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Sensory evaluation of apple cubes (*Granny Smith* var.) impregnated with concentrated grape juice (*Victoria* var.) subjected to convection drying

Evaluación sensorial de cubos de manzana (variedad *Granny Smith*) impregnados con jugo concentrado de uva (variedad *Victoria*) sometidos a secado convectivo

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Technological innovation: Drying pre-treatment to enrich the food matrix with solutes that allow improving nutritional composition.

Area of application: Food products development and sensory evaluation. Food conservation which allows to extend shelf life as a raw material.

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Resumen

En el proceso de deshidratación de frutas se suelen utilizar temperaturas elevadas para reducir el contenido de humedad en poco tiempo. Sin embargo, temperaturas elevadas modifican las características sensoriales debido a la pérdida de compuestos termolábiles, y a las reacciones químicas o enzimáticas que afectan a la aceptación de los frutos deshidratados, siendo parámetros negativos de calidad. El uso de la deshidratación osmótica se ha utilizado como pretratamiento para enriquecer la matriz alimenticia con solutos que mejoran la composición nutricional, proporcionando estabilidad morfométrica y de color. El objetivo de este trabajo fue evaluar la cinética de secado de cubos de manzana (var. *Granny Smith*) impregnados con jugo concentrado de uva (var. *Victoria*) para obtener snacks sensorialmente aceptables. El pretratamiento de impregnación se realizó con jugo concentrado de uva (40°Bx, 25°C, 4 g solución/g producto, y 960 min); se determinó el color, la a_w y la cinética de secado de los cubos de manzana (1.5×1.5×1.5 cm) sometidos a secado por convección (40°C y velocidad del aire de 0.5 m/s). Las curvas de secado se modelaron utilizando los modelos de Newton, Henderson y Pabis, Page, Weibull y la segunda ley de Fick. Los frutos secos pretratados se evaluaron sensorialmente utilizando una escala hedónica de nueve puntos. Los resultados indicaron que las manzanas impregnadas tuvieron una pérdida de agua de 0.53±0.12 g agua/g producto y una ganancia de sólidos de 0.07±0.00 g sólidos/g producto. Además, se determinó que los modelos de Page y Weibull fueron los más apropiados para describir las características de secado de las muestras frescas e impregnadas, respectivamente. La difusividad efectiva del agua de los cubos de manzana fresca e impregnada fue de 11.4×10^{-10} y 0.50×10^{-10} m^2/s, respectivamente. Las muestras frescas e impregnadas requirieron 440 y 850 min de secado convectivo, respectivamente, para obtener frutas de baja humedad (a_w=0.26±0.04 para muestras frescas-secas y a_w=0.36±0.01 para muestras impregnadas-secas). No se observaron diferencias significativas (p<0.05) en el brillo y el tono del color del producto impregnado debido al proceso de secado (ΔE=7.98). Se obtuvo una aceptación en general del producto de 8.57±0.16 y un producto sensorialmente aceptable, especialmente en sabor y aroma.

Palabras clave: cubos de manzana, secado convectivo, impregnación de alimentos, jugo concentrado de uva, evaluación sensorial.

Abstract

Fruit dehydration process generally uses high temperatures to reduce the moisture content in a short time. The high temperature modifies the sensory characteristics due to loss of thermolabile compounds, and chemical or enzymatic reactions that affect the acceptance of dehydrated fruits, being undesirable quality parameters. The use of osmotic dehydration has been used as a pre-treatment to enrich the food matrix with solutes that improve the nutritional composition, provide morphometrical and color stability. The aim of this work was to evaluate drying kinetics of impregnated apple cubes (*Granny Smith* var.) with grape juice concentrate (*Victoria* var.) in order to achieve a sensory acceptable snack. The impregnation pre-treatment was carried out with *Victoria* grape juice concentrate (40°Bx, 25°C, 4 g solution/g product, and 960 min); color, a_w and drying kinetics of apple cubes (1.5×1.5×1.5 cm) subjected to convective drying (40°C and air velocity of 0.5 m/s) were investigated. Drying curves were modeled using selected models: Newton, Henderson & Pabis, Page, Weibull and Fick´s second Law. Dried pre-treated fruits were sensory evaluated using a nine-point hedonic scale. The results indicated that impregnated apples had a water loss of 0.53±0.12 g water/g product and solids gain of 0.07±0.00 g solids/g product. In addition, Page and Weibull models were found to be the most appropriate to describe the drying characteristics of fresh and impregnated samples, respectively. Effective water diffusivity of fresh and impregnated apple cubes was 11.4×10^{-10} and 0.50×10^{-10} m^2/s, respectively. Fresh and impregnated samples required 440 and 850 min, respectively of convective drying to obtain a low moisture fruit (a_w=0.26±0.04 for fresh-dry product and a_w=0.36±0.01 for impregnated-dry product). No significant differences (p<0.05) were observed in the brightness and hue of the impregnated product due to the drying process (ΔE=7.98). It obtained an overall acceptability score of 8.57±0.16, being a sensory acceptable product, especially in taste and aroma.

Key words: apple cubes, convective drying, food impregnation, grape juice concentrate, sensory evaluation.

1. Introduction

Dried fruits can be stored for long periods of time due to their low moisture content. However, depending on the type of product, moisture level and water activity reached during drying, the shelf life could be shorter. Common methods of dehydration involve thermal processes, such as convective, electrodynamic, and solar drying [1]. However, with the application of high levels of thermal energy, the nutritional value of dry products decreases due to the loss of thermosensitive nutrients, and the sensory characteristics are modified due to chemical or enzymatic reactions that affect the acceptance of dry fruits, being undesirable quality parameters [2, 3].

Some studies have implemented the use of osmotic dehydration as a pre-treatment to enrich the food matrix with solutes that allow improving nutritional composition, and providing morphometric and color stability [4, 5]. Osmotic dehydration consists of a simultaneous mass transfer process in which occurs a partial removal of water and leaching of solids from the raw material to the osmotic solution and a gain of solids from the osmotic solution to the raw material through the cell wall of the raw material, since it acts as a semi-permeable membrane [2, 6, 7]. The type of osmotic solution used depends mainly on the compatibility with the matrix subjected to the osmotic process. Generally, hypertonic salt solutions (for vegetables, red meat, fish, shrimp, among others) or sucrose, some sweeteners and syrups from fruits and vegetables are used as osmotic solutions [6]. Natural fruit and vegetable juice concentrates can be used as osmotic solutions, as they present low values of water activity and may provide bioactive compounds to create products with high nutritional value and better quality [8, 9, 10]. The aim of this work is to evaluate the drying kinetics of impregnated apple cubes (*Granny Smith* var.) with grape juice concentrate (*Victoria* var.) in order to achieve a sensory acceptable snack.

2. Materials and Methods

Fresh apples (*Malus domestica* L. var. *Granny Smith*; a_w=0.99±0.00; 9.4±0.1°Bx and pH=4.00±0.02) were locally purchased (San Andrés Cholula, Puebla, Mexico) and stored at 4°C until use. The apples were washed, sanitized in a solution of 100 mg/L peracetic acid for 10 min, peeled and cut into cubes (1.5×1.5×1.5 cm) with a sharp ceramic knife. *Victoria* var. grape juice concentrate (67.9°Bx) was obtained from *Casa Leal Vineyard* (Aguascalientes, Mexico). The juice concentrate was diluted with distilled water to a soluble solids concentration of 40°Bx, which was used as an osmotic agent.

2.1. Impregnation experiments

Fresh apple cubes (m_{p0}) were immersed in *Victoria* grape juice concentrate at a ratio of 1:4 (to avoid excessive dilution) and at a temperature of 25°C during 960 min as proposed by Assis, Morais, and Morais [11]. Subsequently, the samples were removed from the osmotic solution. The excess liquid was removed with absorbent paper, weighed (m_{OD}) and the moisture content (Y_0, fresh, and Y_{DO}, osmodehydrated product) was determined to calculate the water loss (WL), Eq. (1), and solids gain (SG) of the samples, Eq. (2) [12].

$$WL = \frac{m_{p0}Y_0 - m_{DO}Y_{DO}}{m_{p0}} \quad \textbf{(Eq. 1)}$$

$$SG = \frac{m_{DO}(1-Y_{DO}) - m_{p0}(1-Y_0)}{m_{p0}} \quad \textbf{(Eq. 2)}$$

2.2. Drying experiments

After pretreatment, the osmodehydrated apple cubes were subjected to convective drying in an oven (Felisa FE-291AD, Jalisco, Mexico) with vertical air flow (40°C and air velocity of 0.5 m/s). The samples were placed on a stainless-steel mesh, which was just in the middle of the system (to ensure homogeneous conditions). Briefly, the drying curves were obtained by determining the evolution of the dimensionless humidity of each sample (Ψ) by weight change as a function of time, Eq. (3) [1]. Dehydration experiments were performed in triplicate and compared with samples without pre-treatment.

$$\Psi = \frac{\text{moisture content } (t) - \text{equilibrium moisture content}}{\text{initial moisture content} - \text{equilibrium moisture content}} \quad \textbf{(Eq. 3)}$$

2.3. Drying kinetics and modelling

Process modeling plays an important role in the development and optimization of dryers and predict the behavior of food materials [13]. For selection of appropriate mathematical model to predict the drying kinetic, thin-layer drying models (Table 1) were used. The parameters of the models were estimated by non-linear regression. To evaluate the goodness of fit, coefficient of determination (R^2, to determine fitting ability of model), and reduced chi-square (χ^2, to compare deviation between predicted and experimental values) were used [18].

Table 1. Model equations for drying curves.

Model name	Model equation	Reference
Newton (Lewis)	$\Psi = e^{-k_1 t}$	[14]
Henderon & Pabis	$\Psi = a\, e^{-k_2 t}$	[15]
Page	$\Psi = e^{-k_3 t^b}$	[16]
Weibull	$\Psi = e^{-\left(k_4{}^{-1} t\right)^c}$	[17]

k_1, k_2 and k_3 are rate constant (1/min) of Newton, Henderson & Pabis and Page model, respectively; k_4, scale parameter (min); *a* and *b* are the empirical parameters (dimensionless) of Henderson & Pabis model respectively; *c* is the shape parameter of Weibull model, and *t*, time (min).

2.4. Effective moisture diffusivity

Fick's second law describe the distribution of moisture migration or effective diffusion in a food material during thin layer drying [18]. The average effective water diffusion for long drying time was calculated using the analytical simplified solution of Crank for a cubic geometry, described in Eq. (4) [19, 20, 21]. The solution considers constant effective diffusion with a uniform initial distribution of water throughout the product (with equal dimensions), absence of thermal effect in mass transfer [19].

$$\Psi = \frac{8^3}{\pi^6} \exp\left(-\frac{3\pi^2 D_{eff}}{4(L^2)} t\right) \qquad \textbf{(Eq. 4)}$$

where D_{eff} is effective water diffusivity (m^2/s), *L* is the half thickness on each side of the cube (m), *t* is the time (s).

Eq. (4) was linearized as Eq. (5). A plot of experimental ln Ψ *vs. t* give straight line with slope that was used to determine D_{eff}.

$$\ln(\Psi) = -\frac{3\pi^2 D_{eff}}{4(L^2)} t + \ln\left(\frac{8^3}{\pi^6}\right); \quad \text{slope} = -\frac{3\pi^2 D_{eff}}{4(L^2)} \qquad \textbf{(Eq. 5)}$$

2.5. Physicochemical characterization

Water activity. The a_w of the samples was determined based on the dew point using an AquaLab (Aqua Lab, 4TEV, USA), according to the procedure described by López-Malo et al. [22]. The determination was carried out at constant temperature (25°C) and each measurement was made in triplicate.

Moisture determination. The moisture content (g water/g product) of fresh samples (Y_0) and those subjected to osmotic dehydration (Y_{DO}) was determined in a forced convection oven (Felisa FE-291AD, Jalisco, Mexico) at 105°C until constant weight was reached [5].

Color determination. The color parameters (L*, a*, b*) were measured with a colorimeter (Konica Minolta CR-400, Osaka, Japan). Subsequently, the parameters were used to determine Chroma = $(a^{*2}+b^{*2})^{1/2}$, Hue = $\tan^{-1}(b^*/a^*)$ and total color change ($\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$) of 5 different samples [23].

2.6. Sensory analysis

Sensory evaluation of impregnated apple cubes was carried out in the sensory evaluation laboratory of the Universidad de las Americas Puebla (UDLAP).

The product's perceived flavor attributes were previously identify using a focus group method according to ISO standard [24]. Trained assessors (6 persons) developed a list of common flavor descriptors: grape, apple, acid or sweet. The flavor descriptors were quantified with a quantitative descriptor analysis (QDA) method [24, 25]. The QDA was performed with 20 trained judges, who were previously selected considering if they frequent (from time to time) users of dried fruit snacks. The judges scored each attribute according to an unstructured scale considering as boundary values of 0 (imperceptible) to 9 (very intense), score above 5.5 were considered as acceptable [26].

On the other hand, a hedonic scale of nine points (1=dislike extremely, 9=like extremely) were performed with 20 non trained judges. The 9-hedonic scale was used to evaluate color, aroma, taste, and general acceptability of impregnated samples [27, 28].

2.7. Statistical analysis

Data was analyzed using the Minitab 19 software. Variance (ANOVA) and mean comparisons were analyzed by Tukey test considering 95% confidence.

3. Results and discussion

3.1. Pretreatment

Apple cubes were removed from 40°Bx grape juice concentrate after of 960 min of impregnation process. Samples volume was reduced 59.5% compared to fresh sample (Fig. 1). In addition, samples reached a water loss of 0.53±0.12 g water/g fresh product and a solid gain of 0.07±0.00 g solids/g fresh product, which corresponds to a moisture contend decrease of 12.3% (Table 2). This value is similar to others previously reported [29-31]. These authors impregnated apple slices (*Idared* var.) with cherry juice concentrate (25-50°Bx) with an apple to osmotic agent ratio of 1:4 at 40°C during 30 min. Moisture content reduction of treated apple slices was of 12-14% and solids gain of 0.06-0.10 g water/g fresh product. Also, other authors found that osmodehydrated apple cubes (*Royal Gala* var.) with 40°Bx sucrose syrup, a sample to osmotic solution ratio of 1:4 and 25°C, reached the mass transfer equilibrium between 900 and 960 min of process; obtaining values of 0.41 g water/g fresh product and 0.11 g solute/g fresh product [11].

Osmodehydrated apple cubes reduced their a_w approximately 5% in relation to fresh sample (Table 2), similar value as the obtained by Assis et al. [11] who obtained osmodehydrated apple cubes with a_w=0.95.

Color of osmodehydrated samples presented a ΔE of 56.39 with respect to fresh product (Table 2). The ΔE of osmodehydrated samples compared with the color of the grape juice concentrate (L_0^*=19.23±0.16, a_0^*=-0.41±0.05 and b_0^*=0.68±0.11) was 13.89, which implied that the changes in the sample's color were due to color of the impregnated juice. The brightness and the chroma values of the exterior surface of the impregnated samples decreased when compared with the fresh sample. Impregnated apple cubes presented a purple tonality on their exterior surface (Fig. 1).

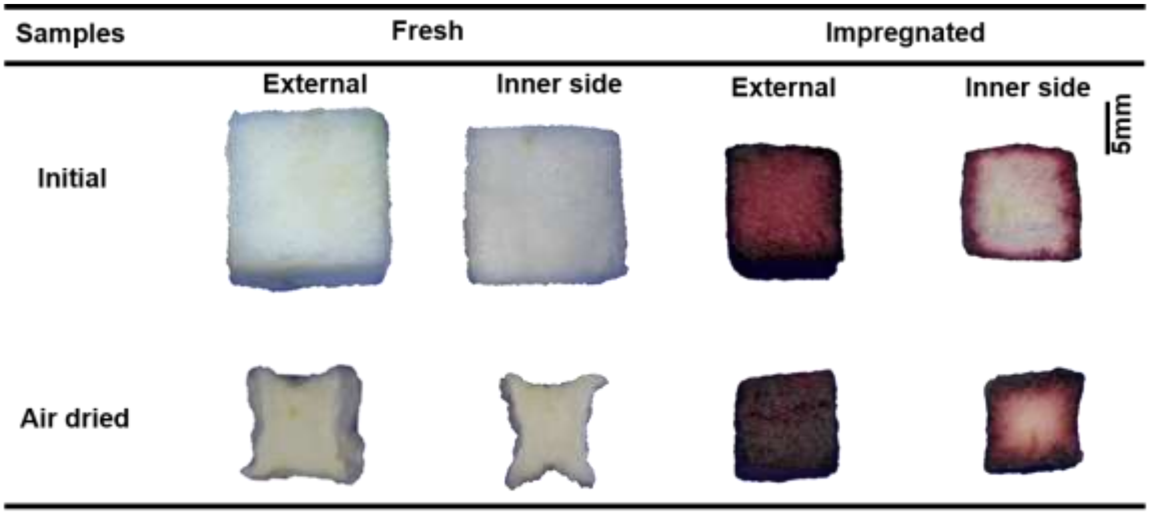

Figure 1. Effect of convective drying on the characteristics of apple cubes fresh and impregnated with grape juice concentrated.

Table 2. Moisture content, water activity and color parameters of dried fresh and impregnated apple cubes.

Parameter	**Samples**			
	Initial		**Air dried**	
	Fresh	Impregnated	Fresh	Impregnated
Moisture content (%)	84.50±0.15a	74.08±2.02b	0.08±0.01c	0.09±0.00c
a_w **(25°C)**	0.99±0.00a	0.94±0.00b	0.26±0.04d	0.36±0.01c
Superficial color				
L^*	75.43±3.26a	22.77±1.99c	64.09±0.23b	21.76±1.57c
a^*	-4.55±2.19d	12.62±2.22a	-1.04±0.00c	5.06±1.47b
b^*	14.55±0.00a	3.92±3.26c	13.27±0.01b	1.56±0.26d
Hue	106.32±0.00a	16.27±10.50c	94.50±0.00b	17.85±3.60c
Chroma	15.27±4.33a	13.47±2.81a	13.31±0.11a	5.31±1.46b
ΔE_1	-	56.39	11.94	56.05
ΔE_2	-	-	-	7.98

Different letters in the same line indicate significant difference ($p<0.05$). ΔE_1: L^*_0=75.42, a^*_0=-4.55, b^*_0= 14.55; ΔE_2: L^*_0=22.77, a^*_0=12.62, b^*_0=3.92.

3.2. Mass transfer characteristics of dried apple cubes

Fig. 2 shows drying kinetics of fresh and impregnated apple cubes. Time required to reach mass transfer equilibrium was 440 and 850 min, respectively. Drying process reduced 78.5% and 45% the volume of fresh and impregnated samples, respectively (Fig. 1). Total reduction of volume of impregnated samples was of 77% in relation to initial volume of fresh product. Also, untreated dry sample reached lower a_w than impregnated dry samples. This behavior may be attributed to solute accumulation at product surface (crust formation) due to impregnation process, which crystallized in the outer layer of the fruit tissue during drying [1, 28]. The crust on the external layer of impregnated product reduced the mass transfer and could be responsible of higher moisture compared with samples without treatment [28, 29]. Cichowska, Samborska, and Kowalska [23] obtained apple cylinders (*Braeburn* var.; 10 mm in diameter and 10 mm in length) osmodehydrated with chokeberry juice (60°Bx, sample to osmotic medium ratio of

1:4 and 120 min process) and dried by convective drying (70°C and an air velocity of 1.5 m/s for 1440 min) a a_w=0.35.

The products obtained after the drying process had a ΔE of 11.94 and 7.98 for fresh and impregnated samples, respectively (Table 2), which indicates that there was no great variation in color during the drying process. The greatest variation was in chroma giving a duller saturation; Cichowska et al. [23] attribute this phenomenon to Maillard's reactions, enzymatic darkening and oxidation of ascorbic acid.

3.2.1. Mathematical modeling of drying curves

Free moisture content against drying times of experimental data was fitted into thin layer models (Fig. 2). The obtained parameters and their corresponding statistical values (R^2 and χ^2) are summarized in Table 3. The higher values of R^2>0.90 are indicative of good fit [18].

The evaluated models fitted satisfactorily the drying curves. Page model gave the highest R^2 values for both conditions (0.999 and 0.990 for fresh and impregnated samples, respectively). The χ^2 was found to varied between 0.00011-0.00113. Page and Weibull model showed lower χ^2 (0.00011-0.00015) in both cases. Other author has found that Page model is the best fit model for describe drying kinetic of elephant foot yam cubes (hot air drying at 40, 50, 60 and 70°C with an air velocity of 2 m/s) [20], mango cubes (hot air drying at 60-80°C) [18], and tomatoes slices (freeze-drying, condenser temperature of -110°C, chamber pressure of 0.1 mbar) [34]. Rates constant (k) of Newton model, Henderson & Pabis model, and Page model were lower for the impregnated samples, which indicates a slower process. Physicochemical changes in osmodehydrated products may cause differences in drying rate [35].

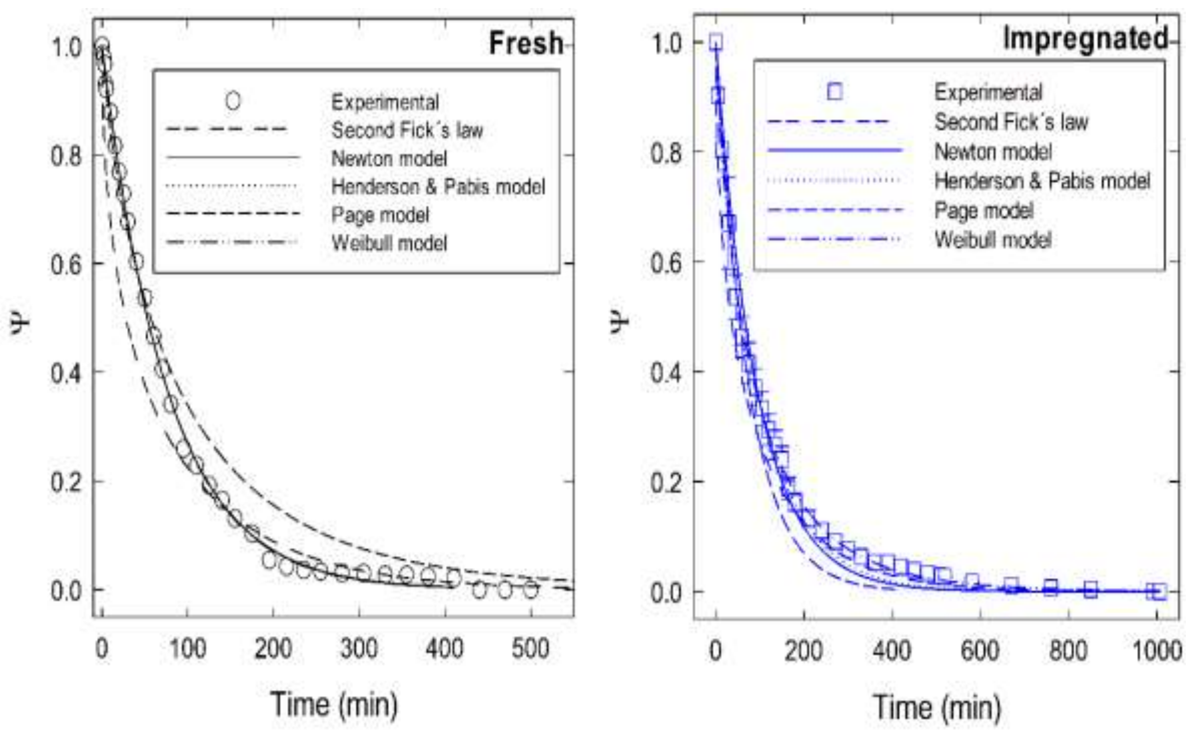

Figure 2. Experimental (dots) and fitted (lines) evolution of free moisture content during convective drying (at 40°C) of apple cubes fresh and impregnated with grape juice concentrated.

Table 3. Mathematical models applied to drying curves of apple cubes fresh and impregnated with grape juice concentrated.

Model		Pretreatment	
Name	**Parameter**	**Fresh (without pretreatment)**	**Impregnated with grape juice concentrated**
Newton	k_1	0.0131	0.0107
	χ^2	1.46×10^{-4}	11.3×10^{-4}
	R^2	0.998	0.986
Henderon &Pabis	k_2	0.0131	0.0098
	a	0.999	0.933
	χ^2	1.50×10^{-4}	7.58×10^{-4}
	R^2	0.999	0.990
Page	k_3	0.0295	0.0125
	b	0.7827	1.0112
	χ^2	1.11×10^{-4}	1.48×10^{-4}
	R^2	0.999	0.999
Weibull	k_4	76.0645	90.2186
	c	1.011	0.7819
	χ^2	1.48×10^{-4}	1.11×10^{-4}
	R^2	0.999	0.999
Fick´s second law	D_{eff}	11.4×10^{-10}	0.50×10^{-10}
	χ^2	20.4×10^{-4}	14.1×10^{-4}
	R^2	0.899	0.951

k_1, k_2 and k_3 are rate constant (1/min) of Newton, Henderson & Pabis and Page model, respectively; k_4, scale parameter (min); *a* and *b* are the empirical parameters (dimensionless) of Henderson & Pabis model respectively; *c* is the shape parameter of Weibull model; and D_{eff} is effective water diffusion (m^2/s).

3.2.2. Moisture diffusivity

Estimated water diffusivities were 11.4×10^{-10} and 0.50×10^{-10} m^2/s for fresh and impregnated samples, respectively. The model fitted appropriately the drying curves (R^2=0.899-0.951 and χ^2=14.1×10^{-4}- 20.4×10^{-4}); however, the corresponding statistical values for the thin layer models were better. This result was due to Crank´s solution of Fick´s second law consider the product geometry and Fig. 1 shows that final product had a different shape or a size reduction [1].

Some authors have found that water diffusivity of osmodehydrated samples (with a smaller volume and less moisture than fresh sample) is lower than that no treated samples [33]. González-Martínez et al. [36] reported coefficients of moisture diffusion of 2.2-5.8×10^{-10} m^2/s and 1.5-3.4×10^{-10} m^2/s during convective drying (45-65°C, 2.2 m/s) of fresh and osmodehydrated pear slices in 55°Bx sucrose solution (at 30°C for 180 min), respectively. Falade & Ogunwolu [37] found moisture diffusivity of banana slices during convective drying (40, 50, 60, 70 and 80°C with air velocity of 1.5 m/s) decreased due to osmotic pretreatment (sucrose solutions, concentration of 52, 60 and 68°Bx, fruit: solution ratio of 1:50 and 720 min). The D_{eff} was 7.53-10.1×10^{-10} m^2/s and 1.29-9.71×10^{-10} m^2/s. These authors associate this behavior to imbibed sugar and partial gelatinization of the starch in the commodities which affected D_{eff} and mass transfer. D_{eff} calculated for the drying of osmodehydrated melon cubes with red grape juice concentrated (60°Bx, 40°C, fruit: solution ratio of 1:10, during 120 min). Bezerra Pessoa et al. [19] and de Farias Aires et al. [38] reported that solids gain can cause the formation of a barrier, making mass transfer into the product difficult during convective drying.

3.3. Sensory evaluation

The sensory evaluation results of dry impregnated cubes indicated that the aroma (8.47±0.11) and flavor (8.78±0.04) were pleasant, but the color (6.30±1.40) was not accepted with the same magnitude since some comments from the judges indicated that the dark color was associated to a burned product. However, other comments indicated that they would buy it, which explains that a general product acceptability of 8.57±0.16 was obtained. On the other hand, the perception of grape (8.88±0.09), apple (8.01±0.04), acid (8.38±0.04) and sweet (7.78±0.04) flavors were sensory acceptable.

4. Conclusions

Page and Weibull model were found to be the most appropriate model to describe the drying characteristic of fresh and impregnated samples, respectively. The convective drying of impregnated apple cubes with concentrated grape juice result in a product with low moisture content and a_w, also, with a very similar color to the osmotic agent. Besides, it was possible to obtain a sensory acceptable product thanks to its flavor and aroma; however, studies are required to verify if the final product preserves nutritional and antioxidant properties.

The color data obtained can be complemented with the behavior of antioxidant compounds during the osmotic dehydration and drying process by considering higher process temperatures (such as 50 and 60°C) to achieve shorter process times.

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