Evaluation of water and sucrose diffusion coefficients during osmotic dehydration of jenipapo (*Genipa americana* L.)

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Abstract

The apparent diffusion coefficients for sucrose and water during osmotic dehydration of jenipapos were determined. Long time experiments (up to 60 h) were carried out in order to determine equilibrium concentrations inside jenipapos, whereas short time experiments (up to 4 h) were performed to provide detailed information on kinetics of water loss and solids gain at the beginning of osmotic treatment. According to the results, mass transfer rates for water and solutes, as well as the apparent diffusion coefficients for sucrose showed to be dependent on sucrose concentration in osmotic solution. The immersion time did not have significant effect ($p > 0.05$) over the diffusion coefficients for sucrose and water.
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1. Introduction

Most tropical fruit are highly perishable, showing a short shelf life post harvest at room temperature, which implies in losses over 30% of production (Chitarra & Chitarra, 1990).

In order to reduce these losses, several researchers make use of drying processes, of which, the osmotic treatment stands out. It has been used mainly as pre-treatment to some conventional processes such as freezing (Pointing, 1973); freeze drying (Hawkes & Flink, 1978); vacuum drying (Dixon & Jen, 1977) and air drying (Nanjundaswamy, Setty, Balachandran, Saroja, & Reddy, 1978), in order to improve final quality, reduce energy costs or even to develop new products (Sereno & Hubinger, 2001).

The process of osmotic dehydration can be characterized by dynamic and equilibrium periods (Rahman, 1992). In the dynamic periods, the rate of mass transfer is increased or decreased until equilibrium is reached, i.e., the net rate of mass transfer is zero. The study of this equilibrium is important to understand the mechanism of mass transfer involved in this system (Baralt, Chiralt, & Fito, 1998), as well as to employ Fick's second law for diffusion in non-stationary solids of different geometry, allowing estimation of apparent diffusion coefficients for water and solutes (Sablani & Rahman, 2003).

The objective of this work was to evaluate the effective diffusion coefficients, based on the analytical solution of Fick's second law, for solvent and solutes transfer during osmotic dehydration of jenipapo.

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2. Materials and methods

2.1. Raw material

Fresh ripe jenipapos (*Genipa americana* L.) were purchased from a local market (Recife—PE). The fruit were selected visually by color (completely brown), size (average diameter of 9.0 cm) and physical damage. After washed in fresh running water and dried with absorbent paper, they were cut into quarters and skin and seeds were removed manually.

2.2. Osmotic treatment

Commercial sucrose dissolved in distilled water was used as osmotic agent. Three levels of sucrose (30%, 50% and 70%) concentrations were selected, according to a 2^2 factorial design including the centre point (Barros Neto, Scarminio, & Bruns, 2001). These concentrations were chosen based on the resulted obtained by Andrade, Metri, Barros Neto, and Guerra (2003).

The experimental design was evaluated using coded levels −1 and 1, the independent variables being sucrose and time and the dependent variables being water and sucrose diffusion coefficients (Table 1).

The process was carried out in glass beakers containing the different concentrations of the osmotic solution and maintained at a controlled temperature (30 ± 1 °C). The sample/solution relation was 1:20 in order to minimize changes in solution concentration during osmosis. Quarters of jenipapo, pre-weighed and tied with colored threads (for identification) were placed in each of the glass beakers.

The osmotic medium was agitated continuously with a magnetic stirrer. Preliminary experiments indicated that agitation promotes moisture loss of jenipapo osmotically treated for 3 h under the same conditions (Fig. 1).

At pre-determined time intervals, quarters of jenipapo were taken out from the glass beakers for analysis. The treated sample was drained for 1 min and slightly wiped with absorbent paper and analyzed.

A first set of experiments was carried out to determine the equilibrium concentrations for water and sucrose. These experiments were performed by osmotically treating jenipapos up to a total time of 60 h, having samples collected at 0, 6, 12, 24, 32, 36, 48 and 60 h.

In order to obtain more detailed information on kinetics of water loss and solids gain, another set of experiments was conducted with jenipapo samples drawn off the solution at shorter time intervals: 0, 0.5, 1, 2, 3, and 4 h.
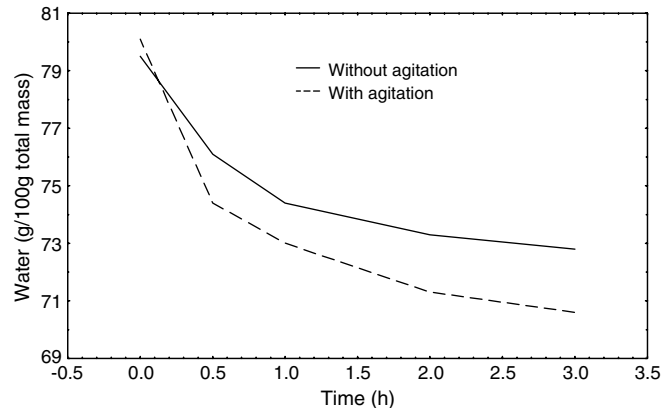

Fig. 1. Water loss in jenipapos during osmotic treatment with or without agitation in solutions of sucrose.

2.3. Analytical methods

Moisture content was determined by placing samples in an air drier at 105 °C at atm. pressure until constant weigh was obtained (AOAC, 1998; Method 985.14). All analyses were made in triplicates. Soluble solids (°Brix) were measured in a refractometer BAUSCH and LOMB.

2.4. Mathematical procedure and statistical analysis

Rates of moisture loss during osmotic dehydration were modeled based on an analytical solution of Fick's second law (Eq. (1)) (Telis, Murari, & Yamashita, 2004). Rates of solids gain were determined by Eq. (2), a modified form of Eq. (1) (Telis et al., 2004).

$$\frac{X - X_{eq}}{X_0 - X_{eq}} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp \frac{(-D(2n+1)^2 \pi^2 t)}{L^2} \quad (1)$$

$$\frac{C_0 - C}{C_0 - C_{eq}} = 1 - \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp \frac{(-D(2n+1)^2 \pi^2 t)}{L^2}$$
$$(2)$$

In the above equations X and C are the moisture content and sugar concentration, respectively, at time t, X_0 and C_0 the initial values of these variables, and X_{eq} and C_{eq} the corresponding equilibrium values. D is the apparent diffusion coefficient and L the slab thickness.

A constant average slab thickness of 0.9 cm was assumed for jenipapo samples during the osmosis.

Analysis of variance (ANOVA) was carried out to see the influence of different variables on diffusion coefficient for solids and water with significance level of 95% using the Statistica 5.0 (Statsoft, 1997) package.

3. Results and discussion

Figs. 2 and 3, show that the velocities of moisture loss and solids uptake were higher in the beginning of the dehydration. The reduction of the water content in the first two

Table 1
Independent variables coded for osmotic dehydration of jenipapo

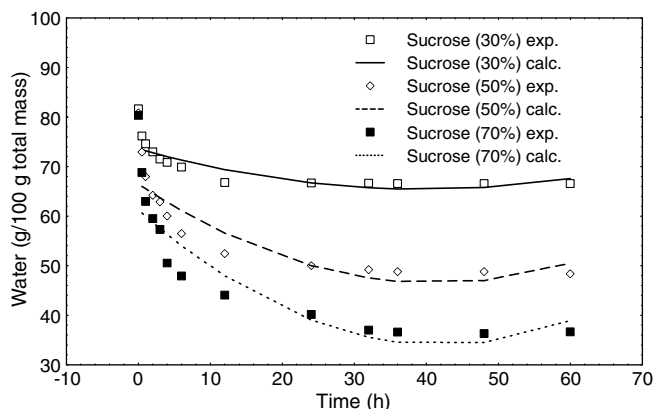| Variables	−1	0	1
Sucrose (%)	30	50	70
Time (h)	4	32	60

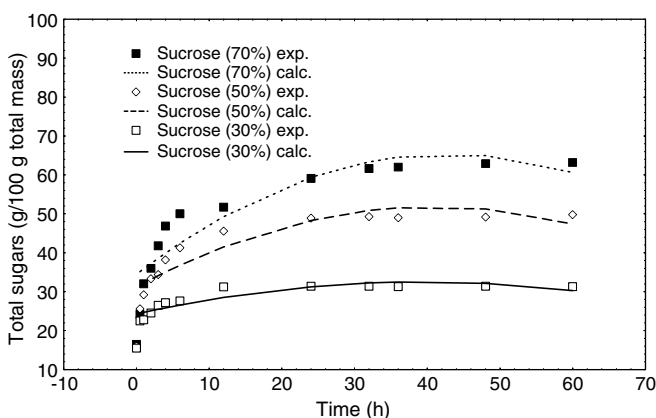Fig. 2. Kinetics of water loss in jenipapo during osmotic treatment in solution of varied sucrose concentrations.

Fig. 3. Kinetics of sugar gain in jenipapo during osmotic treatment in solution of varied sucrose concentrations.

Table 2
Equilibrium concentrations and apparent diffusion coefficients for water during jenipapo osmotic treatment

Experiment number	S (%)	t (h)	Apparent diffusion coefficient D water (10^{-10} m^2/s)	Equilibrium concentration (g/100 g total mass)
1	30	4	7.38	
2	70	4	5.07	
2	30	60	6.90	66.60
3	70	60	4.62	36.60
4	50	32	4.31	48.80
5	50	32	5.98	49.20
6	50	32	5.05	49.00

S = sucrose concentration (%); T = time (h).

Table 3
Equilibrium concentrations and apparent diffusion coefficients for sucrose during jenipapo osmotic treatment

Experiment number	S (%)	t (h)	Apparent diffusion coefficient D sucrose (10^{-10} m^2/s)	Equilibrium concentration (g/100 g total mass)
1	30	4	8.35	
2	70	4	4.49	
2	30	60	7.72	31.0
3	70	60	3.99	62.4
4	50	32	4.91	49.1
5	50	32	5.35	49.3
6	50	32	5.40	49.2

S = sucrose concentration (%); T = time (h).

hours was 10.59%, 19.09% and 25.96% for solution with 30, 50 and 70 °Brix, respectively, these values being much lower than the ones obtained by Kowalska and Lenart (2001) dehydrating carrots and pumpkins, for 30 min, obtaining 47% and 50% of loss moisture, respectively, in a 61.5 °Brix sucrose solution.

After these first hours, the flows of mass tended to decrease considerably until the equilibrium was reached in the fruit/osmotic solution system. This equilibrium was reached around 12, 24 and 32 h of osmosis for the osmotic solutions of 30, 50 and 70 °Brix, respectively, from which significant alteration of water loss and solids gain were not observed. This behavior was different from the one registered by Askar, Abdel-Fadeel, Ghonaim, AbdeL-Gaid, and Ali (1996); Palou, López-Malo, Argaiz, and Welti (1993); Panagiotou, Karathanos, and Maroulis (1999), in the osmotic dehydration of several fruit, such as papaya, peach, apple, banana and kiwi that reached equilibrium around 4 h.

The equilibrium concentrations for water and sucrose determined in jenipapos treated in the different osmotic solution are shown in Tables 2 and 3, respectively. The fact that this equilibrium was reached with longer time is

probably due to the type of membrane of this fruit, characterized as differentially permeable as opposed to semipermeable (Andrade et al., 2003).

Torreggiani, Forni, and Rizzolo (1987) affirm that moisture loss and sugar gain are controlled by the characteristics of the raw materials.

Fig. 2 shows that the increases of solution concentration promoted maximum water loss during the process, due to the increase of osmotic pressure outside the fruit as reported by Mizkahi, Eichler, and Ramon (2001). Similar effect was obtained for sugar gain (Fig. 3), as observed by Telis et al. (2004) dehydrating tomatoes. This behavior can be explained, in part, by the increase of moisture loss of the samples, what would allow solutes to enter the fruit (Telis et al., 2004).

These results show that although higher sugar concentrations favor water loss, they promote higher solids gain. According to Torreggiani (1993), the ideal is to promote the water loss with the minimum solids gain, because the impregnation of the solutes in the food may change the sensory and nutritional properties of the product. Previous results obtained with jenipapo refute this conclusion, because despite the high sugar gain registered, during the osmotic dehydration with crystal and demerara sugar, the final product had a satisfactory acceptability (Andrade et al., 2003).
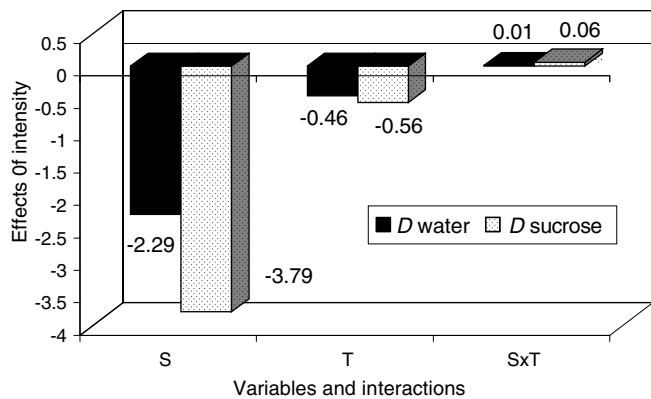
Fig. 4. Effects of variables on apparent diffusion coefficient for water and sucrose during osmotic dehydration of jenipapo fruit.

Three different apparent diffusion coefficients were calculated for water and sucrose at each condition of osmotic treatment. The first one corresponds to the experiment carried out in short periods of time, where the samples were kept in the osmotic solution for 4 h. The second and third coefficients were calculated with longer periods of time of 32 and 60 h, respectively (Tables 2 and 3).

The analysis of variance of the factorial design showed that: the effect of the immersion time over the water and sucrose coefficients was not significant ($p > 0.05$) (Fig. 4); the different sucrose concentrations exerted significant effect ($p < 0.05$) over the diffusion coefficients of this solute, and did not exert significant effect over the water coefficient ($p > 0.05$), although the effect had been -2.29 (Fig. 4).

Regarding the sucrose and water diffusion coefficients for the same immersion times, inverse behavior is observed as the syrup concentration increases (Tables 2 and 3). Similar results were obtained by Rastogi, Nayak, and Raghavarao (2004) in relation to the water diffusion coefficient, when dehydrating carrot slices in sugar syrup (20%, 40% and 60%) for 5 h of immersion at 25 °C temperature.

These tables show that as the treatment time increases, considering the same Brix, both sucrose and water diffusion rates decrease. According to Nsonzi and Ramaswamy (1998) this behavior is due to the formation of a sucrose layer in the surface of the biological material that constitutes a barrier to the moisture loss of the samples. However, according to Telis et al. (2004) this reduction occurs when the water and sucrose concentration inside the fruit is close to the equilibrium value and that as immersion time increases, there is a structural modification in the tissue, mainly of the cells membranes, due to the long exposure to the osmotic solution.

The apparent diffusion coefficient for water and sucrose varied from 4.31×10^{-10} to 7.38×10^{-10} m^2/s and from 3.99×10^{-10} to 8.35×10^{-10} m^2/s, respectively, within the ranges of sucrose concentration and temperature studied in this work. According to Azoubel and Murr (2004) comparisons of diffusivity reported in the literature are difficult due to the different estimation methods and models employed and also because of the variation in the composition and physical structure of the food. As an example, Park, Bin, Brod, and Park (2002) working with pear cubes found that the diffusion coefficient varied from 0.35×10^{-9} to 1.92×10^{-9} m^2/s for water loss and from 0.20×10^{-9} to 3.60×10^{-9} m^2/s for sugar uptake at different temperatures (40–60 °C).

4. Conclusions

Regarding the influence of independent variables over the water and sucrose diffusion coefficients, it was verified that: immersion time did not exert significant influence over the diffusion coefficients for water and sucrose, whereas the osmotic solution concentration influenced only the diffusion coefficient for sucrose. The maximum moisture loss and solutes gain occurred in the higher osmotic solution concentration.

According to the calculus, the range of apparent diffusion coefficient for water and sucrose was of 4.31×10^{-9} to 7.38×10^{-9} m^2/s and of 3.99×10^{-9} to 8.35×10^{-9} m^2/s, respectively.

References

Andrade, S. A. C., Metri, J. C., Barros Neto, B., & Guerra, N. B. (2003). Desidratação Osmótica do Jenipapo (Genipa americana L.). Ciência e Tecnologia de Alimentos, 23(2), 276–281.

AOAC (1998). Official methods of analysis (13th ed.). Washington: Association of Official Analytical Chemists.

Askar, A., Abdel-Fadeel, M. G., Ghonaim, S. M., AbdeL-Gaid, I. O., & Ali, A. M. (1996). Osmotic and solar dehydration of peach fruits. Fruit Processing, 9(1), 258–262.

Azoubel, P. M., & Murr, F. E. X. (2004). Mass transfer kinetics of osmotic dehydration of cherry tomato. Journal of Food Engineering, 61, 291–295.

Baralt, J. M. E., Chiralt, A., & Fito, P. (1998). Equilibrium in cellular food osmotic solution systems as related to structure. Journal of Food Science, 63(5), 836–840.

Barros Neto, B., Scarminio, I. S., & Bruns, R. E. (2001). Planejamento e otimização de experimentos. Campinas: Editora da Universidade Estadual de Campinas, p. 299.

Chitarra, M. I. F., & Chitarra, A. B. (1990). Pós-colheita de frutos e hortaliças fisiologia e manuseio. Lavras, ESAL/FAEPE, p. 220.

Dixon, G. M., & Jen, J. J. (1977). Changes of sugar and acid in osmovac dried apple slices. Journal of Food Science, 42, 1126–1131.

Hawkes, J., & Flink, J. M. (1978). Osmotic concentration of fruit slices prior to freeze dehydration. International Journal of Food Science and Technology, 2, 265–284.

Kowalska, H., & Lenart, A. (2001). Mass exchange during osmotic pretreatment of vegetables. Journal of Food Engineering, 49, 137–140.

Mizkahi, S., Eichler, S., & Ramon, O. (2001). Osmotic dehydration phenomena in gel systems. Journal of Food Engineering, 49(1), 87–96.

Nanjundaswamy, A. M., Setty, G. R., Balachandran, C., Saroja, S., & Reddy, K. B. S. M. (1978). Studies on development of new categories of dehydrated product from indigenous fruits. Indian Food Packer, 22, 91–93.

Nsonzi, F., & Ramaswamy, H. S. (1998). Quality evaluation of osmo-connective dried blueberries. Drying Technology, 16, 705–723.

Palou, E., López-Malo, A., Argaiz, A., & Welti, J. (1993). Osmotic dehydration of papaya: Effect of syrup concentration. Revista Espanola de Ciência e Tecnologia de Alimento, 33(6), 621–630.

Panagiotou, N. M., Karathanos, V. T., & Maroulis, Z. B. (1999). Effect of osmotic agent on osmotic dehydration of fruits. Drying Technology, 17(1/2), 175–189.

Park, K. J., Bin, A., Brod, F. P. R., & Park, T. H. K. B. (2002). Osmotic dehydration kinetics of pear D'anjou (*Pyrus communis* L.). *Journal of Food Engineering, 52*, 293–298.

Pointing, J. D. (1973). Osmotic dehydration of fruits—recent modifications and applications. *Process Biochemistry, 8*, 18–20.

Rahman, M. S. (1992). Osmotic dehydration kinetics of foods. *Indian Food Industry, 15*, 20–24.

Rastogi, N. K., Nayak, C. A., & Raghavarao, K. S. M. S. (2004). Influence of osmotic pre-treatments on rehydration characteristics of carrots. *Journal of Food Engineering, 65*, 287–292.

Sablani, S. S., & Rahman, M. S. (2003). Effect of syrup concentration, temperature and sample geometry on equilibrium distribution dehydration of mango. *Food Research International, 36*, 65–71.

Sereno, A. M., & Hubinger, M. D. (2001). Prediction of water activity of osmotic solutions. *Journal of Food Engineering, 49*, 103–114.

Statsoft (1997). Statistica for Windows 5.0., 1995. Computer program manual. Statsoft Inc., Tulsa.

Telis, V. R. N., Murari, R. C. B. D. L., & Yamashita, F. (2004). Diffusion coefficients during osmotic dehydration of tomatoes in ternary solutions. *Journal of Food Engineering, 61*, 253–259.

Torreggiani, D., Forni, E., & Rizzolo, A. (1987). Osmotic dehydration of fruit. Part 2: Influence of the osmosis time on the stability of processed cherries. *Journal of Food Processing and Preservation, 12*(1), 27–44.

Torreggiani, D, (1993). Osmotic dehydration in fruit and vegetable processing. *Food Research International, 26*(1), 59–68.