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Modelling Osmotic dehydration of lemon slices using new sweeteners

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Abstract

Lemon slices were osmotically dehydrated using the following healthy sweeteners as osmotic agents: tagatose, isomaltulose, oligofructose and aqueous extract of stevia. A kinetic study using a Fickian approach was performed, which also analysed the changes in water activity, total mass, mass of water and mass of soluble solids in lemon slices. The results showed that the greatest value of effective diffusivity (D_e) in osmodehydrated lemon slices was obtained from a combination of oligofructose and stevia. However, the level of water activity (a_w) reached with this syrup was the highest, meaning that the product might be less stable. Additionally, isomaltulose favoured the total mass, whereas tagatose did the opposite. Finally, the syrup recommended for dehydrating lemon slices would be a combination of tagatose, oligofructose and aqueous extract of stevia since its D_e was similar to the value obtained when only oligofructose and stevia were used, but a_w values were lower.

Keywords: lemon, tagatose, isomaltulose, oligofructose, stevia, osmotic dehydration, kinetics.

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Introduction

Citrus fruits have played an important role in the economy and dietary habits in Spain. They are a good source of bioactive compounds like ascorbic acid, polyphenols and carotenoids and have been involved in the prevention of some diseases such as diabetes, obesity, cancer and cardiovascular diseases (Devalaraja *et al.,* 2011; Kim *et al*., 2011). Among these citrus fruits, lemon is the product consumed the least due to its high acidity. However, the addition of sweeteners might be an effective way to counteract this feature. Therefore, the development of new sweet lemon products could promote consumption of this fruit, and in turn, improve the nutritional health of society. Osmotic dehydration (OD) might be a suitable technique for obtaining such products, since it has been widely applied to other fruits, such as oranges (Cháfer *et al*., 2001; Rubio-Arraez, *et al.*, 2015), pears (Park *et al*., 2002), tomatoes (Azoubel and Murr, 2004), apples (Moura *et al*., 2005; Derossi *et al*., 2008; Castelló *et al.,* 2009), apricots (Toğrul and İspir, 2007; İspir and Toğrul, 2009), strawberries (Castelló *et al.,* 2006; Castelló *et al.,* 2010), kiwis (Castro-Giráldez *et al*., 2011) and cherries (Silva *et al*., 2012). Besides, OD has already been studied as an alternative which gives uses to lemon by-products (Masmoudi *et al.,* 2007). OD consists of placing foods in a low water activity solution in order to induce water outflows and inflows of external solutes, resulting in high quality products that can be stored longer.(Shi, 2008). However, the common use of sugars in the OD stage leads to an enhancement in the cariogenic property of the final products as well as an increase in their glycemic index, and can also be linked to different diseases (diabetes, obesity, etc.). Fortunately, there are other new sweeteners available in the market which are non-cariogenic and also have other advantages over conventional sugars or sweeteners, such as isomaltulose, oligofructose, stevia and tagatose (Soto and Del Val*,* 2002; Goyal *et al.*, 2010). Each one is described below.

Isomaltulose is a reducing disaccharide which is naturally present in honey, and sugar cane juice, and its taste is similar to sucrose. The physicochemical properties of isomaltulose enable it to be used a substitute for sucrose in most sweet foods (Lina *et al.,* 2002; Bui *et al.,* 2009; De Oliva-Neto and Menão*,* 2009; Mercali *et al.,* 2011; Peinado *et al.,* 2013). It has a sweetening power of approximately 42% compare to sucrose and it can be used as an alternative to sucrose, because its caloric power is similar (Schiweck *et al*., 1990; Periche *et al*., 2014).

Oligofructose is low in calories, meaning it has multiple health benefits. 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 calcium absorption (Rao, 2001; Franck, 2002; Raschka and Daniel*,* 2005; Bosscher *et al.,* 2006; 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). The sweetening power of this plant is 15 times greater than sucrose, and it has multiple therapeutic properties (antioxidant, antimicrobial, anti-fungal activity, anti-hyperglycemic, anti-hypertensive, anti-inflammatory, anti-tumor, anti-diarrheal and diuretic effects), but it is calorie free (Chatsudthipong and Muanprasat, 2009).

Tagatose is a fructose isomer in milk and milk products. In comparison with other sugars, it has numerous health benefits including a lower glycemic index, and low calorie content. It also reduces the symptoms associated with type II diabetes and it is recommended for patients with obesity or heart diseases (Oh, 2007; Lu *et al.,* 2009; Gardner *et al.,* 2012; Shourideh *et al.,* 2012; Shankar *et al.,* 2013). Tagatose exerts greater osmotic pressure, and hence has less water activity than sucrose at equivalent concentrations (Patra *et al.,* 2009). D-Tagatose is well suited for confectionery products such as chocolate and candies, fudges, caramels, ice cream, soft drinks, and breakfast cereals because tagatose crystallizes easily (FAO/WHO, 2001, 2002, 2003).

In consideration of all the above, the aim of this work is to study the effect of different combinations of healthy osmotic agents (tagatose, oligofructose, isomaltulose and stevia) on the kinetic behaviour of lemon slices in order to obtain mathematical models following second Fick's law. For this purpose, variation of total mass, soluble solids and water mass changes have been analysed over time.

Materials and Methods

Preparation of sample

Eureka Lemons of a similar colour, size and ripeness were selected from an agricultural plot in Llíria (Valencia). The lemons were peeled and cut into 0.5 cm thick slices using a household slicer (Fagor Delice CF- 150).

Osmotic dehydration treatment

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

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

Physicochemical analysis

Soluble solids in the liquid phase in orange 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 analysed gravimetrically following an adaptation of the AOAC method, (2000). Water activity (a_w) was determined by a hygrometer (Decagon CX-1). All determinations were carried out in triplicate.

Kinetic study and modelling

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

Statistical analysis

Statgraphics plus (version 5.1) software was used to perform the statistical analyses, the factor taken into account being the composition of the syrup used in the osmotic dehydration.

Results and Discussion

The average values of composition and water activity for lemons used in these experiments were the following: 83±4% of water, 15.7±0.4% of soluble solids and 0.778±0.002 of water activity. The ºBrix of the osmotic solutions used were 35.15±0.7 for syrup T, 29.50 ±0.7 for syrup OS, 36.30±0.7 for syrup IT and 32.90±0.7 for syrup ITOS. According to these results, tagatose would lead to the highest driving force.

Fig. 1 represents the results of moisture content (x_w), water activity (a_w) and °Brix of lemon slices *versus* time of osmotic dehydration depending on the syrup used. As was expected the longer the time of dehydration the higher the concentration of soluble solids in lemon slices. Other studies with oranges and other fruits (strawberry, apple, apricot) showed similar results (Cháfer *et al.,* 2001; Castelló *et al.,* 2006, 2009; İspir *et al.,* 2009). In the sweeteners studied, noteworthy was that the samples osmodehydrated with oligofructose and stevia showed the highest levels of water activity, while syrup composed only by tagatose led to the lowest increase in soluble solids. However no differences were found in terms of moisture content among the slices treated with the four syrups studied.

The results for variation of total mass (ΔM), water mass (ΔM_w) and soluble solid mass (ΔM_S) recorded in this study were obtained using the following formulas (Shi and Fito, 1994; Fito and Chiralt, 1996) shown in Figure 2.

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

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

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

Where

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)

As can be seen in Fig. 2 samples dehydrated with syrups containing isomaltulose (IT and ITOS) showed the greatest losses of total mass, especially when they were combined with oligofructose and stevia. On the contrary, syrup composed by oligofructose and stevia (OS) kept the mass of lemon slices constant while syrup containing only tagatose (T) led to an increase in total mass in all samples for the whole process. Therefore, tagatose would be more beneficial in the development of osmodehydrated products, since contrary to what is common in this process, it led to an increase in mass.

Consistent with the values of moisture content registered during the process, no differences were found with regard to water and soluble solid mass changes. However, the combination of oligofructose and stevia with or without isomaltulose gave rise to the highest rates of soluble solid mass intake. This behaviour is noteworthy since driving forces recorded for these syrups were lower than in the other cases, and consequently, a lower rate of soluble solid intake would have been expected. It seems that it was more difficult for tagatose molecules to penetrate the structure of the lemon slices whereas for oligofructose it was easier to dehydrate this product.

Moreover, the changes in the composition in the liquid phase of lemon slices were modeled using the eq. (4).

$$Y_s^t = \frac{(z_s^t - y_s)}{(z_s^0 - y_s)} \quad (4)$$

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.

The latter (y_S) was considered to be equal to the equilibrium concentration of each syrup, having the values mentioned at the beginning of this section.

Fig. 3 shows the experimental points $1\text{-}Y_S$ *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 5). In this case, the range of time considered corresponded only to the first 120 minutes of osmotic treatment. 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 osmodehydrated lemon slices (Table 2).

$$1 - Y_s = \left[\frac{4D_e t}{\pi l^2}\right]^{0.5} \quad (5)$$

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

The results of D_e showed that the best fitting was observed when OS syrup was used in the dehydration of lemon slices. Furthermore, syrup composed of oligofructose with stevia extract (OS) presented a higher slope, which corresponded to the highest value of effective diffusivity, whereas syrup made of tagatose showed the longest times of osmodehydration since the effective diffusivity was the lowest. This is consistent with the results relating to water and soluble solid mass changes. Isomaltulose did not significantly affect the values of De for the syrups composed of tagatose or oligofructose.

Conclusions

According to this study, isomaltulose gave rise to the highest mass loss values in the osmodehydrated lemon slices, in contrast with tagatose. However, the level of concentration of soluble solids reached by tagatose would be lower than in the case of the other sweeteners and would be reached more slowly. Oligofructose combined with stevia would lead to a quicker concentration of soluble solids, but also to the highest level of water activity and therefore would potentially be the least stable. To solve this problem it would be recommendable to combine oligofructose, aqueous extract of stevia and tagatose.

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Legends to figures

Figure 1. A) Water activity (a_w) *versus* time B) °Brix *versus* time and C) x_w *versus* time for the lemon slices dehydrated with different osmotic solutions.

Figure 2. A) Variation of total mass (ΔM), B) Variation of water mass (ΔM_w) and C) Variation of soluble solid mass (ΔM_s) for the lemon slices dehydrated with different osmotic solutions.

Figure 3. 1-Driving force of soluble solids (Y_s) *vs.* $t^{0.5}$ (square root of time of dehydration) for the lemon slices dehydrated with different osmotic solutions.

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

	Tagatose	**Isomaltulose**	**Oligofructose**	**Aqueous solution containing 1% of Stevia**	**Water**
Syrup T	30%	-	-	-	70%
Syrup OS	-	-	30%	35%	35%
Syrup IT	10%	20%	-	-	70%
Syrup ITOS	10%	10%	10%	10%	50%

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

	$D_{e\ x\ 10}{}^9$ (m^2/s)	**R^2**
Syrup T	2.27±0.15^a	0.87±0.05
Syrup OS	10.2±0.3^c	0.95±0.01
Syrup IT	4.7±1.9^{ab}	0.91±0.03
Syrup ITOS	9±3^{bc}	0.91±0.02

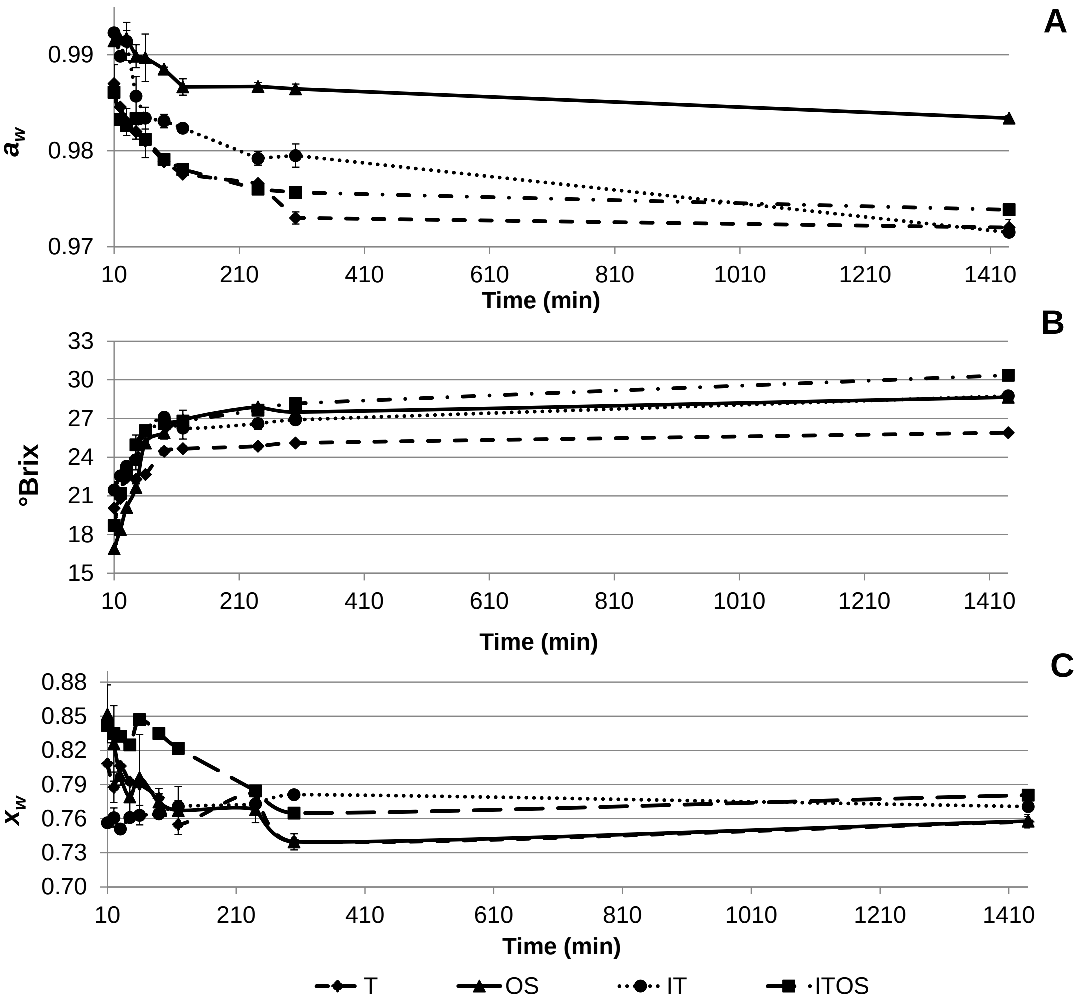

Figure 1. A) Water activity (a_w) *versus* time B) °Brix *versus* time and C) x_w *versus* time for the lemon slices dehydrated with different osmotic solutions

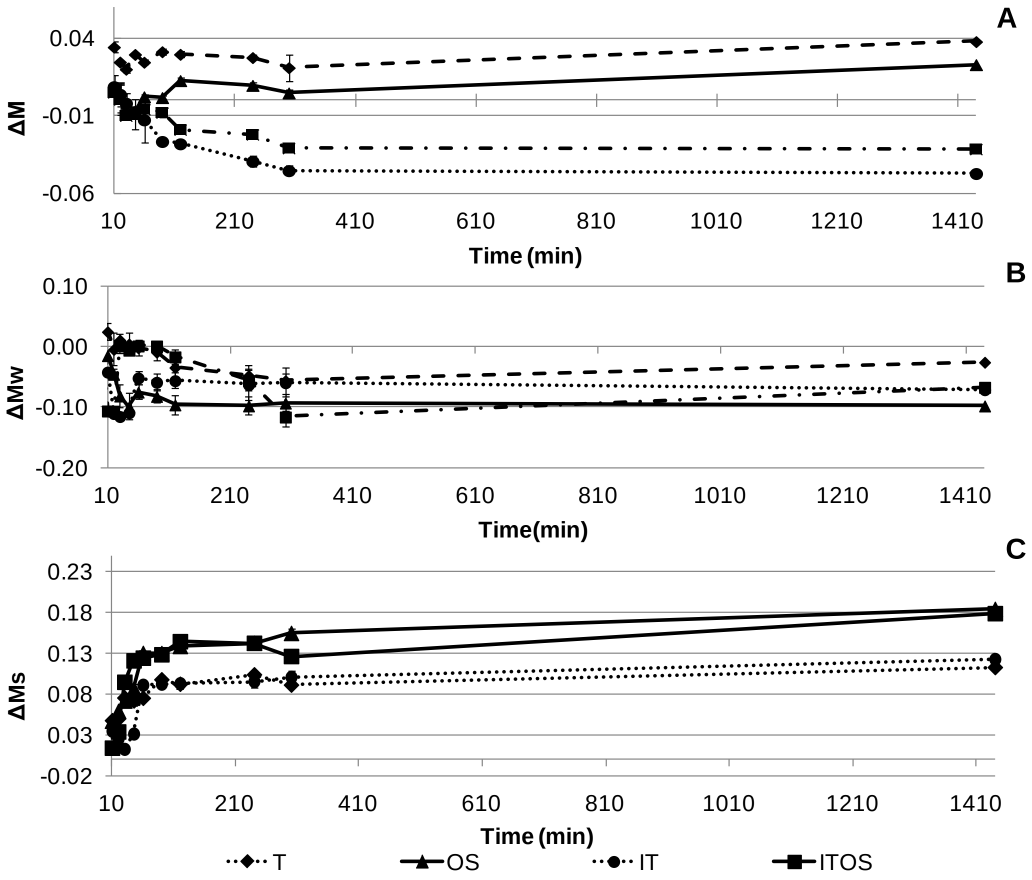

Figure 2. A) Variation of total mass (*ΔM*), B) Variation of water mass (*ΔM*$_w$) and C) Variation of soluble solid mass (*ΔM*$_s$) for the lemon slices dehydrated with different osmotic solutions

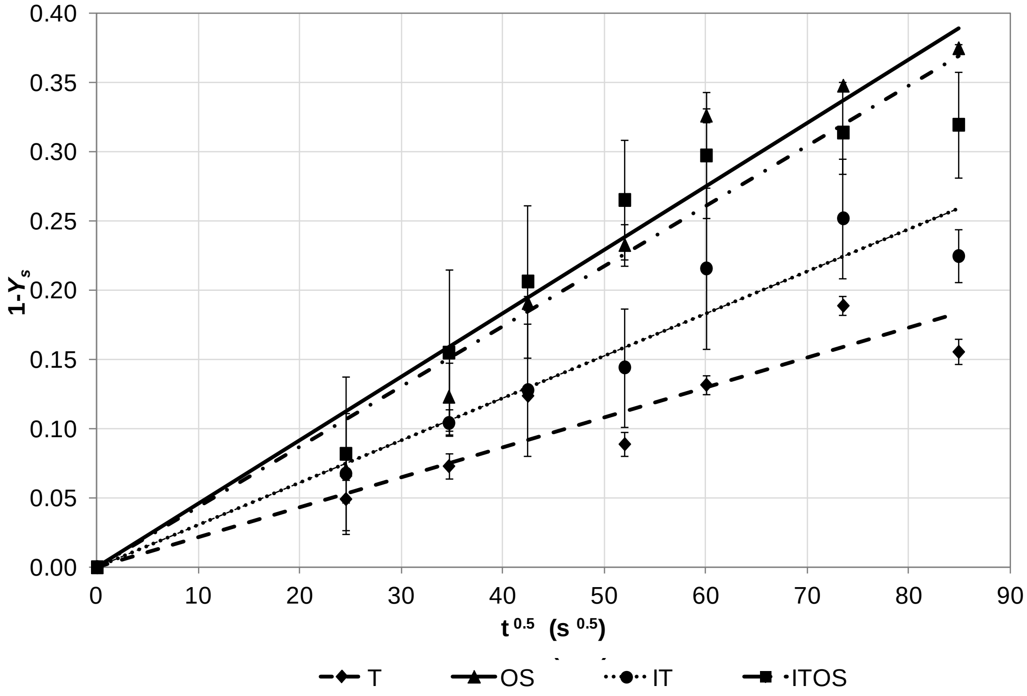

Figure 3. 1-Driving force of soluble solids (Y_s) *vs.* t $^{0.5}$ (square root of time of dehydration) for the lemon slices dehydrated with different osmotic solutions