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Drying of the kernel and fresh and osmotically dehydrated bocaiuva pulps

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ABSTRACT. The fruit of bocaiuva (*Acrocomia aculeata* (Jacq.) Lodd.) is a tropical fruit with potential for technological exploitation. This study determined the drying curves of kernel, fresh and osmotically pre-dehydrated pulps of bocaiuva fruit at temperatures of 60 and 70°C. We used classical mathematical models (Fick, exponential, Page, Henderson and Pabis, two-term exponential, Wangh and Singh) to fit the kinetics. The treatment of experimental data was performed by nonlinear regression. The two-term exponential showed the best fit to the data of drying kinetics of fresh and osmotically pre-dehydrated pulps, the Page model had the best fit to the drying kinetics of the kernel.

Keywords: *Acrocomia aculeata*, kinetics, drying.

Secagem da amêndoa e da polpa de bocaiuva fresca e desidratada osmoticamente

RESUMO. O fruto da bocaiuva (*Acrocomia aculeata* (Jacq.) Lodd.) é um dos frutos tropicais que apresentam potencial de aproveitamento tecnológico. Neste trabalho determinaram-se as curvas de secagem da amêndoa, das polpas *in natura* e pré-desidratada osmoticamente dos frutos da bocaiuva nas temperaturas de 60 e 70°C. Utilizaram-se modelos matemáticos clássicos (Fick, exponencial, Page, Henderson e Pabis, exponencial com dois termos e Wangh e Singh) para o ajuste das cinéticas. O tratamento dos dados experimentais foi realizado por regressão não linear. Concluiu-se que o modelo exponencial com dois termos apresentou melhor ajuste aos dados das cinéticas de secagem da polpa fresca e pré-desidratada osmoticamente, o modelo de Page foi o que melhor se ajustou à cinética de secagem da amêndoa.

Palavras-chave: *Acrocomia aculeata*, cinética, secagem.

Introduction

The palm species *Acrocomia aculeata* (Jacq.) Lodd is widely distributed in Central and South Americas, in Brazil it is mainly found in the States of Pará, São Paulo, Rio de Janeiro, Minas Gerais, Mato Grosso and Mato Grosso do Sul. It belongs to the family *Arecaceae*, popularly known as bocaiuva, macaúba bacaiuveira, coco-drooling, macaw (ALMEIDA et al., 1998). Its fruit has promising potential for agro-industrial use due to the nutritional and sensory characteristics (SILVA et al., 2008). Fruit are still little exploited commercially; its technological use can be a source of food (RAMOS et al., 2008).

Although it has abundant fruiting, bocaiuva has been explored in a rudimentary and home form, far below its economic potential (SANJINEZ-ARGANDOÑA; CHUBA, 2011), probably due to the unknown seasonal and nutritional characteristics. This allows the scientific studies to generate alternative use and conservation.

Among the preservation techniques, dehydration is one of the oldest and relatively simple to be employed. However the food undergoes great changes depending on conditions process. The drying of the bocaiuva pulp is usually made under the sun, without operational control which generates non-standardized products under controlled conditions of temperature and air velocity, drying provides products with improved quality, favoring its conservation.

The modeling of drying processes is essential to their selection and optimization (SANJINEZ-ARGANDOÑA et al., 2011). The use of semi-empirical equations to represent the drying kinetics of the pulp and kernel of the bocaiuva fruit, aims to find a way to represent the drying behavior of best fit to experimental data (BARROZO et al., 1998).

This work analyzed the drying of the kernel, fresh and osmotically pre-dried pulps of bocaiuva at temperatures 60 and 70°C, by applying classical mathematical models in the setting of kinetics, contributing to the technological use of the fruit.

Material and methods

Raw material

Fruit of bocaiuva were collected in Vicentina city, State of Mato Grosso do Sul, Brazil, located at coordinates 22 ° 27 '32.69" S latitude and 54 ° 25' 42.24" W Gr longitude, between October and December 2009.

Preparation of raw material

Fruit were washed, sanitized by immersion in a solution of dichloro s-triazinatriona sodium dihydrate (Sumaveg®) with 200 ppm of active chlorine for 10 min. Then fruit were peeled and pulped manually with stainless steel knife. The seed coats were broken with a vise and the seeds were removed manually. Pulp and kernel were packed separately in polymer packaging, sealed and refrigerated (-18°C) until use.

Physical characteristics of fruit

The diameters (longitudinal and transverse) and the masses of the fruit, rind (epicarp), pulp (mesocarp), tegument (endocarp) and kernel were measured for a sample set of 123 randomly selected fruits using a digital caliper and analytical balance.

Osmotic dehydration

Approximately 100 g of pulp were immersed in 60% sucrose in a proportion pulp: solution of 1:5. The osmotic dehydration was carried out in beakers with the mixture placed on a shaker at 40°C with agitation of 111 rpm for 120 min. After osmotic dehydration, samples were drained, lightly dried and, then placed on trays for drying (SANJINEZ-ARGANDOÑA et al., 2005).

Drying

Drying was carried out in tray dryer with vertical air flow, at a constant speed of 0.5 $m\ s^{-1}$ and two temperature conditions: 60 and 70°C. To maintain the same condition in the sample tray, it was used only a single sample on the dryer.

The amount of water removed during the drying process was determined by periodic weighing of samples using a semi-analytical balance, at intervals of 10 minutes during one hour and 30 minutes until achieving a steady state between the moisture content of the sample and the relative humidity of the drying air, when the sample weight has become constant.

The average initial moisture content and after drying for fresh pulp, pre-dried pulp and kernel was measured gravimetrically in an oven at 70°C for 24 hours (AOAC, 1995).

The experimental data were fitted to the drying following mathematical models: Fick's second law of diffusion (Equation 1) (BARONI; HUMBIGUER, 1998), single exponential (Equation 2) (ABE; AFZAL, 1997), Page (Equation 3) (PAGE, 1948), Henderson and Pabis (Equation 4) (HENDERSON; PABIS, 1961), two-term exponential (Equation 5) (OZDEMIR; DEVRES, 1999), Wang and Singh (Equation 6) (WANG; SINGH, 1978).

$$Y = \sum_{N=0}^{N=1} \frac{8}{(2N+1)^2 \pi^2} \exp\left(\frac{-Def\,(2N+1)^2 \pi^2 \cdot t}{4L^2} \right) \tag{1}$$

$$Y = \exp(-k \cdot t) \tag{2}$$

$$Y = \exp(-k \cdot t^n) \tag{3}$$

$$Y = a \cdot \exp(-k \cdot t) \tag{4}$$

$$Y = a \cdot \exp(-k_0 \cdot t) + b \cdot \exp(-k_1 \cdot t) \tag{5}$$

$$Y = 1 + a \cdot t + b \cdot t^2 \tag{6}$$

Where L is the half-value thickness, *Def* is the effective diffusivity, N is the number of terms in the series, a, b, k k_0, k_1 and n are empirical constants of drying models, t is the time of drying, s; Y is the dimensionless unit defined by Equation 7:

$$Y = \frac{X - X_e}{X_0 - X_e} \tag{7}$$

Where X is the average moisture content at time t, kg H_2O per kg of dry matter; X_e is the equilibrium moisture content, kg H_2O per kg of dry matter; X_0 is the initial moisture content, kg H_2O per kg dry matter.

Statistical analysis

To validate the models, we calculated the coefficient of determination (R^2) and the mean relative error (E), which is defined as the relative difference between experimental and predicted values (Equation 8). The model is considered predictive when presents values of E lower than 10%. The calculation of these parameters was performed using the software Statistica 8.0. The drying experiments were performed in triplicate.

$$E(\%) = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{V_e - V_p}{V_e} \right| \times 100 \tag{8}$$

Where N is the number of experimental data, V_e is the experimental value and V_p is the calculated value.

Results and discussion

Physical characterization of the bocaiuva fruit

The Table 1 lists the biometric characteristics of the fruit. The fruit diameter and yield were similar to those reported by Ramos et al. (2008) and Sanjinez-Argandoña and Chuba (2011) in fruit from the Campo Grande (Mato Grosso do Sul State) and Dourados (Mato Grosso do Sul State) and Presidente Epitácio (São Paulo State), respectively, but showed different proportions of mass of the fruit, peel, pulp and kernel. The edible portion composed of pulp and kernel, represented 47.5% of the total weight of the fruit, representing a good yield for technological exploitation and to provide potential nutritional elements. These differences were also observed by Vera et al. (2005) when physically characterized the pequi fruit in the State of Goiás, and found differences in fruit between areas, plants and even in the same plant; the climatic conditions of different regions where this species is found, the propagation and growth of the palm are natural without any human interference, which explains the variability. For these reasons, we observed the need for research to provide data for the selection of fruit and seeds with characteristics suitable for marketing, processing and breeding in order to obtain fruit with more homogeneous physical, chemical and sensory characteristics, as well as homogeneous culture conditions and commercial production, among others.

Drying kinetics

Samples submitted to drying showed an average initial moisture content (wet basis) of 54.77 ± 0.14 g 100 g^{-1}, 29.63 ± 0.30 g 100 g^{-1} for fresh and osmotically pre-dried pulps and 6.16 ± 0.10 g 100 g^{-1} for the kernel.

Figure 1 shows the drying rate as a function of humidity and time. The drying rate was influenced by temperature and osmotic dehydration at 70°C, the rate of water migration from the food was greater than 60°C, regardless of the pretreatment. However, the osmotically dehydrated samples presented a rapid decrease in the drying rate, especially at 70°C probably due to migration of solute from the sucrose solution during osmotic dehydration towards the wall of the pulp, forming a layer around the pulp, establishing the resistance to the mass transfer. It is also likely that the caramelization of sugars with increasing temperature (70°C) influences in reducing the drying rate, because given a moisture reduction, the rate of drying of pretreated samples becomes similar, without influence of temperature. Thus, the decrease of the drying speed in time is a consequence of the concentration of the solids in the pulp.

Park et al. (2002) observed a similar behavior in the drying process at 40, 60C and 80°C with pear osmotically pre-dehydrated (55° brix solution) at 40°C. The authors attributed this result to the hardening of the surface layer of the fruit samples without osmotic pre-treatment, which prevented mass transport during drying (SANJINEZ-ARGANDOÑA et al., 2005). Dionello et al. (2009) in the drying of pineapple slices verified a higher drying rate for the fresh fruit.

According to Park et al. (2002), the evaporation of water inside the food is influenced by several phenomena such as capillarity, physical and chemical bonding of water to solids in the food, migration of solutes, deformation of the product among others, which offer great resistance. With osmotic pretreatment, physical and chemical characteristics of the food are changed, hindering the migration of water vapor inside the fruit to the outside, hence there is a decrease of the drying speed. Another work carried out with apple and cashew by Mandala et al. (2005) and Azoubel et al. (2009) observed a behavior with the same absorption of solute that occurs in the osmotic process, resulting in an increased internal resistance to mass transfer.

Although the pre-drying of products is slower when osmotically dehydrated, there is the advantage of the impregnation of solids and the consequent

Table 1. Biometric characteristics of bocaiuva fruit and yield.

Biometric characteristics	Mean ± standard deviation	Yield (%)	Reference values		
			Campo Grande[1]	Dourados[2]	Presidente Epitácio[2]
LD (mm)	34.68 ± 2.63	_	_	34.68	33.14
TD (mm)	32.53 ± 1.70	_	33.80	33.39	31.65
Whole fruit (g)	20.47 ± 3.31	_	21.83	21.83	18.86
Peel (g)	3.71 ± 0.63	18.12	4.68	4.54	3.48
Pulp (g)	8.53 ± 1.77	41.67	9.61	8.98	7.90
Tegument (g)	7.04 ± 1.48	34.38	_	_	_
Kernel (g)	1.17 ± 0.21	5.83	0.83	1.35	1.17

LD, longitudinal diameter; TD, cross-sectional diameter. [1]Ramos et al. (2008). [2]Sanjinez-Argandoña and Chuba (2011).

reduction of the tissue permeability of the surface layer of fruit, and reducing the apparent diffusivity of water, acting as the beneficial factors in maintaining stability of dried fruit during storage (DIONELLO et al., 2009).

The importance of osmotic pretreatment is justified by the improved nutritional properties of some sensory and functional characteristics (DIONELLO et al., 2009; SANJINEZ-ARGANDOÑA et al., 2005) as well as maintaining the stability of dried fruit.

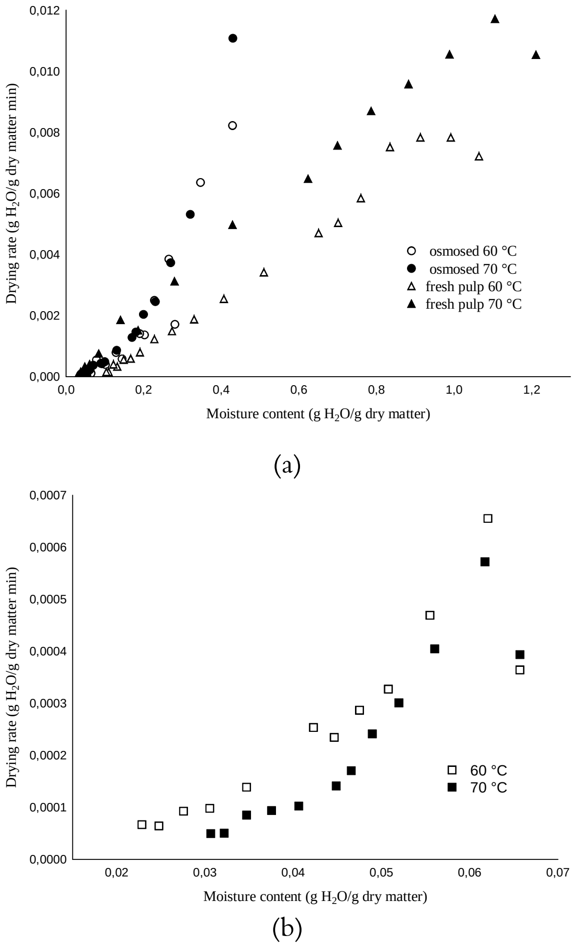

Figure 1. Drying rates of fresh and osmotically pre-treated pulps (a) and kernel (b).

As expected, the air temperature has affected the drying curves, decreasing the drying time of the samples. For all temperatures, the moisture ratio decreased rapidly initially and then slowly declined as advanced the drying time. These results agree with previous observations for different foods (SANJINEZ-ARGANDOÑA et al., 2011; SANTOS et al., 2010).

The calculated values for the constants of the model and statistical analysis are shown in Table 2. It has been found a satisfactory fit of the models evaluated. In terms of correlation coefficient, for the drying of fresh pulp and kernel of bocaiuva, in most cases the models presented a $R^2 > 0.90$.

However, when considering the estimation of errors, it is observed that the two-term exponential and Page models have best fitted the experimental data of drying, with higher value of R^2 and lower mean relative error. The two-term exponential model showed a Pearson coefficient $R^2 > 0.99$ and the average relative error (E) ranged from 0.64 to 9.15%. Page model also showed a Pearson coefficient > 0.99 and an average relative error ranging from 2.88 to 8.85%.

In Page model, it was observed a similar behavior for the fresh pulp and kernel to reduce the parameter *k*, as the parameter *n* increased. For the pre-osmotic treatment the behavior was inverse, probably due to cell damage during osmotic dehydration, increasing the porosity, resulting in increase of the parameter *k* with increasing temperature. Azoubel et al. (2009) also reported increased of the parameter *k* and reduction of *n* by increasing the drying temperature in osmotically pretreated cashew. In the drying of pistachio nuts, Kashaninejad et al. (2007) observed an increase of the parameter *k* and reduction in the parameter *n* with increasing temperature.

Table 2. Constants of the models and criteria for evaluating the best fit for fresh pulp, osmotically dehydrated pulp and kernel of bocaiuva under different conditions.

Model	Parameters	Samples					
		Fresh pulp		Osmotically dehydrated pulp		Kernel	
		60ºC	70ºC	60ºC	70ºC	60ºC	70ºC
Fick	*Deff* (m s^{-2})	7.41 e^{-9}	1.21 e^{-8}	1.08 e^{-8}	1.37 e^{-8}	5.44 e^{-9}	3.68 e^{-9}
	E (%)	9.45	9.78	9.24	9.93	4.66	3.70
	R^2	0.98	0.98	0.97	0.97	0.97	0.97
Page	*k*	0.013	0.009	0.065	0.092	0.032	0.018
	n	0.877	1.054	0.612	0.566	0.767	0.928
	E (%)	8.85	3.32	5.14	5.42	3.67	2.88
	R^2	0.99	0.99	0.99	0.99	0.99	0.99
Simple exponential	*K*	0.007	0.012	0.012	0.015	0.012	0.013
	E (%)	15.86	13.51	38.62	47.48	16.09	8.04
	R^2	0.98	0.99	0.89	0.87	0.96	0.99
Henderson and Pabis	*a*	0.972	1.018	0.841	0.821	0.926	0.987
	k	0.007	0.012	0.008	0.010	0.010	0.013
	E(%)	14.27	9.14	24.32	32.05	10.84	7.15
	R^2	0.99	0.99	0.93	0.92	0.97	0.99
Two-term exponential	*a*	0.911	0.509	0.476	0.534	0.297	0.250
	k_0	0.010	0.012	0.004	0.045	0.046	0.029
	b	0.098	0.509	0.513	0.045	0.711	0.761
	k_1	0.429e^{-3}	0.012	0.035	0.005	0.008	0.010
	E (%)	0.64	9.15	4.95	6.18	3.07	2.50
	R^2	0.99	0.99	0.99	0.99	0.99	0.99
Wang and Singh	*a*	-0.006	-0.007	-0.007	-0.008	-0.010	-0.010
	b	0.849e^{-5}	0.123e^{-4}	0.138e^{-4}	0.152e^{-4}	0.259e^{-4}	0.267e^{-4}
	E (%)	21.92	258.80	41.33	58.20	18.99	21.16

R^2	0.96	0.94	0.77	0.64	0.94	0.97

The Figures 2 and 3 depict the fit of the experimental and predicted data of dimensionless moisture over the drying time. In this paper, the models of Page and two-term exponential had minor errors for fractions of the fruit studied, however, the two-term exponential model showed the best fit for fresh and osmotically treated pulps, as seen in Figure 2. For kernels, the Page model showed the best fit (Figure 3).

Doymaz (2004) obtained with the two-term exponential model the best fit for fresh plums. Azoubel et al. (2009) also obtained good fits for the two-term exponential model for fresh and osmotically dehydrated cashew. Kashaninejad et al. (2007) obtained optimal fit with the Page model for pistachio nuts.

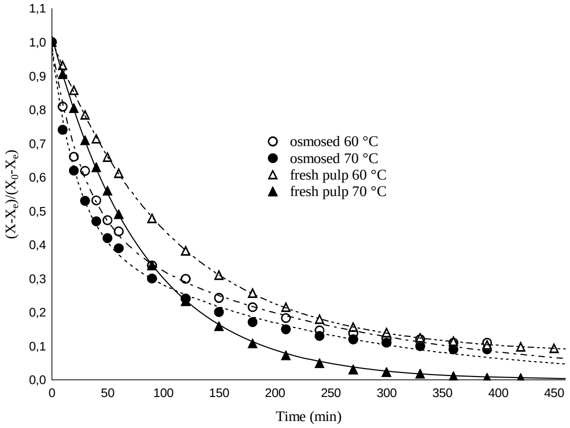

Figure 2. Drying kinetics of fresh and osmotically pretreated pulps and mathematical fit by the two-term exponential function

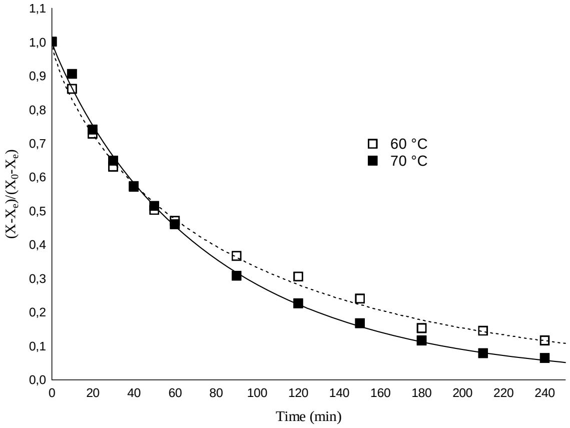

Figure 3. Drying kinetics of the bocaiuva kernel and mathematical fit by the Page function.

Fick's model was also fitted to the experimental data via nonlinear regression to determine the effective diffusivity. It supported the prediction of drying of bocaiuva pulp, which can be verified by the coefficient of determination ($R^2 > 0.97$) and error lower than 10% for temperatures. As can be seen in Table 2, the value of the effective diffusivity increased with increasing temperature, which was expected, since higher temperatures remove water more rapidly. The same was observed by Santos et al. (2010) for carambola.

Conclusion

The yield of pulp bocaiuva had emphasized the commercial potential of this fruit.

The two-term exponential mathematical model provided the best fit for drying curves of fresh and osmotically pre-treated pulps, with errors of 0.64 to 9.15%, with the temperature of 70°C presenting the shorter drying time.

For kernel, under the conditions studied, the Page model provided a good fit for the drying curves with errors of 2.88 to 3.67%, and the temperature of 70°C had a shorter drying time.

Fresh pulp of bocaiuva had a higher convective drying rate than osmotically pre-dehydrated pulps.

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