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Kinetics of osmotic dehydration of orange slices using healthy sweeteners

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Abstract

Orange slices have been osmotically dehydrated using as osmotic agents new healthy sweeteners: isomaltulose, oligofructose and aqueous extract of stevia. A kinetic study was done by analyzing changes in the water activity, total mass, mass of water and mass of soluble solids in orange slices, depending on the combination of sweeteners used in syrups (A: 30% isomaltulose and 70% of water; AS: 30% of isomaltulose, 35% aqueous solution with 1% of stevia and 35% water; B: 20% isomaltulose, 20% oligofructose and 60% water and BS: 20% isomaltulose, 20% oligofructose, 30% aqueous solution with 1% of stevia and 30% water). The results showed that the incorporation of stevia in syrups increased total mass and water mass losses of orange slices. Besides, by fitting second Fick's law effective diffusivities have been obtained in order to estimate the time to reach different concentrations of soluble solids in orange slices.

Introduction

Orange is a food with high content of healthy nutrients and it has great tradition and economic importance in Valencia. The development of new orange products would be a good way to promote the consumption of this fruit, improving the nutritional health of society. In this way, the osmotic dehydration (OD) has been widely used for conservation and design of new products from fruits. OD consists on the introduction of foods in a low water activity solution in order to induce water outflows and inflows of external solutes and therefore allows storing the foods for longer periods improving the stability and quality of products. This treatment depresses the food water activity and improves the biochemical and microbiological stability whereas producing physical and structural changes during its storage (Cháfer *et al*., 2001; Park *et al*., 2002; Gomes Alves *et al*., 2005; Moura *et al*., 2005; García-Segovia *et al*., 2010; Monnerat *et al*., 2010; Castro-Giráldez *et al*., 2011). Nowadays there is an important demand for high quality products in the food market and osmodehydrated oranges with healthy osmotic agents could be very appreciated by consumers. Sugars have been usually used as osmotic agents to obtained osmodehydrated fruits. However, it is widely known that sugars have cariogenic effects and most of them increase the glucose levels in blood and can be related with different diseases (diabetes, obesity, etc…). Fortunately, healthy osmotic agents are already available in the market with beneficial properties for our organisms since they are non-cariogenic and have a low glycemic index (Soto *et al*., 2002; Goyal *et al*., 2010). This is the case of isomaltulose, oligofructose and stevia.

Isomaltulose is a reducing disaccharide which is naturally present in honey, and sugar cane juice, and their taste and viscosities of aqueous solutions appearance are similar to sucrose. The physicochemical properties of isomaltulose (Palatinose®) permit the substitution of sucrose in most sweet foods (De Oliva-Neto *et al*., 2009; Lina *et al*., 2002; Peinado *et al*., 2013). It has a sweetening power of approximately 42% compared to sucrose, and also should be noted that because of its low hygroscopic rate, provides stability to products such as candy, gum and chocolate. It can be an alternative source of energy to sucrose, because its caloric power is similar. However, the solubility at room temperature of isomaltulose (30%) is much lower than sucrose (65%) (Kaga and Mizutani, 1985; Schiweck *et al*., 1990; Periche *et al*., 2014).

Regarding the oligofructose, it is obtained by partial enzymatic hydrolysis of chicory inulin and it is a soluble dietary fiber with prebiotic character to enhance the growth of beneficial gut bacteria and

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calcium absorption. On the other hand, oligofructose is low in calories, which gives multiple health benefits (Bosscher *et al*., 2006; Raschka *et al*., 2005; Rao, 2001). Nowadays, it is used as ingredient in many food products, and it is known that reduced serum insulin and glucose. Oligofructose helps to decrease hepatic fatty acid and triacylglycerol synthesis and coordinates the activity of all lipogenic enzymes (Franck, 2002; Al-Sherajia *et al.*, 2013).

Stevia is a plant that has been consumed as a food and also used as a medicine in some countries such as Japan and Paraguay (Lemus-Mondaca *et al*., 2012). This plant has a sweetening power 15 times greater than sucrose, multiple therapeutic properties (anti-oxidant, anti-microbial, anti-fungal activity, anti-hyperglycemic, anti-hypertensive, anti-inflammatory, anti-tumor, anti-diarrheal and diuretic effects), but it is calorie free (Chatsudthipong *et al*., 2009). Currently, the use of stevia leaves or extracts from stevia was approved by FDA as a dietary supplement in the US, and under similar classifications in several other countries, it has GRAS status (FDA GRAS Database, 2008). In November 2011, the European Commission approved steviol glycosides as food additives (European Commission, 2011).

Therefore, these new healthy sweeteners could be suitable for any sector of the population, even for those with diabetes, obesity or with predisposition to dental caries. Additionally, citric fruits are a good source of bioactive compounds like ascorbic acid, polyphenols and carotenoids that have been shown to be good contributors to the total antioxidant capacity of foods and have been involved in the prevention of some degenerative diseases (Devalaraja *et al.*, 2011; Kim *et al*., 2011).

Thus, the aim of this study was to characterize the kinetic behavior of the dehydrated orange slices using different combinations of healthy sweeteners (isomaltulose, oligofructose and aqueous stevia extract) in order to determine the time needed to obtain different levels of soluble solids concentration in the fruit.

Materials and Methods

Preparation of sample

Valencia Late oranges were used as raw material, selected with similar color, size and maturity stage of an agricultural plot from Líria (Valencia). The oranges were peeled and cut into 0.5 cm thick slices using a household slicer (Fagor Delice CF- 150).

Osmotic dehydration treatment

Isomaltulose (Palatinose™ PST- N, Beneo palatinit), oligofructose (Fructalose® OFP, Sensus) and an aqueous extract with 1% of dry leaves Stevia (*S. rebaudiana Raab*, Vitalfood, Rohrbach, Germany) were used as agents for osmotic dehydration. Table 1 shows the combinations of these three sweeteners used in the four syrups considered and the code assigned.

Table 1. Percentage of sweeteners in the syrups used in the study of osmotic dehydration of orange slices

	Isomaltulose	Oligofructose	Aqueous solution containing 1% of Stevia	Water
Syrup A	30%	-	-	70%
Syrup AS	30%	-	35%	35%
Syrup B	20%	20%	-	60%
Syrup BS	20%	20%	30%	30%

The kinetic study was carried out for 48 hours by analyzing samples at 0, 10, 20, 30, 45, 60, 90, 120, 240, 300 minutes and at 24 and 48 hours. The ratio between syrup and orange slices was 20:1 (w/w) in order to not modify the concentration of soluble solids of the syrup, with constant stirring.

Physicochemical analysis

Soluble solids of liquid phase in oranges slices and syrups were measured by a refractometer (Abbe Refractometer, Atago), obtaining the results in °Brix and also expressed as z_s (kg soluble solids/kg liquid phase). Moisture content (x_w: kg water/kg orange slices) was analyzed gravimetrically followed an adaption of the method AOAC, (2000). Water activity (a_w) was determined by a hygrometer (Decagon CX-1). All determinations were made in triplicate.

Kinetic study and modeling

Variation of total mass, soluble solids and water mass were calculated for all times considered in this study. Besides that, a Fick's model was used to obtain the effective diffusivity (De: m^2/s) of soluble solids (Crank, 1975; Barat *et al.*, 1998; Cháfer *et al*., 2001) depending on the composition of the syrup used.

Results and Discussion

The syrups used for this kinetic study reached 26.5±0.4, 27.7±0.4, 30.0±0.4 y 32.5±0.4 of ºBrix for formulations A, AS, B and BS, respectively. These results show that the highest proportions of solutes in syrups with oligofructose increased the °Brix and the same effect was observed when aqueous extract of stevia was added. Figure 1 represents

Table 2. Results of the effective diffusion coefficient *(D_e)*, slope and correlation coefficient *(R^2)* of Fick's equation for an infinite sheet (Crank, 1975)

	D_e (m^2/s)	Slope	R^2
Syrup A	$2.16\cdot10^{-09}\pm1.2\cdot10^{-10}$	$2.06\cdot10^{-3}\pm0.06\cdot10^{-3}$	0.71±0.02
Syrup AS	$4.7\cdot10^{-09}\pm3\cdot10^{-10}$	$3.20\cdot10^{-3}\pm0.08\cdot10^{-3}$	0.90±0.12
Syrup B	$1.71\cdot10^{-08}\pm3\cdot10^{-10}$	$5.89\cdot10^{-3}\pm0.05\cdot10^{-3}$	0.79±0.05
Syrup BS	$7.08\cdot10^{-09}\pm1.3\cdot10^{-10}$	$3.8\cdot10^{-3}\pm0.03\cdot10^{-3}$	0.68±0.16

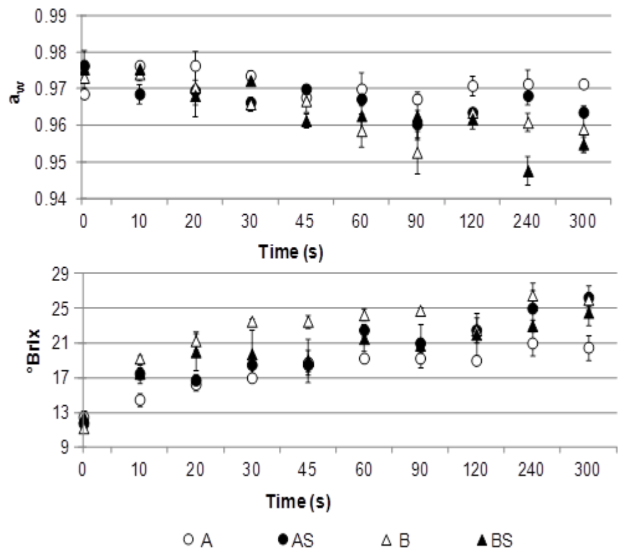

Figure 1. Results in aw and °Brix dehydration function of time for all the treatments studied

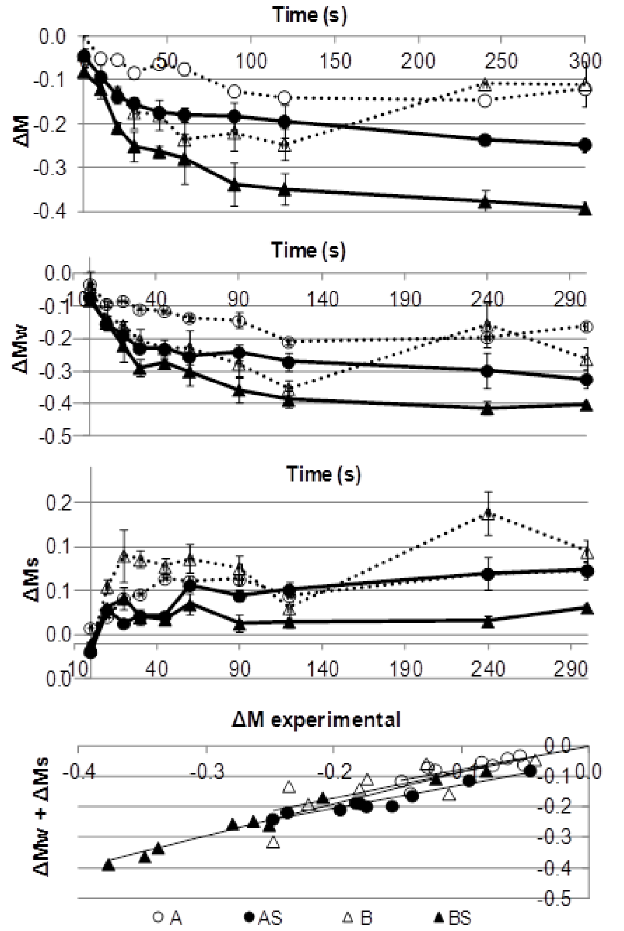

Figure 2. Results of variation of total mass *(ΔM)*, of water mass *(ΔM_w)* and soluble solid mass *(ΔM_s)* as well as material balances recorded in this study

the results of aw and °Brix versus time of osmotic dehydration as a function of the syrup employed. As was expected, the longer the time of dehydration higher the concentration of soluble solids in orange slices, especially for AS and BS. Other studies with orange and other fruits (strawberry, apple, apricot) show similar results (Cháfer *et al*., 2001; Castelló *et al*., 2006, 2009; İspir *et al*., 2009). In accordance with this behavior, the water activity decreased, but less in samples osmodehydrated with syrups containing stevia extracts, indicating the important influence of stevia in this process.

The results of variation of total mass *(ΔM)*, water mass *(ΔM_w)* and soluble solids mass *(ΔM_s)* recorded in this study were obtained with the following formulas (Shi *et al*., 1994; Fito *et al*., 1996) and are presented in Figure 2.

$$\Delta M = \frac{M^t - M^0}{M^0} \quad (1)$$

$$\Delta M_w = \frac{M^t x_w^t - M^0 x_w^0}{M^0} \quad (2)$$

$$\Delta M_s = \frac{M^t x_s^t - M^0 x_s^0}{M^0} \quad (3)$$

Being

M^i : M mass of orange slices (kg) at time i (i=0 or t)

M_w^i : mass of water of orange slices (kg) at time i (i=0 or t)

M_s^i : mass of soluble solids of orange slices (kg) at time i (i=0 or t)

x_w^i : mass fraction of water (kg of water/kg of orange slices) at time i (i=0 or t)

x_s^i : mass fraction of soluble solids (kg of soluble solids/kg of orange slices) at time i (i=0 or t)

There was also checked that the experimental total mass loss was similar to the calculated mass loss by using eq. (4).

$$\Delta M = \Delta M_s + \Delta M_w \quad (4)$$

In coherence with the previous results, both the addition of Stevia and oligofructose in syrups increased total and water mass losses of oranges slices since their driving forces were greater than when only isomaltulose was used.

Moreover, the changes in the composition of the liquid phase of orange slices were modeled using the

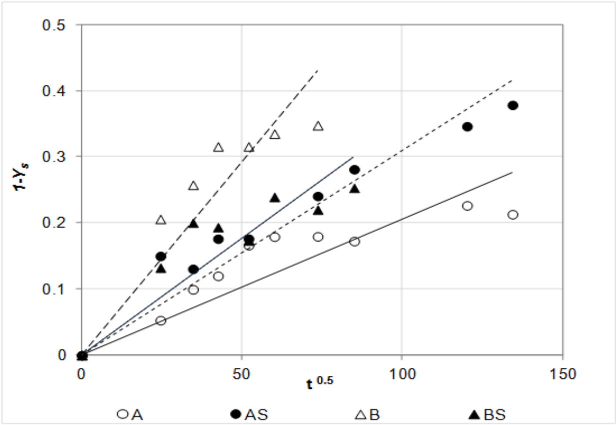

Figure 3. Results 1-Y_s vs. $t^{0.5}$ (square root of time of dehydration) for all the treatments

eq. (5).

$$Y_s^t = \frac{(z_s^t - y_s)}{(z_s^0 - y_s)} \quad (5)$$

Where:

Y_s^t : driving force of soluble solids (dimensionless)

z_s^i : soluble solid mass fraction in the liquid phase at time i (i=0 or t)

y_s: soluble solid mass fraction in the osmotic solution used for dehydration.

Therefore the y_s is the maximum soluble solid concentration that the orange slices could reached at equilibrium.

Figure 3 shows the experimental points of 1-Y_s versus $t^{0.5}$ to adjust them to a simplified Fickian approach for diffusion in a plane sheet, with only one term of the Fick's second law series solution for short times (Crank, 1975) (equation 6). From the fitting of this model, it is possible to obtain the kinetic parameter of effective diffusivity *(D_e)* which allows us to predict the process time required to achieve a specific concentration of soluble solids in orange slices (Table 2).

$$1 - Y_s = \left[\frac{4D_e t}{\pi l^2}\right]^{0.5} \quad (6)$$

Where *t* is time of processing (s) and *l* is half thickness of the dehydrated sample (m).

The results of D_e show that the best fitting was observed when AS syrup was used in dehydration of orange slices. Furthermore, B syrup presented a higher slope, which corresponded to the highest value of effective diffusivity. This would corroborate that the combination of oligofructose with isomaltulose implies a faster dehydration of orange slices due to the highest concentration of soluble solids in those osmotic solutions.

Conclusions

This study makes possible to model the osmotic dehydration behavior of orange slices depending on the combination of different new non cariogenic and prebiotic sweeteners (isomaltulose, oligofructose and stevia) used in the osmotic solution. Thus, the different effective diffusivity has been obtained to predict the required times to dehydrate orange slices. Moreover, it has been checked that stevia aqueous extract enhance the concentration of soluble solids in these products. Therefore these new sweeteners could be used to develop healthier osmodehydrated products also from other fruits.

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