduce post-harvest losses (Chhikara et al., 2018).

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

To obtain a stable foam, several foaming and stabilizing agents, such as egg albumin, isolated from soy protein, methyl cellulose, milk proteins, have been used (Abbasi; Azizpour, 2016). Foaming agents can help prevent bubble collapse during drying and increase the sample's glass transition temperature (Ozcelik et al., 2019). For foam-mat drying, different parameters such as drying temperature, concentration and nature of the blowing agent, amount of trapped air, bubble size and distribution, surface tension, required stirring time, density, foam layer thickness and its composition must be taken into consideration, to the quality of the final product (Hardy; Jideani, 2015).

In view of this, the present work aimed to elaborate foams from formulations with the mixed pulp of jambolan and acerola and additives, evaluate them in terms of physical, physical-chemical characteristics and bioactive compounds and determine the agitation time and layer thickness.

MATERIAL AND METHODS

Raw material

Mature specimens of jambolan (*Syzygium cumini* (L.) Skeels) and acerola (*Malpighia emarginata* DC) were collected in the municipality of Macaíba, state of Rio Grande do Norte, Brazil (latitude: 5° 51' 36" S, longitude 35° 20' 59" O, altitude 15 m). They were selected, washed, sanitized by immersion in chlorinated water (50 ppm) for 15 min and rinsed under running water.

The pulping was performed in a horizontal pulping machine (Itametal®), with a sieve with a 4 mm mesh, followed by refinement in a sieve with a 2 mm mesh to eliminate small fractions of waste. Subsequently, both pulps were filled in polyethylene packaging and stored in a freezer at -18 ° C.

Preparation of formulations and foams

The jambolan and acerola pulps were thawed and the mixed jambolan and acerola pulp was made by mixing equal parts of the two pulps (1:1 m m^{-1}) by homogenizing them in a domestic blender for 1 min. The additive used as a foaming agent in the formulations was albumin (Infinity Pharma®) and as stabilizers, carboxymethylcellulose (CMC) (Neon®), guar gum (GastronomyLab®) and xanthan gum (GastronomyLab®).

Three formulations were prepared with mixed pulp and additives: F1 (mixed pulp + 1.0% albumin + 0.5% xanthan gum); F2 (mixed pulp + 1.0% albumin + 0.5% CMC); F3 (mixed pulp + 1.0% albumin + 0.5% guar gum). The formulations were beaten at 5, 10, 15, 20, 25 and 30 min in a mixer at maximum speed (Arno®, Deluxe, 300 W) to form the foams.

Physical properties of foams

Density

The density of the foams, in triplicate, for the beat times of 5, 10, 15, 20, 25 and 30 minutes, were determined by the relation between the mass and the volume of the foam, placed in a 100 mL aluminum pycnometer (25 ± 1 °C). The results were expressed in g cm^{-3}.

Volumetric expansion was calculated for the beating times, considering the density of the mixed pulp and foam according to Equation 1 (Asokapandian et al., 2015). Overrun= $\frac{\rho_p - \rho_e}{\rho_e} \times 100$ (1). On what: *Overrun* – volumetric expansion (%); ρ_{p-} mixed pulp density (g cm^{1}); ρ_e – foam density (g cm^{1}).

Foam stability

The foam stability for each formulation was determined, in triplicate, according to the Karim e Wai (1999), for each beat time. A system consisting of a 25 mL beaker, a 50 mL short-stemmed glass funnel and a nylon filter was assembled. 15 g of foam was placed in the system filter and taken to the oven with forced air circulation at temperatures of 50, 60, 70 and 80 °C, measuring the volume of liquid drained after 90 min.

The physical-chemical analyzes and bioactive compounds were performed, in quadruplicate, in the mixed pulp and in the foams and expressed on a wet basis (wb). Following the methodologies by Association of Official Analytical Chemists (AOAC, 2016), hydrogen potential (Tecnal, model TEC-2,) was determined, total titratable acidity (TTA), by potentiometric titration with standardized 0.1 M NaOH (g citric acid 100 g^{1}), total soluble solids - TSS (°Brix), water content (g 100 g^{1}), by gravimetry, using a conventional oven at 105 °C until constant mass, ash obtained by calcination in a muffle furnace at 550 ºC and proteins, using the micro "Kjeldahl" method. The TSS/TTA ratio was estimated by the quotient of the values of total soluble solids and total titratable acidity. The measurements of water activity (a_w) were determined by reading at 25 °C in a hygrometer (Aqualab 3TE, Decagon). The total content of soluble sugars was measured by the anthrone method (Yemm; Willis, 1954). The standard curve was prepared using glucose as a standard, at a concentration of 100 µg mL^{1}. The content of reducing sugars was quantified by the colorimetric method (Miller, 1959), using 3,5-dinitrosalicylic acid and the results expressed in g 100^{1} g wb. The standard

curve was prepared using glucose as a standard at a concentration of 2.5 μM mL^{1}. The determination of ascorbic acid was performed according to the Oliveira et al. (2010), by titration with 2,6-dichlorophenol-indophenol (DCFI). The result was expressed in mg 100^{1} g wb. The total phenolic content in the samples was quantified by the spectrophotometric method with Folin-Ciocalteu (Waterhouse, 2006) and the results expressed in mg EAG (gallic acid equivalent) 100^{1} g wb. The standard curve was prepared using gallic acid at a concentration of 100 μg mL^{1}. The concentration of total tannins was quantified by the method of Porter, Hrstich e Chan (1986), using Folin-Denis as reagent. The standard curve was constructed with 0.1 mg mL^{-1} tannic acid standard solution and the results expressed in mg EAT (tannic acid equivalent) 100 g^{-1} wb. The pH difference method was used to measure the total anthocyanin contente (Cohen et al., 2006). Two dilutions of the same sample were made in buffer solutions of pH = 1 (0.025 M potassium chloride) and pH = 4.5 (0.4 M sodium acetate). The extract was produced with an ethanol solution (95%) - HCl (1.5 N) in the proportion of 85:15. The absorbance of each dilution was measured at λ=510 and 700 nm against a distilled water blank using a spectrophotometer (Coleman, 35 D), after 24 hours of rest in refrigeration (8 ± 1 °C) and the results expressed in mg of cyanidin-3-glycoside equivalent 100 g^{-1} wb.

Total flavonoids and antocyanins were established according to the method described by Francis (1982). In which, the extract was produced with an ethanol solution (95%) - HCl (1.5 N) in the proportion of 85:15. The absorbance readings were made on a spectrophotometer (Coleman, 35 D) at 374 (flavonoids) and 535 (antocyanins) nm, after 24 hours of rest in refrigeration (8 ± 1 °C). The concentration of flavonoids was expressed in mg 100^{1} g wb. Total carotenoids were estimated according to the methodology described by Lichtenthaler (1987). The results were expressed in mg 100^{1} g wb.

Foam mat thickness assessment

The foams of formulations F1, F2 and F3, in triplicate, were spread on stainless steel trays in layer with thicknesses of 0.5; 1.0 and 1.5 cm and taken to oven drying with forced air circulation at 70 °C and air speed of 1.0 m s^{1} (FANEM, model 320E). The loss of water during drying was monitored by weighing the trays at regular intervals of time, until successive weighing did not show mass variation. After the drying process, the dried samples were scraped, with a spatula, from the trays, crushed in a mini processor (Mallory, model Oggi) and the water content was determined in an oven at 105 °C until constant mass, and the powder yield (Equation 2). $R = \frac{\left(P_f - P_i\right)}{P_i} x\ 100$ (2) On what: R – yield (% m m^{1}); P_f - dry sample mass (g); P_i - foam mass (g).

The selection of the best foam layer thickness for drying was evaluated using the yield, water content and drying time values of each formulation.

Statistical analysis

The analyzes of the physical-chemical parameters and bioactive compounds were carried out in triplicate and the data submitted to analysis of variance (ANOVA) by the F test and the means compared by the Tukey test at 5% of significance, with the software Assistat version 7.7 beta (Silva; Azevedo, 2016).

RESULTS AND DISCUSSION

The average density of the mixed pulp of jambolan and acerola was equal to 1.04 ± 0.01 g cm^{-3}, being similar to that of acerola pulp with 1.038 g cm^{-3} and the fruit of jambolan of 1.04 g cm^{-3}. The densities of the foams in the formulations as a function of the tapping time are shown in Table 1.

Density averages varied significantly between formulations and beat times. It was observed that the F3 foam (mixed pulp + 1% albumin + 0.5% guar gum), among the tested formulations, presented the lowest densities in all the beating times, with the lowest density value occurring in the 5 minutes. For foams F2 and F3 the lowest density value occurred, respectively, after 20 and 30 minutes of agitation. Industrially, shorter beat times are desirable as they lead to higher productivity and lower energy costs.

For Soares et al. (2001), the density values considered ideal for drying in a foam-mat are between 0.1 and 0.6 g cm^{-3}, since foam with lower density remains stable for a longer period, thus reducing the drying time. Given these values, it appears that all tested formulations reached satisfactory density values.

It can be seen that for F1 there was a tendency to reduce the density with the beat time; for F2, the decrease occurred up to 20 min followed by an increase ($p<0.05$). This decrease

Table 1: Average values of foam density of formulations (F1; F2 and F3) as a function of beating time

Beating time (min)	Density (g cm^{-3})		
	F1	F2	F3
10	0.74 ± 0.01^{bA}	0.63 ± 0.01^{bB}	0.24 ± 0.00^{cC}
15	0.72 ± 0.00^{cA}	0.52 ± 0.01^{cB}	0.30 ± 0.01^{bC}
20	0.55 ± 0.00^{dA}	0.39 ± 0.00^{fB}	0.30 ± 0.01^{bC}
25	0.55 ± 0.01^{dA}	0.41 ± 0.01^{eB}	0.31 ± 0.01^{bC}
30	0.47 ± 0.01^{eB}	0.50 ± 0.01^{dA}	0.34 ± 0.00^{aC}

Means followed by the same lowercase letters in columns and uppercase letters in lines do not differ statistically by Tukey's test at 5% probability.
F1 - albumin (1%) + xanthan gum (0.5%); F2 - albumin (1%) + CMC (0.5%); F3 - albumin (1%) + guar gum (0.5%)

in the density of the foams occurs due to the incorporation of air during the stirring step, since the high stirring speed promotes an increase in the shear rate, favoring the division of air bubbles and reduction of the interfacial tension and surface tension of the liquid to form an interfacial film (Hardy; Jideani, 2015).

In formulation F3, already at the 5 min beat time, the foam showed a density below 0.6 g cm^{-3}, after which it showed an increasing trend with the beat time ($p<0.05$). Dabestani e Yeganehzad (2018) reported that the appropriate tapping time can have a positive effect on the volume and stability of the foam, since excessive tapping time causes thinning of the lamella, changes in the bubble shape and rupture of the lamella. The appropriate beat time for each solution is a function of the chemical properties of the surfactant molecules, together with the surface tension and total viscosity.

Close density values for foam layer drying were found by Franco et al. (2015) for the foam of yacon juice with ovoalbumin (10-20%), which presented densities from 0.16 to 0.83 g cm^{-3}; by Araújo et al. (2017) for acerola pulp foam with albumin (2-10%), with densities in the range of 0.53 to 0.74 g cm^{-3}.

Salahi, Mohebbi e Taghizadeh (2014) when adding albumin and xanthan gum to the cantaloupe melon pulp for foaming found that the increase in albumin from 1 to 3% caused a significant reduction in density and an increase in xanthan gum (0.05 to 0.2%) had an adverse effect on foam expansion by increasing foam density. They reported that xanthan gum can increase the viscosity of the liquid, making it difficult to incorporate air and consequently reducing the volume expansion. This behavior was also demonstrated by the higher density of the F1 foam and longer beat time.

Regarding the volumetric expansion of the foams, the significant difference ($p<0.05$) between the three formulations and between the beating times (Table 2) is noticeable. It is observed that the F3 foam (1% albumin + 0.5% guar gum) presented the highest values of volumetric expansion in relation to the other formulations.

Table 2: Average values of the volumetric expansion (overrun) of the foams of the formulations (F1; F2 and F3) as a function of beating time

Beating time (min)	Volumetric expansion (%)		
	F1	F2	F3
10	40.19 ± 1.48^{cC}	65.25 ± 1.90^{dB}	321.11 ± 7.31^{bA}
15	44.06 ± 0.93^{cC}	99.70 ± 3.22^{cB}	245.10 ± 7.05^{cA}
20	86.96 ± 1.60^{bC}	168.12 ± 2.27^{aB}	245.92 ± 7.43^{cA}
25	87.97 ± 2.91^{bC}	153.12 ± 3.24^{bB}	234.71 ± 7.60^{dA}
30	119.26 ± 2.78^{aB}	107.71 ± 3.54^{cC}	202.07 ± 4.22^{eA}

Means followed by the same lowercase letters in columns and uppercase letters in lines do not differ statistically by Tukey's test at 5% probability.
F1 - albumin (1%) + xanthan gum (0.5%); F2 - albumin (1%) + CMC (0.5%); F3 - albumin (1%) + guar gum (0.5%)

It appears that the F3 foam obtained a greater overrun (377.43%) in the shortest stirring time (5 min), followed by the F2 foam (168.12%) at 20 min and the F1 foam (119.26%) at 30 min of stirring. The overrun is a parameter used to indicate the amount of air incorporated during the formation of the foam, it is correlated to the density of the foam, the lower the density the greater the volumetric expansion. The numerous presence of air bubbles, small and uniform, is able to maintain the foam structure during drying (Franco et al., 2016).

There is an increase in volumetric expansion with increased tapping time for formulations F1 and F2. However, the F3 formulation showed the opposite behavior, that is, a reduction in the volumetric expansion with the increase of time. According to Blasco, Vinas e Villa (2011), proteins bind to the air-liquid interface and still interact with the coverslip (bubble wall) by means of electrostatic or hydrophobic forces, hydrogen bonds or covalent bonds. This interaction leads to the formation of cohesive viscoelastic films that are able to support the thickness of the film, resulting in foam with a higher percentage of volumetric expansion.

The overrun values found are for some beat times and formulations within the range observed by Ozcelik et al. (2019) for raspberry pulp foams with potato protein, maltodextrin and pectin (79.19 to 447.48%); by Affandi et al. (2017) for black cumin *(Nigella sativa)* foams with egg albumin and methyl cellulose (45 and 328%), reaching the highest percentages after 5 and 8 minutes of beating similar to that observed in the F3 foam.

Tan e Sulaiman (2019), when evaluating vinegar foams *(Hibiscus sabdariffa L.)* with the addition of egg albumin (5 to 20% w w^{-1}), found an overrun of 100 to 283%, provided by the high concentration of the foaming agent. Higher values were found for F3 at 5 and 10 minutes, with only 1% albumin and 0.5% guar gum. According to Ospina et al. (2012), due to the high affinity of guar gum with water, it provides a very high viscosity in aqueous systems, even in low doses and in a short time.

Fig. 1 shows the stability curves of the foams submitted to different temperatures in the oven (50, 60, 70 and 80 °C) for 90 min, expressed in terms of volume of liquid drained from the foam as a function of the beat time. The results demonstrated the effectiveness of hydrocolloids (xanthan gum, CMC and guar gum) on foam stability, even at the relatively low concentrations used, probably related to the increase in viscosity that contributes to the retention of the liquid phase in the foam structure.

It is observed that formulation F1 presented the largest volumes of drained liquid (0.1 to 1.2 mL), disfavoring xanthan gum in foam stability in relation to the other hydrocolloids used, followed by formulation F2 (0.1 to 0.5 mL). Formulation F3, on the other hand, did not present drained liquid (0 mL) regardless of the stirring time and temperature, due to the great pseudoplastic capacity of guar gum, a very important characteristic in stabilizing suspensions and emulsions.

In general, the volumes of liquid drained from the tested formulations were small, indicating their stability. Higher volumes (3.3–28.7 mL) were found by Abbasi e Azizpour (2016) when evaluating the effect of albumin and methylcellulose concentration on the stability of cherry foam *(Prunus cerasus* L.); by Dabestani e Yeganehzad (2018) when evaluating the effect of addition in different concentrations of Persian gum (0.05; 0.1 and 0.15) and xanthan gum (0.05; 0.1 and 0.15) in pasteurized egg white foams checking drained liquid volume of 30-70 mL and 0-60 mL, respectively, with 5 minutes of beating.

Fig. 2 shows the experimental data of foam density with *overrun* (volumetric expansion) as a function of the beat times of the F1 formulations; F2 and F3. Based on the lowest density value and the highest overrun, the best stirring times were selected. Therefore, the time of 30 minutes was considered adequate for the beat of formulation F1 (1% albumin + 0.5% xanthan gum), 20 minutes for formulation F2 (1% albumin + 0.5% CMC) and 5 minutes for formulation F3 (1% albumin + 0.5% guar gum). During the beating of the formulation the air is incorporated forming air bubbles and consequently forming the foam.

Shaari et al. (2017) when determining the effect of the beat time (10, 20 and 30 min) on the pineapple foam (Ananas comosus) with albumin (5, 10 and 20%) found the lowest density (0.28 g cm^{-3}) and the biggest overrun (79.20%) was for the 10 minutes beat time. Beating time of 5 minutes for foaming was used by Maciel et al. (2017) to prepare guava pulp foams (Psidium guajava L.) with albumin (4 and 8%).

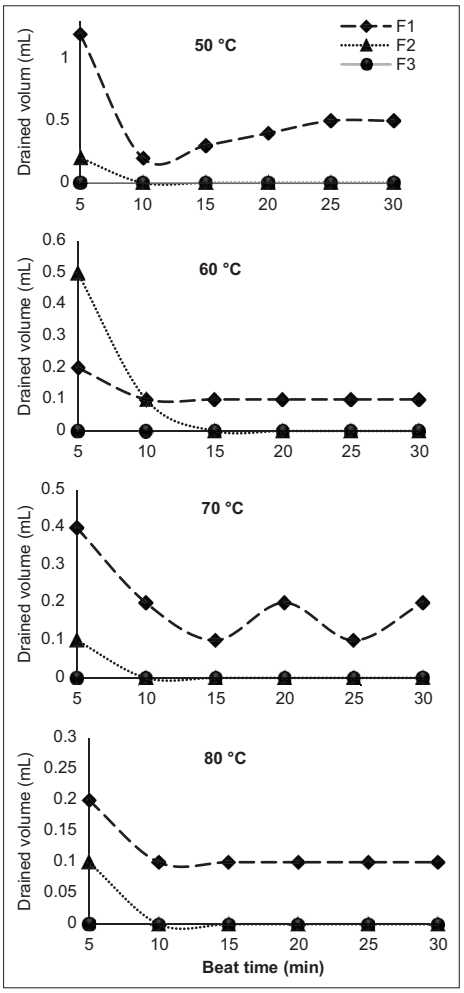

Fig 1. Volume of liquid drained from the foams of the formulations (F1, F2 and F3) as a function of beating time at different temperatures. Formulations: F1 - albumin (1%) + xanthan gum (0.5%); F2 - albumin (1%) + CMC (0.5%); F3 - albumin (1%) + guar gum (0.5%).

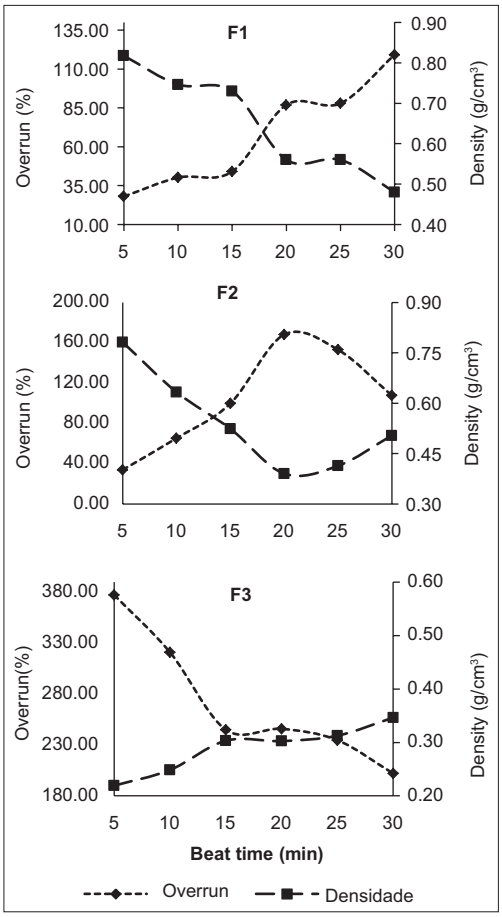

Fig 2. Overrun and Density averages as a function of the beat time of Formulations F1; F2 and F3. Formulations: F1 - albumin (1%) + xanthan gum (0.5%); F2 - albumin (1%) + CMC (0.5%); F3 - albumin (1%) + guar gum (0.5%).

Table 3: Physicochemical characterization of mixed pulp and foam formulations

Parameter	Mixed pulp	F1	F2	F3
Water content [1]	88.86±0.09^{a}	87.66±0.02^{b}	87.47±0.05^{c}	87.49±0.09^{c}
a_w	0.990±0.001^{ab}	0.989±0.001^{b}	0.991±0.001^{ab}	0.990±0.001^{a}
Proteins[1]	0.80±0.02^{c}	1.97±0.02^{b}	2.04±0.02^{a}	2.00±0.01^{b}
Hydrogen potential	3.65±0.00^{ab}	3.32±0.00^{b}	3.90±0.00^{a}	3.70±0.00^{ab}
Total soluble solids[2]	9.41±0.01^{b}	8.61±0.01^{c}	9.41±0.01^{b}	9.61±0.01^{a}
Total titratable acidity[3]	0.97±0.01^{a}	0.82±0.01^{b}	0.82±0.01^{b}	0.80±0.01^{b}
Ratio (SST/TTA)	9.73±0.12^{d}	10.53±0.06^{c}	11.51±0.07^{b}	11.95±0.06^{a}
Ash[1]	0.40±0.01^{a}	0.31±0.01^{c}	0.39±0.01^{a}	0.38±0.01^{b}
Totals sugars[1]	5.30±0.01^{c}	4.68±0.01^{d}	7.27±0.06^{a}	6.98±0.01^{b}
Reducing sugars [1]	0.02±00^{c}	0.04±00^{a}	0.03±00^{b}	0.03±00^{ab}
Nonreducing sugars[1]	5.02±0.01^{c}	4.042±0.01^{d}	6.80±0.06^{a}	6.53±0.01^{b}
Ascorbic acid[4]	1014.98±00^{a}	714.02±00^{d}	716.69±01^{c}	721.46±01^{b}
Total phenolic content[5]	875.30±0.68^{a}	798.08±0.56^{c}	796.83±0.00^{d}	828.79±0.00^{b}
Tannins[6]	989.50±1.05^{a}	948.88±2.06^{b}	947.60±1.00^{b}	932.55±0.59^{c}
Flavonoids [4]	14.27±0.03^{a}	13.75±0.06^{b}	9.39±0.03^{d}	10.90±0.03^{c}
Anthocyanins[7]	67.42±1.03^{a}	60.63±0.54^{b}	66.72±0.32^{a}	64.94±0.24^{a}
Carotenoids[4]	2.83±0.01^{a}	1.44±0.01^{b}	1.35±0.02^{d}	1.41±0.01^{c}

[1] – g 100^{-1} g bu; [2] - °Brix; [3] – g ^{c}itri^{c} acid 100^{-1} g bu; [4] – mg 100^{-1} g bu; [5] – mg gallic acid equivalent 100^{-1} g bu; [6] – mg tannic acid equivalent 100^{-1} g bu; [7] – mg Cyanidin-3-glycoside equivalent 100^{-1} g bu. Means followed by the same lowercase letters in lines do not differ statisti^{c}ally by Tukey's test at 5% probability. F1 - albumin (1%) + xanthan gum (0.5%); F2 - albumin (1%) + CMC (0.5%); F3 - albumin (1%) + guar gum (0.5%)

The compositions of mixed jambolan and acerola pulp, as well as formulations F1, F2 and F3 are shown in Table 3.

The formulated samples showed significant differences ($p<0.05$) in the water content in relation to the mixed pulp, but with a maximum difference of less than 1.4 g 100 g^{-1}.

Darniadi, Ho e Murray (2017) evaluated the effect of maltodextrin and whey protein isolate on the properties of blueberry before dehydration, in which the sample had 89.78 g 100 g^{-1} of water content, analogous to that found in mixed pulp and formulations.

All samples showed high water activity ($a_w>0.97$), with the formulations showing no differences ($p<0.05$) in relation to the mixed pulp and indicating that they have a high amount of water available for biochemical and microbiological reactions. Lemos et al. (2019) determined the acerola pulp a_w of 0.989, which corroborates the mixed pulp and the formulations.

It appears that the mixed pulp has a low protein content and a high water content, so the mixed pulp cannot form foam without the addition of foaming and stabilizing agents. According to Asokapandian et al. (2015), a foaming agent is a surfactant material, used to reduce the surface tension between two liquids and thus facilitate the formation of foam. Proteins are considered good foaming agents because they create a dense layer around the incorporated air bubbles, reducing surface tension and also providing high stability through their hydrophobicity and rearrangements, which allow rapid adsorption at the air-water interface. The protein content of the formulations is close to each other and exceeds that of the mixed pulp, the result of the use of albumin in the preparation of foams. Sabino, Brito e Silva Júnior (2018) reported protein content of 1.4 g 100^{-1} g for jambolan and Prakash e Baskaram (2018) quantified 0.40 g 100^{-1} g protein for acerola.

Mixed pulp and formulations were classified as very acidic ($pH<4.0$), according to Franco et al. (2016). The pH of all samples showed little variation between the mixed pulp and the formulations, whose additives did not cause measurable changes in acidity. Mariano-Nasser et al. (2017), when evaluating the physicochemical characteristics of fruits of eight aceroleira cultivars, reported pH values of 2.8 to 3.4.

The values of total soluble solids in the formulations and in the pulp were very close with small significant differences. Sousa et al. (2020) found in acerola pulps produced and sold in Santarém-PA, a value of 10.24 °Brix. Seraglio et al. (2018) verified total soluble solids of 10.50 °Brix in mature jambolan.

For the titratable acidity there was no significant difference between the formulations, but the averages of the three were lower and differed from the mixed pulp ($p<0.05$). A value similar to that of mixed pulp and formulations was found in acerola pulp (0.90 g 100 g^{-1}) by Prakash et al. (2016). Coelho et al. (2016) found a total acidity of 2.0% in the jambolan pulp. A variation of citric acid in fruits between 0.08 to 1.95 g 100^{-1} g implies a mild flavor with good acceptance by the consumer. In addition, some organic acids present in fruits are volatile, which contributes to a more pleasant aroma (Chitarra; Chitarra, 2005).

The TSS/TTA ratio is one of the most widely used forms of flavor evaluation, being more representative

than the isolated measurement of sugars or acidity. There were statistically significant differences ($p<0.05$) between the ratio of all samples, with lower values for mixed pulp and higher for formulation F3. Machado; Monteiro e Tiecher (2019) studying the pulp of *Physalis peruviana* L. not pasteurized during 120 days of storage at -18 °C found variation in the ratio with an interval of 8.78 to 11.07.

The formulations and the mixed pulp showed variation in ash contents, with statistical differences not associated with additives. Santos et al. (2019) when evaluating the pineapple, plum, persimmon, orange, apple, papaya, melon and strawberry pulps observed variations in the values between 0.26 and 0.47 g 100 g^{-1}.

The total sugars showed significant differences between the pulp and formulations, but in percentages that exceed what could be attributed to the addition of the foam promoters, which must be explained by the natural variability of the mixed pulp samples. Monteiro et al. (2018), studying Sapota-do-Solimões (*Quararibea cordata* Vischer) reported total sugar content of 4.2 g 100^{-1} g, placing the samples of mixed pulp and the three formulations between common values determined in fruit pulps.

The levels of reducing sugars, despite significant differences between them, had little expressive absolute values, constituting a minor fraction in all samples. Helt, Navas e Gonçalves (2018) observed, in studies with orange and red pitanga (*Eugenia uniflora*), reducing sugar levels of 1.86 g 100 g^{-1} and 1.72 g 100 g^{-1}, respectively.

Non-reducing sugars followed the same behavior as total sugars, with the highest value in sample F2, followed by F3, mixed pulp and F1, confirming the difference between samples. Khalid et al. (2017), working with 'Kinnow' mandarin, found 5.3 g 100 g^{-1} for non-reducing sugars.

The ascorbic acid concentration of the mixed pulp was reduced by about 30% in the three formulations, which showed identical values, degradation probably associated with the incorporation of air in the stirring process, promoting oxidative degradation. Cruz et al. (2018), when comparing the antioxidant activity of ripe and green acerola extracts with synthetic antioxidants (BHA and BHT), found ascorbic acid levels from 298.93 to 566.86 mg 100 mL^{-1}. The ascorbic acid content of the mixed pulp was similar to that found by Nazareno, Acevedo e Cardoso (2019) in acerola pulp (1015.42 mg 100 g^{-1}). Babu et al. (2019) found in the characterization of jambolan ascorbic acid content in the range of 25 to 44.67 mg 100 g^{-1}.

The concentration of phenolic compounds was reduced significantly between the mixed pulp and the formulations, and these, however, this difference did not exceed 9%, between the mixed pulp and the F2 formulation. Croda et al. (2017), studying mixed juçara juice and guarana, before and after pasteurization, determined concentrations of phenolic compounds with levels of 679.72 mg 100 mL^{-1} and 679.67 mg 100 mL^{-1}, respectively.

Carvalho et al. (2017) found in jambolan fruits the content of 122 mg 100 g^{-1} of phenolic compounds. Brandão et al. (2019), studying the extraction process of phenolic compounds in jambolan pulp, managed to quantify the range between 126.8 to 214.6 mg EAG 100 g^{-1}. Rezende, Nogueira e Narain (2017), when comparing conventional extraction and ultrasound-assisted extraction for the bioactive compounds of the acerola residue, verified the range of phenolic compounds from 470 to 1280 mg EAG 100 $g^{-1.}$

The content of total tannins in the mixed pulp surpassed that of formulated pulps in percentages between 4.1 and 5.76%, with significant differences between all samples. Muniyandi et al. (2019), analyzing the antioxidant capacity of *Rubus* species, verified tannin contents between 777 and 62832 mg 100 g^{-1}.

All samples showed flavonoids with significant differences between them, with the mixed pulp without additives surpassing the formulations, followed by the F1 sample and, with more pronounced differences, the F1 and F2. Souza et al. (2020) evaluating the acerola pulp pointed out flavonoid contents of 15.46 mg 100 g^{-1} similar to the mixed pulp.

The anthocyanin content remained at statistically similar values between three of the four samples, with a higher absolute value in the mixed pulp sample and exceeding the F1 formulation by 11%. Orsavová et al. (2019), studying the currants, reported anthocyanin values of 68.68 mg 100 g^{-1} in Black Negus cultivar and 60.34 mg 100 g^{-1} in NS 11 cultivar.

In the carotenoid content, the incorporation of the additives reduced them in relation to the mixed pulp, reaching 50% or less, of the sample F2, reductions probably due to the incorporation of air bubbles in the stirring process. For Chen et al. (2014), oxidation is the main cause of carotenoid losses, stimulated by air, light, enzymes and metals, forming compounds with lower molecular weight. Irías-Mata et al. (2018) verified the total of carotenoids in the murici pulp, finding a content of 39.4 μg100 g^{-1} in the yellow pulp and 31.4 μg 100 g^{-1} in the red pulp.

Table 4 shows the results of drying times, powder yield and water content of the formulations after drying in a

Table 4: Drying time, powder yield and water ᶜontent of the formulations in the different foam mat thicknesses

Formulations	Layer thickness (cm)	Time (min)	Yield (%)	Water content (% wb)	Water content (% db)
F1	0.5	300	10.63±0.17[a]	9.04±0.65[c]	11.04±0.78[c]
	1.0	390	10.57±0.10[c]	11.54±0.32[b]	13.50±0.43[b]
	1.5	750	10.43±0.08[b]	12.20±0.24[a]	14.76±0.35[a]
F2	0.5	330	11.27±0.10[a]	12.64±0.31[b]	14.47±0.41[b]
	1.0	390	11.15±0.92[a]	15.16±0.30[a]	17.88±0.41[a]
	1.5	870	10.45±0.05[a]	15.85±0.43[a]	18.84±0.61[a]
F3	0.5	210	11.36±0.02[a]	10.95±0.14[c]	12.29±0.18[c]
	1.0	240	10.45±0.09[c]	12.89±0.51[b]	14.80±0.67[b]
	1.5	510	10.82±0.02[b]	14.57±0.23[a]	17.05±0.31[a]

Means followed by the same lowercase letters in do not differ statistically by Tukey's test at 5% probability. wb – wet base; db – dry base; F1 - albumin (1%) + xanthan gum (0.5%); F2 - albumin (1%) + CMC (0.5%); F3 - albumin (1%) + guar gum (0.5%)

foam layer with three layer thicknesses (0.5; 1.0 and 1.5 cm) at room temperature 70 °C. It appears that there was a significant influence of the thickness of the foam layer on the evaluated parameters, with the 0.5 cm thick layer providing the highest yields and the shortest drying times and water contents in all formulations.

It is observed that formulation F3 obtained the shortest drying times, and F1 the lowest water content. Dehghannya et al. (2018) when investigating the effect of the thickness of the foam layer (0.4; 0.5 and 0.6 cm) on the drying in foam layer of lemon juice observed that the increase in thickness led to a reduction of 3,11% in the powder solubility index in water and 33.33% in the drying rate. In addition to reducing the quality of the final product, affecting the color, chroma index and darkening aspects. The 0.5 cm thick layer was used by Carvalho et al. (2017) in the drying in foam layer at 60, 70 and 80 °C of jambolan pulp with Emustab®, Super Liga Neutra® and maltodextrin as additives.

Matos et al. (2022) reported when drying formulations F1, F2 and F3 made with mixed jambolan and acerola pulp that the dried samples resulted in low values of water content, water activity and with good flow properties.

CONCLUSIONS

The foam made with the combination of mixed pulp added with albumin combined with guar gum showed the best values of density - in the shortest time -, overrun, density × overrun ratio, lowest volume drained at temperatures of 50 to 80 ºC; in addition to the best combination of drying time, layer thickness and yield. In all of the aforementioned criteria, the combination albumin with CMC showed intermediate results, while the combination albumin with xanthan gum, obtained less favorable results.

The incorporation of additives and the foaming mixture changed the composition of the formulations in relation to the mixed pulp (control), increasing the ratio and the protein content, in addition to reducing the levels of ascorbic acid, total phenolic compounds, tannins, flavonoids and carotenoids.

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