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Osmotic dehydration of *Carica papaya* var. Maradol: Mass transfer and sensory analysis

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Cyntia María D´Aquino de los Santos[1]
cyntia.daquino.san@cobach.edu.mx • ORCID: 0000-0002-2768-5033,

María Celina Luján-Hidalgo[2]
maria.lh@tuxtla.tecnm.mx • ORCID: 0000-0002-5720-9652

Lucia María Cristina Ventura-Canseco[2]
lucia.vc@tuxtla.tecnm.mx • ORCID: 0000-0001-6983-0430

Miguel Abud-Archila[2]
miguel.aa@tuxtla.tecnm.mx • ORCID: 0000-0002-4509-7964

1 Colegio de Bachilleres de Chiapas, Tuxtla Gutiérrez, México

2 Tecnológico Nacional de México/Instituto Tecnológico de Tuxtla Gutiérrez, División de Estudios de Posgrado e Investigación, Tuxtla Gutiérrez, México.

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Carica papaya var. Maradol is an important fresh produce grown in Chiapas, Mexico. However, their shelf life is very short so they should be processed to increase their useful life. The objective of this work was to evaluate the effect of the temperature and sucrose concentration of the osmotic solution on water loss and solute gain during the osmotic dehydration of papaya slices. For this, slices of 5 mm thick were dehydrated by osmosis in sucrose solutions at 40, 50, 60, and 70°Brix kept at 50, 60, and 70°C for 6 h, keeping a solid: solution ratio of 1:5 (weight: volume). Water loss and solute gain were adjusted with the Azuara equation to obtain the effective diffusivities of water and sucrose. Sensory analysis of the samples was carried out using a nine-point hedonic test. The results were analyzed using a variance analysis, and the means were compared with Tukey's test ($p < 0.05$). The average diffusivities for water varied between 4×10^{-10} and 7.2×10^{-10} $m^2 s^{-1}$; while for sucrose they were 3.62×10^{-10} a 8.4×10^{-10} $m^2 s^{-1}$. Sensory analysis showed that osmotic dehydration significantly influenced the acceptance of papaya. Osmotic dehydration using an osmotic solution at 50°C, at 50°Brix for 6 h allowed obtaining papayas with a water loss of 49%, a sucrose gain of 14%, and a good level of acceptance. These processing conditions increase the shelf life of papaya and could be used for industrial purposes.

Keywords:

Effective diffusivity; water loss; solute gain; hedonic test.

Drying is a preservation method commonly used in the food industry, whose primary objective is to increase its shelf life by evaporation of water. At present, the process of dehydration of fruits and vegetables is carried out mainly using hot air and freeze-drying. Dehydration by freeze-drying largely preserves the quality of food, however, it is a process that is very expensive compared to other dehydration processes. Conversely, drying or dehydration with hot air can cause several important changes in food such as changes in color (enzymatic and non-enzymatic reactions) and taste; as well as changes in its texture and nutritional quality, to mention a few. Hot air drying significantly decreases the acceptance of dehydrated papaya compared to fresh fruit (Abud-Archila *et al.*, 2002). These sensory characteristics are important, as they are what define the product's degree of acceptance by the consumer (Radojˇcin *et al.*, 2022).

In recent decades, osmotic drying, at atmospheric or vacuum pressures (Saleena *et al.*, 2021) is an alternative for the processing of perishable products to preserve, to a large extent, the quality of the final product. This consists of the removal of water by immersion of the food in an osmotic solution, such as a solution with high concentrations of sugar or NaCl. Osmotic dehydration is a complex process where various parameters influence: the type and concentration of the osmotic agent, the temperature and agitation of the osmotic solution, the immersion time, the fruit: osmotic solution ratio, as well as the shape, size, and structure of the tissue (Bashir *et al.*, 2020), however, the temperature and concentration of the agent are paramount in the mass transfer.

Osmotic dehydration improves food's shelf life, and the products obtained will present, depending on the conditions of the process, attractive sensory characteristics and "similar" to the original product before processing. During food processing, the color and texture of food have been studied mainly as sensory attributes, with color being one of the most influential in the acceptance of a product, without forgetting the taste. Lopez *et al.* (2021), point out that the osmotic agent plays a very important role in the sensory and physical attributes of the product. In addition, several studies were reported where osmotic drying prevents undesirable color changes, as in the case of bananas and apples (Krokida *et al.*, 2000a), papaya (Islam *et al.*, 2019), as well as in vegetables, such as potatoes and carrots (Krokida *et al.*, 2000b). While osmotic drying prevents color changes, the processing time is also important. In that sense, the grapes' loss of color was minimized when the time of osmotic dehydration was short, as reported by Nsonzi and Ramaswamy (1998). Regarding the degree of global acceptance of a product, Romero-Bello (1995) and Madamba and López (2002) reported that osmotic drying allows obtaining products with a good degree of global acceptance for the case of pineapple and mango, respectively. During osmotic drying, the mass transfer between the fruit and the osmotic solution can be identified (Saleena *et al*., 2021). Mass transfer (water loss and solid gain) during osmotic dehydration has been modeled by several authors (Azuara *et al*., 1992; Lazarides *et al*., 1997; Waliszewski *et al*., 2002; Islam *et al*., 2019). Models based on diffusion theory (Fick's law), irreversible thermodynamics, multicomponent diffusion, and hydrodynamic flow have been thoroughly discussed by Shi and Le Maguer (2002).

The objective of the present work was to determine the effect of temperature, osmotic solution concentration, and impregnation time on water loss, solid gain, and hedonic test acceptance of papaya slices and to model water loss and solid gain during osmotic dehydration.

MATERIALS AND METHODS

Raw Material

Maradol papaya fruits (*Carica papaya*) of the same size and without any post-harvest treatment were provided by the company AGROMOD SA de CV of the San Juan ranch in Villa de Acala, Chiapas, Mexico. Fruits, with about 90% yellow-orange color, were washed with soap and water and peeled manually. Subsequently, after the removal of the seeds, slices of 25 x 20 mm with 5 mm thickness were obtained. The initial humidity of the fresh papaya was determined in a vacuum oven at 60°C for 48 h or up to constant weight.

Osmotic dehydration

The papaya pieces were immersed in a temperature-controlled sucrose solution maintaining a fruit: osmotic solution (p:v) ratio of 1 to 5. The papaya pieces were kept immersed in the sucrose solution in continuous stirring for 6 h at a controlled temperature with the help of a heating grill with magnetic stirring. Subsequently, sampling was carried out every 30 minutes to monitor the dehydration kinetics. Which, approximately 10 g of papaya were extracted from the system every 30 min and the weight (0.001 g) was determined with the help of an electronic scale. The samples were then washed with distilled water to remove the surface sucrose, and the wastewater was removed with a paper towel. The moisture content of the samples was finally determined in a vacuum oven at 60°C for 48 h or until the weight variation was not greater than 0.001 g.

During osmotic dehydration kinetics, the water loss (WL) of the sample was calculated using equation (1):

$$WL = \frac{P_o X_o - P_t X_t}{X_o} \tag{1}$$

where P_o is the initial papaya's weight; Pt is the papaya's weight (in grams) at time t, X_o is the initial moisture content (g water / g initial, wet base) and, X_t is the papaya's moisture content at time t (g water / g initial, wet base).

Solid gain during osmotic dehydration was also determined with the help of equation (2):

$$SG = \frac{W_o MS_o - W_t MS_t}{X_o} \tag{2}$$

where MS_o is the initial fraction of dry matter (initial g/g) and MS_t is the dry matter fraction at time t (g/g initial).

The effect of the temperature and sugar concentration of the osmotic solution was evaluated using an experimental factorial design with three repetitions. The sugar concentrations studied were 40, 50, 60, and 70°Brix, while the temperature of the solution was 50, 60, and 70°C. A total of 36 treatments were performed.

Mathematical model

The osmotic dehydration kinetics (water loss and solid gain) of papaya was modeled using an empirical model (equation 3) as reported by Azuara *et al.* (1992) and Solgi *et al.* (2021).

$$\frac{\mathrm{WL}}{\mathrm{WL}_\infty} = \frac{s_1 t}{1 + s_1 t} \tag{3}$$

$$\frac{\mathrm{SG}}{\mathrm{SG}_\infty} = \frac{s_2 t}{1 + s_2 t}$$

where WL and SG are water loss and solid gain during osmotic dehydration, t is time, WL_∞ and SG_∞ are water loss, and tissue solid gain in equilibrium; and s_1 and s_2 are the empirical parameters of the model (equation 3) to be identified.

These empirical parameters (s_1 and s_2) were identified for each kinetic, using the modified Simplex method (Van Nievuwenhuijzen *et al.*, 2001) through the minimization of the objective function, called error (equation 4):

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(WL_{\exp} - WL_{sim}\right)^2}{n}} \quad y \quad \sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(SG_{\exp} - SG_{sim}\right)^2}{n}} \tag{4}$$

where n is the number of values, the subscript "exp" correspond to experimental values, and the subscript "sim" corresponds to the values simulated by the model.

Finally, the diffusivity (Di) of water and solids, as a function of empirical parameters(s), was calculated using equation 5 (Waliszewski *et al*., 2002):

$$D_i = -\frac{4L^2}{\pi^2 t} \ln\left\{ \frac{\pi^2}{8}\left[1 - \frac{s_i t}{1+s_i t}\right] - \frac{1}{9}\left[\frac{\pi^2}{8}\left(1 - \frac{s_i t}{1+s_i t}\right)^9\right]\right\} \tag{5}$$

For each kinetic, values s_1 and s_2 were identified, which were used to calculate instantaneous diffusivity (Di) at time t. The effective diffusivities of water and sucrose were eventually expressed as an average of instantaneous results (Azuara *et al*., 1992).

Evaluation of acceptance of osmotically dehydrated papaya by hedonic test

After osmotic drying, all samples were stored in refrigeration (approximately at 5°C). Before the sensory test, the samples were left to balance at room temperature (approximately 30°C) for 2 h. Subsequently, a nine-point structured hedonic test was used to determine the level of acceptance of the samples according to Wichchukit and O'Mahony (2022). Due to the number of samples to be evaluated (12 treatments), the sensory analysis was carried out in three sessions on different days to avoid consumer fatigue. All samples were evaluated by 80 untrained judges. The sensory evaluation was carried out in a supermarket in the city of Tuxtla Gutiérrez, Chiapas, Mexico. The results were analyzed with a bidirectional analysis of variance ($p < 0.05$), and the means were compared using the Turkey's test with the help of the Statgraphics plus XV1 program.

RESULTS AND DISCUSSION

Water Loss and Solid Gain

Water loss and solute gain have been identified as the main factors that modify mass transfer during osmotic dehydration. The papaya's water loss and solid gain were influenced by processing time, temperature, and sucrose concentration (Figures 1 and 2). Water loss and solute gain increase rapidly in the first two hours, but after three hours, these values remained almost constant until the end of the process (6 h) for all processing conditions. These results were consistent with the literature (El-Aouar *et al*., 2006). The results also show that water loss (after 6 h of processing) varied between

34% and 70%; while the variation of solid gain was from 10% to 25%, depending on the sucrose concentration and the temperature of the solution (Figure 1).

Water loss (Figure 1a) and solid gain (Figure 2a) increased with solution temperature. This could be explained because by increasing the temperature of the solution, the permeability of the papaya tissue possibly increased, facilitating water loss. In addition, water loss decreased when a low sucrose concentration was used (40°Brix, Figure 1b). This could be explained because the sucrose concentration gradient between the papaya and the osmotic solution was lower. However, solid gain increased when a low sucrose concentration was used (40°Brix). The driving force for moisture transport from tissues to the solution is provided by the higher osmotic pressure of the concentrated solution (Radojˇcin *et al.*, 2022).

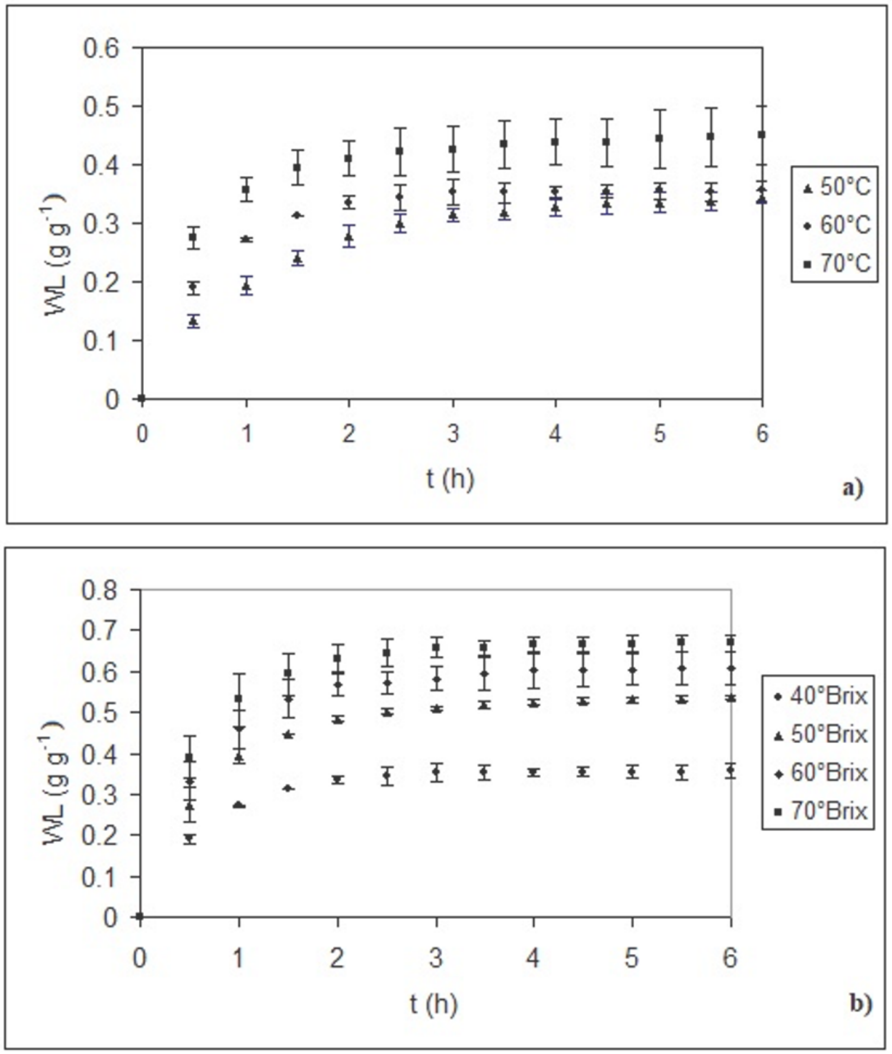

Figure 1. Water loss (WL) during osmotic dehydration of papaya at 40°Brix (a) and 60°C (b).
Source: Own elaboration

On the other hand, when the concentration of sucrose in the solution is higher, the impregnation rate probably increases faster in the first minutes of the process causing sucrose to accumulate outside the sample. In this case, the accumulation of sucrose on the surface of the papaya probably formed a semipermeable film in the papaya, preventing the exit of water and the entry of sucrose. Saputra (2001) and Waliszewski *et al.* (2002) found similar results to ours with a pineapple osmotic dehydration. But different results for papaya were reported by Rodrigues *et al.* (2003) who published that mass transfer during osmotic dehydration of papaya increases with the temperature and concentration of the osmotic solution. The differences could be attributed to the additives (citric or lactic acid and sodium lactate or calcium chloride) used by these authors in the osmotic solution, compounds that were not used in this work. In addition, the differences found could also be attributed to the variety of the fruit, as well as to the soil and environmental conditions where the papayas were grown.

On the other hand, the water loss (WL) and solute gain (SG) reported in this paper are higher than those published by Jain *et al.* (2011), who found for a papaya that the WL was 28% and the SG was 4% when dehydration was performed at 60oBrix, 37°C and 4.25 h of osmotic dehydration. The differences may be because these authors used 37°C in the dehydration process, which resulted in decreased mass transfer. In addition, these authors used a syrup volume: fruit weight ratio of 4:1 (mL:g), and the osmotic dehydration time was 4.25 h.

During osmotic dehydration, sucrose is impregnated in the papaya, and at the same time, the papaya loses water. So, when a low syrup: fruit ratio (v:w) is used, for example, 4:1, i.e. 4 mL of solution per gram of fruit, the osmotic solution is diluted by the loss of water from the papaya in the first hours of the process causing a lower sucrose gradient between the solution and the papaya. This causes a decrease in the rate of impregnation and dehydration of the fruit.

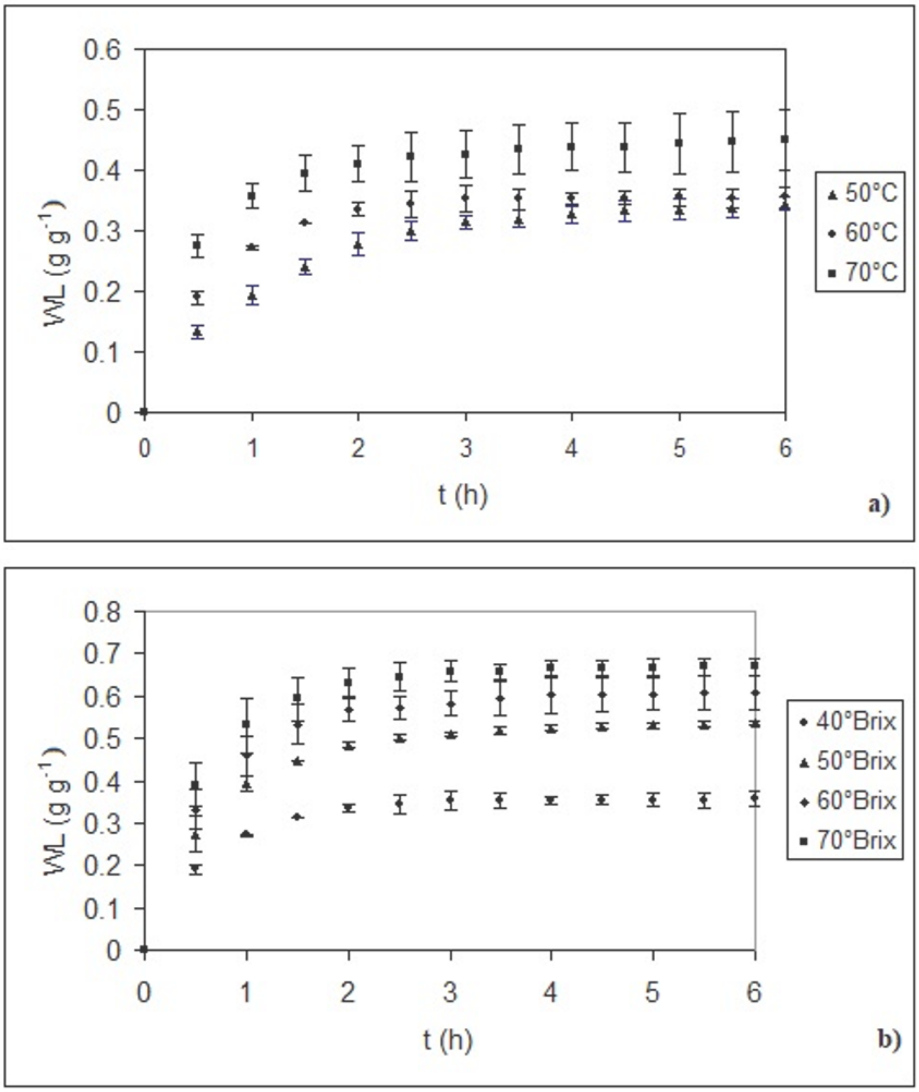

Figure 2. Solid gain (SG) during a papaya osmotic dehydration at 50°Brix (a) and 60°C (b).
Source: Own elaboration

Water Loss and Solid Gain Modeling

The parameters s_1 and s_2 of the Azuara model, identified for each kinetic, are shown in Table 1. Results ranged from 1.91 to 5.05 for water loss with a maximum error of 3.7% and between 1.5 and 5.86 for solid gain with a maximum error of 1.7%. The quality of the fit can be seen in Table 1, represented as the prediction error (σ), as well as in the graphs in Figure 3, where the model (equation 3) simulated very well the kinetics of osmotic dehydration in terms of water loss and solid gain. The graphs show that the increase in temperature causes an increase in the speed of water loss and solid gain, especially during the first 2 h of the process. Subsequently, the curves tend to behave *quasi*-stable, which is probably because, during the first hours of the process, the mass transfer increases. Afterward, the speed of movement of solutes is reduced, to such a degree that the solids accumulated on the surface no longer allow for further water loss.

Table 1

Values of s_1 and s_2 for water loss and solid gain respectively to the empirical model (equation 3)

Sucrose concentration (°Brix)	Temperature (°C)	s_1	σ (Error)	s_2	σ (Error)
40	50	1.91	0.0226	1.61	0.0109
40	60	3.90	0.0206	1.58	0.0146
40	70	4.16	0.0136	1.50	0.017
50	50	3.18	0.0261	3.42	0.0082
50	60	3.26	0.0268	3.04	0.0108
50	70	5.05	0.0177	3.06	0.0087
60	50	3.52	0.0273	4.88	0.0042
60	60	3.77	0.0303	3.23	0.0087
60	70	3.91*	0.0256	2.66	0.007
70	50	3.29	0.0372	3.44	0.007
70	60	4.35	0.0316	5.86	0.0059
70	70	4.82	0.0244	3.63	0.0063

σ was calculated with equation 4

Source: Own elaboration

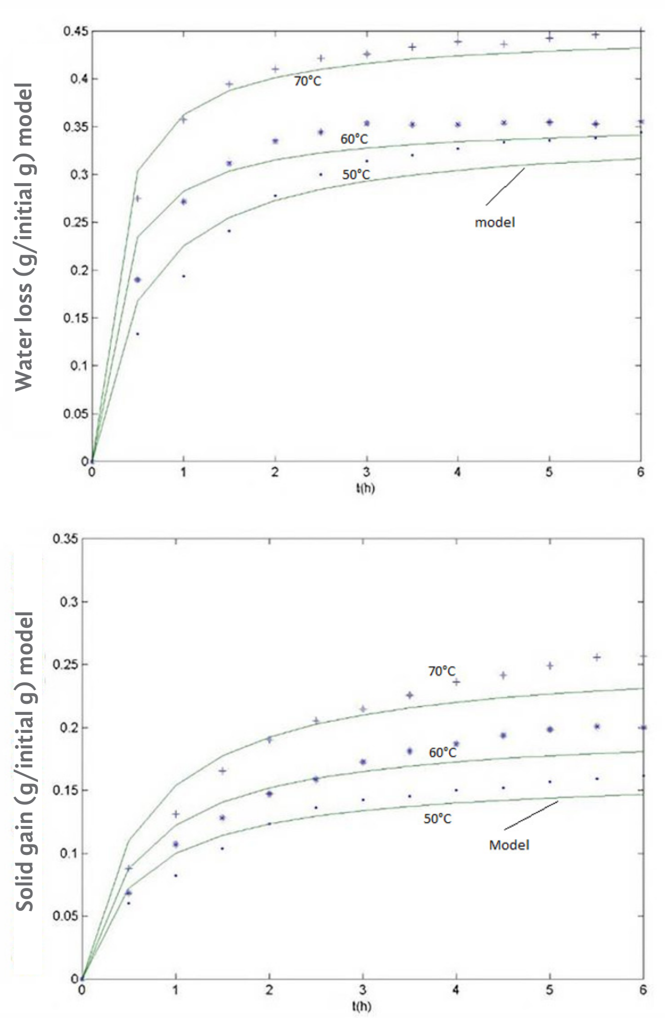

Figure 3. Water loss and solid gain experimental and predicted during the papaya osmotic dehydration at 40°Brix and different temperatures (•50°C, * 60°C, + 70°C, - model). Source: Own elaboration

The values of effective diffusivity of water and solids (sucrose) were obtained using equation 5. Diffusivity values increased with sucrose concentration, however, these decreased at high concentrations (60 and 70°Brix). This could be because a layer of sucrose formed on the papaya's surface, preventing the diffusion of water and sugar as explained above. The mean effective diffusivities calculated with equation 5 were between 4×10^{-10} and 7.2×10^{-10} $m^2 s^{-1}$ for water loss and between 3.62×10^{-10} and 8.4×10^{-10} $m^2 s^{-1}$ for solid gain. These values are like those reported by Solgi *et al.* (2021) for osmotic dehydration of *Ziziphus jujuba*, with effective diffusivities between 2.7 and 5.96×10^{-10} $m^2 s^{-1}$. However, these values are ten times lower than those reported by Islam *et al.* (2019), who reported average effective diffusivity values for water loss and solute gain of 2.25×10^{-9} to 4.31×10^{-9} $m^2 s^{-1}$ and 3.01×10^{-9} a 5.61×10^{-9} $m^2 s^{-1}$, respectively during the papaya osmotic dehydration.

The differences could be attributed to the fact that they used a fruit:solution ratio of 1:4 (w/v), and the duration of the osmotic process was 240 min, in addition to the fact that they used another variety of papaya. Mendoza and Schmalko (2002) found an effective water diffusivity approximately two times greater (13×10^{-10} m^2 s^{-1}) than those found in this research for slices of papaya with 10 mm thickness as opposed to the 5 mm thickness used in this work. In the case of sucrose diffusivity, Mendoza and Schmalko (2002) reported a diffusivity of 34.7×10^{-10} m^2 s^{-1} for papaya. The difference could be attributed to the fact that these authors used slices 10 mm thick, and the mass transfer was on a single side of the slice, as well as those authors used another variety of papaya.

Sensory Evaluation of Papaya Osmodeshydrated

The hedonic scale is a test commonly used to determine the acceptance degree of a product as reported by Guadalupe-Tapia (2022) and López-Quevedo (2022). The variance analysis of the hedonic test results of the osmotically dehydrated papaya is shown in Table 2. In Table 2, the calculated distribution value F is greater than the F value of the tables, which indicates that there is a significant statistical difference ($p < 0.05$) between the treatments and the judges who performed the evaluation. These results are different from those reported for the sensory analysis of the osmotically dehydrated pineapple (Romero-Bello, 1995) and the osmotically dehydrated mango (Madamba and López, 2002), whose authors found that there was no statistically significant difference between their treatments. This difference is attributed to Romero-Bello (1995) using a 5-point hedonic test, and we used a 9-point test, while Madamba and López (2002) carried out the acceptance analysis with only ten judges.

Table 2

Variance analysis for the degree of acceptance of the osmotically dehydrated papaya at different sucrose concentration conditions and temperatures

Source:	GL	Sum of squares	Var	F-ratio	F (0.05)
Treatment	11	71.053	6.459	3.3	1.8
Judges	79	228.3073	2.8899	1.476	1.3
Residuals	869	1701.0302	1.957		
Total	959	2000.3906			

Source: Own elaboration

The Tukey's test, represented in Table 3, shows that the products with the highest acceptance were samples F (50°Brix, 70°C) and B (50°Brix, 50°C), and of lower acceptance was the sample H (60°Brix, 60°C).

Table 3

Tukey's test for the average degree of acceptance of the osmotically dehydrated papaya to different processing conditions

Code of the Treatment	Sucrose concentration (°Brix)	Temperature (°C)	Average degree of acceptance	
F	50	70	7.1875	a
B	50	50	7.0625	a
J	40	70	6.8875	abc
A	40	50	6.875	abc
D	60	70	6.825	abc
I	50	60	6.7375	abc
C	70	60	6.7125	abc
E	40	60	6.5625	abc
G	70	50	6.525	abc
L	70	70	6.4875	abc
K	60	50	6.3125	bc
H	60	60	6.2625	c
		LSD	0.10	

Equal lowercase letters next to the value of the acceptance degree mean that there is no statistically significant difference between treatments. LSD= least significant difference.

Source: Own elaboration

For samples F and B, a score higher than 7 were obtained, that is, the judges rated it as "I moderately like it"; and for the H sample "I kind of like it". However, in the same Table 3, it is observed that the difference between the treatments is *only* from a point of the hedonic scale, which indicates that all the samples had a good acceptance and that, probably, the consumer judge has difficulty identifying if there are differences between the treatments. This suggests that the product has a very good degree of acceptance. Tukey's test for judges was not conducted because the judges were not trained. From the above results, it is recommended to dry the 5 mm thick papaya for 6 h at 50°Brix and 50°C, which will cause a water loss of 49% and a solid gain of 14%, obtaining a product with a reasonable level of acceptance with a view to the commercialization of an osmotically dehydrated papaya product with a shelf life of not less than three months at room temperature. In addition, this treatment is the one that will allow the lowest energy consumption since less heating will be required to keep the process at 50°C.

CONCLUSIONS

The results show that water loss and solid gain from papaya slices during osmotic dehydration were affected by process time, sucrose concentration and solution temperature. The mathematical model simulated water loss with an average error of 3.7% and 1.7% for solid gain. This model could be used to predict the osmotic process to other conditions. The average diffusivities for water varied between 4 x 10-10 and 7.2 x 10-10 m^2 s^{-1}; while for sucrose they were 3.62 x 10-10 to 8.4 x 10-10 m^2 s^{-1}. The results showed that the temperature and sucrose concentration of the solution during osmotic dehydration of papaya affected the sensory acceptance of Maradol papaya. The best treatment that increased water loss and decreased solid gain was 50°Brix with 50°C during 6 h of process.

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