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China Agricultural University, 17 Qinghua East Road

Beijing100083, P.R. China

Symposium founder:

Professor Arun S. Mujumdar

TheNationalUniversityof Singapore

10 Kent Ridge Crescent

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Session 6A (Room A, 10:30-12:30, Thursday, 29 August 2002)

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Osmotic Dehydration

EFFECT OF OSMOTIC DEHYDRATION IN SUCROSE SOLUTION IN THE DRYING KINETICS OF CASHEW APPLE (*Anacardium occidentale* L.)

P. M. Azoubel*, R.V. Tonon and F. E. X. Murr

Food Engineering Department – FEA - UNICAMP
Caixa Postal 6121- CEP 13083-970, Campinas, SP- Brazil
pazoubel@ceres.fea.unicamp.br

ABSTRACT

The influence of osmotic dehydration in sucrose solution (52% w/w) for 165 minutes in the drying kinetics of cashew apple was studied. Drying tests were conducted using a fixed bed dryer at three different temperatures (50, 60 and 70°C) and air velocity of 2.1 m/s. Results showed that an increase of the air temperature favoured the decrease of the drying time of the product. The water effective diffusion coefficients were determined according to Fick's second law applied to a thin slab and were found to be in the order of 10^{-10} m^2/s. The effective diffusion coefficient decreased for the osmosed cashew apple, indicating a less favoured diffusional process. However, the pretreated samples were characterized by a flexible structure, by a smaller shrinkage and by presenting a more natural coloration. The activation energy,calculated using Arrhenius equation, was found to be 36.45 kJ/mol for fresh fruit and 26.63 kJ/mol for the osmosed sample.

Keywords: cashew, osmotic dehydration, drying, effective diffusivity, activation energy.

INTRODUCTION

The cashew nuts are widely popular products of the cashew tree (*Anacardium occidentale* L.), while the use of the cashew apple is restricted to a few countries (Cecchi and Rodrigues-Amaya, 1981), the greater part being wasted. In Brazil, the wastage rate exceeds 90% of its production (Carraro and Cunha, 1994) due to the nonavailability of sufficient storage, transportation and processing facilities (Paiva et al., 1997).

The drying of a solid is a commom form of preservation of food, where the moisture content is reduced to a lower level, preventing the growth of mould and stopping the bacterial action (Hawlader at el., 1991). Air drying

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* Corresponding author (pazoubel@ceres.fea.unicamp.br)

offers dehydrated products that can have an extended life of a year, however the quality of a conventionally dried product is usually drastically reduced from that of the original foodstuff (Ratti, 2001).

Osmotic dehydration is a useful technique for the partial removal of water from the cellular material, such as fruits and vegetables, without a phase change and is often applied as a pretreatment process, which reduces the physical, chemical and/or biological changes during drying at high temperatures (Kowalska and Lenart, 2001). It is based on the immersion of foods, whole or in peaces, in sugars or salts aqueous solutions of high osmotic pressure, originating two major simultaneous counter-current flows: an important water flow out of the food into the solution and a transfer of solute from the solution into the food, which are both due to the water and solute activity gradients across the cellular membrane (Torreggiani, 1993).

The aim of this work was to evaluate the influence of the osmotic dehydration prior to conventional drying on the rate of moisture transport of cashew apple.

MATERIAL AND METHODS

Sample preparation

Fresh cashew apples were obtained from a local market. The fruits were sorted visually for size, maturity level (soluble solids content from 10 to 12°Brix) and physical damage. The average initial moisture content was 85.7% w/w. Sound fruits were selected for experiments, the nuts were separated manually and the cashew apple was cut into 0.5 cm thick slices. The average slice diameter was 5 cm.

Osmotic pre-treatment

For the osmotic dehydration, slices of cashew apple were submerged in 600 mL beakers containing a 52% (w/w) sucrose solution and maintened inside a shaker (Tecnal, model TE421) at 34°C and agitation of 80 rpm. The weight ratio of osmotic medium to fruit sample was 10:1 to avoid significant dilution of the medium and subsequent decrease of the driving force during the process. After 165 minutes, samples were removed from the sugar syrup, drained and the excess of solution at the surface was removed with absorbent paper.

Air drying

For the drying process, a continuous flow fixed bed dryer was used and the tests were conducted at three different temperatures (50, 60 and 70 °C) and constant air velocity of 2.1 m/s for fresh and osmosed cashew apple. The samples were spread uniformly on a stainless steel perforated tray. It was used a thermal-hygrometer (TESTO, model 635) to measure the processing temperature and the air humidity. The air flow rate was monitored by an anemometer (AIRFLOW, model LCS 6000). The drying curves were determined by periodic weighing of the tray on a semi-analytical scale.

Mathematical model

In most case of drying of food materials, the constant rate period is absent. The experimental data on drying in the falling rate period may be analysed by a diffusional model. Fick´s second law of diffusion has been used by several investigators (Hawlader et al., 1991; Park, 1998; Azoubel, 1999) to study diffusion of water through the material to the surface from which water evaporates and is given by the following equation:

$$\frac{\partial X}{\partial t} = D_{eff} \frac{\partial^2 X}{\partial x^2} \tag{1}$$

where:
X= moisture content (kg/kg dry matter);
t= time (s);
D_{eff}= water effective diffusivity (m^2/s);
x= length (m)

Considering the cashew apple slice as a flat plate with initially uniform moisture distribution, negligible external resistance to mass transfer and no shrinkage, the solution for Fick's equation (Crank, 1975) is:

$$\frac{X - X_e}{X_o - X_e} = \frac{8}{\pi^2} \sum_{i=0}^{\infty} \frac{1}{(2i+1)^2} \exp\left[-(2i+1)^2 \pi^2 D_{eff} \frac{t}{4L^2} \right] \tag{2}$$

where:
X_e= equilibrium moisture content (kg/kg dry matter);
X_o= initial moisture content (kg/kg dry matter);
L= half of slab thickness (m).

For long drying time and for moisture rates [(X- X_e)/(X_o- X_e)] less than 0.6, generally only the first term of the equation (2) is used (Rao and Rizvi, 1986). For low values of equilibrium moisture content (X_e), it is possible to consider [(X- X_e)/(X_o- X_e)]= X/X_o (Uddin et al., 1990). Under these conditions the following approximation can be made:

$$\ln\left(\frac{X}{X_o}\right) = \ln\left(\frac{8}{\pi^2}\right) - \pi^2 D_{eff} \frac{t}{4L^2} \tag{3}$$

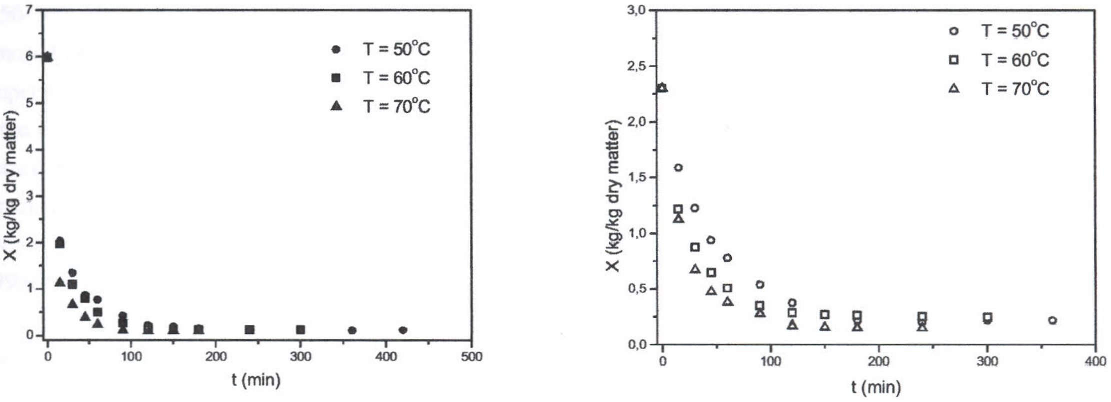
The diffusion coefficient D_{eff} can be measured from the slope of the plot of ln(X/X_o) against t/L^2 or t.

RESULTS AND DISCUSSIONS

For the fresh cashew apple having moisture content of 85.7% (wet basis, w/w), large quantity of water has to be removed in order to achieve a shelf-stable product. In the present work, the drying kinetics of fresh and osmosed samples was studied and the results obtained from experiments are presented in this section.

Osmotic dehydration

The osmotic pretreatment of cashew apple in a 52% (w/w) sucrose solution for 165 minutes yielded a product with increased dry matter content. The increase was due to concentration of constitutive dry matter and uptake of sucrose from the hypertonic solution the solid (the solid gain was around 6%). The osmotic dewatering resulted in a product having moisture content of 69.7% (wet basis).



(a) (b)

Figure 1. Moisture content versus drying time for: (a) fresh and (b) osmosed cashew apple

Air drying

In air drying of cashew apple samples, the osmotic pretreatment and the drying temperature were investigated. Figure 1 shows some typical plots of the variation of the moisture content against drying time for both fresh and osmosed samples. It can be seen that the equilibrium moisture content was low for all conditions studied. Thus, it was negleted in equation (2).

Figure 2 shows the variation in drying rate as function of moisture content. For the given experimental conditions, no constant drying rate was observed, what implied that a film of water did not exist at the surface of the cashew apple and whatever water reached the surface from within the sample evaporated almost imediately, as observed by Hawlader et al. (1991) when drying tomatoes. Higher temperatures increased the drying potential for the transport of moisture, increasing the drying rate. When the samples were pretreated lower rates were obtained.

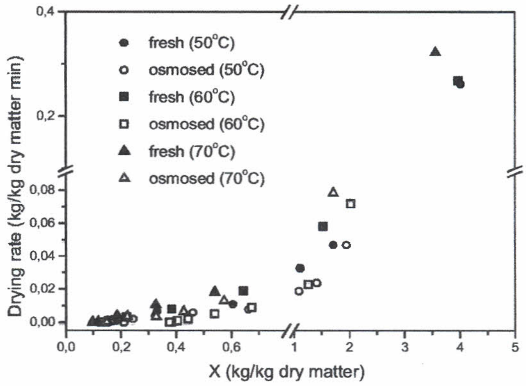


Figure 2. Drying rate versus moisture content

The effective diffusivity was determined using only the first term of Fick's solution series, as described by equation (3). Table 1 presents the obtained values of diffusivity for all conditions studied (regression coefficients > 0.94). Diffusivities obtained for other fruits reported in literature are quite similar in order of magnitude: 3.21-12.67x10^{-10} m^2/s for fresh apple at 30-60°C and 1.98-9.79x10^{-10} m^2/s for osmosed apple at 30-90°C (Simal et al., 1997), 0.30-0.94x10^{-10} m^2/s for fresh cherry tomato at 50-70°C and 0.30-0.54x10^{-10} m^2/s for osmosed cherry tomato at 50-70°C (Azoubel, 1999), 0.32-10.90x10^{-10} m^2/s for fresh pineapple at 50-80°C and 0.39-10.50x10^{-10} m^2/s for osmosed pineapple at 50-80°C (Uddin et al., 1990). When the samples types were compared at a given air dry bulb temperature, it was observed that the water diffusion coefficients decreased when osmosis was done. The differences in the diffusion rates (and drying rates) can be attributed to the compositional changes which occur in the osmotic pretreatment. The uptake of sucrose and the loss of water which occurs in osmosis gives increased internal resistance to moisture movement. Thus, when drying at the same air conditions, drying rates will be lower for osmosed samples than non-osmosed. Similar results were obtained by Rahman and Lamb (1991) for pineapple and by Karathanos et al. (1995) for apple.

Table 1: Effective diffusion coefficients for cashew apple

	D_{eff}. 10^{10} (m^2/s)	
T (°C)	Fresh	Osmosed
50	10.3	5.4
60	16.5	6.9
70	22.7	9.6

The time required to achieve a moisture content of 0.33 kg/kg dry matter (25% wet basis), according to the legislation for dried foods, are presented in Table 2. It is seen that the fresh samples had lower values. Jayaraman et al. (1990) observed that for pretreated cauliflower the drying time was increased slightly due to the humectant effect of sucrose.

Table 2: Drying time

	Drying time (min)*	
T (°C)	Fresh	Osmosed
50	100	136
60	67	97
70	50	71

*Time to obtain moisture content corresponding to 0.33 kg/kg dry matter (25% wet basis)

The temperature dependency of effective diffusivity may be used to calculate the activation energy for drying. Arrhenius equation was used for this purpose, as described by the following equation:

$$D_{eff} = A.\exp\left(\frac{E_a}{RT}\right) \tag{4}$$

where:

E_a = activation energy (kJ/mol);

A = constant;

R = universal gas constant (kJ/mol K);

T = temperature (K)

A plot of ln D_{eff} against (1/T) should yield a straight line and from the slope activation energy is calculated. The values of activation energy and the correlation coefficients are presented in Table 3. The activation energy was much lower for osmosed than fo fresh samples, indicating that temperature had less influence on drying rate of those samples. These results are similar to those found by Simal et al. (1997).

Table 3: Activation energy for diffusion in cashew apple

Sample	E_a (kJ/mol)	R^2
Fresh	36.453	0.991
Osmosed	26.634	0.989

The dried previously osmosed samples were characterized by a flexible structure, by a more natural coloration and by smaller shrinkage. As observed by Uddin et al. (1990) for pineapple, during osmosis some sugar molecules diffuse into the pore structure, resulting in less degree of shrinkage in osmosed samples in drying.

CONCLUSION

Air drying of cashew apple did not show any constant drying rate period. The osmosed samples were found to have lower drying rates, requiring more time to reach the same final moisture content as fresh cashew apple. The water effective diffusivity during air drying decreased with the increase of solid gain during the osmotic prestep. However, the osmosed samples had a more natural colour, a more flexible structure and smaller shrinkage when compared with dried cashew apple with no preliminary treatment.

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