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Influência da temperatura de secagem de jambo vermelho (Syzygium malaccense) em camada de espuma

Influence of foam-mat drying temperature of red jambo (*Syzygium malaccense*)

Influencia de la temperatura de secado del jambo rojo (Syzygium malaccense) en la capa de espuma

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Resumo

O cerrado brasileiro constitui um dos biomas mais ricos do mundo, com espécies frutíferas nativas e exóticas, no entanto pouco exploradas. Diante dessa diversidade, destaca-se o jambo vermelho, um fruto exótico com características sensoriais marcantes, porém altamente perecível, com vida de prateleira reduzida. A secagem em camada de espuma é uma técnica que auxilia na conservação dos frutos, originando um produto em pó com características desejáveis, como elevada porosidade e capacidade de reidratação. Nesse sentido, esse trabalho objetivou analisar a influência da temperatura de secagem, além de avaliar a cinética e modelagem matemática dos dados experimentais. Ainda, foram determinadas as propriedades físico-químicas da polpa de jambo in natura e pós o processo de secagem em camada de espuma. A secagem foi realizada em estufa de circulação de ar nas temperaturas de 50, 60, 70ºC, empregando uma concentração de 4,5% (m/m) de emulsificante. Os modelos matemáticos Lewis, Midilli e Kucuk e Page foram ajustados aos dados experimentais, sendo o melhor ajuste obtido utilizando os modelos de Midilli e Kucuk e Page. Os pós da fruta apresentaram pH ácido (em torno de 3,5), o teor de vitamina C diminuiu conforme o aumento da temperatura (108,16; 88,58 e 62,16 mg, para as temperaturas de 50, 60 e 70 ºC, respectivamente) e o teor de cinzas aumentou significativamente nas amostras secas em pó devido a adição de agentes espumantes.

Palavras-chave: Frutas do cerrado; Modelagem matemática; Vitamina C.

Abstract

The Brazilian cerrado is one of the richest biomes in the world, with native and exotic fruit species, but little explored. Given this diversity, stands out the red jambo, an exotic fruit with remarkable sensory characteristics, but highly perishable, with reduced shelf life. Foam-mat drying (FMD) is a technique that aids in the preservation of fruits, resulting in a powder product with desirable characteristics such as high porosity and rehydration capacity. In this sense, this work aimed to analyze the influence of drying temperature, besides evaluating the kinetics and mathematical modeling of experimental data. In addition, the physicochemical properties of fresh jambo pulp were determined and after the foam layer drying process. Drying was performed in an air circulation oven at 50, 60, 70ºC, using a concentration of 4.5% (w/w) emulsifier. The Lewis, Midilli and Kucuk and Page mathematical models were adjusted to the experimental data, being the best fit obtained using the Midilli and Kucuk and Page models.

The fruit powders presented acidic pH (throne of 3.5), the vitamin C content decreased as the temperature increased (108.16; 88.58 and 62,16 mg at 50, 60 and 70ºC , respectively) and ash content increased significantly in dry powder samples due to the addition of foaming agents.

Keywords: Cerrado fruits; Mathematical modeling; Vitamin C.

Resumen

El cerrado brasileño es uno de los biomas más ricos del mundo, con especies de frutas nativas y exóticas, pero poco explorado. Dada esta diversidad, destaca el jambo rojo, una fruta exótica con características sensoriales notables, pero altamente perecedera, con una vida útil reducida. El secado de la capa de espuma es una técnica que ayuda a preservar las frutas, lo que da como resultado un producto en polvo con características deseables, tales como alta porosidad y capacidad de rehidratación. En este sentido, este trabajo tuvo como objetivo analizar la influencia de la temperatura de secado, además de evaluar la cinética y el modelado matemático de datos experimentales. Además, se determinaron las propiedades fisicoquímicas de la pulpa de jambo fresca y después del proceso de secado de la capa de espuma. El secado se realizó en un horno de circulación de aire a 50, 60, 70ºC, utilizando una concentración de emulsionante de 4,5% (p/p). Los modelos matemáticos Lewis, Midilli y Kucuk y Page se ajustaron a los datos experimentales, siendo el mejor ajuste obtenido utilizando los modelos Midilli y Kucuk y Page. Los polvos de fruta mostraron un pH ácido (trono 3.5), el contenido de vitamina C disminuyó a medida que aumentó la temperatura (108.16; 88.58 y 62.16 mg a 50, 60 y 70 ºC, respectivamente) y El contenido de cenizas aumentó significativamente en muestras de polvo seco debido a la adición de agentes espumantes.

Palabras clave: Frutos del Cerrado; Modelado matemático; Vitamina C.

1. Introduction

The Brazilian cerrado is one of the richest biomes in the world, with vast renewable natural resources, yet many native and exotic fruit species with nutritional potential and striking sensory attributes are still unexplored. These characteristics make these fruits promising for the development of healthy and innovative food products (Morzelle et al., 2015; Souza et al., 2012).

Faced with such diversity, stands out the red Jambo (Syzygium malaccense), also known as Malay apple, Malay rose, nakavita, jambu merah, jambu bol, jambo, otaheite cashew, mountain apple and pommerac, is an obovoid fruit of red and smooth skin and white and juicy pulp, with similar flavor the green grapes. In Brazil, its harvest season usually occurs during spring and fall flowering, the fruit is highly perishable and its shelflife shortened, ranging from 3 to 6 days after harvest (Fernandes & Rodrigues, 2018).

In this sense, drying is a technique that helps in the conservation of fruits, preserving nutrients and active and antioxidants compounds (Sogi et al., 2015). Among the drying methods, foam-mat drying (FMD) stands out, which consists of mixing the pulp or fruit or vegetable juice with a stabilizing agent in order to obtain a stable foam, dried at temperatures ranging from 50 to 80ºC. The dried product is ground at the end of the process originating a powder product. As main advantages, FMD provides a higher drying rate compared to conventional drying, due to its larger surface area exposed to the heated air, reducing the energy expenditure of the process, adding value to the product, as it increases its porosity and rehydration capacity. Thus, it is essential to study the proper conditions to obtain a quality final product. (Abbasi & Azizpour, 2016).

Therefore, the present study aimed to analyze the influence of temperature and drying kinetics, as well as the physicochemical properties of jambo pulp after the foam-mat drying process.

2. Methodology

For the development of this work were used as raw materials the fruits of jambo, from the local market of Colíder, Mato Grosso, Brazil. Fruit processing and analysis were performed at the Chemistry Laboratory of the Mato Grosso State University (UNEMAT), Barra do Bugres, Mato Grosso, Brazil.

The fruits were selected according to the ripening stage, being cleaned in running water, manually pulped, and then stored under freezing at -18ºC in a commercial freezer for 24h. Subsequently, the jambo pulp was ground and homogenized and for the preparation of foam were tested 4.0, 4.5 and 5% (w/w) of emulsifier, with the aid of a commercial mixer, for 8 minutes at full speed. The concentration of 4.5% (w/w) emulsifier was selected because it has better stability. The foam formed was distributed in Petri dishes and taken to a forced-air oven for drying under controlled temperatures.

2.1 Drying kinetics and mathematical modeling

Samples of 10g of foam were carefully spread in Petri dishes and placed in a forced-air oven (CienLab, CE-480, Brazil) at 50, 60 and 70 ° C. The dried pulp foams were removed from the Petri dishes with the aid of a spatula, stored and identified according to material type, date and experimental conditions.

Drying curves were established for the samples subjected to the described conditions, by following up the moisture loss recorded by varying the mass of the samples at time intervals of 15 minutes. Mass losses during drying were obtained with the aid of a semi-analytical balance (Shimadzu, AY220, Japan) accurate to 0.0001 g. The tests were prolonged until they reached equilibrium conditions (constant mass). The moisture ratio (MR) was determined according to Equation 1.

$$MR = \frac{(M - M_e)}{(M_i - M_e)} \quad (1)$$

M: product water content (decimal d.b.); Mi: initial water content of product (decimal d.b.); Me: product equilibrium water content (decimal d.b.)

To evaluate the behavior of moisture loss over time, semi-empirical models were used. Considering the equilibrium humidity as the humidity reached when the drying rate is canceled, the moisture ratios (MR) were calculated. Therefore, the Excel program was used to perform the calculations and modeling. To represent the drying kinetics of jambo pulps dried by FMD, the mathematical models of Lewis (1921), Midilli and Kucuk (2002) and Page (1949) were used, as shown in Table 1.

Table 1 - Mathematical models used to describe drying kinetics

Model	Equation	
Lewis	$X_{ad} = \exp(-kt)$	(2)
Midilli and Kucuk	$X_{ad} = a\exp(-kt^n) + b$	(3)
Page	$X_{ad} = \exp(-kt^n)$	(4)

X_{ad}: moisture content (dimensionless); t: drying time (min); k: drying coefficient (min^{-1}); a, b, n: model constants (dimensionless)

2.2 Physicochemical analysis

Fresh Pulp and dried jambo powder were subjected to analyzes of gravity moisture content (method 014/IV), acidity content (method 310/IV), pH (method 014/IV) and ash content (method 364/IV) and vitamin C content (method 364/IV) according to the Adolf Lutz Institute handbook (2008). All analyzes were performed in triplicate.

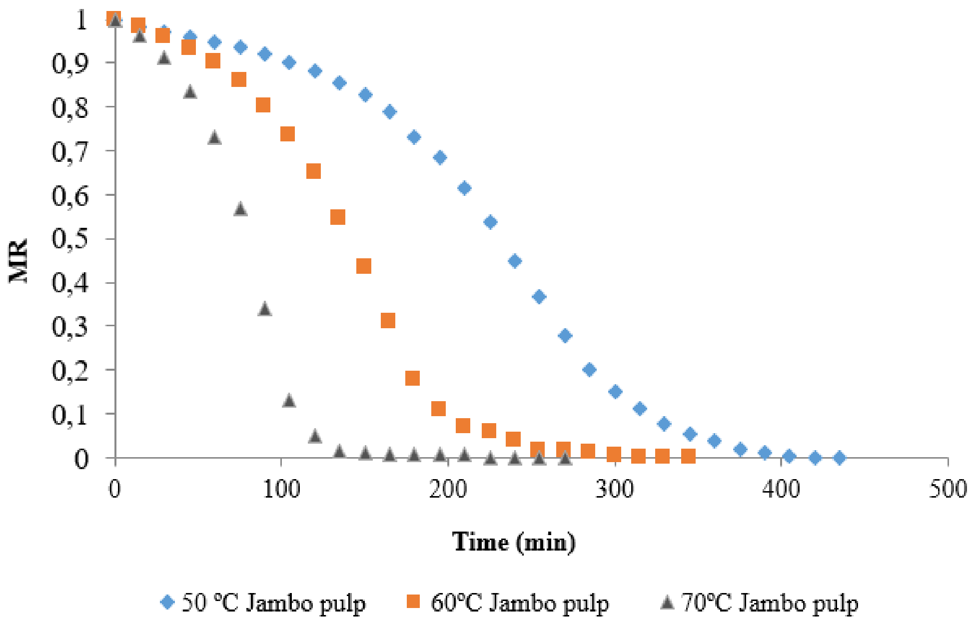
The comparison of the means obtained in the physicochemical analysis was performed by applying the Tukey test ($p < 0.05$) using the Statistica software, version 7.0.

3. Results and Discussion

3.1 Drying kinetics and mathematical modeling

The drying curves of the jambo pulp are shown in Figure 1 in the dimensionless form of moisture content (MR versus time). The dried jambo foams at 50, 60 and 70 ° C the time required to reduce the water content was 435, 345 and 270 min, respectively. Also, according to Brooker et al. (1992) the external conditions of air velocity, temperature and relative humidity directly affect the drying process.

Figure 1 - Drying curves of jambo pulp foam at temperatures of 50 ºC, 60 ºC and 70 °C



As expected, drying time was shorter when higher temperatures were applied, behavior caused by increased drying rate in view of the higher temperature gradient between air and foam, resulting in steeper curves due to higher heat transfer from air to material (Akpinar et al., 2003). Such temperature effect was also observed in the drying of banana foam (Falade & Okocha, 2012) yacon juice (Franco et al., 2015), uvaia (Branco et al., 2016; Rigueto et al., 2018) and mango (Lobo et al., 2017).

Table 2 shows the parameters of the Lewis, Midilli and Kucuk and Page mathematical models, adjusted to the experimental data of the drying of the jambo foams, as well as the correlation coefficients and mean errors.

As can be seen in Table 2, the Page and Midilli and Kucuk models presented the best adjustments in relation to the models employed. Still, the Midilli and Kucuk model presented the best correlation and the lowest estimated average error in most of the studied conditions. The Lewis model presented the lowest correlation and highest error in all the studied conditions in relation to the other models.

Table 2 - Parameters of mathematical models adjusted for drying kinetics of fresh jambo pulp and dried powders at 50 ºC, 60 ºC and 70 °C

Models	**Parameters**	**50 ºC**	**60 ºC**	**70 ºC**
Lewis	k (min^{-1})	0.003928	0.007501	0.016327
	R^2	0.934508	0.952302	0.936698
	Error	10.10511	8.320634	6.389394
Midilli and Kucuk	a	1.027480	1.021589	1.044937
	b	0.000000	0.000000	0.000000
	k (min^{-1})	0.000008	0.000019	0.000454
	n	2.136168	2.166661	1.738084
	R^2	0.988761	0.995288	0.990215
	Error	1.810217	0.856110	0.875622
Page	k (min^{-1})	0.000016	0.000035	0.000076
	n	1.993566	2.044333	2.123105
	R^2	0.985063	0.992539	0.993460
	Error	2.101454	1.017440	0.561332

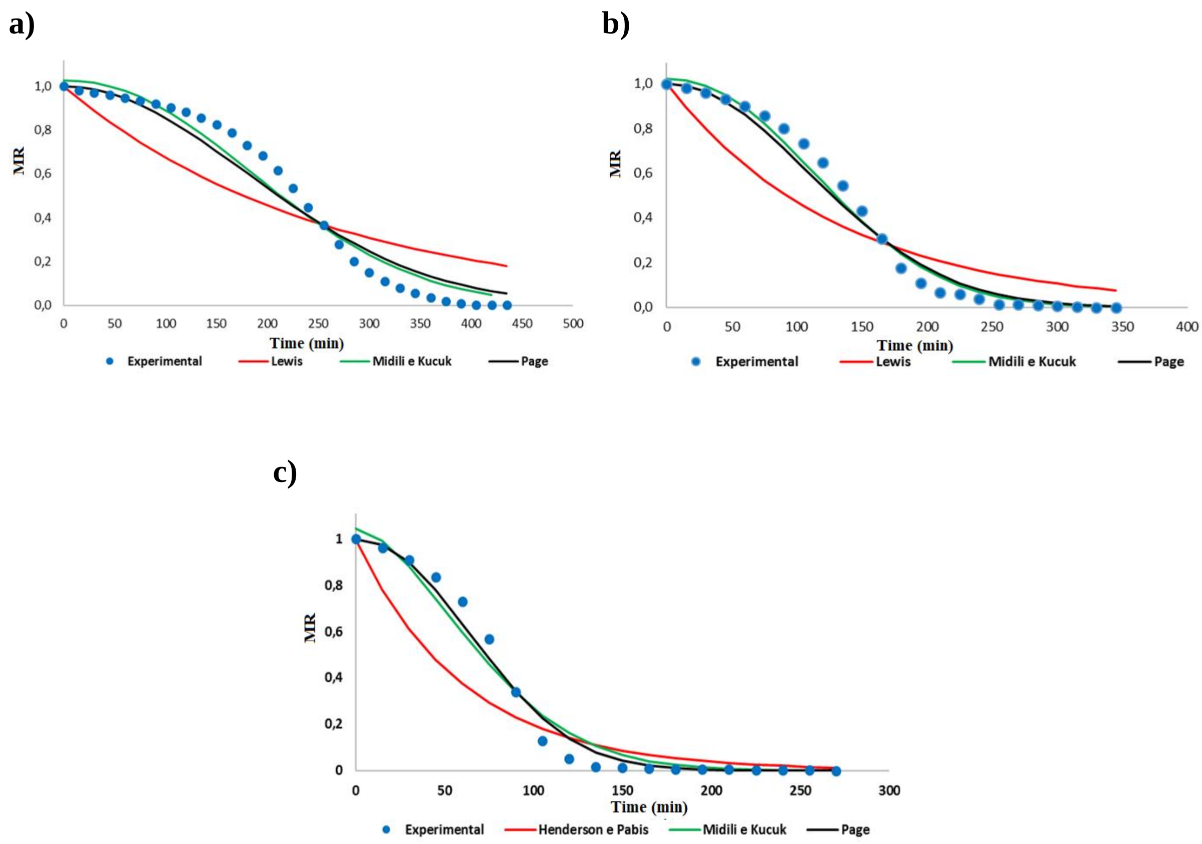
According to Samapundo et al. (2007) values below 10% of relative mean error indicate good suitability for practical purposes, therefore, it is found that the proposed models are appropriate to describe the phenomenon of foam-mat drying of jambo pulp and also to determine the transition point between the constant and decreasing drying period.

Figures 2 (a), (b) and (c) shows the curves adjusted according to the models of Lewis, Midilli and Kucuk and Page, under the conditions of 50, 60 and 70 °C, respectively, to the experimental data of jambo dried by FMD.

The profiles of the drying curves confirm that the models that best fit the experimental data were Midilli and Kucuk and Page. The good adjust of the Midilli and Kucuk and Page models to the experimental drying data of jambo was also verified by Pereira (2018), who evaluated three mathematical models to describe the drying kinetics of jambo, obtaining adjustments (R^2) of 0.9966, 0.9950 and 0.9790 for the Midilli and Kucuk, Page and Lewis models, respectively.

The use of alternative pretreatments to optimize the drying process has been objectified in several studies, as in Oliveira et al. (2010), who evaluated the influence of ultrasonic pretreatment before air drying to promote dehydration of jambo. The authors observed that during the ultrasonic treatment in distilled water, the fruit lost sugar. In addition, effective water diffusivity increased by about 28% after ultrasound, reducing total drying time by more than 27%.

Figure 2 - Adjustments of the Lewis, Midilli and Kucuk and Page models for foam-mat drying of jambo pulp at a) 50 ºC, b) 60 ° C and c) 70 ° C



The increase in effective water diffusivity due to the application of ultrasound as a pretreatment was also reported by Fernandes & Rodrigues (2008), applying it to dehydration of jambo and other fruits, favoring the increase of sugar content.

Da Silva et al. (2016) evaluated the use of ultrasound, osmotic dehydration and vacuum as pre-treatments for melon drying and found that the use of ultrasound or a combination of ultrasound and vacuum improved the drying efficiency of this fruit and thus present themselves as an alternative. to traditional drying.

3.2 Physicochemical analysis

The evaluated parameters of the physicochemical characterization of fresh jambo pulp and powder produced from foam composed of frozen jambo pulp and 4.5% (w/w) Emustab, dehydrated at 50, 60 and 70 ºC, are presented in Table 3.

Table 3 - Physicochemical characterization of fresh jambo pulp and after foam-mat drying

Analyze	Fresh pulp	Dried pulps		
		50 ºC	60 ºC	70 ºC
Moisture (%)	88.9±0.09[a]	15.37±0.19[b]	11.86±3.29[bc]	10.34±0.42[c]
Acidity (%)	6.2±0.08[a]	10.09±0.29[b]	11.2±0.08[b]	12.1±0.13[c]
pH	3.52±0.03[a]	3.5±0.02[a]	3.49±0.02[b]	3.47±0.01[c]
Ashes (%)	0.46±0.07[a]	2.88±0.05[b]	2.95±0.06[b]	3.01±0.03[b]
Vitamin C (mg)	30.93±3.84[a]	108.16±2.8[b]	88.58±1.48[c]	62.16±3.12[d]

* Means followed by the same letters on the lines do not differ significantly by the Tukey test ($p<0.05$)

Augusta et al. (2010) physically and chemically characterized the peel and pulp of red jambo, highlighting the importance of physicochemical characterization to evaluate fruit quality and provide reliable information on its nutritional value, yield and shelf life.

The moisture, pH, ash and vitamin C parameters obtained for the fresh pulp of jambo (Table 3) approximate the characterization performed by Augusta et al. (2010). However, the application of heat commonly used in traditional dehydration processes was expected to cause changes in the physical and structural properties of dry products (Barbosa-Cánovas et al., 2005), which was observed in virtually all parameters determined for jambo dried pulp, except for the pH.

Moisture reduction achieved through the foam layer drying method is critical to hamper microbial growth and the development of physicochemical reactions (Zotarelli, 2014). Table 3 further shows that the drying process increased the total titratable acidity of the dried pulp compared to the fresh sample, which may be explained by the almost complete removal of the aqueous part of the pulp, causing the concentration of acids present in the fruit. Such phenomenon was also observed by Rigueto et al. (2018), using the same method for drying uvaia in the same temperature range as the present study.

The pH values ranged from 3.52 (fresh pulp) to 3.47 (drying at 70 °C), with values progressively regressing with increasing drying temperature. Also, it is noted (Table 3) that the pH of fresh jambo and the powder obtained at 50ºC showed no significant difference (p>0.05), such difference was observed from the dry powders at 60 and 70 ºC.

Ash contents did not differ statistically (p>0.05) between the three temperatures studied, there was only difference between fresh pulp (0.46%) and the powders (≅ 3%). This increase may be related to the presence emulsifier in powder samples obtained after foam-mat drying (Rigueto et al., 2018).

All the pulps submitted to the foam drying process presented higher vitamin C content than the fresh pulp, being observed an inversely proportional relation with the increase of the drying air temperature with the retention of vitamin C. Thus, 50 °C is the most suitable temperature for dehydration of jambo, aiming at higher levels of vitamin C.

Chambers et al. (1996) explain that fruits subjected to low drying temperatures may favor the stabilization of ascorbic acid and, consequently, increase its vitamin content, while increased warming and luminosity may lead to the reduction of vitamins, as already reported by other authors who studied vegetables different (Fernandes et al., 2014; Mehta et al., 2007; Kadam; Lata; Pandey, 2005). Azevêdo (2010) related the lower pigment concentration of dehydrated jambo samples to the thermal effect associated with a possible oxidation generated by the drying process.

Vitamin C content was one of the parameters evaluated by Vega-Gálvez et al. (2009), when studying the effect of hot air on under the red pepper constituents (*Capsicum annuum* L. var. *Hungarian*). The authors found that vitamin C content also decreased with increasing temperature (from 50 ° C to 90 °C), but in contrast to the present study, fresh red pepper had a higher amount of vitamin C than red pepper submitted drying at 50 °C.

4. Conclusions

According to the obtained data, it is concluded that the increase of the drying temperature favored the reduction in the drying time of the jambo foams. Regarding mathematical modeling, the Page and Midilli and Kucuk models provided the best adjustments to the experimental drying data at the three temperatures studied.

In physicochemical analysis, the fresh jambo pulp showed acid character, with increase of acidity and ash after foam-mat drying. In addition, dried 50 °C jambo pulp showed higher vitamin C retention due to lower foam exposure temperature.

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