# OSMOTIC DEHYDRATION OF PUMPKIN (*Cucurbita moschata*) IN SUCROSE AND SUCROSE-SALT SOLUTIONS. EFFECT OF SOLUTION COMPOSITION AND SAMPLE SIZE

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*Abstract*— **Mass transfer during osmotic dehydration (OD) of Anco pumpkin cubes was studied as a function of sample size and composition and concentration of sucrose dehydrating solution. Models of Azuara and Hawkes & Flink were adjusted to the experimental data and optimal dehydrating conditions could be specified. For equal solutes concentration, higher weight losses were reached for smaller size samples. The addition of 2% NaCl increased Water Loss (WL) and lowered Solids Gain (SG) for the solution of higher sucrose content. Prediction capacity of the simplified models was very good under the tested working conditions. In brief, OD can be optimized using 1 cm side cubes dehydrated in binary or ternary solutions at the higher sucrose content (55ºBx), maximizing WL and minimizing SG.**

*Keywords*— **Anco pumpkin; osmotic dehydration; size; sucrose; sodium chloride.**

## I. INTRODUCTION

During last decades, per capita consumption of fruits and vegetables has noticeably increased; besides, buyers prefer products with high quality, low processing and easy to prepare and consume. That is why, numerous processing methods have been studied that allow obtain new products, nutritious, innocuous and of fresh appearance (Simpson *et al*., 2007). Osmotic Dehydration (OD) is one of them. It is a Unit Operation used to partially withdraw water from a high-water content material by dipping it in a hypertonic solution. In cellular foods, water withdrawal is based on the phenomenon of osmosis through cell membranes (Rastogi *et al.*, 2005). Water diffusion from the food to the solution is accompanied by a counter-diffusion of solutes from the solution to the interior of the food (Chenlo *et al.*, 2008). Both transfers are due to the gradient in osmotic pressure (chemical potential) between food and solution (Salvatori and Alzamora, 2000; Rastogi *et al.*, 2002). Osmotic dehydration usually precedes other preservation processes like refrigeration, freezing, final dehydration (hot air, vacuum, microwaves), preserves, etc.; it is also used in certain minimally processed foods (Chiralt *et al*., 2001).

Pumpkin of the variety anco (Cucurbita moschata) is a vegetable broadly produced and consumed in Central and South America. It is one of the vegetables most consumed in the Northwest of Argentina due to its low cost and availability along all the year. It has a high content of carotenoids, constituting an important input of vitamin A (González *et al.*, 2001), potassium, vitamins $B_2$, C and E and vegetable fiber (de Escalada Plá *et al*., 2007).

Anco is highly consumed fresh or cooked due to low cost, availability, nutritious quality, good taste and easiness of cleaning, peeling and cooking. Notwithstanding, OD of anco pumpkin –as a possible first stage to further processing - is a little studied subject. There is only about half a dozen of papers related to it. But no paper makes a study intended for the later processing of the OD anco in refrigerated storage (as a ready to eat vegetable, for salads or for pot stews). Osmotic dehydration can be used as a pretreatment (first stage of processing) to later obtain a more stable final product, by refrigeration with or without modified atmosphere or by freezing (dehydrofreezing), constituting an interesting alternative for the development of local industries. As said, literature relative to OD of anco pumpkin is very scarce (Castilho Garcia *et al.*, 2007; Lee and Lim, 2011; Arballo *et al*., 2012; Bambicha *et al.*, 2012; Bellocq, 2013), compared to that of other products like apples, mango, potatoes, carrots, meats and fishes, etc. That is why it is very important to characterize mass transfer during OD under specified working conditions feasible to be adopted for industrial processing.

Mass transfer rate depends on numerous factors such as composition, concentration, temperature and stirring of osmotic solution; type, composition, structure, shape and size of food material, process time, etc. (Rastogi *et al.*, 2002; Sablani and Rahman, 2003).

Numerous studies have been developed to better understand mass transfer during OD of vegetable tissues and mathematically model the process. In fact, the high structural complexity of cellular foods makes difficult the use of complex mathematical models, due to the need of numerous parameters that are difficult to measure or predict. That is why, phenomenological, empirical or semi-empirical methods are applied that relate WL and SG with some of the process variables (time, and mostly solution concentration) through very simple mathematical relations, whose parameters are only valid for the case under study (Ochoa-Martínez and Ayala-Aponte, 2005). An empirical model, widely used, is that of Azuara. It is based in the adjustment of experimental data to simplified equations derived of mass balances for WL and SG, that require adjustable parameters or values for relative rate constants (Azuara *et al*., 1992). Another model frequently used is that of Hawkes and Flink, based in Fick´s diffusion law. It assumes constant solution concentration and negligible external resistance to mass transfer (Hawkes and Flink, 1978). Both models allow the calculation of mass transfer coefficients. No published studies using these methods related to OD of pumpkin were found.

The objectives of this research work were:

- To study the effect of product size and of nature and concentration of the osmotic solution over mass transfer kinetics during OD of anco pumpkin cubes; adjust experimental data to empirical models to determine mass transfer rates, calculate effective diffusion coefficients and evaluate the adequacy of these methods for simulating experimental data.
- To select the most appropriate conditions for the OD of anco cubes - intended for further processing -, based on the previous data.

## II. MATERIALS AND METHODS

### A. Materials

Anco pumpkins, acquired in a local market, were selected based in their soluble solids content, measured with a hand refractometer and expressed in °Bx, having between 8 and 14 °Bx. Products were washed, peeled and cut into cubes of 1.0 or 1.5 cm side.

Six osmodehydrating solutions were tested: binary solutions of sucrose of 45 and 55 °Bx, and ternary solutions of sucrose-sodium chloride obtained adding 1 or 2 % NaCl to the binary solutions.

### B. Osmotic Dehydration

Anco samples, previously weighed, were placed in metallic grid baskets that were dived into the osmotic solution, contained in a thermostatized bath. Constant temperature (30 °C) and stirring (480 rpm) were used, maintaining a ratio solution: product higher than 30:1 to avoid the effect of dilution.

At different immersion times (0.5, 1, 2, 3, 5 and 8 h), samples of at least 5 cubes were randomly withdrawn, washed in distilled water to eliminate traces of solution and dried with tissue paper. Samples were weighed in analytical balance and their content of sol-ids was determined drying to constant weight in a vacuum oven at 60°C (AOAC, 2006).

### C. Mass transfer parameters

Weight Reduction ($WR$), Water Loss ($WL$) and Solids Gain ($SG$) were calculated according to Agnelli *et al.* (2005):

$$WR_t(\%) = \left(\frac{m_0 - m_t}{m_0}\right) \times 100 \qquad (1)$$

$$WL_t(\%) = \left[\left(1 - \frac{TS_0}{100}\right) - \left(1 - \frac{TS_t}{100}\right)\left(1 - \frac{WR_t}{100}\right)\right] \times 100 \qquad (2)$$

$$SG_t(\%) = \left[\left(1 - \frac{WR_t}{100}\right)\frac{TS_t}{100} - \frac{TS_0}{100}\right] \times 100 \qquad (3)$$

where $m_0$ and $m_t$ are, respectively, the mass of sample, initial and dehydrated during a period $t$; $TS_0$ and $TS_t$ represent, respectively, the total solids content, initial and after a dehydration period $t$.

Process efficiency was evaluated using the index $WL/SG$ (Mayor *et al.*, 2006), as high values of this ratio mean that water loss was favored respect to solids gain.

### D. Mathematical modeling

Models of Azuara and Hawkes and Flink were used to describe mass transfer from and to the food during OD. The mathematical model established in Azuara *et al.* (1992) for $WL$ and $SG$ is given in Eq. 4 and 5:

$$WL_t = \frac{s_1\, t\, WL_\infty}{1 + s_1\, t} \qquad (4)$$

$$SG_t = \frac{s_2\, t\, SG_\infty}{1 + s_2\, t} \qquad (5)$$

where $WL_t$, $WL_\infty$ and $SG_t$, $SG_\infty$ are water loss and solids gain after a dehydration time t and at equilibrium, respectively; $s_1$ and $s_2$ are rate constants related to water loss and solids gain, respectively.

Linearizing Eq. 4 and 5 as function of time, parameters $s_1$, $s_2$, $WL_\infty$ and $SG_\infty$ re obtained from their graphical plot. Besides, relating the model to the first root solution of Fick´s law, the effective diffusion coefficient ($D_e$) can be calculated as given in Eq. 6 (Azuara *et al.*, 1992).

$$D_e = \frac{\pi t}{4}\left[\left(\frac{s_1 l}{1 + s_1\, t}\right)\left(\frac{WL_\infty^{mod}}{WL_\infty^{exp}}\right)\right]^2 \qquad (6)$$

In Eq. 6 $WL_\infty^{mod}$ and $WL_\infty^{exp}$ correspond to experimental and modeled water loss at equilibrium. Due to the fact that food shape is cubic, $l$ in Eq. 6 must be one third of cube side (Rastogi and Niranjan, 1998).

Hawkes and Flink model is given in Eq. 7:

$$\frac{WL}{WL_\infty} = 2\left(\frac{D_e t}{\pi\, l^2}\right)^{1/2} \qquad (7)$$

Plotting $WL$ vs. $t^{1/2}$, $D_e$ is obtained from the slope of the straight line (Hawkes and Flink, 1978).

Changing in Eq. 6 and 7 $WL$ for $SG$ and $s_1$ by $s_2$, the diffusivity of solids can be obtained.

### E. Statistical Analysis

Average value and standard deviation of data were calculated as well as the fitting of models to experimental data by the correlation coefficient ($R^2$) and the Root Mean Square (RMS). The statistical significance of effects was analyzed through their variances (ANOVA) and, as a comparison method, the test of Least Significant Differences (LSD) or Fisher test with a confidence level of 95% was used.

## III. RESULTS AND DISCUSSION

Experimental values for $WR$, $WL$ and $SG$ are plotted in Fig. 1 that shows the prevalence of $WL$ respect to $SG$. In all tests main variations occur during the first three hours of dehydration, with a later lower rate tending to equilibrium.

$WR$ was higher for the smaller cubes for equal concentration of osmotic solution; e.g., after 3 h dehydration in 45°Bx-2% solution, 1 cm side cubes lost 48.03% of weight meanwhile those of 1.5 cm decreased their weight by only 29.04% (Fig. 1.a). In most cases higher NaCl content in the osmodehydrating solutions meant higher $WR$ and $WL$ values, independently of sucrose concentration, with the same trends as those determined by other authors (Sacchetti *et al*., 2001; Telis *et al.*, 2004; Ozdemir *et al*., 2008; Monnerat *et al*., 2010; Mercali *et al.*, 2011). Similar values of $WL$ were obtained by Kowalska and Lenart (2001) for 1.0cm side cubes of pumpkin cv Melonowa OD in sucrose solution at 61.5 %.

The effect of sample size on dehydration rate was analyzed by Van Nieuwenhuijzen *et al*. (2001) in apple rings. They attributed the increase of $WL$ for samples with lower characteristic dimension to the higher specific area (surface/volume ratio). This behavior was verified for other products (Chavarro-Castrillon *et al*., 2006; Salvatori and Alzamora, 2000).

Adding of salt at the lower concentration (1%) did not produce noticeable increase in $SG$. When NaCl concentration was 2%, in most cases, an increase in $SG$ was determined. Same results were found by other authors working with ternary solutions with low salt content (Lerici *et al*., 1984; Sacchetti *et al*., 2001; Jokié *et al.*, 2007). For higher amounts of salt addition (5% or higher) an increase in $SG$ with salt concentration is evident (Azoubel and Xidieh Murr, 2004, Telis *et al*., 2004). The effect of salt addition on SG seems to depend of salt concentration via an increase in the osmotic pressure gradient and the consequent loss of functionality of cell membrane, what allows the input of solids (Jokié *et al.*, 2007, Herman-Lara *et al.*, 2013). On the other hand, significant differences were found for $SG$ under diverse sucrose concentrations (Fig. 1c and c'), in accordance with results obtained by Singh *et al.* (2008) with carrot cubes 1.0 cm side, Mújica-Paz *et al*.(2003) for apple slices OD under vacuum and Pereira *et al.* (2006) for red guavas. Lower values of SG were determined when using binary and ternary solutions of sucrose at

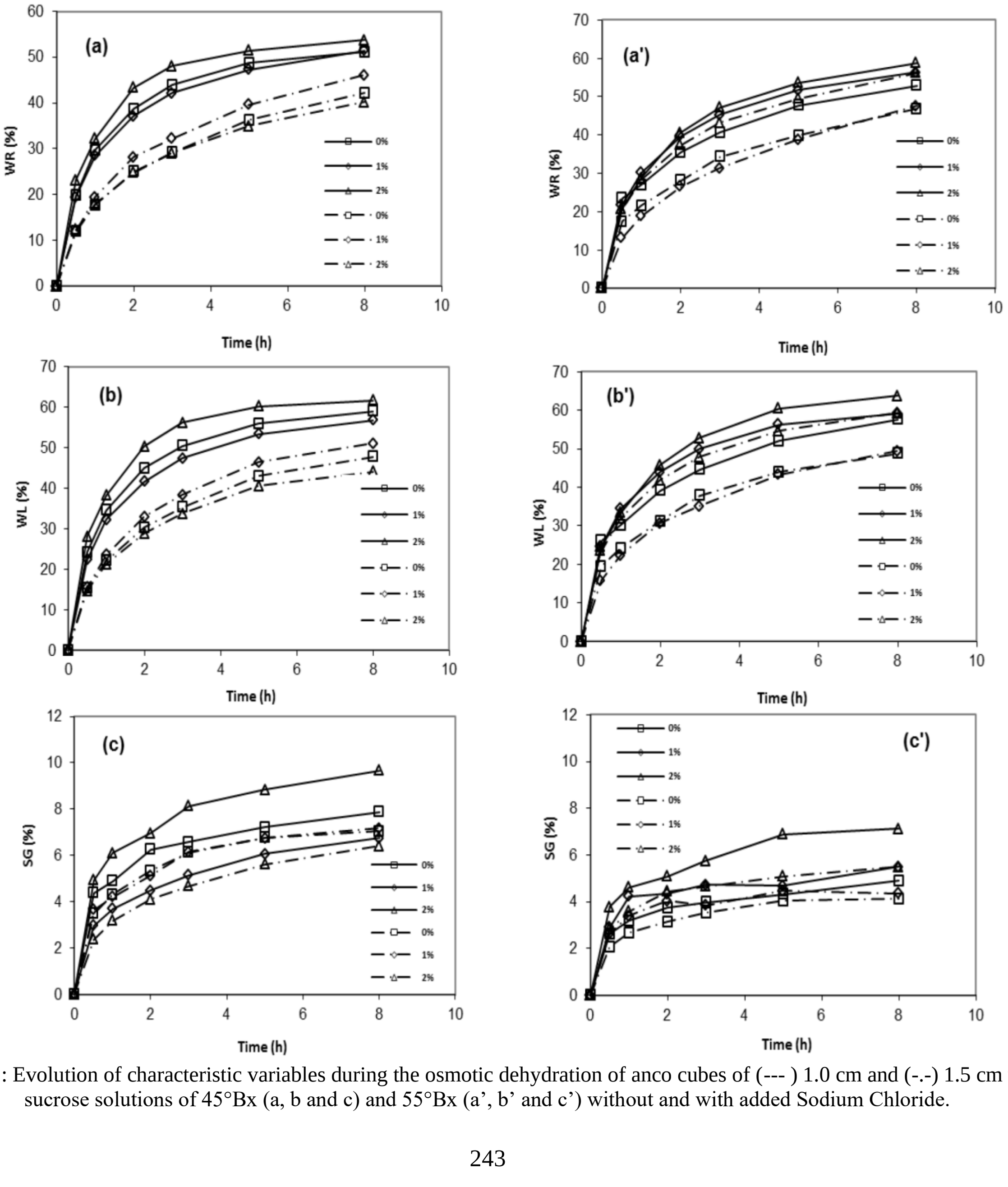

Figure 1: Evolution of characteristic variables during the osmotic dehydration of anco cubes of (--- ) 1.0 cm and (-.-) 1.5 cm with sucrose solutions of 45°Bx (a, b and c) and 55°Bx (a', b' and c') without and with added Sodium Chloride.

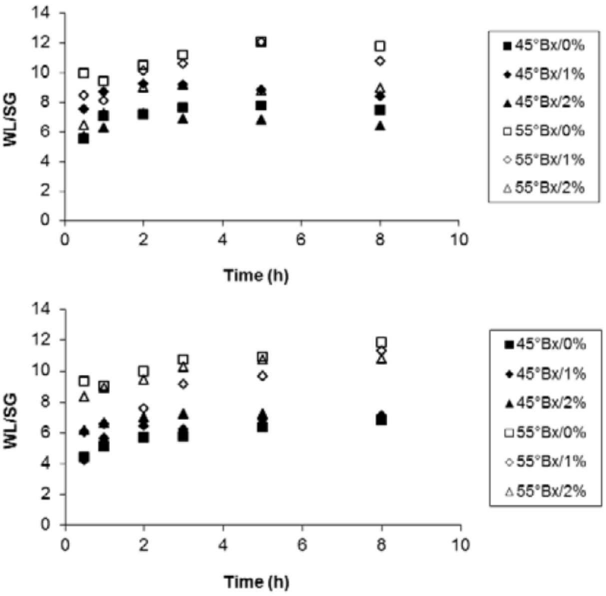

Figure 2: WL/GS index in cubes of (a) 1.0 and (b) 1.5 cm side de-hydrated in binary and ternary solutions.

55°Bx. Ferrari and Hubinger (2008) attributed this behavior to the increase of resistance to soluble solids penetration owed to higher solution viscosity, which determines the formation of a surface layer of sugar (candying effect).

$WL/SG$ index is given in Fig. 2 a and b for cubes of 1.0 and 1.5 cm, respectively. The highest values of the index were obtained for binary and ternary solutions with 55°Bx of sucrose. Furthermore, the index remains almost constant after 3 h of dehydration. According to the intended later use of the product this is an important characteristic. Mayor *et al.* (2006) observed a similar trend during OD of 1.5 cm diameter cylinders of pumpkin of other variety (Cucurbita Pepo L.) in solutions of NaCl at 10%. The highest values were for binary solutions of 55°Bx, being 11.22 and 10.72 for cubes of 1 and 1.5 cm, respectively. Kowalska and Lenart (2001) obtained lower values (8.09) after 3 h of OD of pumpkin cubes of a different cv (Melonowa), and with a lower ratio solution: product which means lower dehydrating power due to solution dilution during processing.

Table 1 shows the values of diffusion coefficients calculated using the different models. Calculated values had a very good fitting for both models ($R^2 > 0.98$), in no case RMS was higher than 10%. In general, water diffusion coefficients calculated using Hawkes & Flink model resulted significantly higher ($\alpha = 0.05$) than those given by the model of Azuara. On the other hand, no significant differences were determined for solids diffusion coefficients calculated by both methods. Cubes size had a significant effect on diffusion coefficient, being this higher for the bigger sizes. Falade *et al.* (2007) found similar results when working with melon slices of different thicknesses. This behavior could be attributed to the fact that diffu-sion coefficient varies with water content. Bigger samples lose less water and gained less solids, simplified prediction models leading to higher values of the coefficients (Singh *et al.*, 2007).

Table 1: Diffusion coefficients of water and solids obtained with the models of Azuara and Hawkes & Flink for OD anco cubes.

| | | Water | | | | Solids | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Azuara | | Hawkess & Flink | | Azuara | | Hawkess & Flink | |
| | Size (cm) | $D_{e,w}$ $\times 10^{10}$ (m$^2$/s) | RMS (%) | $D_{e,w}$ $\times 10^{10}$ (m$^2$/s) | RMS (%) | $D_{e,w}$ $\times 10^{10}$ (m$^2$/s) | RMS (%) | $D_{e,w}$ $\times 10^{10}$ (m$^2$/s) | RMS (%) |
| 45°Bx | | | | | | | | | |
| 0% | 1.0 | 3.55 | 1.95 | 4.52 | 4.28 | 3.05 | 5.58 | 3.96 | 5.95 |
| | 1.5 | 7.02 | 3.38 | 9.06 | 3.36 | 6.05 | 5.13 | 7.03 | 4.05 |
| 1% | 1.0 | 3.50 | 1.34 | 4.46 | 4.11 | 1.82 | 6.10 | 2.25 | 4.50 |
| | 1.5 | 9.11 | 2.13 | 11.48 | 3.36 | 4.98 | 7.75 | 6.68 | 2.55 |
| 2% | 1.0 | 3.93 | 3.29 | 4.83 | 3.83 | 2.06 | 5.31 | 2.60 | 3.19 |
| | 1.5 | 6.98 | 2.55 | 9.63 | 2.56 | 6.15 | 9.41 | 7.70 | 2.80 |
| 55°Bx | | | | | | | | | |
| 0% | 1.0 | 2.14 | 7.28 | 2.40 | 2.05 | 2.12 | 6.81 | 2.53 | 5.18 |
| | 1.5 | 5.90 | 7.06 | 6.36 | 1.93 | 6.02 | 3.89 | 6.98 | 5.47 |
| 1% | 1.0 | 3.38 | 1.94 | 4.15 | 3.50 | 1.61 | 6.48 | 2.70 | 9.59 |
| | 1.5 | 6.29 | 2.59 | 8.13 | 4.71 | 6.65 | 5.93 | 5.08 | 8.08 |
| 2% | 1.0 | 2.48 | 3.92 | 4.67 | 3.64 | 3.70 | 6.15 | 1.72 | 4.42 |
| | 1.5 | 7.16 | 3.13 | 8.73 | 2.62 | 6.52 | 3.25 | 6.16 | 5.01 |

Furthermore, lower sucrose concentration lead, in general, to higher water diffusion coefficients. In the same sense, Rodrigues and Mauro (2008) found - when working with apple slices in sucrose solutions – that water diffusion coefficient lowers when sucrose concentration increases meanwhile solids diffusion coefficient remains almost constant. On the other hand, Castilho Garcia *et al.* (2007) did not find a dependence of $D_{e,w}$ with the type of osmotic solution, attributing this behavior to a conjunction of opposing factors. The addition of NaCl did not modify noticeably the value of $D_{e,w}$. Surely, higher water loss due to NaCl implies higher volume contraction and – at the same time – lower diffusion coefficient (that is proportional to water content). These factors may counterbalance to give similar results with the approximate methods.

## IV. CONCLUSIONS

Higher solution concentration and process time and lower sample size increase $WR$ and $WL$. $SG$ is favored by low solution concentration.

The higher rates of $WL$ and $SG$ during OD of anco cubes were obtained during the first three hours of treatment; at higher process times variation rates lower and these variables tend to constant values.

At equal concentration of the OD solution, smaller samples underwent higher $WL$.

It was observed that the addition of 2% NaCl increases $WL$ and that $SG$ are lower when sucrose concentration is the highest.

The higher efficiency of OD, calculated with the index $WL/SG$ was for binary and ternary sucrose solutions of 55°Bx (without or with addition of NaCl).

The accuracy of prediction models was very high.

Mass diffusivities calculated with the models by Azuara and Hawkes & Flink, both for water and solids, increase with sample size and lower with sucrose concentration. Water diffusion coefficients calculated with Hawkes & Flink model were significantly higher.

In the range of working conditions tested, OD can be optimized using cubes of 1.0 cm side and binary or ternary sucrose solutions at 55°Bx, when the objective is to reach the highest water loss and – simultaneously – the lower solids uptake.

Additional studies are necessary to determine the influence of partial dehydration in later shelf life of the final refrigerated or frozen product and on its quality characteristics.

## REFERENCES

Agnelli, M.E., Marani, C.M. and Mascheroni, R.H. (2005) Modelling of heat and mass transfer during (osmo) dehydrofreezing of fruits. *Journal of Food Engineering*. **69**, 415-424.

AOAC (2006) *Official Method of Analysis of AOAC International*, 18th Edition.

Arballo, J.R, Bambicha, R.R., Campañone, L.A., Agnelli, M.E. and Mascheroni, R.H. (2012) Mass transfer kinetics and regressional desirability optimisation during osmotic dehydration of pumpkin, kiwi and pear. *International Journal of Food Science & Technology*. **47**, 306-314.

Azoubel, P.M. and Xidieh Murr, F.E. (2004) Mass transfer kinetics of osmotic dehydration of cherry tomato. *Journal of Food Engineering*. **61**, 291-295.

Azuara, E., Beristain, C.I. and Garcia, H.S. (1992) Development of a mathematical model to predict kinetics of osmotic dehydration. *Journal of Science and Tecnnology*. **29**, 239-242.

Bambicha, R.R., Agnelli, M.E. and Mascheroni, R.H. (2012) Optimización del proceso de deshidratación osmótica de calabacita en soluciones ternarias. *Avances en Ciencias e Ingeniería*. **3**, 121-136.

Bellocq, C.E. (2013) *Deshidrocongelación de zapallo anco*. Tesis de Maestría en Tecnología de Alimentos, UTN FRBA, Argentina.

Castilho Garcia, C., Mauro, M.A. and Kimura, M. (2007) Kinetics of osmotic dehydration and air-drying of pumpkins (Cucurbita moschata). *Journal of Food Engineering*. **82**, 284-291.

Chavarro-Castrillon, L.M., Ochoa-Martinez, C.I. and Ayala-Aponte A. (2006) Efecto de la madurez, geometría y presión sobre la cinética de transferencia de masa en la deshidratación osmótica de papaya (Carica papaya L., var. Maradol). *Ciência e Tecnologia Alimentaria*, **26**, 596-603.

Chenlo, F., Moreira, R., Torres, M.D. and Ferra, J. (2008) Deshidratación osmótica de castaña en medios estáticos y dinámicos de sal, sacarosa y glucose. *Ciência e Tecnologia de Alimentos.* **6**, 117-129.

Chiralt, A., Martínez-Navarrete, N., Martínez-Monzó, J., Talens, P., Moraga, G., Ayala-Aponte, A. and Fito, P. (2001) Changes in mechanical properties throught osmotic processes cryoprotectant effect. *Journal of Food Engineering*. **49**, 129-135.

de Escalada Plá, M., Ponce, N., Stortz, C., Gerschenson, L. and Rojas, A.M. (2007) Composition and functional properties of enriched fiber products obtained from pumpkin (Cucurbita moschata Duchesne ex Poiret). *LWT- Food Science and Technology*. **40**, 1176-1185.

Falade, K.O., Igbeka, J.C. and Ayanwuyi, F.A. (2007) Kinetics of mass transfer, and colour changes during osmotic dehydration of watermelon. *Journal of Food Engineering.* **80**, 979-985.

Ferrari, C.C. and Hubinger, M.D. (2008) Evaluation of mechanical properties and difussion coefficients of osmodehydrated melon cubes. *International Journal of Food Science and Technology*, **43**, 2065-2074.

González, E., Montenegro, M., Nazareno, M. and López, B. (2001) Carotenoid composition and vitamin A value of an Argentinian squash (Cucurbita moschata). *Archivos Latinoamericanos de Nutrición.* **51**, 395-399.

Hawkes, J. and Flink, J.M. (1978) Osmotic concentration on fruit slice prior to freeze dehydration. *Journal of Food Processing and Preservation*. **2**, 265-284.

Herman-Lara, E., Martínez-Sánchez, C.E., Pacheco, A., Carmona-García, H., Ruiz-Espinosa, R., Ruiz-López, H. and Irving, I. (2013) Mass transfer modeling of equilibrium and dynamic periods during dehydration of radish in NaCl solutions. *Food and Bioproducts Processing.* **91**, 216-224.

Jokié, A., Gyura, J., Ljubinko, L. and Zavargó, Z. (2007) Osmotic dehydration of sugar beet in combined aqueous solutions of sucrose and sodium chloride. *Journal of Food Engineering*, **78**, 47-51.

Kowalska, H. and Lenart, A. (2001) Mass exchange during pretreatment of vegetables. *Journal of Food Engineering*. **49**, 137-140.

Lee, J.S. and Lim, L.S. (2011) Osmo-dehydration pretreatment for drying of pumpkin slice. *International Food Research Journal*. **18**, 1223-1230.

Lerici, C.L., Pinnavaia, G., Dalla Rosa, M. and Bartolucci, L. (1985) Osmotic dehydration of fruit: influence of osmotic agents on drying behaviour and product quality. *Journal of Food Science*. **50**, 1217–1219.

Mayor, L., Moreira, R., Chenlo, F. and Sereno, A.M. (2006) Kinetics of osmotic dehydration of pumpkin with chloride solutions. *Journal of Food Engineering.* **74,** 253-262.

Mercalli, G.D., Marczak, L.D.F., Tessaro, I.C. and Noreña, C.P.Z. (2011) Evaluation of water, sucrose and NaCl effective diffusivities during osmotic dehydration of banana (Musa sapientum, shum.). *LWT-Food Science and Technology*. **44**, 82-91.

Monnerat, S.M., Pizzi, T.R.M., Mauro, M.A. and Menegalli, F.C. (2010) Osmotic dehydration off apples in sugar/salt solutions: Concentration profiles and effective diffusion coefficients. *Journal of Food Engineering*. **100**, 604-612.

Mújica-Paz, H., Valdez-Fragoso, A., López-Malo, A., Palou, E. and Welti-Chanes, J. (2003) Impregnation and osmotic dehydration of some fruits: effect of the vacuum pressure and syrup concentration. *Journal of Food Engineering*. **57**, 305–314.

Ochoa-Martínez, C.I. and Ayala-Aponte, A. (2005) Modelos Matemáticos de transferencia de masa en deshidratación osmótica. *Ciencia y Tecnología Alimentaria*. **4**, 330-342.

Ozdemir, M., Ozen, B.F., Dock, L.L. and Floros, J.D. (2008) Optimization of osmotic dehydration of diced Green peppers by response surface methodology. *LWT-Food Science and Technology*. **41**, 2044-2050.

Pereira, L.M., Ferrari, C.C., Mastrantonio, S.D.S., Rodrigues, A.C.C. and Hubinger, M.D. (2006) Kinetic Aspects, Texture, and Color Evaluation of Some Tropical Fruits during Osmotic Dehydration. *Drying Technology*. **24**, 475–484.

Rastogi, N.K. and Niranjan K. (1998). Enhanced mass transfer during osmotic dehydration of high pressure treated pineapple. *Journal of Food Science*. **63**, 508–511.

Rastogi, N.K., Raghavarao, K.S.M.S. and Niranjan, K. (2005) *Emerging Technologies for food processing*, Elsevier, Oxford, U.K.

Rastogi, N.K., Raghavarao, K.S.M.S., Niranjan, K. and Knorr, D. (2002) Recent development in osmotic dehydration: Methods to enhance mass transfer. *Trends in Food Science and Technology*. **13**, 58-69.

Rodrigues, A.E. and Mauro, M.A. (2008) Effective diffusion coefficients behavior in osmotic dehydration of apple slices considering shrinking and local concentration dependence. *Journal of Food Process Engineering*. **31**, 207-228.

Sablani, S.S. and Rahman, M.S. (2003) Effect of syrup con-centration, temperature and sample geometry on equilibrium distribution coefficients during osmotic dehydration of mango. *Food Research International*. **36**, 65-71.

Sacchetti, G., Gianoti, A. and Dalla Rosa, M. (2001) Sucrose-salt combined effects on mass transfer kinetics and product acceptability. Study on apple osmotic treatments. *Journal of Foods Engineering*. **49**, 163-173.

Salvatori, D. and Alzamora, S.M. (2000) Structural changes and mass transfer during glucose infusion of apples as affected by blanching and process variables. *Drying Technology*. **18**, 361-382.

Simpson, R., Jiménez, M., Carevic, E. and Grancelli, R. (2007) Aceleración de la deshidratación osmótica de frambuesas (Rubus idaeus) por medio de calentamiento óhmico. *Archivos Latinoamericanos de Nutrición*. **57**, 192-195.

Singh, B., Kumar, A. and Gupta, A.K. (2007) Study of mass transfer kinetics and effective diffusivity during osmotic dehydration of carrots cubes. *Journal of Food Engineering*. **79**, 471-480.

Singh, B., Panesar, P.S. and Nanda, V. (2008) Optimization of osmotic dehydration process of carrot cubes in sucrose solution. *Journal of Food Process Engineering*. **31**, 1-20.

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

Van Nieuwenhuijzen, N.H., Zareifard, M.R. and Ramaswamy, H.S. (2001) Osmotic drying kinetics of cylindrical apple slices of different sizes. *Drying Technology*. **19**, 525-545.

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