Contemporary Engineering Sciences, Vol. 11, 2018, no. 12, 571 - 581
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2018.8247

Kinetics of Mass Transfer During Melon Osmotic Dehydration

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Abstract

The aim of this research was to study the kinetics mass transfer during melon osmotic dehydration. A 3^2 factorial design was carried out where the factors with their respective levels were temperature (30°C, 40°C and 50°C), soluble solids concentration (40°Brix, 50°Brix and 60°Brix) and thickness of the sample (30mm). The response variables were: weight loss, solids gain and calculation of the water and solids diffusivity coefficients. It was observed that weight loss increased with increasing temperature and concentration of osmotic solution as well. The same occurred with the gain of solids, which increased at higher temperature and greater Brix degree of the solution. It was also illustrated that at a higher temperature the diffusivity of the water gradually increased. It was also shown that at concentrations of 40°Brix, the diffusivity of the water was greater. Osmotic dehydration can be an alternative for the preservation of melon, because it allows the incorporation of solutes and decreases the moisture content, which favours having less water available for the development of microorganisms.

Keywords: weight loss, soluble solids, diffusivity, moisture

1. Introduction

Melon (*Cucumis melo L.*) is a fruit of high economic value. In terms of production, it is a widely cultivated crop. Fresh melon is perishable and deteriorates rapidly. In order to take advantage of the potential health benefits of melon and add value to the fruit, drying represents one of the possible conservation methods to extend shelf life and potentially increase fruit use. On the other hand, drying can significantly affect the quality of melon products, including colour change, reduction of bioactive compounds and texture. Drying is the most common method of food preservation and is used to reduce post-harvest loss and to produce several dried fruits that can be consumed directly or used in processed foods. Conventional air drying consumes a lot of energy and is therefore very expensive because it is a simultaneous heat and mass transfer process accompanied by a phase shift. A pretreatment may be used to reduce the initial water content of the fruit or may be used to modify the structure of the fruit tissue [1].

Osmotic dehydration is a water removal process that involves soaking food, mainly fruits and vegetables, in a hypertonic solution, such as concentrated sugar syrup. This results in two large simultaneous flows of mass transfer to counterflow, namely, the flow of water from the product to the surrounding solution and the infusion of solutes into the product [2]. There is a third flow of natural solutes such as sugars, organic acids, minerals and salts that filter from the food to the solution [3, 4], which is quantitatively negligible, but may be important for the sensory and nutritional value of the product [5]. Osmotic dehydration is one of the energetically efficient means of removing moisture from a food, since water does not undergo a phase change to be removed from the product. Osmotic dehydration has received considerable attention because of its low energy and temperature requirements compared to other dehydration methods [6, 7]. Other benefits of osmotic dehydration include effective inhibition of polyphenol oxidase (PPO), prevention of loss of volatile compounds, including vacuum, and minimizing heat damage to colour and taste during dehydration [8].

Colour affects consumer acceptance of a product, which often represents about 40% of acceptance criteria [9]. Non-enzymatic browning during drying is the main cause of colour degradation. Changes that occur during dehydration, which significantly affect colour, are therefore considered to be the main determinant of quality, and their levels are highly dependent on the temperature-moisture-time history of the product. The aim of this research was to study the effect of osmotic conditions on mass transfer during osmotic melon dehydration.

2. Methodology

Mature melons with a known agricultural history were used. The melons were stored in a ventilated room at 28 ± 2°C. The average moisture content of melon was 92.5% (wet base). Commercial sucrose was purchased at a local market in the Cartagena de Indias market.

2.1 Melon osmotic dehydration

A required amount of sucrose was dissolved in a measured volume of water to prepare solutions of 40°Brix, 50°Brix and 60°Brix. The melon was washed, peeled and cut into rectangular (50 × 30 mm) and thick (30 mm) plates using a very sharp stainless steel blade. Samples were weighed in triplicate of each thickness and immersed in sucrose solutions, maintaining a ratio of 1:25 fruit: solution. The osmotic process was carried out at three different temperatures (30°C, 40°C and 50°C). The samples were checked gravimetrically at a one-hour interval during the first three hours of osmotic process, and then at two-hour intervals for 10 h. To determine the equilibrium weights, the samples were left in osmotic solution and gravimetrically monitored until three consecutive constant weights were reached. Dry weights of fresh melon and similarly dimensioned osmodehydrated melon were dried according to kiln drying methods. Based on these data, water loss (WL) and solid gain (SG) were determined according to the Panagiotou *et al*., [6] method (Equation 1 and 2).

$$Water\ Loss\ (WL) = \frac{(M_0 - m_0) - (M - m)}{M_0} \tag{1}$$

$$Solid\ Gain\ (SG) = \frac{m - m_0}{M_0} \tag{2}$$

Where M_0 is the initial mass of fresh melon (g), M is the mass of melon after time (t) of osmotic dehydration (g), m is the dry matter of melon (g) after time (t) of osmotic dehydration, m_0 is the initial dry matter of melon plate (g). To describe a 2L thick plate that has the uniform initial amount of water or solids, subjected to osmotic dehydration under constant conditions, one could consider Fick's unidirectional diffusion model Crank, [10] using the following initial and boundary conditions:

Uniform initial amount MC (z, 0) =MC (0)

Symmetry of concentration $\left.\frac{\partial \mathrm{MC}(t)}{\partial \mathrm{z}}\right|_{\mathrm{z}=0} = 0$

Equilibrium content at surface $\mathrm{MC}(L, t) = \mathrm{MC}_{\mathrm{eq.}}$

It becomes three dimensions (Crank, 1975):

$$\frac{X_t - X_e}{X_0 - X_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{2n-1} \times \exp\left((-2n-1)^2\frac{\pi^2 D_{ew} t}{4L^2}\right)(-2n-1)^2\frac{\pi^2 D_{ew} t}{4L^2}$$

$$MR = \frac{X_t - X_e}{X_0 - X_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{2n-1} \times exp\left((-2n-1)^2\frac{\pi^2 D_{ew} t}{4L^2}\right)(-2n-1)^2\frac{\pi^2 D_{ew} t}{4L^2}$$

$$SR = \frac{S_t - S_e}{S_0 - S_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{2n-1} \times exp\left(-(2n-1)^2\frac{\pi^2 D_{ew} t}{4L^2}\right)$$

Where D_{ew} is the effective diffusivity of water (m^2/s), D_{ew} is the effective diffusivity of solute (m^2/s), t is the time (s), L is the slab thickness (m), MR is the moisture ratio, SR is the ratio of solids, X (t) is the moisture content of melon slab after time (t), X_o is the moisture content of melon slab before osmotic dehydration (g H_2O /g dry solid), $X_{(e)}$ is the moisture content of melon in equilibrium (g water / g dry solid), $S_{(t)}$ is the melon solid content after time (t), S_o is the melon solid content before osmotic dehydration, S_e is the melon solid content in equilibrium (g).

$$\ln MR = A - Bt \quad (3)$$

$$B = \frac{\pi^2 D_e}{4L^2} \quad (4)$$

Here,

$A = \text{Constant} = \ln(8/\pi^2)$ Fixed

Slope B is calculated by tracing ln MR against time Brennan, [11]. Similarly, the moisture ratio can be replaced with the ratio of S_R solids, as shown in Equation (5). In S_R, it is now traced as a function of time, and solid diffusivity can be obtained from the slope.

2.2 Statistical analysis

The Statgraphics Centurion 16.103 statistical package was used for the analysis of variance. Data were tabulated in Microsoft Excel and interpreted using descriptive statistics. Data were expressed as the average of trials conducted in triplicate.

3. Results

Figures 1, 2 and 3 show that water loss and solids gain augmented with increased concentration of the osmotic solution. The increase in solids gain and water loss with solution concentration is due to the high concentration difference between melon solution and osmotic solution which increased the diffusion rate of the exchange of solute and water with osmotic solution. Higher temperatures appear to promote faster water loss through swelling and plasticization of cell membranes, as well as improved water transfer characteristics on the surface of the product. Water losses are greater than solid gain. This behavior occurs in the tissue because the selective permeability of cell membranes allows the transport of small molecules such as water, but restricts the transport of larger molecules such as sucrose [2].

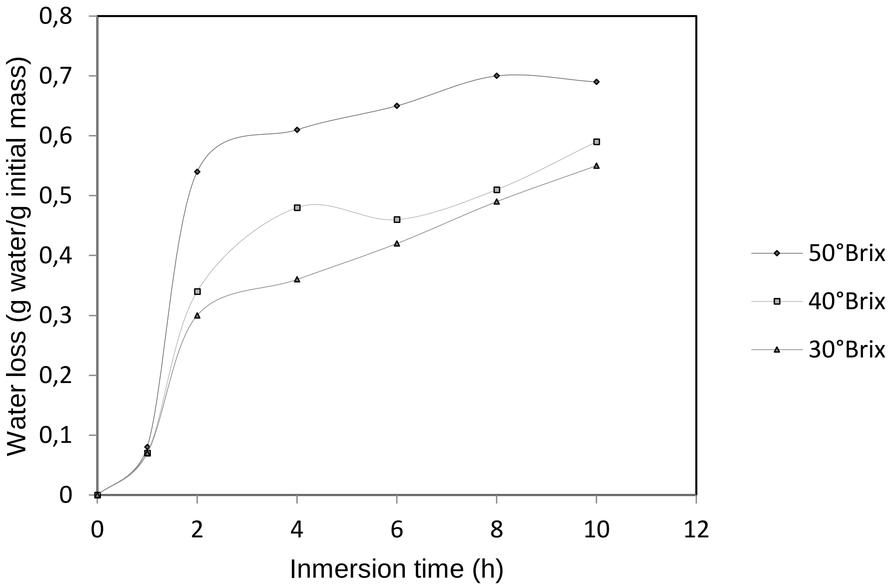

Figure 1. Water loss in melon sheets at 30°C

Falade et al., [12] during osmotic dehydration of melon slices, reported that water loss and solids gain increased with decreasing sample thickness. This is due to the width ratio and the increased surface area in contact with the osmotic solution. Nabawanuka [14] reported similar results with bananas and carrots, respectively, when dipped in sucrose solution. Cells in direct contact with the osmotic solution lose water and release turgor pressure. As the samples become smaller, the proportion of these cells in the osmotic tissue increases substantially due to the increased area of the contact surface with the osmotic solution.

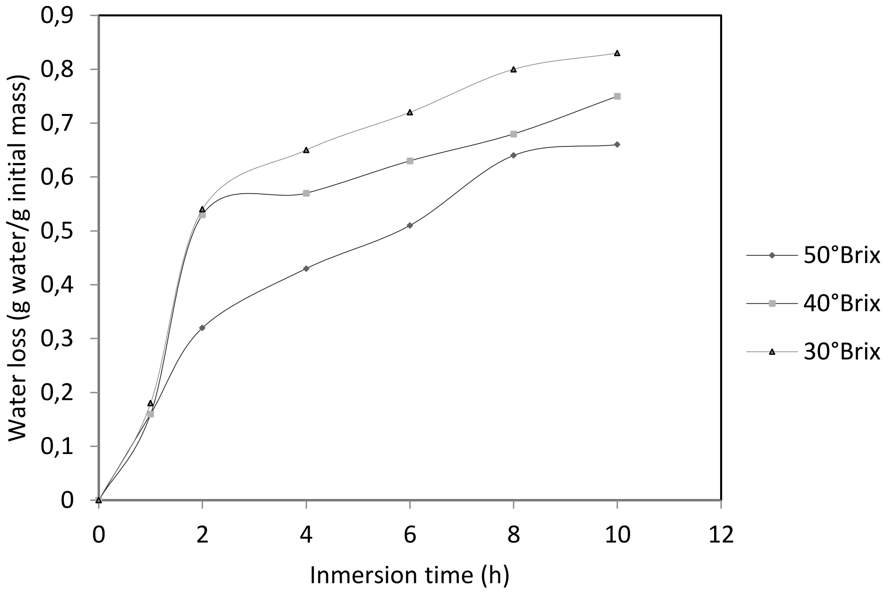

Figure 2. Water loss in melon sheets at 40°C

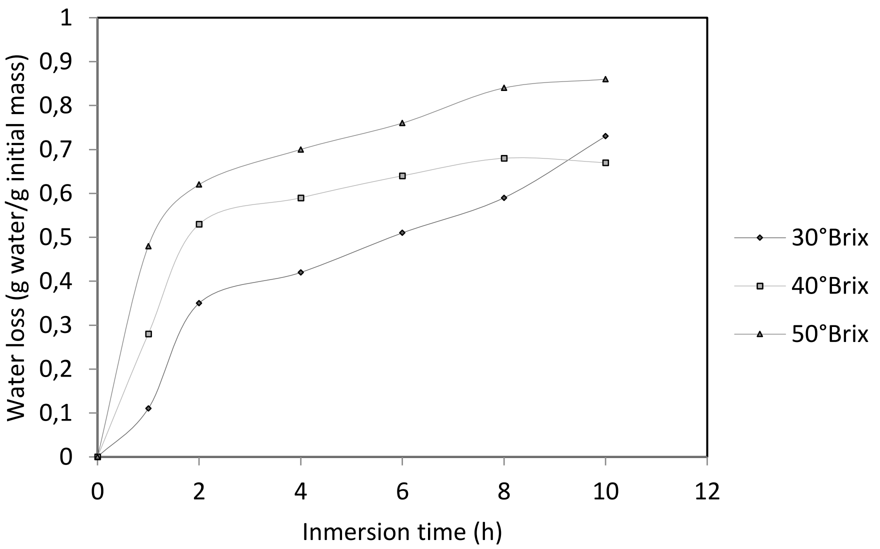

Figure 3. Water loss in melon sheets at 50°C

An increase in water loss and solids gain was also observed. This could be due to the large osmotic power difference between melon solutes and the surrounding hypertonic sucrose solution. An increase in the concentration of osmotic solution increases this gradient and, in turn, the driving force. In addition, due to the open structure of the tissue there is also the diffusion of the hypertonic solution and the hydrodynamic gain of the external solution. Singh et al., [14] observed a higher increased water loss and solution gain in carrot cubes with increased immersion time for all process conditions. They indicated that both water loss and solutes gain were higher in the initial phase of osmosis than in the subsequent period.

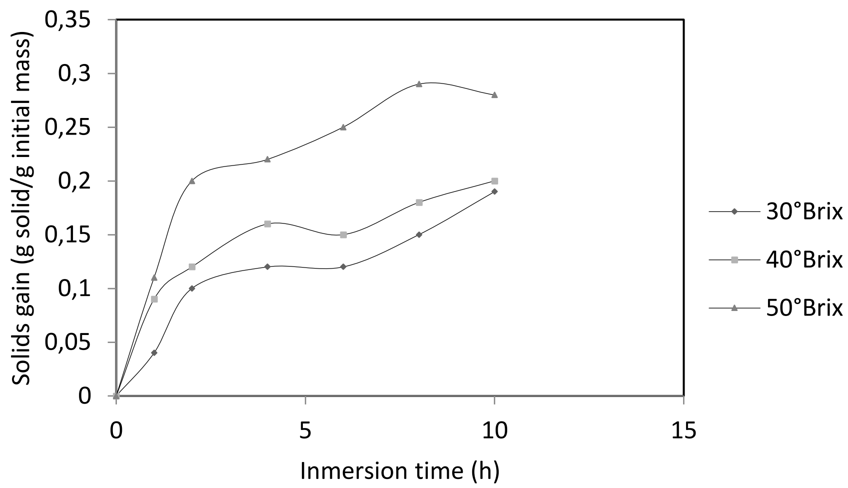

Figure 4. Gain of solids in melon sheets at 30°C

Figure 5 shows that the solids gain was greater with the increase in Brix degree and temperature increase. In addition, over time the solids increased until they reached a period of equilibrium. If observed in detail, the lower concentrations of Brix degree (30 and 40), the behavior was similar during the last three times of dehydration, this could be due to the reason that over time, as moisture moves from the sample to the solution and the solution from one solution to another, osmotic conduction potentials for moisture and solutes transfer decrease. In addition, rapid water loss and absorption of solids near the surface at first may have led to structural changes leading to compaction of these surface layers and increased resistance to mass transfer for water and solids [14].

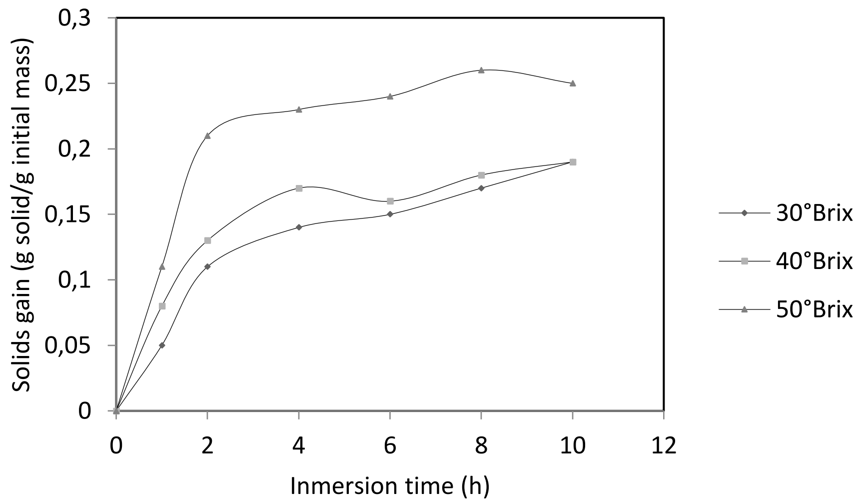

Figure 5. Gain of solids in melon sheets at 40°C

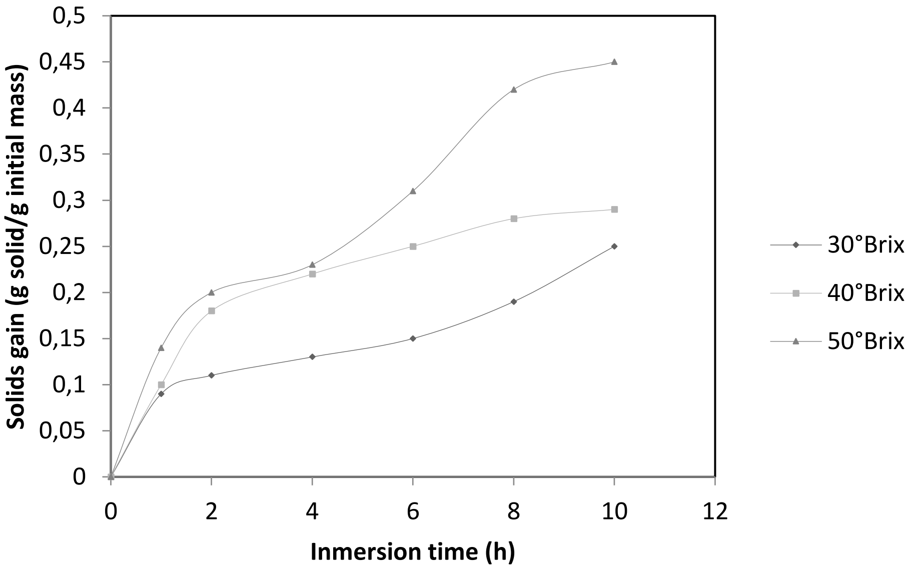

Figure 6. Gain of solids in melon sheets at 50°C

The water diffusivities (Equation 4) and solids (Equation 5), were calculated from the slope of the data of ln MR and ln SR according to the immersion time. The calculated values of water and solid diffusivities for melon are shown in Tables 1 and 2, respectively. It is illustrated that at a higher temperature the diffusivity of the water gradually increased. In addition, there is evidence that at concentrations of 40°Brix, the diffusivity of the water was greater. This was tested by Rastohi and Raghavarao [15], who found that the value of the coefficient of effective diffusion of water and solute depended on the concentration and temperature of the osmotic solution. The transport coefficient De increases with an increase in the concentration of osmotic solution due to changes in the physical properties of foods such as porosity and cellular permeability. In addition, the values found in this study were different from those found by Azoubel and Murr [2], who reported that the effective diffusion coefficients ranged from 4.3×10^{-10} to 1.77×10^{-9} m^2/s for water loss and 4×10^{-11} to 5.4×10^{-10} m^2/s for solutes gain during osmotic dehydration of Cherry tomatoes in a mixture solution of sucrose and sodium chloride at 25°C. The results of this study were consistent with Rodrigues and Fernandes [16] which showed that the diffusivity of water decreased after two hours in osmotic treatment and this can be caused by the incorporation of solids into the fruit that increases resistance to water diffusion. The effective diffusivity of water in fruits depends on the structure of the tissue, since the cell walls act as a semi-permeable membrane and also on the porosity of the fruit.

Table 1. Water diffusivities for melon sheets

Solution concentration (°Brix)	Melon thickness (mm)	Water diffusivity (m^2/s)		
		Temperature of the solution (°C)		
		20	30	40
30	30	5,89E-04	5,82E-04	4,40E-04
40	30	8,11E-04	9,11E-04	8,99E-04
50	30	5,30E-04	5,95E-04	8,99E-04

Results regarding water loss and gain of melon solids were expected and were due to the gradient of water and sugar concentration between fruit and liquid medium. Changes in water diffusivity during the dehydration stage were due to phenomena in the tissue structure of melons. This was verified by Fernandes *et al*., [1], who observed that the cell walls became distorted and smaller in all regions of the samples. In some regions, junctions between adjacent cells were present and intercellular spaces were reduced. Pectin soluble in chelate is the substance that contributes most to cell adhesion and firmness, and according to microscopic images can be solubilized in the early stages of osmotic dehydration. The diffusion of water within the fruit became easier when cell wall membranes ruptured and the effective diffusivity of water increased. After 2 hours, most of the cells collapsed and the diffusivity of the water reached a maximum value.

Table 2. Solid diffusivities for melon foils

Solution concentration (°Brix)	Melon thickness (mm)	Solid diffusivity (m^2/s)		
		Temperature of the solution (°C)		
		20	30	40
40	30	5.89E-04	5.82E-04	4.40E-04
50	30	8.11E-04	9.11E-04	8.99E-04
60	30	5.30E-04	5.95E-04	8.99E-04

In turn, Falade et al., [12] reported that the diffusivities of water and solids increased with the temperature and concentration of the solution, decreasing with the increase in thickness of the samples. They also reported that the values ranged from 1,030 $\times 10^{-9}$ to 3,54 $\times 10^{-9}$ m^2/s for water loss and from 1,117 $\times 10^{-8}$ to 8,54 $\times 10^{-9}$ m^2/s for solids gain. Consequently, they observed that the diffusivities of water and solids increased with the temperature and concentration of the solution, decreasing with the increase in thickness of the samples.

4. Conclusions

The osmotic dehydration of melon was studied by analyzing moisture kinetics and soluble solids. It was found that the higher the concentration of the osmotic solution and the higher the temperature, the weight loss increased and the percentage of water loss decreased considerably. Water and solids diffusivities increased in the mean range of Brix degree concentration, but decreased again at higher concentration. Osmotic dehydration can be an alternative for the preservation of melon, because it allows the incorporation of solutes and decreases the moisture content, which favors having less water available for the development of microorganisms.

References

[1] F.A. Fernandes, M.I. Gallão, S. Rodrigues, Effect of osmotic dehydration and ultrasound pre-treatment on cell structure: melon dehydration. LWT-Food Science and Technology, **41** (2008), no. 4, 604-610. https://doi.org/10.1016/j.lwt.2007.05.007

[2] P.M. Azoubel, F.E.X. Murr, Mass transfer kinetics of osmotic dehydration of cherry tomato, *Journal of Food Engineering*, **61** (2004), no. 3, 291-295. https://doi.org/10.1016/s0260-8774(03)00132-8

[3] K.N. Waliszewski, V.T. Pardio, M. Ramirez, Effect of EDTA on color during osmotic dehydration of banana slices, *Drying Technology*, **20** (2002), no. 6, 1291-1298. https://doi.org/10.1081/drt-120004052

[4] L.A. Gallo, D.F. Tirado, D. Acevedo, Deshidratación osmótica: una revisión, *Revista ReCiTeIA*, **15** (2015), no. 1, 1-12.

[5] S.S. Sablani, M.S. Rahman, D.S. Al-Sadeiri, Equilibrium distribution data for osmotic drying of apple cubes in sugar-water solution, *Journal of Food Engineering*, **52** (2002), no. 2, 193-199. https://doi.org/10.1016/s0260-8774(01)00103-0

[6] N.M. Panagiotou, V.T. Karathanos, Z.B. Maroulis, Effect of osmotic agent on osmotic dehydration of fruits, *Drying Technology*, **17** (1999), no. 1-2, 175-189. https://doi.org/10.1080/07373939908917524

[7] D. Acevedo, D. Tirado, L. Guzmán, Deshidratación osmótica de pulpa de tamarindo (*Tamarindus indica* L.): influencia de la temperatura y la concentración, *Revista UDCA Actualidad & Divulgación Científica*, **17** (2014), no. 1, 123 – 130.

[8] M.K. Krokida, Z.B. Maroulis, G.D. Saravacos, The effect of the method of drying on the colour of dehydrated products, *International Journal of Food Science and Technology*, **36** (2001), no. 1, 53-59. https://doi.org/10.1046/j.1365-2621.2001.00426.x

[9] P. Baardseth, G. Skrede, T. Naes, M.S. Thomassen, A. Iversen, L. Kaaber, A comparison of CIE (1976) L* a* b* values obtained from two different

instruments on several food commodities, *Journal of Food Science*, **53** (1988), no. 6, 1737-1742. https://doi.org/10.1111/j.1365-2621.1988.tb07830.x

[10] J. Crank, *The Mathematics of Diffusion*, 2nd ed., Oxford University, Press, London, 1975.

[11] J.G. Brennan, *Food Dehydration: A Dictionary and Guide*, Butterworth-Heinemann Ltd, Oxford. 1994.

[12] K.O. Falade, J.C. Igbeka, F.A. Ayanwuyi, Kinetics of mass transfer, and colour changes during osmotic dehydration of watermelon, *Journal of Food Engineering*, **80** (2007), no. 3, 979-985. https://doi.org/10.1016/j.jfoodeng.2006.06.033

[13] J. Nabawanuka, *Osmotic Dehyration of Bananas*, Diss., Silsoe College, Cranfield University, 1993.

[14] B. Singh, A. Kumar, A.K. Gupta, Study of mass transfer kinetics and effective diffusivity during osmotic dehydration of carrot cubes, *Journal of Food Engineering*, **79** (2007), no. 2, 471-480. https://doi.org/10.1016/j.jfoodeng.2006.01.074

[15] N.K. Rastogi, K.S.M.S. Raghavarao, Mass transfer during osmotic dehydration: determination of moisture and solute diffusion coefficients from concentration profiles, *Food and Bioproducts Processing*, **82** (2004), no. 1, 44-48. https://doi.org/10.1205/096030804322985308

[16] S. Rodrigues, F.A.N. Fernandes, Dehydration of melons in a ternary system followed by air-drying, *Journal of Food Engineering*, **80** (2007) 678–687. https://doi.org/10.1016/j.jfoodeng.2006.07.004

Received: March 3, 2018; Published: March 29, 2018