

Effect of air drying on quality characteristics and mass transfer kinetics of osmotically dehydrated sea buckthorn by stevia

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Abstract

Sea buckthorn is ranked among the most significant super foods worldwide. Its fruits and leaves are used as fresh or dried in food, pharmaceutical and cosmetic industry. As super food any pre-treatment should sustain this property and hence this research was focused on osmotic dehydration of sea buckthorn by stevia also a super food. Therefore, water loss, sugar gain, acidity, ascorbic acid and water diffusivity were evaluated during osmotic dehydration of sea buckthorn by two stevia solutions, 15° and 30°Brix and following were air-dried at 50°C by comparing the effect of steam blanching per case. Steam blanched samples exhibited increased water loss at the end of the process, 55% at 30°Brix and 48% at 15°Brix, compared to untreated samples where losses were 43% (30°Brix) and 28% (15°Brix) respectively. Ascorbic acid was significantly reduced, exceeding 50% in steam blanched samples and 23% in untreated samples. Steam blanched samples dehydrated at 15°Brix exhibited 82% dry matter increase and only 39% the untreated samples. Similarly, samples dehydrated at 30°Brix exhibited 84% dry matter increase and 53% when no steam blanching was applied. Solid gain was seven times less compared to water loss which is attributed to high molecular weight of steviol glycoside. The osmotic dehydration and air-drying curves were described effectively by *Peleg* and *Fick* models, and *Logarithmic* and *Fick* models respectively, having in all cases $R^2_{adj} > 99\%$ and $SEE < 0.2$. The water diffusivity of steam blanched samples was $3.2-5.57 \times 10^{-11} \text{ m}^2/\text{s}$ for water loss and $1.27-2.03 \times 10^{-11} \text{ m}^2/\text{s}$ for solid gain at 30°Brix and $2.12-4.27 \times 10^{-11} \text{ m}^2/\text{s}$ and $0.91-1.98 \times 10^{-11} \text{ m}^2/\text{s}$ at 15°Brix. Finally, the water diffusivity of steam blanched samples during air-drying was $2.11-2.29 \times 10^{-11} \text{ m}^2/\text{s}$ and $1.56-1.66 \times 10^{-11} \text{ m}^2/\text{s}$ in the case of untreated samples.

1. Introduction

Sea buckthorn (*Hippophaes rhamnoides L*) is among the most important superfoods and is used for its fruits as well its leaves. Its fruits are consumed either as fresh or dried mainly in the pharmaceutical and cosmetic industry. Sea buckthorn has many nutritional benefits as it has been reported to contain more than 190 essential compounds in seeds, pulp, fruit and juice, such as vitamins A, K, C, B1, B2 and E, fatty acids, lipids, organic acids, amino acids, carbohydrates, folic acid, tocopherols, flavonoids, phenols, terpenes and tannins which have beneficial effects on health (Bal *et al.*, 2011).

The composition of sea buckthorn juice varies according to cultivar, growing conditions, harvest time, ripeness and processing technology. Has been found to contain high quantities of ascorbic acid ranging between

28 to 2,500 mg/100 g. The pH of sea buckthorn juice ranges from 2.7 to 3.1 which do not favour ascorbate oxidase activation and therefore ascorbic acid is largely retained during juice processing. The soluble solids content ranges from 7.0 up to 22.7°Brix. The sea buckthorn juice is characterized by high quantities of various organic acids so its acidity ranges from 3.5 to 7.3% (Zeb, 2004).

Stevia is a natural sweetener used in food and beverage industry as a sugar substitute. A part of stevia is 15 to 30 times sweeter than a part of sucrose (Savita *et al.*, 2004). Stevia plant (*Stevia rebaudiana Bertoni*) belongs to the family of *Compositae* or *Asteraceae*, subfamily of *Eupatorieae*. Have been identified 280 species to belong at stevia genus but only *Stevia rebaudiana* has intense sweetening power (Lemus-Mondaca *et al.*, 2012). The stevia plant is a good source

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of carbohydrates, proteins, fibres, metals, essential and non-amino acids. The physical and chemical characteristics of the extracted stevioside, as well as its thermal and acid stability along with its superior sensorial characteristics, have spread its use in food and beverage industry (Abou-Arab *et al.*, 2010). The objectives of this study were (i) to conduct osmotic dehydration of sea buckthorn maintaining its superior nutritional value adopting an equal nutritional value hypertonic medium, this of stevia, (ii) to evaluate the water loss, sugar gain, acidity, ascorbic acid concentration and water diffusivity of sea buckthorn (var. *Chuyskaya*) initially osmotically dehydrated in two stevia solutions, 15°Brix and 30°Brix and then air-dried at 50°C by comparing the effect of steam blanching application to each tested case.

2. Materials and methods

Sea buckthorn fruits (var. *Chuyskaya*) were supplied from Agricultural Co-operative of Karditsa (Northern Greece). The fruits were transported to the laboratory where defective fruits (injured, overripe, etc) were discarded. Measurements of weight, acidity, soluble solids and ascorbic acid were carried out in two groups of 50 fruits each. In group A, the 50 fruits weighed 38.15 g and in group B, 35.77 g; the total soluble solids was 9.1% and 8.2% respectively; for group A the malic acid was 0.34%, the citric acid, 0.54% and the ascorbic acid, 487.2 ppm while for group B the malic acid was 0.31%, the citric acid, 0.51% and the ascorbic acid, 490.9 ppm. The average initial moisture content was 9.83 ± 0.2 kg_w/kg_{dm} and was estimated gravimetrically using a vacuum oven (VD 53, Binder, Germany) at 70°C for 24 hrs (AOAC, 1997).

Four experimental series were osmotically dehydrated at 40°C, two in 30°Brix solutions and two in 15°Brix solutions, and upon completion of osmosis, the samples were air-dried at 50°C. The weight ratio of the osmotic solution to fruit sample was 28:1 (30°Brix) and 24:1 (15°Brix) based on Yadav and Singh (2014) review. Since stevia is 15-30 times sweeter than sucrose, a higher dilution ratio was adopted than the one is normally used in sucrose solutions (Yadav and Singh, 2014). The difference between the two experimental series per stevia solution was based on the application or not of steam blanching for 3 mins. In each experimental series 25 g per sample were placed in small perforated pouches and immersed in two stevia solutions. Six replicates were used per experimental series. The samples were osmotically dehydrated for 6 hrs in 750 mL beakers containing the stevia solutions and the samples were weighed in hourly intervals. Upon removal from the osmotic solutions, the samples were drained and the

excess of the stevia solution removed with absorbent paper. The solid content of the osmotically dehydrated fruits was determined gravimetrically using a vacuum oven (VD 53, Binder, Germany) at 70°C for 24 hrs (AOAC, 1997). Measurements regarding total soluble solids, acidity and ascorbic acid were conducted in two replicates as follows. The remaining samples were air-dried at 50°C until steady weight was achieved. Upon drying, hourly weighing of the samples was carried out. At the end of the air-drying, the acidity, the total soluble solids and the ascorbic acid of the dried samples were evaluated. The dried samples were pulped, diluted with 10 mL of deionised water and filtered so the remaining juice to be used for measurements of the total soluble solids, acidity and ascorbic acid. The geometric mean diameter in terms of *Feret* diameter was estimated by image analysis employing ImageJ 1.46r image analysis software (Research Services Branch, NIMH, Bethesda, USA). For this purpose, twenty randomly selected sea buckthorn berries were photographed by a digital camera Konica Minolta Dimage Z2 (4.0 Mpixel) and analysed so the mean diameter was measured as 0.707 cm.

2.1 Theoretical aspects, water and solute diffusivity estimation

The water adsorption/desorption during osmotic dehydration has been described by theoretical or semi-theoretical models. Also, a number of empirical models have been used to solve the diffusion problem. The most employed empirical model in literature (Park *et al.*, 2002; Azoubel and Murr, 2004), for water adsorption/desorption in foods during osmosis belongs to Peleg (1988),

$$MC_t = MC_o \pm \frac{t}{K_1 + K_2 t} \quad (1)$$

where MC_t is the moisture content (kg_w/kg_{dm}) for immersion time t (min), MC_o is the initial moisture content (kg_w/kg_{dm}), K_1 is the temperature dependent *Peleg* constant [h/(kg_w/kg_{dm})] related to dehydration rate at the beginning of the process, $\left(\frac{dMC_t}{dt} = \pm \frac{1}{K_1}\right)$ and K_2 is *Peleg* constant (kg_w/kg_{db})⁻¹ determined by the moisture concentration $\ln\left(\frac{MC_t - MC_o \pm \frac{1}{K_2} \cdot t}{MC_o \pm \frac{1}{K_2} \cdot t \rightarrow \infty}\right)$ equilibrium. The \pm sign in Equation 1 corresponds to adsorption (+) and desorption (-) respectively.

The air-drying curves have been simulated by various semi-empirical models (Henderson, 1974; Whith *et al.*, 1978; Wang and Singh, 1978; Sharaf-Eldeen *et al.*, 1980; Zhang and Litchfield, 1991; Diamente and Munro, 1993; Yağcıoğlu *et al.*, 1999; Karathanos, 1999; Yıldız and Ertekýn, 2001; Pakowski and Mujumdar, 2006) based on the analytical solution of *Fick* equation (cf. in Table 1). In many cited studies the *Logarithmic* model has been found to simulate efficiently experimental air-

drying curves (Xanthopoulos, Lambrinos and Manolopoulou, 2007; Xanthopoulos, Oikonomou and Lambrinos, 2007; Xanthopoulos *et al.*, 2010).

Considering sea buckthorn fruit as a sphere of uniform initial water (MC_o) and solids content, the analytical solution of *Fick* equation for constant process conditions is given by Crank (1975).

$$MR = \frac{MC_t - MC_e}{MC_o - MC_e} = \frac{6}{\pi^2} \cdot \sum_{n=1}^{\infty} \frac{1}{n^2} \cdot \exp\left(-n^2 \cdot \frac{\pi^2 \cdot D \cdot t}{r_e^2}\right) \quad (2)$$

Where n is the number of terms taken in the series, D is the effective diffusivity (m^2/s), t is the process time (s) and r_e is the mean geometric radius (m).

Considering the first term ($n = 1$) of the series (Equation 2) derives an error over 60% (Efremov and Kudra, 2005) at the beginning of the process ($F_o = 0$). The estimation error drops to 4% when 15 terms are considered, whereas 58 terms are needed to achieve error close to 1%. Efremov and Kudra (2005) minimized this error by integrating the correction factor α' (cf. to Equation 3) without considering many terms.

$$MR = \exp(-\pi^2 \cdot F_o^{\alpha'}) \quad (3)$$

Where F_o is the Fourier number. For spherical shape, the correction factor $\alpha' = 0.83$ results in a maximum relative error of $\pm 17\%$. Equation 3 is solved with respect to D as follows,

$$D = \frac{r_e^2}{\pi^{2/\alpha'} \cdot t} \cdot (-\ln MR)^{1/\alpha'} \quad (4)$$

Mundada *et al.* (2010) employed the analytical solution of *Fick* equation to estimate the diffusion coefficient of solid gain, Equation 5,

$$SGR = \text{solids gain ratio} = \frac{C_t - C_e}{C_o - C_e} = \exp(-\pi^2 \cdot F_o^{\alpha'}) \quad (5)$$

The geometric mean of the diffusion coefficient was estimated for water loss ($D_{WL|avg}$) and solid gain ($D_{SG|avg}$) during the osmotic dehydration as well as for water loss

(D) during the air-drying of the sea buckthorn as follows (Lentzou *et al.*, 2019).

2.2 Osmotic dehydration and hot air-drying

The osmotic solutions of stevia used in this study

$$D_{w,s|avg} = \left(\prod_{i=1}^n D_i \right)^{\frac{1}{n}} \quad (6)$$

consisted of 500 mL deionised water and 209 g stevia powder, case of 30°Brix solution, and 91 g of stevia powder, case of 15°Brix aqueous solution. Dilution of stevia in the deionised water was carried out by means of a heated magnetic stirrer (RCT basic, IKA-Werke GmbH & Co. KG, Germany) whose heating plate was set to 40° C. To sustain the hypertonic solutions at 40° C throughout the osmotic process, the beakers containing the osmotic solutions were placed inside a water bath at 40° C and the osmotic solutions in the beakers were agitated in regular intervals.

Weighing of the mass was carried out by an electronic balance (KERN, PCB-440, Japan) having ± 0.01 g accuracy. Based on the previous measurements the water loss (Equation 7) and solid gain (Equation 8) were estimated as follows (Panagiotou *et al.*, 1999),

$$WL = [(M_o - m_o) - (M_t - m_t)] / M_o \quad (7)$$

$$SG = (m_t - m_o) / m_o \quad (8)$$

Where m_o , m_t are the initial dry matter and the dry matter in any time (kg); M_o , M_t are the initial mass and the mass in any time (kg); MC_o , MC_t is the initial moisture content and the moisture content in any time (kg_w/kg_{dm}). The water loss (Equation 7) express the diffused water ($kg_{water\ loss}/kg_{initial\ mass\ of\ fruit}$) from the fruit to the osmotic solution due to osmotic pressure deficit between fruit and solution and solid gain (Equation 8) express the diffused solids ($kg_{solids\ gained}/kg_{initial\ mass\ of\ fruit}$) from the osmotic solution into the fruit.

Air-drying of the osmotic dehydrated samples was

Table 1. Semi-empirical drying models

	Models	Reference
Lewis (Newton)	$MR = \exp(-kt)$	Pakowski and Mujumdar, (2006)
Page	$MR = \exp(-kt^n)$	Diamente and Munro, (1993)
Mod. Page	$MR = \exp[-(kt)^n]$	Whith <i>et al.</i> (1978)
Henderson and Pabis	$MR = a \exp(-kt)$	Zhang and Litchfield (1991)
Logarithmic	$MR = a \exp(-kt) + c$	Yağcıoğlu <i>et al.</i> (1999)
Two term	$MR = a \exp(-k_o t) + b \exp(-k_1 t)$	Henderson (1974)
Exponential two term	$MR = a \exp(-kt) + (1-a) \exp(-akt)$	Sharaf-Eldeen <i>et al.</i> (1980)
Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)
Diffusion approach	$MR = a \exp(-kt) + (1-a) \exp(-kbt)$	Yaldız and Ertekyn (2001)
Mod. Henderson and Pabis	$MR = a \exp(-kt) + b \exp(-k_o t) + c \exp(-k_1 t)$	Karathanos (1999)

MR = moisture ratio; a,b,c = model constants, k, k_o, k_1 drying constants (h^{-1}) and t = drying time (h)

carried out in an atmospheric drying oven (Heraeus T5028, Thermo Scientific, Austria) at 50°C for 15 hrs. Upon drying completion, dry matter was estimated gravimetrically using a vacuum oven (VD 53, Binder, Germany) at 70°C for 24 hrs (AOAC, 1997). Based on the previous measurements the moisture content $MC = (M_t - m_f)/m_f$ and the moisture ratio $MR = MC_t/MC_0$ were estimated, where m_f is the dry mass of the product (kg), M_t is the mass of the product at any time (kg), MC_0 and MC_t are the initial moisture content and the moisture content at any time respectively (kg_w/kg_{dm}).

2.3 Total soluble solids, acidity and ascorbic acid

Measurement of the total soluble solids in the juice of the osmotic dehydrated and the air-dried fruits was carried out by a digital refractometer (SR-400, Japan) having $\pm 0.25^\circ$ Brix accuracy. The total soluble solids were expressed as g of solid per 100 g of juice (Brix). Measurement of the fruit's acidity in the juice of the osmotic dehydrated and air-dried fruits was carried out by a digital acidity meter (GMK-708, UK) having the accuracy of $\pm 0.05\%$. Prior to the malic and citric acids measurement, dilution of 0.33 mL of juice into 20 mL of deionised water was carried out. The acidity was expressed in g of malic/citric acid per 100 g of juice.

The ascorbic acid was measured by an automatic titrator (HI902C, HANNA, USA) using a 0.02 N iodine buffer. For the measurement of the ascorbic acid, 15 mL of filtered fruit juice was diluted in a 250 mL beaker adding 100 mL of demineralised water, 8mL of 16% sulphuric acid and 3 g of potassium iodide.

2.4 Statistical analysis

Analysis of variance (ANOVA) was carried out to identify significant effects of process parameters employing Statgraphics Centurion XVI (Statpoint Technologies, Virginia, USA) at significance level of $P \leq 0.05$. Mean values were subjected to Fisher's Least Significant Difference test (LSD) at $P \leq 0.05$. This statistical test is liberal with respect to the comparison wise error rate but is powerful to detect true differences. Nonlinear regression was carried out by the Statgraphics Centurion XVI (Statpoint Technologies, VA, USA) at significance level $P \leq 0.05$ employing the *Levenberg-Marquardt* optimisation algorithm (Mason *et al.*, 2003).

3. Results and discussion

3.1 Kinetics of water loss and solid gain

In the osmotic process, two parameters are of great interest, water loss (Equation 7) and solid gain (Equation 8). In most of the cited studies the water loss curves (Figure 1a) exhibit initially a characteristic increase

corresponding to high rate of water loss and solid gain followed by a falling rate at the later stages. The high water loss rate and solid gain at the initial stage of osmosis are due to higher osmotic driving forces between the fresh fruit and the surrounding hypertonic medium. The shape of the water loss curves during osmotic dehydration has been extensively reported (Panagiotou *et al.*, 1999; Azoubel and Murr, 2004; Mundada *et al.*, 2010; Ganjloo *et al.*, 2012). Increasing the concentration of the osmotic solution increases the pressure deficit which leads to higher water loss and solid gain although not to the same extent. In most of the cited cases has been reported faster water loss than solid gain (Azoubel and Murr, 2004).

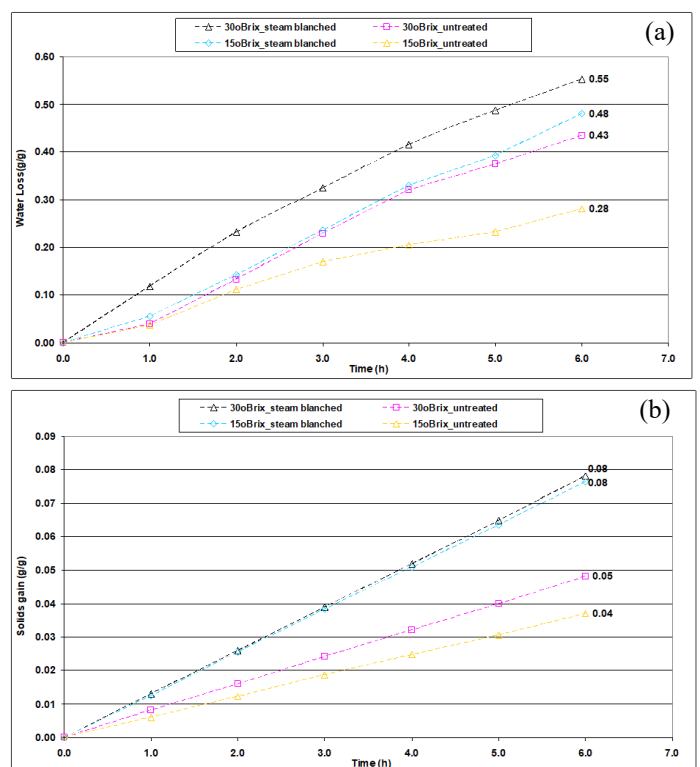


Figure 1. Water loss (a) and solid gain (b) of osmotic dehydrated sea buckthorn (*var. Chuyskaya*). Data points are the means of six replicates.

In Figure 1a is presented the water loss during the osmotic dehydration. It is observed that the steam blanched samples exhibited increased water loss, so their final values were 55% and 48% at 30°Brix and 15°Brix osmotic solutions respectively, compared to untreated samples that were 43% and 28% for the osmotic solutions of 30°Brix and 15°Brix, respectively. This response can be attributed to disintegration of the waxy layer of the sea buckthorn epidermis taking place during steam blanching. The previous results are in agreement with those of Araya-Farias *et al.* (2014), who reported that steam blanching facilitates water loss during osmosis.

Panagiotou *et al.* (1999) evaluating the osmotic potential of glucose and sucrose reported that the former

resulted in increased water loss compared to the latter, under the same osmotic solution concentration and treatment duration due to the higher osmotic effect of glucose compared to that of sucrose. The previous osmotic effect was attributed to sucrose's molecular weight (342.3 g/mol) which is approximately twice that of glucose (180.16 g/mol) and results in roughly half-molecular concentration of sucrose solutions and consequently significantly lower osmotic pressure of the sucrose than the glucose solutions. Steviol glycoside molecular weight is 318.4 g/mol which rank stevia to the same approximately osmotic potential of sucrose. From Figures 1a and b, it can be seen that solid gain is seven times smaller of water loss. This response can be attributed to the high molecular weight of steviol glycoside that favours water loss at the expense of solid gain as Mundada *et al.* (2010) explained. On the other hand, Hawkes and Flink (1978) reported that the progressive accumulation of solids during the osmotic dehydration, form a surface layer on the external cellular layer of sea buckthorn, which acts as a barrier against water loss and solid gain.

The *Peleg* model (Equation 1) was tested for its goodness of fitting water loss experimental data during the osmotic dehydration (Table 2). The fitting efficiency was very good in all the tested cases as this can be seen from the statistical estimates $R^2_{adj} > 99\%$ and $SEE < 0.2$. The fitting efficiency can also be seen in Figure 2 as well as the effect of steam blanching on the final moisture ratio which after 6h of osmotic dehydration was almost 50% less in the case of the steam blanched samples at 30°Brix compared to those not be steamed blanched at 15°Brix. The K_1 values for all the tested cases (pre-treatment × solution concentration) are seen in Table 2. The reciprocal of K_1 describes the initial mass transfer rate, e.g., the higher the $1/K_1$ the higher the mass transfer rate. Based on the $1/K_1$ values it is seen that as the osmotic solution concentration increases, increases the $1/K_1$ and therefore the initial mass transfer rate. The effect of steam blanching on the previous response is also obvious (cf. to Table 2) increasing the $1/K_1$ value by 63% in the 15°Brix solution and by 75% in the 30°Brix solution. The K_2 value is related to equilibrium mass transfer terms, e.g., the higher the $1/K_2$ value, the higher the equilibrium moisture content. The previous trend agrees with the respective variation of moisture content

during the osmotic dehydration seen in Figure 2.

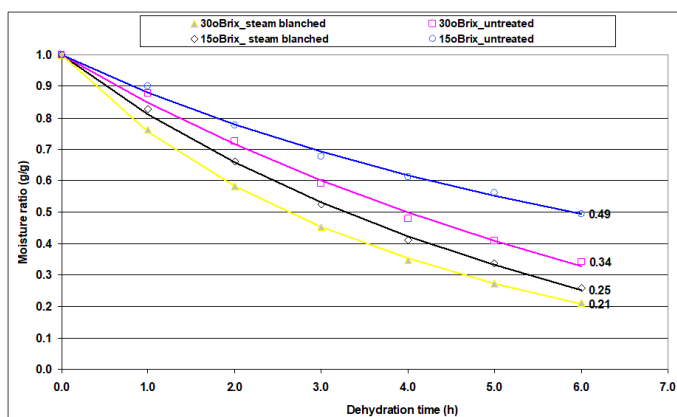


Figure 2. Experimental osmotic dehydration curves (points) of untreated and steam blanched sea buckthorn (*var. Chuyuskaya*) with the simulated values (solid lines) from Peleg model (Equation 1). Data points are the means of six replicates.

The effective diffusivities of water loss and solid gain were estimated employing *Fickian* diffusion (Table 3). It is observed that diffusivity is increased as solute concentration increases from 15°Brix to 30°Brix as was expected. In the present study during the osmotic dehydration, the water diffusivities were ranged from $3.2 - 5.57 \times 10^{-11} \text{ m}^2/\text{s}$ for water loss and $1.27 - 2.03 \times 10^{-11} \text{ m}^2/\text{s}$ for solid gain at 30°Brix and $2.12 - 4.27 \times 10^{-11} \text{ m}^2/\text{s}$ for water loss and $0.91 - 1.98 \times 10^{-11} \text{ m}^2/\text{s}$ for solid gain at 15°Brix. Comparison of water diffusivity values found in literature should be carried out with great caution. Different experimental methods and conditions, mathematical analysis (analytical approach, method of slopes, regular regime method, numerical solution of water transport equations) and applied boundary conditions as well as different varieties of different physiological state and anatomy (peel, mesocarp, endocarp), should be taken into account otherwise the drawn conclusions could be misleading (Xanthopoulos *et al.*, 2012). Park *et al.* (2002) working with pear cubes (case of no peel) found that water diffusivity was $0.35 - 1.92 \times 10^{-9} \text{ m}^2/\text{s}$ for water loss and $0.20 - 3.60 \times 10^{-9} \text{ m}^2/\text{s}$ for solid gain at 40-60°C. Lazarides *et al.* (1997) reported values $1.42 - 4.69 \times 10^{-10} \text{ m}^2/\text{s}$ for water diffusivity and $0.73 - 2.41 \times 10^{-10} \text{ m}^2/\text{s}$ for solid gain of apple slices (case of no peel) at 20-50°C and sucrose solution concentrations 45-65°Brix. Mundada *et al.* (2010) reported diffusivity for water loss and solid gain as $2.72 - 5.12 \times 10^{-10} \text{ m}^2/\text{s}$ and $1.47 - 5.15 \times 10^{-10} \text{ m}^2/\text{s}$ during osmotic dehydration of

Table 2. *Peleg* model parameters and goodness of fit for water loss during osmotic dehydration.

Treatment		k_1	k_2	R^2_{adj}	SEE	$1/k_1$ kg _w /kg _{dm} h	$1/k_2$ kg _w /kg _{db}
30°Brix	B	0.346	0.074	99.97	0.044	2.89	13.514
	NB	0.606	0.055	99.46	0.182	1.65	18.182
15°Brix	B	0.486	0.071	99.85	0.101	2.058	14.085
	NB	0.794	0.046	99.52	0.121	1.261	21.739

B = steam blanched; NB = no steam blanched

pomegranate arils in sucrose solution at 35-55°C and 40-60°Brix. Panades *et al.* (2008) reported water diffusivity $0.69-1.47 \times 10^{-10}$ m²/s during osmotic dehydration of guava (case of no peel) in sucrose solution. Khoiyi and Hesari (2007) reported diffusivity $1.06-4.06 \times 10^{-9}$ m²/s of water loss and $7.69-3.13 \times 10^{-9}$ m²/s for solid gain of apricot slices (case of no peel) in sucrose solution.

Table 3. Diffusivity for water loss and solid gain during the osmotic dehydration and air-drying of sea buckthorn (*var. Chuyskaya*).

Treatment		Osmotic dehydration		Air-drying
		Water loss	Solid gain	
		D _{WL avg} m ² /s	D _{SG avg} m ² /s	D _{eff} m ² /s
30°Brix	B	5.57×10^{-11}	2.03×10^{-11}	2.29×10^{-11}
	NB	3.20×10^{-11}	1.27×10^{-11}	1.66×10^{-11}
15°Brix	B	4.27×10^{-11}	1.98×10^{-11}	2.11×10^{-11}
	NB	2.12×10^{-11}	0.91×10^{-11}	1.56×10^{-11}

B = steam blanched; NB = no steam blanched

3.2 Ascorbic acid

The analysis of variance (Table 4) showed that only steam blanching (treatment) affected significantly the ascorbic acid concentration ($P < 0.05$). The previous response is expected since ascorbic acid is thermal sensitive and highly unsaturated, making it susceptible to degradation due to oxidation and heat treatment. The ascorbic acid concentration in Table 5 is higher than the one reported from Beveridge *et al.* (2002) and Araya-Farias *et al.* (2011) for the *Indian Summer cultivar* which was 175 mg/100 g and 184 mg/100 g respectively. Zeb (2004) reported that the variation of ascorbic acid in sea buckthorn depends on whether is measured on the seeds (64.4-92.7 mg/100 g of seed), juice (216 mg/100 g of berries) or pulp upon juice and pulp removal (481 mg/100 g of berries). Variations among most nutrients within origin or between origins offer prospects for future study. The high variability in sea buckthorn composition found in literature depends on the variety, maturity and growing location (Beveridge *et al.*, 1999). As it is seen in Table 5, the steam blanched samples exhibit a higher reduction of the initial ascorbic acid (control) compared to untreated samples. In particular, the steam blanched samples exhibited 52% and 71% reduction of the initial ascorbic acid at 15°Brix and 30°Brix stevia solutions respectively (Table 5). Santos and Silva (2008) reported increased ascorbic acid losses, even 50%, along with increased water losses for different osmotic solutions due to steam blanching application that caused cracks on the waxy layer of fruit epidermis. On the other hand, the untreated samples exhibited less ascorbic acid losses of 23% and 28% respectively in the

stevia solutions of 30°Brix and 15°Brix. Santos and Silva (2008) attributed the increased retention of ascorbic acid in the final product, at the formation of a coherent layer of sugars on their epidermis acting as a barrier to water transport and ascorbic acid loss.

Table 4. ANOVA of the factors and their interactions affecting the ascorbic acid of sea buckthorn (*var. Chuyskaya*) per stevia solution and treatment.

Source	df	F-Ratio	P-Value
Main effects			
A: Stevia solution	1	0.65	0.435 ^{NS}
B: Treatment	4	43.88	0.000*
Interactions			
A × B	4	3.12	0.056 ^{NS}
Residual	12		
Total	21		

NS = not significant; * = significant at $P \leq 0.05$; df = degree of freedom

Table 5. Average ascorbic acid of the osmotic dehydrated sea buckthorn (*var. Chuyskaya*) per stevia aqueous solution and treatment. Values in the parenthesis are the ascorbic acid loss.

Treatment		Ascorbic acid (mg/L)	
		15°Brix	30°Brix
Control	5	495.03	495.03
OD.B.	1	238.5 (52%)	145.2 (71%)
OD.NB.	2	354.4 (28%)	379.2 (23%)
OD.B.D.	3	26.4 (95%)	44.0 (91%)
OD.NB.D.	4	96.5 (80%)	173.7 (65%)

OD.B = osmotic dehydrated and steam blanched; OD.NB = osmotic dehydrated with no steam blanched; OD.B.D = osmotic dehydrated, steam blanched and dried; OD.NB.D = osmotic dehydrated with no steam blanched and dried.

Upon osmotic dehydration, the samples were air-dried; the steam blanched samples at the end of the air drying had higher ascorbic acid losses of 95% and 91% for the 15°Brix and 30°Brix osmotic solutions respectively, while the untreated samples exhibited ascorbic acid losses of 80% and 65% respectively. As was expected, osmotic dehydration and air-drying involve thermal treatments and as such, causes a significant reduction of the ascorbic acid since it is thermally sensitive making it susceptible to degradation due to oxidation and heat processing. The previous results are consistent with those of Santos and Silva (2008) and Araya-Farias *et al.* (2011) who reported that the preservation of the nutrients in the sea buckthorn, especially that of the ascorbic acid depends on the temperature-time integral as well as the final moisture content of the produce.

3.3 Total soluble solids and acidity

The analysis of variance (Table 6) showed that the

Table 6. ANOVA of the factors and their interactions affecting the total soluble solids, citric and malic acidity of sea buckthorn (*var. Chuyskaya*) per stevia solution and treatment.

Source	df	TTS		Citric acid		Malic acid	
		F-Ratio	P-Value	F-Ratio	P-Value	F-Ratio	P-Value
Main effects							
A: Stevia solution	1	1.97	0.176 ^{NS}	0.08	0.775 ^{NS}	0.58	0.457 ^{NS}
B: Treatment	4	18.84	0.000*	24.97	0.000*	4.12	0.013*
Interactions							
A × B	4	2.44	0.081 ^{NS}	18.11	0.000*	7.19	0.0009*
Residual	20						
Total	29						

NS = not significant; * = significant at $P \leq 0.05$; df = degree of freedom

total soluble solids were significantly affected by steam blanching ($P < 0.05$). The four experimental series, regarding the total soluble solids, were differed significantly among them as well as with the control samples. It was observed that the total soluble solids increase during the osmotic dehydration was higher in steam blanched samples against those not to, compared to the control samples (Table 7). This response is expected since steam blanching disintegrates the waxy layer of fruits epidermis causing cracks, facilitating likewise the influx of the osmotic solution into the mesocarp. This observation is in line with Araya-Farias *et al.* (2011) findings according to whose, steam blanching increases drastically total soluble solids in osmotically dehydrated sea buckthorn. A difference in the total soluble solids upon air-drying completion was also observed, as air-drying of the steam blanched samples resulted in higher total soluble solids compared to samples that had not been steam blanched (Table 7).

Table 7. Total soluble solids and dry matter of the osmotic dehydrated sea buckthorn (*var. Chuyskaya*) per stevia aqueous solution and treatment. Values in the parenthesis are the dry matter increase.

Treatment	30°Brix		15°Brix	
	°Brix	Dry matter g	°Brix	Dry matter g
Control	8.9	2.32	8.9	2.32
OD.B.	12.75	-	10.5	-
OD.NB.	11.55	-	9.5	-
OD.B.D.	12.27	4.28 (84%)	11.73	4.23 (82%)
OD.NB.D.	7.53	3.56 (53%)	7.17	3.23 (39%)

OD.B = osmotic dehydrated and steam blanched; OD.NB = osmotic dehydrated with no steam blanched; OD.B.D = osmotic dehydrated, steam blanched and dried; OD.NB.D = osmotic dehydrated with no steam blanched and dried.

In addition, it was observed that the dry matter increase (Table 7) during the osmotic dehydration (Equation 3) was significantly affected by the steam blanching application. In particular, the samples that had been steam blanched and then osmotic dehydrated in 30°Brix solution, exhibited an increase of 84% in the dry

matter while the samples that had not been steam blanched an increase of 53%. Similarly, the samples osmotically dehydrated in 15°Brix solution exhibited 82% dry matter increase when steam blanching had been preceded, and only 39% when the samples had not steam blanched. The effect of stevia solutions was not so pronounced in the steam blanched samples as far as the total soluble solids and the dry matter concerns (Table 7) probably due to accumulation of solids on the external cellular layer that acts as a barrier against the uptake of solids as has been previously explained.

Table 8. Average acidity of the osmotic dehydrated sea buckthorn (*var. Chuyskaya*) per stevia solution and treatment.

Treatment	30°Brix		15°Brix	
	Citric acid mg/L	Malic acid mg/L	Citric acid mg/L	Malic acid mg/L
Control	0.53	0.43	0.53	0.43
OD.B.	0.47	0.29	0.45	0.25
OD.NB.	0.41	0.22	0.41	0.21
OD.B.D.	0.32	0.15	0.38	0.18
OD.NB.D.	0.38	0.19	0.24	0.13

OD.B = osmotic dehydrated and steam blanched; OD.NB = osmotic dehydrated with no steam blanched; OD.B.D = osmotic dehydrated, steam blanched and dried; OD.NB.D = osmotic dehydrated with no steam blanched and dried.

Beveridge *et al.* (2002) reported that quantitatively the most important organic acid in sea buckthorn is malic acid, but smaller quantities of citric, tartaric, and succinic acid exists, contributing to total titratable acidity. The acid values reported in the literature, range 1.11-2.34 mg/100 g for malic acid and 0.042-0.234 mg/100 g for citric acid depending on the variety, maturity and growing location (Beveridge *et al.*, 1999). In the present study, the tested variety of sea buckthorn exhibited higher citric acid concentration as can be seen in Table 8. The analysis of variance (Table 6) showed that the acidity regarding the citric and malic acids was significantly affected by the interaction of steam blanching with the stevia solution concentration ($P < 0.05$). From Table 8, it is seen that the malic and

citric acid concentrations tend to decrease during the osmotic dehydration and the following air-drying, reaching in some cases even 60-70% reduction compared to control samples.

3.4 Drying kinetics during hot-air drying

The initial moisture content of the samples subjected to osmotic dehydration and air-drying, was ranged between 1.93-2.28 kg_w/kg_{dm} in the case of 30°Brix (steam blanching) and 2.28-2.88 kg_w/kg_{dm} in the case of 15°Brix (steam blanching). Respectively, the initial moisture content of the untreated samples was ranged between 1.73-2.42 kg_w/kg_{dm} in the case of 30°Brix and 2.28-2.50 kg_w/kg_{dm} in the case of 15°Brix. In Figure 3 are seen the experimental drying curves of sea buckthorn at 50°C along with the predicted moisture content curves by the *Logarithmic* model (Table 1). The moisture content decreases exponentially with drying time and thus, drying appears to take place at the falling rate period. The coefficients of *Logarithmic* model calculated from the non-linear regression are presented in Table 9. As can be seen, the *Logarithmic* model describes efficiently the experimental drying curves based on the statistical estimates $R^2_{adj} > 99\%$ and $SEE \leq 0.025$. In Figure 3 is observed that the steam blanching samples in both osmotic solutions were dried faster, approximately 4-5 hours shorter than the untreated samples (16-17 hrs), a fact that comes as a consequence of weakening of the waxy layer lying on fruit's peel due to steam blanching.

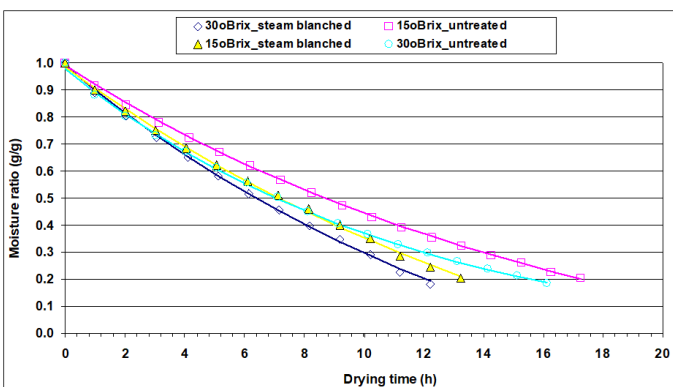


Figure 3. Experimental air-drying curves (points) of untreated and steam blanching sea buckthorn (*var. Chuskyaya*) with the simulated values (solid lines) from the *Logarithmic* model, $MR_f = 0.2$ (cf. to Table 1). Data points are the means of three replicates.

Table 9. Coefficients of *Logarithmic* model (cf. to Table 1) per experimental series.

	Treatment	a	b	c	R^2_{adj}	SEE
30°Brix	B	3.43	5.75×10^{-2}	-1.29	99.89	0.019
	NB	2.64	5.78×10^{-2}	-0.54	99.96	0.009
15°Brix	B	4.17	4.96×10^{-2}	-1.63	99.87	0.025
	NB	2.52	8.42×10^{-2}	-0.2	99.85	0.024

B = steam blanching; NB = no steam blanching

Figure 4 presents the water diffusivity against the moisture content for all the experimental series during the air-drying. It is noted that the water diffusivity of the steam blanching samples lie above the untreated ones and in particular the water diffusivity of steam blanching samples range between $2.11-2.29 \times 10^{-11} \text{ m}^2/\text{s}$ while those of untreated samples between $1.56-1.66 \times 10^{-11} \text{ m}^2/\text{s}$. Kyriakopoulou *et al.* (2013) attributed this response to thermal pre-treatment that reduced the resistance of water diffusion through product's epidermis, in the present case, reducing the waxy layer lies on sea buckthorn epidermis. Since estimation of the water diffusivity was carried out at the same drying temperature (50°C), its apparent sharp rise as the moisture ratio decreases in the drying curves, is driven solely by the moisture content. Saravacos and Maroulis (2001) reported that water diffusivity increases as moisture content decreases in porous foods due to porosity formation, which facilitates water transport within the drying product. At very low moisture contents ($MR < 0.1$) the strongly bound water in food matrix forces water diffusivity to be reduced sharply.

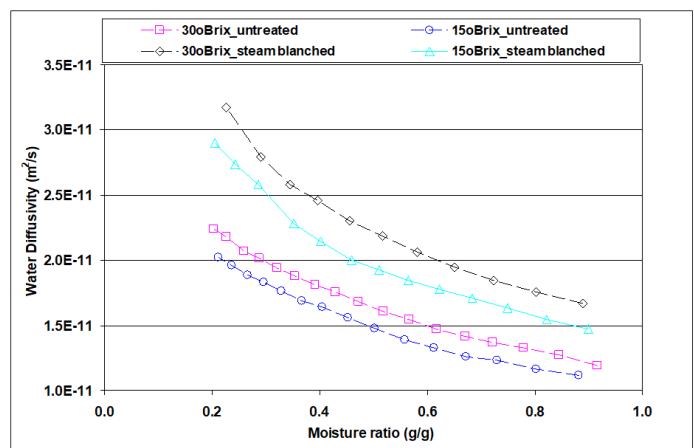


Figure 4. Water diffusivity of sea buckthorn (*var. Chuskyaya*) vs moisture ratio (dimensionless) for all the experimental series ($MR_f = 0.2$). Data points are the means of three replicates.

4. Conclusion

Solution concentration and steam blanching pre-treatment had a significant effect on the solid gain and water loss during the osmotic dehydration of sea buckthorn while both increased with increasing solution concentration but not to the same extent. In particular, solid gain was seven times lesser compared to water loss

fact that was attributed to the high molecular weight of steviol glycoside which favours water loss at the expense of solid gain. Peleg model described efficiently the mass transfer kinetics at the studied experimental cases based on the statistical estimates $R^2_{adj} > 99\%$ and $SEE \leq 0.18$. Steam blanching caused significant reduction of the ascorbic acid concentration and facilitated the total soluble solids and dry matter gain, reaching up to 84%. The Logarithmic model found to describe efficiently the experimental drying curves based on the statistical estimates $R^2_{adj} > 99\%$ and $SEE \leq 0.025$. The water diffusivity in steam blanched samples was higher than in the untreated ones and in particular the water diffusivity of steam blanched samples ranged between $2.11-2.29 \times 10^{-11} \text{ m}^2/\text{s}$ while those of untreated samples between $1.56-1.66 \times 10^{-11} \text{ m}^2/\text{s}$.

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