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Research Article

Kinetic Study of the Osmotic Pretreatment and Quality Evaluation of Traditional Greek Candied Pumpkin

Lazou AE, Giannakourou MG*, Lafka TI and Lazos ES

Laboratory of Chemistry, Analysis & Design of Food Processes, Department of Food Technology, Faculty of Food Technology & Nutrition, Technological Educational Institute of Athens, Athens, Greece

***Corresponding author:** Giannakourou MG, Laboratory of Chemistry, Analysis & Design of Food Processes, Department of Food Technology, Faculty of Food Technology & Nutrition, Technological Educational Institute of Athens, Athens, Greece, Tel: +30 2105385511; E-mail: mgian@teiath.gr

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Abstract

Candied pumpkin, a traditional Greek dessert, derives by Osmotic Dehydration (OD), followed by air-drying. Appropriate manufacturing procedures require an understanding of factors affecting mass transfer and quality attributes. Mass transfer and diffusion kinetics were studied using Fick's law, including investigation of product quality characteristics (structural, textural and sensorial). The experimental design included the independent variables: blanching time (t_{bl}: 1,3,5 min), blanching temperature (T_{bl}: 85,90,95°C), osmotic dehydration temperature (T_{osm}: 75, 85, 95°C) and sugar content in osmotic solution (C_{osm}: 65, 70, 75°Brix). It was found that the increase of process temperature and sugar content affected both mass transfer and diffusion coefficients. Mass transfer reached a plateau at 150 min. Both textural and structural characteristics were highly dependent on process conditions. Principal Component Analysis (PCA) showed a correlation between instrumental and sensorial attributes with process parameters, permitting the optimum conditions to be defined. Such data could be used to optimize and standardize procedures for manufacturing of high quality candied products.

Keywords

Diffusion coefficients; Kinetics; Osmotic dehydration; Pumpkin; Quality; Traditional candied fruit

Introduction

Candying is one of the most popular methods to preserve fruits and vegetables, which also produces attractive food ingredients, sometimes characteristic of a particular region or country [1-3]. Besides traditional procedures, candying can be also achieved through an osmotic dehydration process aiming at the reduction of water activity and the increase of sugar content of the products, resulting in products with longer shelf-life and different sensory attributes [4]. The most popular candying process, mostly implemented at a household level, consists of immersing pumpkin pieces in sugar solutions of increasing °Brix for about 7 days, while the diluted solution is appropriately reconstituted every next morning. The candied product is then air dried, in order to reach approximately 17-20% moisture content and water activity lower than 0.8. This procedure leads to well accepted candied products, but it is time-consuming and cannot be easily standardized and fixed [5].

Osmotic dehydration process involves immersing fruits or vegetables (whole or in pieces) into solutions of high carbohydrate or salt concentrations. During osmotic processing, water flows from the product into the osmotic solution, while osmotic solute is transferred from the solution into the product with a rate depending on process conditions (e.g., temperature, time, pressure, solute concentration, food types, food's previous handling and processing) [6-9]. Simultaneously, leaching of small amounts of product-soluble compounds (sugars, acids, minerals and vitamins), that may affect the sensory and nutritional characteristics of the product is observed [10,11]. The kinetics of OD processes is usually evaluated in terms of water loss, weight loss and solid gain [11,12] and depends mainly on the characteristics of the raw material and on operational conditions [13].

After the candying process, chemical composition of candied fruits and vegetables is radically changed, affecting almost all its principal sensory, physicochemical and chemical attributes. Moisture and water activity change significantly, as well as color, texture, and other sensory attributes. Measuring these changes during osmotic treatment allows for a better understanding of the influence of the process parameters on the chemical and physical properties of candied products. This is important for an optimized process design and production of products of superior quality.

The aim of this work is to describe the influence of the OD process conditions (blanching time and temperature, osmosis temperature and sucrose concentration) on mass transfer kinetics during OD process and quality characteristics of the final candied pumpkin products. In order to describe diffusion during osmotic treatment, the best known and most used phenomenological model is the Fick's law of diffusion, and, based on these original equations, [14] presented analytical solutions for different geometries (slabs, cylinders and spheres) and for different boundary conditions. The ultimate goal is to relate the observed changes in quality characteristics and transport properties of the final product with the changes in the process parameters and be able to propose an optimized candying procedure.

Materials and Methods

Sample preparation

Pumpkin (*Cucurbita maxima*, var. Long Island Cheese) fruit samples were purchased in a local market in Athens. The fruits were selected based on their appearance and state of ripeness, which was evaluated from total soluble solids content using a digital refractometer (ATAGO hand refractometer, Japan). The total soluble solids content of raw material was 11.0 ± 0.7 Brix (average ± standard deviation).

Selected pumpkin samples were carefully transferred to the lab, sorted, washed and cut into 4x3x1 cm slabs. Before candying, they were blanched in hot water at temperatures 85, 90 and 95°C for 1, 3 or 5 minutes, according to experimental design (Table 1), and immediately cooled.

Osmotic dehydration

Osmotic solutions were prepared with commercial sucrose and distilled water. A mass ratio of at least 1:10 between fruit samples and osmotic solution was used in all experiments, in order to avoid significant changes on sugar solution concentration during the experiments.

Independent Variables	Levels		
	1	2	3
t_{bl}, Blanching Time (min)	1	3	5
T_{bl}, Blanching Temperature (°C)	85	90	95
T_{osm}, Osmotic Dehydration Temperature (°C)	75	85	95
C_{osm}, Osmotic Solution Concentration (°Brix)	65	70	75

Table 1: Experimental design of osmotic dehydration of pumpkin (Central Composite Design).

Fresh-cut pumpkin slabs were osmotically treated in OD sugar solutions of different concentrations (65, 70 and 75°Brix), freshly prepared the same day. The process temperature was 75, 85, and 95°C for time duration up to 200 min (Table 1) and the experiment was conducted in a thermostatic bath (POLYSCIENCE water bath, 10 L), with temperature being constantly controlled and checked.

At the selected sampling times, pre-weighed samples were removed from the osmotic solution and blotted gently with a tissue paper in order to remove the excess coating solution and then weighed. Four replicate samples were removed and measured each time and the average values were taken.

Experimental design

The design of experiments was a three level central composite design resulting in 9 osmotic dehydration tests, with two replications. The independent variables were blanching time - t_{bl} (1, 3, and 5 min); blanching temperature - T_{bl} (85, 90, and 95°C); osmotic dehydration temperature - T_{osm} (75, 85, and 95°C) and osmotic solution concentration - C_{osm} (65, 70 and 75°Brix) (Table 1), with codes indicating level of treatment conditions, for example, sample 2222 corresponding to t_{bl} = 3 min, T_{bl} = 90°C, T_{osm} =85°C and C_{osm}= 70°Brix).

Determination of physicochemical properties during osmotic dehydration

Water content (X_w) and total soluble solids (X_s) were measured in fresh and treated samples, at several time intervals, to determine the compositional changes promoted by Osmotic Dehydration (OD). The moisture content was determined gravimetrically by drying at 105°C for 24 h. Total soluble solids were determined by a refractometer (ATAGO hand refractometer, Japan). X_w and X_s data are necessary in order to calculate mass transfer during OD process, through equations (1) and (2), Water Loss (WL) and Solid Gain (SG) parameters, namely. Water activity (a_w) was monitored during process using an a_w-meter (Aqua LAB 4TEV, Decagon Devices, Inc., USA). All measurements were made in triplicate, and the mean values were reported.

Mass transfer parameters and changes were followed by using Water Loss (WL) (Equation 1) and Solid Gain (SG) (Equation 2):

$$WL = \frac{(M_0 - m_0) - (M - m)}{m_0} \quad \text{(g of water/g initial dry matter)} \quad \text{(eq.1)}$$

$$SG = \frac{m - m_0}{m_0} \quad \text{(g of total solids/g initial dry matter)} \quad \text{(eq.2)}$$

where M_0 is the initial mass of fresh material before the osmotic treatment, M is the mass of pumpkin samples after time t of osmotic treatment, m is the dry mass of pumpkin after time t of osmotic treatment and m_0 is the dry mass of fresh material. The purpose of this kinetic study was to select the optimum osmo-dehydration time for each combination of the main influencing parameters (t_{bl}, T_{bl}, T_{osm}, C_{osm}), in order to produce osmo-dehydrated samples, before proceeding to the next step, which is air drying.

Air drying

The osmo-dehydrated pumpkin slabs, from each experimental condition, were subsequently air dried at 70°C (Apex Construction Ltd., England), until they reached moisture content of 18-20% (w.b.) (based on the traditional candied product). The samples were then stored in polyethylene bags and kept refrigerated until further properties analysis, which took place within 24 hours after their production.

Determination of sensory properties of the final osmo-air dried (candied) product

Measurement of CIEL ab values [15] with a Handy Colour Tester (Model H-CT, SUGA Test Instruments) was performed. A standard white plate (Calibration plate CR-200) was used to standardize the instrument under "C" illuminant condition according to the CIE (Commission International de l' Eclairage) and the parameter L/L_0 was assessed, where L_0 is the initial value, before osmotic treatment. An average value of 4 replicates was reported.

Texture analysis was carried out using a texture profile analyzer (TA.XT2i; Stable Micro Systems, UK), with 60-mm compression probe. The operating conditions of the instrument were as follows: 3 mm/s pre-test speed, 1 mm/s test speed, 1 mm/s post-test speed, and 50% sample deformation. A force-time curve was recorded by the instrument and four textural attributes including hardness, springiness, cohesiveness, and brittleness were measured. An average value of 5 replicates was reported.

The apparent density of the candied pumpkins was determined using (Equation 3):

$$\rho_a = \frac{m}{V_a} \quad \text{(eq.3)}$$

where m is the mass of the samples (kg) and V_a the apparent volume (m^3). Apparent volume of the samples was measured by immersing the samples in n-heptane and by determining the volume displacement with an accuracy of 0.05 ml [16]. The results are the average of 5 replicate measurements.

The apparent shrinkage of the final candied pumpkins was determined by (Equation 4):

$$S_a = \frac{V_a}{V_{ai}} \quad \text{(eq.4)}$$

where V_a is the apparent volume of the final product (as in equation (3)) at a given moisture content (samples moisture content ~ 18-20%) and V_{ai} is the initial apparent volume. The volumes were determined by the liquid displacement method [17].

For micro-structural observation, candied pumpkins were cut in slices and examined by SEM (JEOL, JSM-6510LV, JEOL Ltd., Japan) at 20 kV. Samples were previously coated with gold. For the macro-structural observation, whole and sliced candied pumpkins were observed by Olympus Stereo Microscope (Stereoscope SZ61, Olympus, Center Valley, PA, USA).

Sensory properties were evaluated applying Quantitative Descriptive Analysis (QDA) with a 20-member trained panel and using an appropriate questionnaire with a scoring scale 1-9, for main quality parameters (color, appearance, elasticity, hardness, cohesiveness, sweet/bitter taste, flavor, drip loss, overall acceptance etc). Since organoleptic assessment is of major importance for the acceptance of a newly introduced product, a special training was performed and specific guidelines were given to assessors, including a detailed explanation of the terminology used (Table 2).

Mathematical modelling

Calculation of the diffusion coefficient

In this work, it was assumed that pumpkin slabs may be considered as having an infinite slab shape of thickness 2L, initially at uniform moisture and solute concentrations C_{w0} and C_{s0}, respectively. At t = 0 the material is immersed in a sugar solution with constant concentration and temperature. It is assumed that the solution temperature and concentration remain constant during osmotic dehydration. This condition is well established by selecting a high solution to solid mass ratio (approximately 10/1). Also, constant equilibrium moisture and solute concentrations at the surface (negligible external resistance to mass transfer) of the material are considered. In these conditions, the unsteady-state one-dimensional mass transfer in the solid material can be described by the following general Equation 5, based on Fick's law of diffusion:

$$\frac{\vartheta C}{\vartheta t} = D_{eff} \frac{\vartheta^2 C}{\vartheta x^2} \quad (eq.5)$$

where D_{eff} is the effective moisture diffusivity ($m^2\ min^{-1}$). The following boundary conditions are assumed (Equation 6):

Sensory Attribute	Characteristic	Description	Intensity (scale 1 to 9)
General Appearance	Appearance	Glossy/cohesive/uniform surface	Low-High
	Color	Basic coloring	Light to dark colored
	Porosity	Identification of a grid after cutting the slab	Low-High
	Drip Loss	Liquid leakage when compressing the slab	Low-High
Flavor	flavor	General assessment	Low-High
Texture	Hand touch perception/elasticity	Assessment of sample behavior to cutting/stretching/chewing	Low-High
	Mouth feel, chewiness	Perception of chewiness	Easy to hard
	Adhesion/gumminess	Perception of a sticky mass when chewing inside the mouth	Low-High
	Crispiness	Perception of a characteristic sound at first bite	Low-High
	Rehydration	Rehydration and softening of the sample using mouth saliva	Low-High

Table 2: Terminology used in sensory evaluation of the final candied pumpkin slices.

$$C(x,0)=C_0 \text{ at } t=0$$
$$\frac{\vartheta C}{\vartheta x}=0 \text{ at } x=0$$
$$C(L,t)=C_e \text{ at } x=L \quad (eq.6)$$

where x is the spatial coordinate, C=C(x,t) and subscripts 0 and e refer to initial and equilibrium state, respectively.

Average dimensionless concentrations (space-mean concentrations), ϕ(t), could be obtained by applying the method of separation of variables to Equation 5, to yield concentration distribution, C(x, t) and then taking the spatially average, arriving at [4,18]:

$$\varphi(t)=\frac{\overline{C}(t)-C_e}{C_o-C_e}=\frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left[-\frac{\pi^2(2n+1)^2D_{eff}}{4L^2}t\right]\ (eq.7)$$

in which C is the mass of water (w) or solute (s) per volume of the osmodehydrated tissue. C_0 is the initial content per volume, C_e is the equilibrium content per volume, D_{eff} is the effective moisture diffusivity ($m^2\ min^{-1}$), L is the half thickness (drying from both sides) of pumpkin slabs (m) (L=0.05 ± 0.010 mm), and t is the osmotic treatment time (min). For long drying times, n=1, the series of Equation (7) can be simplified by using just the first term and the following mathematical expression can be obtained:

$$\ln(\varphi)=ln\left(\frac{8}{\pi^2}\right)-\left(\frac{\pi^2D_{eff}}{4L^2}\right)t\ (eq.8)$$

Therefore, for water, Equation (7) can be written as follows [19]:

$$\ln\frac{(C_{wt}-C_{w\infty})}{(C_{wo}-C_{w\infty})}=ln\left(\frac{8}{\pi^2}\right)-\left(\frac{\pi^2D_{effw}}{4L^2}\right)t\ (eq.9)$$

and, for solute, correspondingly (Equation 10):

$$\ln\frac{(C_{st}-C_{s\infty})}{(C_{so}-C_{s\infty})}=ln\left(\frac{8}{\pi^2}\right)-\left(\frac{\pi^2D_{effs}}{4L^2}\right)t\ (eq.10)$$

where C_{wt} and C_{st} is the water and solute concentration at time t, C_{w0} and C_{s0} is the initial water and solute concentration and $C_{w\infty}$ and $C_{s\infty}$ is the equilibrium water and solute concentration, which can be determined by experiments at a long time length.

Without considering samples' shrinkage during the osmotic procedure, volume of the material and thus L in the right hand side of Equations 9 and 10 is constant [19]. Also, concentrations of the left hand side of Equations 9 and 10 can be replaced by the following drying data, for water (Equation 11) and the solute (Equation 12) respectively:

$$\frac{(C_{wt}-C_{w\infty})}{(C_{wo}-C_{w\infty})}=\frac{\frac{M-m}{V_t}-\frac{M_\infty-m_\infty}{V_\infty}}{\frac{M_O-m_O}{V_O}-\frac{M_\infty-m_\infty}{V_\infty}}\ (eq.11)$$

where M_∞ and m_∞ is the sample mass and the dry mass, respectively at the equilibrium phase.

$$\frac{(C_{st}-C_{s\infty})}{(C_{so}-C_{s\infty})}=\frac{\frac{m}{V_t}-\frac{m_\infty}{V_\infty}}{\frac{m_O}{V_O}-\frac{m_\infty}{V_\infty}}\ (eq.12)$$

Assuming $V_0=V_t=V_\infty$, concentrations in the left hand side part of equations 9 and 10 are replaced by mass data, already measured during the osmotic procedure. Since values of moisture and solids content are experimentally determined, the first part of equations 9 and 10 is calculated. Therefore, diffusivities (both for water and solute) are typically determined by plotting experimental data (first part of equations 9 and 10) versus drying time t, because the plot gives a straight line with a slope as $(\pi^2D_{eff}(w\ or\ s))/(4L^2)$ [20].

Statistical analysis

The purpose of statistical analysis was two-fold: initially, the influence of the main independent variables of osmotic dehydration process, as described in table 1, on selected mass transfer parameters and quality characteristics of candied pumpkins was assessed using Analysis of Variance (ANOVA) and Duncan's multiple range test to detect significant differences between samples. Significant differences were defined at $p < 0.05$. Furthermore, Principal Component Analysis (PCA) was implemented to investigate correlations between instrumental and sensory attributes. The purpose was to find which factors lead to different candied pumpkins in terms of sensory, textural and structural characteristics. All analysis was performed using Statistica software (Statistica Release 7, Statsoft Inc. Tulsa, OK, USA).

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Results and Discussion

Kinetic study of the Osmotic Dehydration (OD)

In all cases, a_w was found to decrease vs. time during the osmotic treatment of pumpkin slabs, as expected, with the temperature (Figure 1a) and osmotic solution concentration (Figure 1b) having the most important impact on a_w lowering. Similarly, the Water Loss (WL) is plotted vs. time (Figure 2a and d) revealing the same prominent effect of T_{osm} and C_{osm}, compared to the effect of blanching parameters, especially time, which do not seem to alter significantly mass transfer phenomena. The mass transfer reached a plateau at 150 min. This is the optimum time selected for candied pumpkin production.

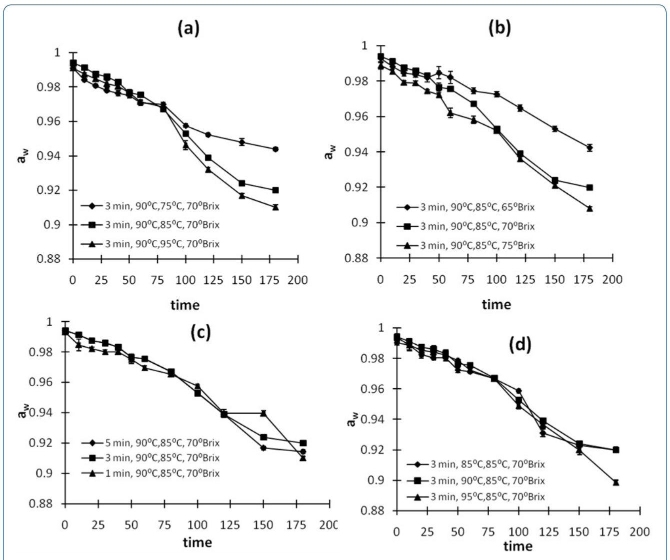

Figure 1: a_w vs time showing the effect of: (a) T_{osm}, (b) C_{osm}, (c) t_{bl} and (d) T_{bl}.

(Points are the mean values and error bars show the standard deviation of the three measurements)

If we consider WL, a_w and SG values at that time (after 150 min) of equilibrium (symbolized as WL_∞, $a_{w\infty}$ and SG_∞) values), Appropriate Statistical Analysis (ANOVA) confirms the former observation, i.e., that all influencing factors besides blanching time, i.e. T_{osm}, C_{osm}, and T_{bl} have a significant effect on WL_∞, $a_{w\infty}$ and SG_∞ (data not shown). Values of these parameters and their standard deviations were calculated: $WL_\infty = 6.66 \pm 0.69$, $a_{w\infty} = 0.919 \pm 0.014$ and $SG_\infty = 1.60 \pm 0.44$.

Water activity (a_w) of the final products, after both OD and the subsequent air drying was systematically measured, with a_w reaching a final value of about 0.663($\pm$ 0.042), which corresponds to a shelf-stable product.

Textural characteristics of candied pumpkin

The textural characteristics of candied pumpkin were calculated from Texture Profile Analysis (TPA) curves. An evaluation of hardness, cohesiveness, springiness and brittleness was performed and values are summarized in table 3. The analysis of variance showed that process

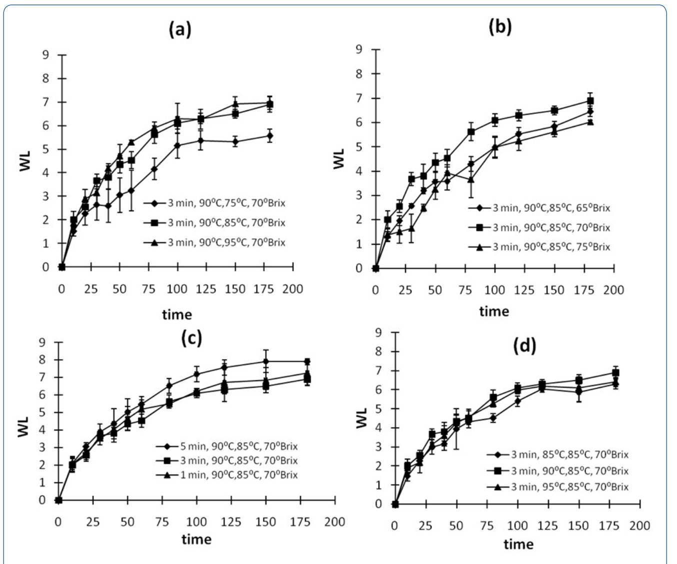

Figure 2: WL vs time showing the effect of: (a) T_{osm}, (b) C_{osm}, (c) t_{bl} and (d) T_{bl}.

(Points are the mean values and error bars show the standard deviation of the four measurements)

parameters affected significantly the texture of candied pumpkins ($p<0.05$).

The increase in blanching time increased the cohesiveness and brittleness of samples, while hardness and springiness were decreased. The increase in blanching temperature decreased samples hardness, springiness and cohesiveness and increased their brittleness. The blanching procedure is a pre-treatment which favours the mass transfer during OD, through the destruction of tissue structure, resulting in the promotion of solid uptake [21,22]. Consequently the final product will have reduced hardness and firmer texture.

The raise in OD temperature increased candied pumpkin hardness, and depressed their cohesiveness, brittleness and springiness, as shown in table 3. The hardness of candied pumpkins was 3.83 N at T_{osm} 75°C and raised at 10.52 N at T_{osm} 95°C. The values for springiness, cohesiveness and brittleness of candied products were significantly ($p<0.05$) lower at higher process temperatures. The concentration of osmotic solution had great influence on products textural characteristics. The hardness and cohesiveness of candied pumpkin were increased as the C_{osm} increased. The products produced at higher solution concentrations had lower values of springiness and brittleness. The springiness of the candied pumpkins had a 33% reduction at 75° Brix solution concentration. The reduction of the samples brittleness was more evident at 75° Brix osmotic solution concentrations, as at concentrations 65 and 70° Brix, values of brittleness were not significantly different. The OD temperature and the concentration of osmotic solution affect significantly mass transfer phenomena. The candied osmodehydrated pumpkins became more brittle and less tough as the water content was reduced and the solid content was increased, and this may be related to the reinforcement of the cell walls due to the increase

Sample code	t_{bl} (min)	T_{bl} (°C)	T_{osm} (°C)	C_{osm} (°Brix)	Hardness (N)	Springiness	Cohesiveness	Brittleness
1222	1	90	85	70	6.35 ± 0.66^{b}	0.92 ± 0.08^{b}	0.33 ± 0.03^{de}	1.93 ± 0.12^{d}
2122	3	85	85	70	10.93 ± 0.89^{a}	1.06 ± 0.11^{a}	0.48 ± 0.02^{b}	1.92 ± 0.09^{d}
2212	3	90	75	70	3.83 ± 0.59^{c}	0.90 ± 0.07^{b}	0.56 ± 0.04^{a}	3.05 ± 0.13^{a}
2221	3	85	85	65	7.04 ± 0.16^{b}	0.84 ± 0.03^{c}	0.28 ± 0.03^{e}	2.83 ± 0.13^{b}
2222	3	90	85	70	6.29 ± 0.23^{b}	0.76 ± 0.02^{d}	0.40 ± 0.02^{c}	2.70 ± 0.10^{b}
2223	3	90	75	75	10.15 ± 0.53^{a}	0.56 ± 0.04^{g}	0.59 ± 0.02^{a}	1.86 ± 0.12^{d}
2232	3	90	95	70	10.52 ± 0.92^{a}	0.63 ± 0.05^{f}	0.32 ± 0.03d^{e}	2.19 ± 0.14^{c}
2322	3	95	85	70	3.69 ± 0.48^{c}	0.69 ± 0.08^{e}	0.37 ± 0.02^{cd}	3.10 ± 0.10^{a}
3222	5	90	85	70	3.48 ± 0.67^{c}	0.74 ± 0.03^{d}	0.52 ± 0.02^{b}	3.21 ± 0.19^{a}

Table 3: Textural characteristics of candied pumpkin (TPA test).

$^{a-h}$ Different letters within a column indicate significant difference ($p<0.05$) among samples according to Duncan's mean values comparison test

in sucrose concentration in the osmodehydrated pumpkin tissues [4].

Structural Characteristics of candied pumpkins

The changes in structural characteristics of the candied pumpkins are caused due to the combined effect of the two main processes used for their production, the osmotic dehydration and air drying. The apparent density and shrinkage of candied products were influenced by the process conditions (Figure 3). The apparent density of the products decreased with osmotic dehydration processing parameters (temperature and osmotic solution concentration) and blanching temperature and increased with the blanching time. The apparent shrinkage of candied pumpkins varied from 0.25 to 0.32. Osmotic dehydration is a well known pretreatment that prevents the structure collapse during air drying and improve the final product shape and texture [23,24]. Especially when high concentrations of osmotic solutions are used, as in the candying process, the solids within food matrix are highly increased. The observation of macro and micro structure of the candied products agrees with this fact.

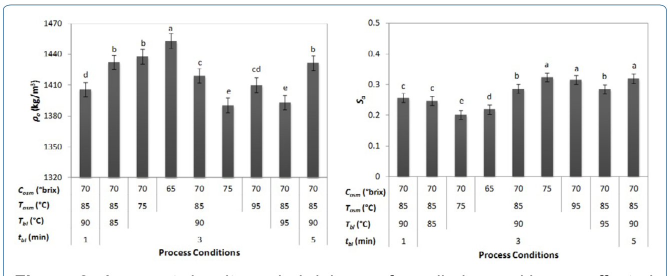

Figure 3: Apparent density and shrinkage of candied pumpkins as affected by process conditions. Different letters indicate significant difference ($p<0.05$) among samples according to Duncan's mean values comparison test and error bars show the standard deviation for the five replicates.

As the concentration of osmotic solution increases the structure becomes denser, with lesser cell walls, as can be observed on figure 4. The temperature of osmotic dehydration had similar effect. The product at higher temperature had more compact structure (Figure 4, T_{osm} effect), which may be a result of the increased mass transfer phenomena at higher temperatures.

Color loss (darkening) of candied pumpkin

L/L_0 is reported in table 4, showing that darkening of the initial bright yellow color of pumpkin occurs after blanching, osmotic dehydration and air drying of samples. In this case, blanching duration seems to affect significantly color loss, with the mildest conditions (t_{bl} = 1 min and T_{bl}=90˚C) having the best color retention among all samples. On the other hand, osmotic treatment parameters do not seem to have an important impact on brightness of yellow color.

Quantitative descriptive analysis of the final products

ANOVA analysis indicated that for the sensory characteristics shown in table 4 there was a sample effect. Non-significant attributes were excluded from further data analyses. Especially when adhesion, sweet taste and overall acceptance are concerned, samples prepared using t_{bl} = 3 min, T_{bl} = 90˚C, T_{osm}=85 or 95°C and C_{osm} = 70˚Brix showed the highest acceptance, which agrees with the findings for color (L/L_0), texture and structure. These specific samples showed good levels of acceptability for all sensory attributes examined.

Properties correlation

The instrumental and sensorial properties of candied pumpkins (structural, textural, appearance, taste, overall acceptance) were subjected to principal component analysis in order to investigate their between relationships. Figure 5 shows the bi-plot of the first 2 PCs, PC 1 and PC 2. They accounted for 64.6% of the total variance, with 42.7% explained by the first one.

The properties correlation revealed that sensorial hardness was high positively correlated with springiness (almost overlapping in the right upper part of the plot) and these attributes were negatively correlated with sweet taste and overall acceptance (overlapping in the left part of the bi-plot). The brittleness and apparent density were negatively correlated with hardness. This suggests that the higher apparent density will result in a more brittle and softer product. Apparent density was negatively correlated with shrinkage. These findings suggest that the most acceptable products had higher

Quality attributes/sample codes	(1222) 1 min 90°C 85°C 70°Brix	(2122) 3 min 85°C 85°C 70°Brix	(2212) 3 min 90°C 75°C 70°Brix	(2221) 3 min 90°C 85°C 65°Brix	(2222) 3 min 90°C 85°C 70°Brix	(2223) 3 min 90°C 85°C 75°Brix	(2232) 3 min 90°C 95°C 70°Brix	(2322) 3 min 95°C 85°C 70°Brix	(3222) 5 min 90°C 85°C 70°Brix
Instrumentally measured color (L/L_0)	*0.799 ± 0.041^{a}	0.658 ± 0.086^{b}	0.646 ± 0.022^{b}	0.658 ± 0.021^{b}	0.642 ± 0.068b^{c}	0.698 ± 0.030^{b}	0.630 ± 0.007b^{c}	0.623 ± 0.086^{bc}	0.546 ± 0.083^{c}
Color	5.9^{ac}	4.7^{ab}	4.8^{ab}	4.5^{ab}	5.8^{ac}	4.1^{b}	7.1^{c}	5.3^{ab}	6.0^{ac}
Elasticity	3.7^{ab}	2.3^{a}	3.6^{ab}	3.2^{ab}	4.2^{b}	3.2^{ab}	4.5^{b}	2.6^{a}	3.8^{ab}
Hardness	6.8^{a}	5.4^{ac}	6.6^{a}	6.5^{ac}	5.2^{ac}	6.2^{ac}	2.1^{b}	4.6^{c}	6.3^{ac}
Adhesion	6.2^{a}	5.9^{a}	5.8^{a}	6.1^{a}	5.2^{ab}	5.5^{ab}	3.8^{b}	6.6^{a}	5.9^{a}
Sweet taste	4.5^{a}	4.9^{a}	4.9^{a}	4.8^{a}	5.6^{a}	4.8^{a}	6.9^{b}	5.3^{a}	5.0^{a}
Overall acceptance	4.4^{a}	3.7^{a}	3.8^{a}	3.2^{a}	5.9^{b}	3.8^{a}	7.5^{c}	4.3^{a}	4.6^{a}

Table 4: Instrumentally measured color loss (L/L_0) and mean ratings in a 1-9 scale of the perceived intensity of the sensory attributes for candied pumpkin slabs (final products), produced by different procedure parameters (t_{bl}, T_{bl}, T_{osm} and C_{osm})

*: mean value ± standard deviation of 4 replicates

$^{a-d}$: Different letters within a row indicate significant different mean values for each considered attribute ($p<0.05$), applying Duncan post hoc test

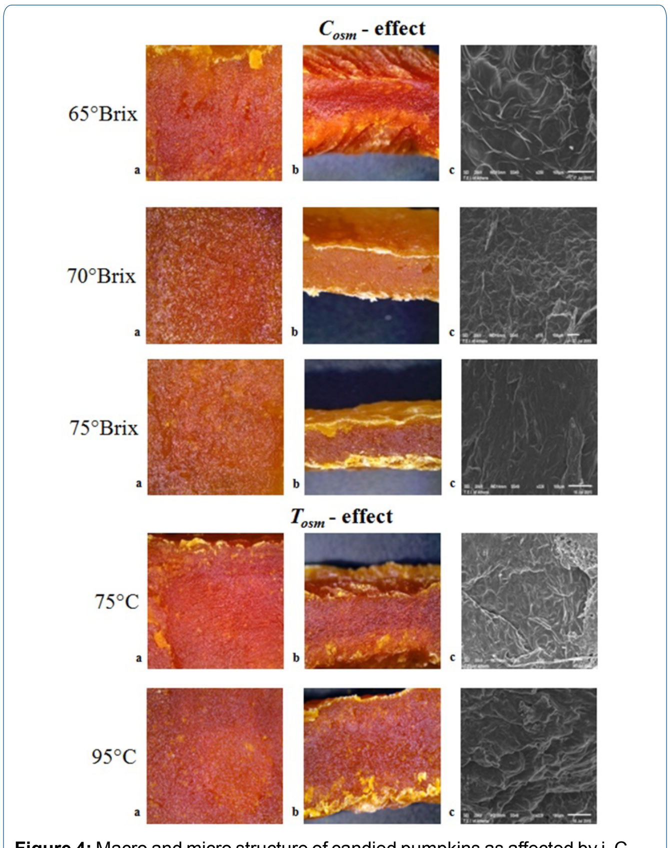

Figure 4: Macro and micro structure of candied pumpkins as affected by i. C_{osm}, ii. T_{osm}. Samples were blanched at 90°C for 3 min (a. horizontal cross-section, b. cross section, c. SEM photo cross section). The macro-photographs were taken at x0.67 and SEM photographs at x250.

values of sweet taste, were elastic and relatively soft in texture. From the sample correlation, the process variables that produced the most acceptable products were t_{bl}: 3min, T_{bl}: 90˚C, T_{osm}: 85˚C and 95˚C and C_{osm}: 70˚Brix.

Mass transfer model: Evaluation of water and sucrose effective diffusion coefficients

Effective diffusivity is an important mass transfer property in osmotic dehydration, widely used to model the mass transfer kinetics of water and osmotic agent and the influence of the process parameters on their mass transfer kinetics [4]. As described in Materials and Methods section, mass balance equations based on Fick's second law were numerically solved in order to estimate the effective diffusivities for water (D_{effw}) and solute (D_{effs}) for the different parameters of the experimental design. Table 5 shows the respective effective diffusivities for all experiments performed, as well as their standard deviation. In most cases, the good fitting observed between the model and the experimental results, for each of the four process parameters' combination (t_{bl}, T_{bl}, T_{osm}, C_{osm}), indicates that the Fickian model, in its present form applied for slab geometry, could be deemed adequate for describing the results.

The experimental values of the effective diffusivity (Table 5) for the different parameters examined were in the range 10^{-9} to 10^{-10} (m^2s^{-1}) and are in general agreement with other similar works in recent literature [4,18,19,25,26]. Temperature and sucrose concentration of the osmotic solution had a significant influence mostly on water effective diffusion coefficients (Tables 5) in a positive way, meaning that as osmosis temperature or osmotic solution concentration increases, D_{effw} increases too. These results simply confirm the well recognized assumption that diffusion process, as well as other similar mechanisms are temperature-dependent phenomena. The influence of temperature on the water and sucrose effective diffusion can be due to the swelling and fracturing of cell membranes, higher moisture diffusion rates within the product, and better water transfer on the surface due to lower viscosity of the osmotic medium (as a result of increased temperature of the osmotic solution) [4,27].

Regarding C_{osm} (osmotic solution concentration) impact, the former trend seems to be inversed in the case of solute effective diffusion, an observation that agrees with [4,28,29] for their studies with pumpkin, pineapples and watermelon, respectively. The reasons for these behaviour can be related with several structural changes, such as an extensive dehydration of the surface cells with a resulting shrinkage

Sample code	t_{bl} (min)	T_{bl}(°C)	T_{osm} (°C)	C_{osm} (°Brix)	D_{effw} (m^2/s) (*10^9)	D_{effs} (m^2/s) (*10^9)
1222	1	90	85	70	1.93 ± 0.26*	0.53 ± 0.16*
2122	3	85	85	70	2.79 ± 0.28	0.57 ± 0.13
2212	3	90	75	70	1.47 ± 0.18	0.36 ± 0.16
2221	3	85	85	65	1.69 ± 0.09	0.67 ± 0.10
2222	3	90	85	70	2.55 ± 0.22	0.37 ± 0.10
2223	3	90	75	75	2.97 ± 0.24	0.28 ± 0.10
2232	3	90	95	70	2.83 ± 0.60	0.98 ± 0.59
2322	3	95	85	70	2.98 ± 0.41	0.76 ± 0.21
3222	5	90	85	70	2.42 ± 0.30	0.85 ± 0.21

Table 5: Diffusion coefficients of water and solute (sucrose) estimated using Fick's law.

*: Mean of four replicates ± standard deviation

reducing transport properties or to hindering effects due to the sucrose accumulated in the thin subsurface layer causing tissue compacting and an extra mass transport barrier, etc. [4,27,30]. As far as the other two parameters (blanching time and temperature) are concerned, Table 5 clearly indicates that they do not play a significant role neither to water nor to solute diffusion.

Conclusion

The mass transfer phenomena during osmotic dehydration of pumpkin were affected significantly by blanching pre-treatment, as well as by osmotic procedure conditions (temperature and solution concentration). The mass transfer reached a plateau at 150 min. Blanching affected significantly colour loss, with the mildest conditions (t_{bl} = 1 min and T_{bl} = 85°C) showing the best retention. Textural and structural characteristics of candied pumpkin were affected by process conditions. The higher the apparent density, the lower the shrinkage and the texture became softer and more brittle. Based on properties correlation, the optimum OD conditions for the production of traditional candied pumpkin chosen were: t_{bl}: 3min, T_{bl}: 90°C, T_{osm}: 85°C and 95°C and C_{osm}: 70°Brix. These conditions, followed by air drying led to a well accepted pumpkin product, with good sensory attributes and a lowered a_w value, which makes the final candied product a shelf stable food item.

Regarding the effect of the four process parameters chosen on the mass transfer kinetics of water and solute, diffusion mechanism was successfully modelled by solving numerically the mass balance equations for unsteady state Fick's diffusion. This model provided an easy and rather accurate prediction of the effective diffusion coefficients of water and sucrose from the available experimental values. Temperature and sucrose concentration had a significant influence mostly on water diffusion, which was found to increase as the solution temperature increased for both water and sucrose. Blanching time and temperature did not seem to influence to a significant level effective diffusivities.

In conclusion, the different mass transfer and diffusion kinetics, transport properties and quality indices observed for the different osmotic dehydration pre-process (blanching) and process parameters resulted in final products with significantly different chemical composition and physical/sensory characteristics, which merit further study, in order to design an optimized and standard procedure for a well accepted candied pumpkin product.

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