MUTIS
Vol. 12 (2) julio – diciembre del 2022
https://doi.org/10.21789/22561498.1810
ARTÍCULO DE INVESTIGACIÓN

Convective Drying Kinetics of Squash Epicarp of Cucurbita Maxima and Its Uses in Developing Gluten-Free Bread

Cinética de secado por convección del epicarpio de calabaza de Cucurbita Maxima y sus usos en el desarrollo de pan sin gluten

Natali López Mejía[ac], Nelly Bibiana Morales Posada[ad] y Hugo Fabian Lobatón García [be]

[a] Grupo Integrado de Investigación en Ciencias Culinarias y Gastronómicas, Facultad de Arte, Comunicación y Cultura, Tecnología en Gastronomía, Universitaria Agustiniana, Colombia

[b] Facultad de Ingeniería , Universitaria Agustiniana, Colombia

[c] natali.lopez@uniagustiniana.edu.co | https://orcid.org/0000-0001-9136-5205

[d] bibiana.morales@uniagustiniana.edu.co | https://orcid.org/0000-0003-1488-8357

[e] hugo.lobaton@uniagustiniana.edu.co | https://orcid.org/0000-0003-1240-5913

Citation: López Mejía, N., Morales Posada, N. B. y Lobatón García, H. F. (2022). Convective Drying Kinetics of Squash Epicarp of Cucurbita Maxima and Its Uses in Developing Gluten-Free Bread. *Mutis, 12*(2). https://doi.org/10.21789/22561498.1810

Recibido: 10 de septiembre del 2021
Aceptado: 1 de febrero del 2022

ABSTRACT

This study was conducted to obtain semi-empirical mathematical models that represent the convective drying kinetics of squash epicarp at different temperatures (55, 65 and 75°C/10% RH/ drying speed 1ms^{-1}). The best drying condition was selected to obtain flour, which was then characterized and used for the preparation of gluten-free bread. Subsequently, the effect of incorporating squash epicarp flour (SEF) into 4 levels (0-control, 15, 20 and 25g / 100 g of flour) on the sensory acceptance of the bread was evaluated. The results of this study are that the two-term model best describes the curve obtained at 55 °C, and the logarithmic model best describes the curves obtained at 65 °C and 75 °C. The temperature of 65 °C was selected as the best drying condition. Finally, the highest acceptance and purchase intention was obtained from the bread produced with 15 g SEF / 100 g of flour.

Keywords: logarithmic model; sensory acceptance; food waste; bread gluten-free.

RESUMEN

Con este estudio se obtuvieron modelos matemáticos semi-empíricos que representan la cinética de secado convectivo del epicarpio de zapallo a diferentes temperaturas (55, 65 y 75 ° C / 10% HR / velocidad de secado 1ms^{-1}). Se seleccionó la mejor condición de secado con la que se obtuvo la harina, la cual se caracterizó y utilizó para la elaboración de la torta libre gluten. Posteriormente, se evaluó el efecto de incorporar harina de epicarpio de calabaza en 4 niveles (control 0, 15, 20 y 25g / 100 g de harina) sobre la aceptación sensorial de la torta. Como resultados se obtuvo que el modelo de dos términos describe mejor la curva obtenida a 55 ° C, y el modelo logarítmico describe mejor las curvas obtenidas a 65 ° C y 75 ° C. Se seleccionó la temperatura de 65 ° C como la mejor condición de secado. Finalmente, la mayor aceptación e intención de compra se obtuvo en el pan formulado con 15 g / 100 g de harina de epicarpio de calabaza.

Palabras clave: modelo logarítmico; aceptación sensorial; desperdicio de alimentos; pan sin gluten.

INTRODUCTION

While the demand of food worldwide increases, nearly a third of its global production is wasted. Resources, such as land, water, energy and other supplies are used to produce food with low added value and CO_2 is unnecessarily generated in the process. (Jenny Gustavsson Christel Cederberg Ulf Sonesson, 2012). It is necessary that all the countries of the world focus their attention on implementing strategies to achieve the United Nation's Sustainable Development Goals, which are zero hunger and sustainable consumption and production (FAO, 2021). To align with such goals and continue generating social and economic value, the primary sector requires developing new processes to prevent the unnecessary production of food and to find new uses for industrial food waste. This implies a shift into taking advantage of, for example, vegetable peels and seeds. This material is usually regarded as an environmental and economic problem but includes components, such as starch, cellulose, dietary fiber and a diversity of bioactive compounds and antioxidants that are of great interest for the food industry (Bemfeito *et al*., 2020). The use of waste can also mean a decrease in industrial costs and the development of new product portfolios (O'Shea *et al.*,2012).

Squash, known in Colombia as *ahuyama*, is a vegetable native to tropical and subtropical areas of the world (Yadav *et al.*, 2010). This vegetable is cultivated in large numbers in countries such as India, China, Mexico, and Argentina (Food and Agriculture Organization of the United Nations, 2014). Particularly in the American continent, humans have domesticated five species: *Cucurbita maxima, Cucurbita moschata, Cucurbita pepo, Cucurbita argyrosperma ex mixta*, and *Cucurbita ficifolia*. *Cucurbita maxima* stands out because of its high antioxidant content of carotenes and other substances capable of neutralizing free radicals to inhibit degenerative diseases such as cancer (Kulczynski & Gramza-Michałowska, 2019). The squash epicarp (SE) represents approximately 12% of the total weight of the fruit and its nutritional value is even higher than that reported for the mesocarp due to its higher content of amino acids, such as alanine, aspartic acid, glycine, histidine, isoleucine, lysine, methionine, phenylalanine, proline, serine, threonine, and valine. In addition, SE contains α-tocopherol, β-carotene, and β-cryptoxanthin (Kim *et al.*, 2012; Lima *et al.*, 2021). Squash epicarp flour (SEF) has also high contents of dietary fiber (28.81%), protein (0,4 - 12.50%), phosphorus (319.33 mg/100 g), iron (42.99 mg/100 g), and ascorbic acid (18.90 mg/100 mg) (Mala & Kurian, 2016; Lima *et al.*, 2021). Thus far, there have been studies on the use of SE in extruded snacks (Norfezah, Hardacre and Brennan, 2011) and some have included SE together with squash mesocarp to make flour for food formulations and used to make cookies (Aziah *et al*., 2011).

The increasing number of people diagnosed with celiac disease opens an opportunity for SEF to be used for the production of gluten-free products. The celiac disease is the inflammation of the small intestine, it decreases the absorption of nutrients, such as minerals, amino acids, fats, and vitamins, and can cause chronic effects over time (Murray, 1999). As there is no cure for this disease, the only treatment is eliminating foods that contain gluten, specifically wheat, barley, rye or oats, which are difficult to exclude because their proteins confer properties of cohesion, extensibility and elasticity (Arendt *et al.*, 2002). Gluten is used in most applications of the baking industry, but alternatives have been reported with amaranth (Nasir *et al.*, 2020), chia flour (Coronel et al., 2021), banana flour (Amini Khoozani *et al*., 2020), quinoa flour

(Wang *et al*., 2021), rice flour (Franco *et al*., 2020) and corn flour (Jalali *et al.*, 2020). However, optimal formulations to create products with adequate sensory and nutritional properties are still under study. Research has not been conducted regarding the nutritional contribution of pumpkin epicarp flour to gluten free products.

On the other hand, dehydration to obtain flour is one of the most important industrial operations and one of the oldest methods of food preservation. It is still used today because it provides a long shelf life to many different products and substantial weight and volume reductions (Akpinar & Bicer, 2005). Dehydration is used to obtain proteins, vitamins, minerals, and dietary fiber, which are indispensable components of functional foods due to their easy incorporation into products, such as desserts, yogurt, ice cream, cookies, breads, instant soups, or snacks (Marín *et al*., 2006). However, it is necessary to standardize the drying process by obtaining kinetics that allow predicting the drying times with different conditions (temperature, relative humidity, and drying speed) to select the settings that require less time (less energy expenditure) and produce the least changes in the quality of the biological material.

For all the above, the objective of the present research was to obtain mathematical models describing the drying kinetics of squash epicarp, to select the drying condition that requires less time in the process and produces the least changes in the material. In addition, the objective of the present study was to develop gluten-free bread with SEF as a source of dietary fiber and protein as well as to analyze its sensory acceptance.

Material and Methods

Raw Material

Squash (Cucurbita maxima) from the Boyacá variety and other raw materials, such as corn flour, paipa cheese, whole eggs, butter, sugar, baking soda, and salt, were obtained in a local market in Bogotá (Paloquemao, Bogotá DC). The average weight of each pumpkin fruit was 9,430 g; their average diameter was 45 cm, and their average height was 28 cm. The mass of the epicarp (peel) was 1,152 g and had 480 g of seed. To obtain SEF, the fruits were selected according to their ripening state (stage 3 of maturation in accordance with the percentage of orange color of the skin, which was 90%). Additionally, other physicochemical parameters of the fresh fruit were measured: 8.67±0.06 % dry material; pH: 6.41±0.05; °Brix: 5.11±0.09, discarding those showing signs of deterioration or bruises. The selected fruits were washed to remove foreign material and then disinfected with peracetic acid (300 ppm). In total, 28,292.00 g of whole squash were processed, from which 24,038.00 g of pulp, 1,440.00 g of seed and 3,456.00 g of shell were obtained. Each fruit was divided into eight similar parts, and the seeds were removed and scalded (60°C/10 min). Fruits were cooled to 25 ± 1°C, and the epicarp was separated from the mesocarp. The epicarp was processed into rectangular geometric shapes (3.61 x 3.01 x 0.35 cm) and then dried with an initial load of 200 g per tray. Once dry, the epicarp was ground and sieved until obtaining a particle size of less than 210 µm (particles passing through an ASTM 70 sieve with an opening size of 210 µm).

Convective Drying

Drying was performed in a convection oven (RATIONAL, SCC WE 61G, Germany) with dry heat in accordance with the equipment program at a speed of 1.0 m/s at different temperatures usually used for foods rich in carotenoids (55 °C, 65 °C, and 75 °C) (Nakilcioğlu-Taş *et al*., 2021; Song *et al.*, 2018; Yang *et al.*, 2018;

Lima *et al.*, 2021) until a moisture content of approximately 9-11% dry weight (DW) was obtained. Each condition was performed in triplicate. Wet samples (200 g) were placed into six trays. Sampling was performed every 20 min for a total of 300 min and every 60 min for a total of 600 min. The moisture content (M) was measured at each point using a moisture balance (OHAUS, MB45, Switzerland).

Determination of Critical and Equilibrium Moisture Contents

After the squash epicarp was dried for 20 h (1200 min), the moisture content was measured again to estimate the moisture equilibrium (Me), which was used to calculate the moisture ratio (MR) using Equation (1), as reported by Geankoplis (2006). The point at which the moisture content results showed a linear trend was considered the critical moisture content (Mc).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

In which, Mt is the moisture content on a dry weight basis in the time t (kg/kg); Me is equilibrium moisture content on a dry weight basis (kg/kg); Mo is initial moisture content (time = 0) on a dry weight basis (kg/kg).

Mathematical Modeling of Drying Kinetics

The drying kinetics were modeled in the decreasing rate period because the constant period was short and represented by a straight-line equation. The models shown in Table 1 were used.

Table 1. Mathematical models for drying kinetics of squash epicarp.

Model name	Model
Lewis	MR=exp(-kt)
Page	MR=exp($-kt^n$)
Henderson and Pabis	MR=a exp(-kt)
Logarithmic	MR=a exp(-kt)+c
Two terms	MR=a exp($-k_0t$)+bexp($-k_1t$)
Two Exponential Terms	MR= a exp(-kt)+(1-a)exp(-kat)

Source: Authors**.** MR: Moisture Ratio; t: drying time (min); k: drying constant; a, b, c and n are adjustment coefficients.

Mathematical Modeling of Drying Kinetics and Drying Time in The Falling Rate Period

To identify the effective diffusion coefficient, Fick's second law (Equation 2) was used for a non-stationary state on an infinite flat plate because the controlling factor was mass diffusion in this period. The equation solved by (Crank, 1975) was used. It is presented as diffusion through an infinite flat plate for extended drying times (Equation 3). The resistance to water vapor transfer at the surface was considered negligible.

Once De was known for each drying temperature, the drying time in the decreasing rate period was calculated using Equation (4). The total time was calculated as the sum resulting from the drying time in the constant drying rate period and the drying time in the decreasing drying rate period.

$$\frac{\partial M}{\partial t} = De\frac{\partial^2 M}{\partial L^2} \tag{2}$$

$$M^* = \left[\frac{M_t - M_e}{M_0 - M_e}\right] = \frac{8}{\pi^2}\left[e^{-Det\left(\frac{\pi}{2L}\right)^2}\right] \tag{3}$$

$$t = \frac{4L^2}{\pi^2 D_e} ln\frac{8\,(M_0 - M_e)}{\pi^2(M - M_e)} \tag{4}$$

In which t is time (min); M is moisture content d.b. (kg water /kg d.b.); Mt is moisture content on a dry weight basis in the time t (kg/kg); Me is equilibrium moisture content on a dry weight basis (kg/kg); Mo is initial moisture content (time = 0) on a dry weight basis (kg/kg); De is effective diffusion coefficient (m2s-1); L is thickness (m).

Proximate Analysis of Squash Epicarp Flour (SEF)

The proximate analysis consisted of measuring the moisture (Gravimetry), protein (ISO 1871 Determination of Nitrogen by the Kjeldahl Method, 2009), dietary fiber (McCleary *et al.*, 2012), fat (Association of Official Analytical Chemist [AOAC], 2003), and ash contents of SEF (AACC 08-01: Ash -Basic Method , 2001)

Application of SEF

The gluten-free, yeast-free bread prepared for the present study was made following the *enyucado* recipe, a traditional dish from the Colombian Atlantic coast. The bread was prepared using corn and dry epicarp in different proportions (0 – control, 15, 20, and 25 g SEF/100 g of flour with the optimal temperature condition). These proportions were selected because previous studies reported that amounts of high-fiber flours greater than 25% produce textures and flavors that are not pleasant for the consumer (López-Mejía & Morales-Posada, 2020; Arslan *et al.*, 2019). To make the bread, all the components per 100 g of mixture were first weighed on a balance (FENIX LEXUS, Spain) (flour, 40.82 g; water, 20.41 g; *paipa* cheese, 20.41 g; egg, 10.20 g; butter, 6.12 g; sugar, 0.82 g; baking soda, 0.82 g; and salt, 0.41 g). Then, the components were mixed in a bowl and kneaded until a dough with a homogeneous consistency was obtained. Subsequently, the dough was subjected to a relaxation time of 30 min (Decock & Cappelle, 2005). The dough was divided later into small portions (19 g), placed in a tray, and baked in an oven (RATIONAL, SCC WE 61G, Germany) for 15 min at 176 °C.

Sensory Analysis of Gluten-Free Bread (GFB)

A sensory evaluation to measure the acceptability of consumers and their intention of purchase of the different formulations of the gluten-free bread produced was performed in the afternoon after the breads were finished. An untrained group of thirty people, students from the Technology in Gastronomy program of Universidad Agustiniana, aged 18 to 50, was consulted and participated voluntarily (non-probabilistic convenience sample). Attributes such as color, aroma, taste, and sponginess were analyzed. The following hedonic scale of 5 points was used: 5 corresponded to "like very much"; 4 corresponded to "like"; 3 corresponded to "neither like nor dislike"; 2 corresponded to "dislike"; and 1 corresponded to "dislike very much". The scale used to evaluate purchase intention included the following 3 points: 1 corresponded to "would not buy"; 2 corresponded to "might or might not buy"; and 3 corresponded to "would buy".

Experimental Design and Statistical Analysis

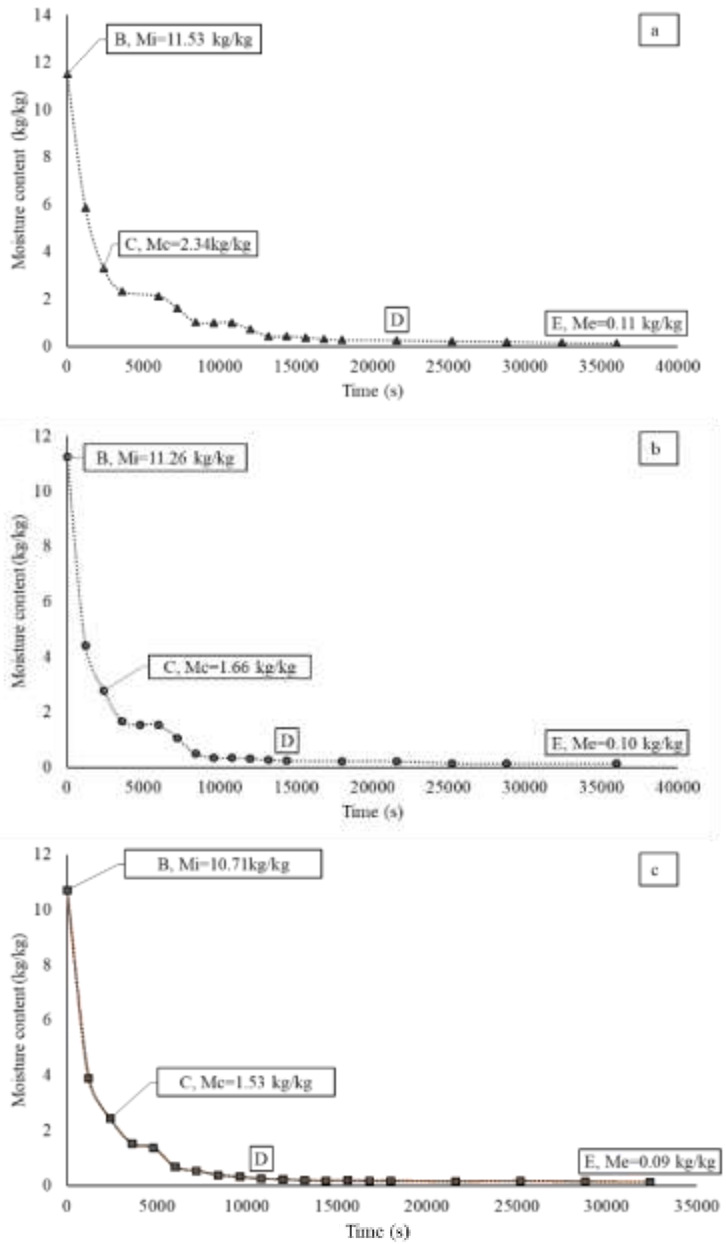
A unifactorial multivariate design was performed to evaluate the effect of squash epicarp flour on the acceptability of gluten-free bread. To evaluate the fitness of the mathematical models in the experimental data, the following statistical coefficients were used: sum of squared errors (SSE) and coefficient of determination R^2. The models considered to have the best fits were those with lower values of SSE and values of R^2 closer to 1. The models were solved using Excel (2013) with the SOLVER function. Additionally, an analysis of variance (ANOVA) and a Tukey's test were performed to identify significant differences ($P<0.05$). Pearson's correlation ($P<0.05$) was used to determine which attributes were decisive in the purchase intention of the participants.

Results and Discussion

Drying Kinetics

Figure 1 shows the experimental drying curves with the corresponding experimental parameters considered for the mathematical modeling of the drying curves of SE at different temperatures under a constant drying rate (1 ms-1). The figure shows that the initial moisture content of the SE was in a range of 10.71 to 11.53 kg/kg DB, and the critical moisture content decreased with the temperature (2.34 kg/kg for 55 °C; 1.66 kg/kg for 65 °C; and 1.53 kg/kg DB for 75 °C). The equilibrium moisture (Me) obtained for the SE ranged from 0.11 to 0.09 kg/kg DB. Therefore, this parameter was considered as the drying end point. This figure also shows that the constant speed period passes quickly in the first 3,600 s (60 min), reducing the moisture content of the solid around 79 %. That is, the water on the surface evaporated faster than the speed with which the water moved to the surface causing contraction of the surface layer that resists the subsequent passage of steam. On the other hand, the same physical-chemical characteristics of the biological material (high carbohydrate and protein content) help the formation of a layer that prevents the migration of water to the surface, this phenomenon is intensely evident as the dehydration rate increases (higher temperature) (Vázquez-Chávez & Vizcarra-Mendoza, 2008).

Figure 1. Experimental average dimensional moisture during the drying of pumpkin epicarp (*Cucurbita maxima*, var. Boyacá) at different temperatures, a) 55 ºC two-term model, b) 65 ºC logarithmic model and c) 75 °C logarithmic model).



Mathematical Modeling of Drying Kinetics

The models obtained were used to control the drying process, and each model was specific to the drying conditions studied (Xia & Sun, 2002). The values of SEE and R2 ranged from 0.00 – 0.07 and from 0.47-1.00 and, respectively, indicated that the highest R2 values and lowest SSE values were obtained with the two-term (55 °C and 65 °C), logarithmic (65 °C and 75 °C), and Henderson and Pabis (65 °C) models (Table 2). Therefore, the two-term model was considered the most appropriate to describe the drying curve at 55 °C, and the logarithmic model was considered the most appropriate to describe the curves at 65 °C and 75 °C (Figure 2).

Table 2. Results of the mathematical models applied to the drying curves of squash epicarp (Cucurbita maxima) at different temperatures.

Model	**55 °C**	**65 °C**	**75 °C**
Lewis	k = 0.0165 SSE = 0.00 R^2 = 0.97	k = 0.0242 SSE = 0.01 R^2 = 0.97	k = 0.0283 SSE = 0.01 R^2 = 0.89
Page	k = 0.1161 n = 0.605 SSE = 0.00 R^2 = 0.96	k = 0.0060 n = 1.3416 SSE = 0.00 R^2 = 0.99	k = 0.1348 n = 0.6207 SSE = 0.00 R^2 = 0.91
Modified page	k = 2.00 n = 1.00 a = 0.0467 SSE = 0.07 R^2 = 0.47	k = 1.34 n = 0,35 a = 63.5873 SSE = 0.00 R^2 = 0,89	k = 0.22 n = 0.5419 a = 1.3451 SSE = 0.00 R^2 = 0.91
Henderson and Pabis	k = 0.0130 a = 0.604 SSE = 0.00 R^2 = 0.97	k = 0.0335 a =1.6802 SSE = 0.00 R^2 = 0,91	k = 0.0156 a = 0.4768 SSE = 0.04 R^2 = 0.93
Logarithmic	k = 0.0140 a = 0.674 c = 0.0053 SSE = 0.00 R^2 = 0.98	k = 0.0356 a =1.8092 c = 0.0077 SSE = 0.00 R^2 = 0,95	k = 0.0177 a = 0.5080 c = 0.0103 SSE = 0.00 R^2 = 0.99
Two terms	**k_1 = 0.0584** **k_0 = 0.0107** **a = 0.4174**	**k_1 = 0.0401** **k_0 = 0.0070** **a = 0.0493**	**k_1 = 0.0686** **k_0 = 0.0127** **a = 0.3390**

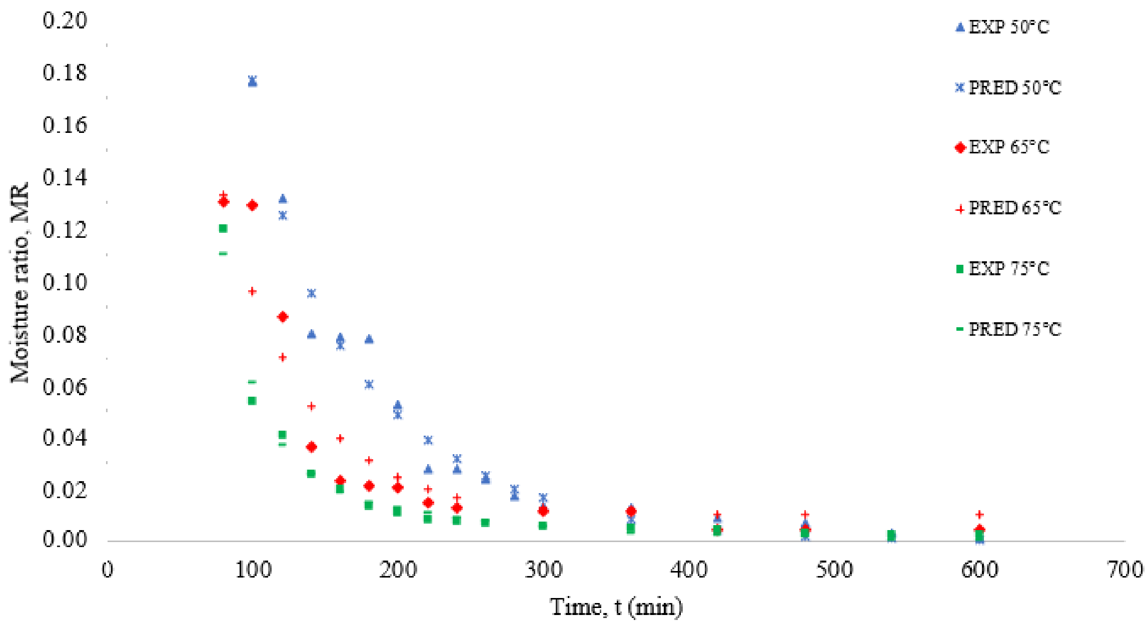
	b = 12.0189 **c = 0.0103** **SSE = 0.00** **R^2 = 0.98**	**b = 2.0256** **c = 0.0103** **SSE = 0.00** **R^2 = 0.88**	**b = 1.0000** **c = 0.0103** **SSE = 0.00** **R^2 = 0.90**
Two exponential terms	k = 0.0322 a = 0.4037 SSE = 0.00 R^2 = 0.98	k = 0.0242 a = 0.9987 SSE = 0.01 R^2 = 0.97	k = 0.0633 a = 0.3408 SSE = 0.05 R^2 = 0.92

k: drying constant; a, b, c and n: adjustment coefficients, SSE: Sum of Errors to the Square, R^2: coefficient of determination.

The constant k corresponding to the decreasing exponential value obtained for the different models depends on the temperature, since it increases as the temperature increases (Table 2). This trend can be clearly seen in the values of the models for temperatures of 55 and 75 ° C. The same behavior has already been documented by Puente-Díaz *et al*. (2013).

Figure 2 represents the experimental variation of the dimensionless moisture content ratio on a dry weight basis (MR) in the decreasing drying rate period over time for SE slices at different temperatures and the predicted variation. Temperature affected the slope of the drying curve, with a steeper slope for the curve obtained at 75 °C. Similar moisture kinetics on a dry basis have been reported for other biological matrices where most of the water was removed in the period of constant drying rate, a period in which the water transfer resistance is low while the rate of evaporation is high. The inflection time for the different drying temperatures was observed from minute 300, time in which about 80% of the water content was reduced, while longer times have been reported for other types of residues, of 420 min for unchopped carrot residue and 350 min for chopped carrot residue (Bas-Bellver *et al.*, 2020). This difference is due to the fact that the structure of the squash shell of the variety used has 2 types of structures, a rigid one (made up of the outer part of the shell) and a soft one (the moister part) that is in contact with the pulp. Said soft structure –made up of a high proportion of dietary fiber– is much more porous and facilitates the transfer process of mass.

Figure 2. Predicted and experimental average dimensional moisture ratio during the drying of pumpkin epicarp (*Cucurbita maxima*, var. Boyacá) at different temperatures (55 Δ – two terms, 65◊ - logarithmic and 75 °C □ - logarithmic) with Two terms model in the period of decreasing velocity.



Effective Diffusivity and Drying Time

Table 3 shows the effective diffusivity calculated for different drying temperatures. The effective diffusivity model used was adjusted with R2 values greater than 0.9. The values of De increased significantly with the temperature (p<0.05), obtaining a range of 6.45–9.82 x 10-9 m2s-1 due to the increase in the rate of heat supply from the air to the product and the acceleration of water diffusion within the tissue. The De values found were in the range reported for dehydrated foods (10-12 to 10-8 m2s-1) (Joardder *et al.*, 2020). Thus, drying times in the decreasing drying rate period were 14.19 h (55 °C), 11.11 h (65 °C), and 9.50 h (75 °C), indicating a 32.29% decrease when the temperature was increased from 55 °C to 75 °C and a 22% decrease when the temperature was increased from 55 °C to 65 °C. Authors like Joardder *et al.* (2020) have reported a similar trend of increased diffusivity with temperature for biological materials such as eggplant, carrot and radish. On the other hand, since no similar studies were found with squash epicarp, it was compared with that reported for squash pulp flour. Such is the case of the study conducted by Guiné *et al.* (2012), which shows a shortening of the drying time with an increase in temperature from 30 ° C to 70 ° C, obtaining a transfer coefficient of mass (De) of 3.12x10-8 (m2s-1), higher than that obtained in this study for the squash epicarp. This difference may be due to the film that makes up the shell, which functions as a barrier to transfer mass, as well as the variety and operational conditions such as the speed of the drying air and the geometry used (cylindrical shape for that study).

On the other hand, it is observed that the acceptability of the color decreases when the drying temperature increases. Such fact may be directly related to the degradation of this pigment, which is very prone to oxidation and isomerization processes that increase with exposure to light and high temperatures and can also generate unpleasant flavors. Therefore, low drying temperatures increase its retention. Such behavior has already been documented for several years by other authors for carrots (Park, 1987), beets (Negi and Roy, 2000), tomato (Toor & Savage, 2006), among others.

Based on these data, the temperature of 65 °C was selected as the drying condition to be used for the dehydration of the SE because it did not significantly affect the sensory acceptance of color (Table 3).

Table 3. Values of effective diffusivity, drying time and sensory acceptance of the color of the dried squash epicarp at different temperatures.

Temperature (°C)	*$D_e x10^{-9}(m^2s^{-1})$	*Time D_p (h)	*Time C_p (h)	SSE	R^2	Color
55	6.45±0.11[b]	14.19±0.04[a]	1.36±0.04[a]	0.00087	0.98	4.30±0.48[a]
65	7.03±0.06[b]	11.10±0.04[b]	1.03±0.06[b]	0.00215	0.95	3.90±0.57[a]
75	9.82±0.06[a]	9.50±0.02[c]	1.00±0.10[b]	0.00020	0.99	2.70±0.67[b]

D_e: Effective diffusivity, D_p: Declining period, C_p: Constant period, R^2: adjustment coefficient and SSE: Sum of Errors to the Square. The values correspond to the mean ± SD (n = 3) for color the values correspond to the mean ± SD (n = 30). Different letters in the same column indicate significant differences because of temperature ($p < 0.05$; Tukey).

Proximal Analysis of SEF

Squash epicarp is a food waste with high nutritional potential. When SE is subjected to the drying and grinding processes, some flour is obtained that can be used for various food applications. The SEF in the present study was characterized with the following properties (g/100 g d.b): dry matter content of 91.02 ± 0.01, protein content of 16.35 ± 0.01, dietary fiber content of 37.99 ± 0.01, fat content of 5.66 ± 0.01, and ash content of 9.35 ± 0.01 g/100g. Lower dietary fiber (28.81 g/100 g) and dietary protein contents for pumpkin epicarp have been reported by Mala & Kurian (2016). Additionally, Carolina *et al*. (2016) reported a slightly higher protein content with 17.99 ± 0.08g/100 g and lipids with 7.02 ± 0.11 g/100g. These differences may be due to the variety and cultivar studied, different crop conditions and state of fruit ripening. The proximal composition of SEF was compared to that of squash mesocarp (SM), which showed lower contents of protein (9.32 ± 0.01 g/100 g), fat (2.16 ± 0.01 g/100 g), and fiber (30.51 ± 0.01 g/100 g) but a higher ash content (10.95 ± 0.02 g/100 g). As compared to previously reported values for wheat flour (WF; 2.00 -3.00 g/100 g), SE was considered to have high fiber levels (Zhou *et al*., 2021).

Sensory analysis of GFB

Table 4 shows the results of the sensory acceptability and purchase intention tests obtained for GFBs enriched with SEF (SEF 65 °C) in different proportions. SEF had a significant ($p<0.05$) effect on the grade obtained for each attribute evaluated. The acceptance of attributes, such as color and odor, increased when the SEF increased compared to the control formulation since its orange tones augmented, probably due to the carotenoids present in the biological matrix (Salami *et al.*, 2021). In contrast, the acceptance of attributes such as taste and sponginess increased when SEF decreased compared to the control formulation. This result is in turn related to an increase of dietary fiber content. Similar results have been obtained by Coronel *et al*. (2021), who reported that sensory acceptance of bread decreases when the content of chia flour increases. According to the Pearson correlation, the attributes that most influenced the acceptability and purchase intention of participants were taste (coefficient of 0.085; p = 0.00) and sponginess (coefficient of 0.514, p = 0.00). The low scores for sponginess were due to the loss of dough elasticity because there was not enough gas retention, which resulted in firm bread. Similarly, Carolina *et al*. (2016) reported lower volume and sponginess of the bread due to the increase in the proportion of gluten-free flour in the formulation, since the increase in dietary fiber content interrupts the protein structure, which causes the loss of gases, in this case caused by baking powder.

The low scores for flavor were due to the intense and unpleasant residual taste of the rind, which may be improved by adding raw materials to mask the flavor. Regarding the formulation of the breads, the highest acceptance and purchase intention was obtained by the bread produced with 15 g SEF / 100 g of flour (Figure 3).

Figure 3. Gluten-free, yeast-free bread made with dehydrated squash epicarp (65 ° C) (SEF-15).

Table 4. Results of sensory evaluations of gluten-free bread enriched with squash epicarp flour (*Cucurbita maxima*).

Attribute	SEF-25	SEF-20	SEF-15	Control
Color	3.60 ± 0.68[a]	3.75 ± 0.64[a]	3.05 ± 0.60[b]	2.80± 0.55[b]
Odor	3.15 ± 0.75[a]	3.35 ± 0.93[a]	3.60 ± 0.94[a]	3.00 ±0.00[a]
Taste	2.55 ± 0.89[b]	3.00 ± 0.90[b]	3.10 ± 0.90[b]	4.60±0.50[a]
Sponginess	2.65 ± 0.88[c]	2.60 ± 0.94[c]	3.50 ± 0.95[b]	4.40±0.50[a]
Purchase intention	1,50 ± 0.76[b]	1.85 ± 0.81[b]	2.05 ± 0.83[ab]	2.55±0.51[a]

SEF: Squash Epicarp Flour. The reported values correspond to the mean ± standard deviation (n = 30). Different letters in the same row indicate significant differences by effect of SEF (p< 0.05; Tukey).

Conclusion

Out of the six mathematical models evaluated, the two-term model best describes the curve obtained at 55 °C, and the logarithmic model best describes the curves obtained at 65°C and 75 °C with a coefficient of adjustment greater than 0.9. Temperature affected the course of the drying curve, showing a steeper slope for the curve obtained at 75 °C, which was reflected in the drying time (10.50 h). Although the shortest drying time was obtained at 75 °C, 65 °C was selected for the drying of the pumpkin epicarp and the subsequent elaboration of flour with a drying time of 12.13 h. The processing time was reduced by 22% at 65 °C compared to 55 °C, and the sensory acceptance of color was maintained.

Squash epicarp flour was characterized as presenting a high content of protein and dietary fiber, even higher than the vegetable flours reported by other authors. SEF can be used as a promising raw material in the production of products with low contents of these macronutrients. As for color and odor, their acceptance increased when SEF increased compared to the control formulation. However, the taste was negatively affected. In contrast, the acceptance of the attributes of taste and sponginess increased when SEF decreased. This flour can be used in the preparation of wrapped bread with acceptable sensory properties at a level of 15 g/100 g of flour (Figure 3).

Acknowledgements

The authors thank Jardín Botánico de Bogotá for providing us with their laboratory services, especially to the Scientific Sub Direction and the engineer Diana Carolina Corzo Barragán.

References

Akpinar, E. K., & Bicer, Y. (2005). Modelling of the drying of eggplants in thin-layers. *International Journal of Food Science and Technology*, *40*(3), 273–281. https://doi.org/10.1111/j.1365-2621.2004.00886.x

American Association of Cereal Chemists. (2001). AACC 08-01: Ash -basic method , Paul, MN, USA.

Amini Khoozani, A., Kebede, B., & El-Din Ahmed Bekhit, A. (2020). Rheological, textural and structural changes in dough and bread partially substituted with whole green banana flour. *LWT*, *126*, 109252. https://doi.org/10.1016/j.lwt.2020.109252

Arendt, E. K. , O'brien, C. M., Gormley, T. R., & Ronan, T. (2002). Development of Gluten-Free Cereal Products. *Repository UCD*. http://hdl.handle.net/10197/6892

Arslan, M., Rakha, A., Xiaobo, Z., & Mahmood, M. A. (2019). Complimenting gluten free bakery products with dietary fiber: Opportunities and constraints. *Trends in Food Science & Technology*, *83*, 194–202. https://doi.org/10.1016/J.TIFS.2018.11.011

Aziah, A. A. N., Ho, L. H., Komathi, C. A., & Bhat, R. (2011). Evaluation of Resistant Starch in Crackers Incorporated with Unpeeled and Peeled Pumpkin Flour. *American Journal of Food Technology*, *6*(12), 1054–1060. https://doi.org/10.3923/ajft.2011.1054.1060

Bas-Bellver, C., Barrera, C., Betoret, N., & Seguí, L. (2020). Turning Agri-Food Cooperative Vegetable Residues into Functional Powdered Ingredients for the Food Industry. *Sustainability*, *12*(4), 1284. https://doi.org/10.3390/su12041284

Bemfeito, C. M., Carneiro, J. de D. S., Carvalho, E. E. N., Coli, P. C., Pereira, R. C., & Vilas Boas, E. V. de B. (2020). Nutritional and functional potential of pumpkin (Cucurbita moschata) pulp and pequi (Caryocar brasiliense Camb.) peel flours. *Journal of Food Science and Technology*, *57*(10), 3920–3925. https://doi.org/10.1007/S13197-020-04590-4

Carolina, A., Staichok, B., Rayssa, K., Mendonça, B., Guerra, P., Santos, A. dos, Gonçalves, L., Garcia, C., & Damiani, C. (2016). Pumpkin Peel Flour (Cucurbita máxima L.)-Characterization and Technological Applicability. *Journal of Food and Nutrition Research*, *4*(5), 327–333. https://doi.org/10.12691/jfnr-4-5-9

Coronel, E. B., Guiotto, E. N., Aspiroz, M. C., Tomás, M. C., Nolasco, S. M., & Capitani, M. I. (2021). Development of gluten-free premixes with buckwheat and chia flours: Application in a bread product. *LWT*, *141*, 110916. https://doi.org/10.1016/j.lwt.2021.110916

Crank, J. (1975). *The Mathematics of Diffusion*. Oxford University, 2nd ed., Vol. 1.

Decock, P., & Cappelle, S. (2005). Bread technology and sourdough technology. *Trends in Food Science & Technology*, *16*(1–3), 113–120. https://doi.org/10.1016/J.TIFS.2004.04.012

Food and Agriculture Organization of the United Nations - FAO. (2021). *ODS 12. Producción y consumo responsables | Objetivos de Desarrollo Sostenible | Organización de las Naciones Unidas para la Agricultura y la Alimentación*. https://www.fao.org/sustainable-development-goals/goals/goal-12/en/

Food and Agriculture Organization of the United Nations - FAO. (2014). *FAOSTAT*. https://www.fao.org/faostat/en/#data/QC

Franco, V. A., García, L. G. C., & Silva, F. A. da. (2020). Addition of hydrocolidics in gluten-free bread and replacement of rice flour for sweet potato flour. *Food Science and Technology*, *40*(suppl 1), 88–96. https://doi.org/10.1590/fst.05919

Geankoplis, C. J. (2006). *Procesos de transporte y principios de procesos de separación (incluye operaciones unitarias).* Compañía Editorial Continental CECSA. 4th Edición.

Guiné, R. P. F., Henrriques, F., & João Barroca, M. (2012). Mass Transfer Coefficients for the Drying of Pumpkin (Cucurbita moschata) and Dried Product Quality. *Food and Bioprocess Technology*, *5*(1), 176–183. https://doi.org/10.1007/s11947-009-0275-y

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R. & Meybeck, A. (2011). *Pérdidas y Desperdicio de Alimentos en el Mundo – Alcance, Causas y Prevención.* Organización de las Naciones Unidas para la alimentación y la agricultura. https://www.fao.org/sustainable-food-value-chains/library/detalles/es/c/278445/

International Organization for Standardization - ISO. (2009). ISO 1871 determination of nitrogen by the Kjeldahl method, Geneva.

Jalali, M., Sheikholeslami, Z., Elhamirad, A. H., Haddad Khodaparast, M. H., & Karimi, M. (2020). The effect of the ultrasound process and pre-gelatinization of the corn flour on the textural, visual, and sensory properties in gluten-free pan bread. *Journal of Food Science and Technology*, *57*(3), 993–1002. https://doi.org/10.1007/s13197-019-04132-7

Joardder, M. U. H., Alsbua, R., Akram, W., & Karim, M. A. (2020). Effect of sample rugged surface on energy consumption and quality of plant-based food materials in convective drying. *Drying Technology 39*(10), 1339–1348. https://doi.org/10.1080/07373937.2020.1745824

Kim, M. Y., Kim, E. J., Kim, Y.-N., Choi, C., & Lee, B.-H. (2012). Comparison of the chemical compositions and nutritive values of various pumpkin (*Cucurbitaceae*) species and parts. *Nutrition Research and Practice*, *6*(1), 21. https://doi.org/10.4162/nrp.2012.6.1.21

Kulczynski, B., & Gramza-Michałowska, A. (2019). The Profile of Carotenoids and Other Bioactive Molecules in Various Pumpkin Fruits (Cucurbita maxima Duchesne) Cultivars. *Molecules, 24*(18), 3212. https://doi.org/10.3390/MOLECULES24183212

Lima, P. M., Dacanal, G. C., Pinho, L. S., Pérez-Córdoba, L. J., Thomazini, M., Moraes, I. C. F., & Favaro-Trindade, C. S. (2021). Production of a rich-carotenoid colorant from pumpkin peels using oil-in-water emulsion followed by spray drying. *Food Research International*, *148*, 110627. https://doi.org/10.1016/J.FOODRES.2021.110627

López-Mejía, N., & Morales Posada, N. B. (2020). Optimización de la formulación de tallarines libres de gluten enriquecidos con pulpa de zapallo deshidratada empleando el método de diseño de mezclas. *Brazilian Journal of Food Technology*, *23*. https://doi.org/10.1590/1981-6723.29918

Mala, K. S., & Kurian, A. E. (2016). Nutritional composition and antioxidant activity of pumpkin wastes international journal of pharmaceutical, chemical and biological sciences nutritional composition and antioxidant activity of pumpkin wastes. *Research Journal of Pharmaceutical, Biological and Chemical Sciences 6*(3), 336-34

Marín B, E., Lemus M, R., Flores M, V., & Vega G, A. (2006). la rehidratación de alimentos deshidratados. *Revista Chilena de Nutrición*, *33*(3). https://doi.org/10.4067/S0717-75182006000500009

McCleary, B. v., DeVries, J. W., Rader, J. I., Cohen, G., Prosky, L., Mugford, D. C., Champ, M., & Okuma, K. (2012). Determination of insoluble, soluble, and total dietary fiber (CODEX definition) by enzymatic-gravimetric method and liquid chromatography: Collaborative study. *Journal of AOAC International*, *95*(3), 824–844. https://doi.org/10.5740/jaoacint.CS2011_25

Murray, J. A. (1999). The widening spectrum of celiac disease. *The American Journal of Clinical Nutrition*, *69*(3), 354–365. https://doi.org/10.1093/AJCN/69.3.354

Nakilcioğlu-Taş, E., Coşan, G., & Ötleş, S. (2021). Optimization of process conditions to improve the quality properties of healthy watermelon snacks developed by hot-air drying. *Journal of Food Measurement and Characterization*, *15*(2), 2146–2160. https://doi.org/10.1007/S11694-020-00808-3

Nasir, S., Allai, F. M., Gani, M., Ganaie, S., Gul, K., Jabeen, A., & Majeed, D. (2020). Physical, Textural, Rheological, and Sensory Characteristics of Amaranth-Based Wheat Flour Bread. *International Journal of Food Science*, *2020*, 1–9. https://doi.org/10.1155/2020/8874872

O'Shea, N., Arendt, E. K., & Gallagher, E. (2012). Dietary fibre and phytochemical characteristics of fruit and vegetable by-products and their recent applications as novel ingredients in food products. *Innovative Food Science & Emerging Technologies*, *16*, 1–10. https://doi.org/10.1016/J.IFSET.2012.06.002

Park, Y. W. (1987). Effect of Freezing, Thawing, Drying, and Cooking on Carotene Retention in Carrots, Broccoli and Spinach. *Journal of Food Science*, *52*(4), 1022–1025. https://doi.org/10.1111/j.1365-2621.1987.tb14266.x

Puente-Díaz, L., Ah-Hen, K., Vega-Gálvez, A., Lemus-Mondaca, R., & Scala, K. di. (2013). Combined Infrared-Convective Drying of Murta (Ugni molinae Turcz) Berries: Kinetic Modeling and Quality Assessment. *Drying Technology*, *31*(3), 329–338. https://doi.org/10.1080/07373937.2012.736113

Salami, A., Asefi, N., Kenari, R. E., & Gharekhani, M. (2021). Extraction of pumpkin peel extract using supercritical CO2 and subcritical water technology: Enhancing oxidative stability of canola oil. *Journal of Food Science and Technology*, *58*(3), 1101–1109. https://doi.org/10.1007/S13197-020-04624-X/TABLES/5

Song, J., Wei, Q., Wang, X., Li, D., Liu, C., Zhang, M., & Meng, L. (2018). Degradation of carotenoids in dehydrated pumpkins as affected by different storage conditions. *Food Research International*, *107*, 130–136. https://doi.org/10.1016/J.FOODRES.2018.02.024

Toor, R. K., & Savage, G. P. (2006). Effect of semi-drying on the antioxidant components of tomatoes. *Food Chemistry*, *94*(1), 90–97. https://doi.org/10.1016/j.foodchem.2004.10.054

Vázquez-Chávez, L., & Vizcarra-Mendoza, M. (2008). Secado por lecho fluidizado del trigo y su calidad. *Revista Mexicana de Ingeniería Química*, *7*(2), 131–137. http://rmiq.org/ojs311/index.php/rmiq/article/view/1815

Wang, X., Lao, X., Bao, Y., Guan, X., & Li, C. (2021). Effect of whole quinoa flour substitution on the texture and in vitro starch digestibility of wheat bread. *Food Hydrocolloids*, *119*, 106840. https://doi.org/10.1016/j.foodhyd.2021.106840

Xia, B., & Sun, D.-W. (2002). Applications of computational fluid dynamics (CFD) in the food industry: a review. *Computers and Electronics in Agriculture*, *34*(1–3), 5–24. https://doi.org/10.1016/S0168-1699(01)00177-6

Yadav, M., Jain, S., Tomar, R., Prasad, G. B. K. S., & Yadav, H. (2010). Medicinal and biological potential of pumpkin: an updated review. *Nutrition Research Reviews*, *23*(2), 184–190. https://doi.org/10.1017/S0954422410000107

Zhou, Y., Dhital, S., Zhao, C., Ye, F., Chen, J., & Zhao, G. (2021). Dietary fiber-gluten protein interaction in wheat flour dough: Analysis, consequences and proposed mechanisms. *Food Hydrocolloids*, *111*, 106203. https://doi.org/10.1016/J.FOODHYD.2020.106203