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Drying and analysis of waste from potatoes, carrots, and chayote for food purposes

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Abstract

Vegetable peels are rarely used in food preparation, causing the loss of several nutrients. Such residues ca produce flour as a possible food source with added nutritional and economic value. Thus, the objective was to evaluate the nutritional quality and the color of the flours obtained from the peels of potato, carrot, and chayote subjected to drying at the temperatures of 40, 50, 60, and 70 °C, as well as analyzing the drying kinetics. The peels were removed, packed in an isothermal box with ice, and taken to the laboratory. Then they were washed in running water to remove dirt and unwanted parts and sanitized. After this stage, they were broken into 2 cm lengths. The drying was carried out in 150 g of peels in triplicate for each raw material. Subsequently, nutritional quality, color, and drying models were determined. Flours obtained from drying at higher temperatures showed higher protein content and lower lipid content. The higher the temperature, the shorter the drying time for the flour. All flours presented excellent nutritional quality. Among the models studied for potato peels, Wang and Singh, Midilli, and Logarithmic are the most suitable. For chayote and carrot peels, the Midilli model is the most adequate. Using vegetable residues added to food formulations presents itself as an excellent nutritional source, besides adding flavor and texture to foods.

Keywords: flour, food waste, nutritional source, food preparation, peels

Introduction

During food preparation, several nutrients are lost through the stalks, peels, and seeds. These become a severe problem, as waste causes environmental pollution (Silva & Jorge, 2014) and, in many cases, could even be reused for food preparation. Therefore, fruit peels have gained popularity, as they have a rich composition (Lim et al., 2006).

A viable alternative is the production of food flour through the dehydration process since these processed residues represent a socioeconomic and food potential, constituting an option to increase the family income of small and micro industries, contributing to sustainability, job and income generation (Sousa et al., 2020).

Drying the waste reduces the moisture content through evaporation, concentrating the nutrients and discouraging the multiplication of microorganisms (Barbosa; Lobato, 2016).

This process is essential in food technology, as it can preserve the physical and chemical properties and reduce the moisture content to values suitable for storage (Jorge et al., 2021).

The application of mathematical models is of fundamental importance to represent the drying process, given the diversity of structure and composition of biological materials and the influence these characteristics exert on heat and mass transfer phenomena (Mendonça et al., 2015).

Some authors have also studied the drying kinetics of jackfruit residue (Sousa et al., 2021), pineapple residue (Alexandre et al., 2013), jabuticaba peel (Costa et al., (2016), and banana peel (Gonçalves et al., 2017).

In this context, the objective was to evaluate the nutritional quality and color of flours obtained from potato (Solanum tuberosum), carrot (Daucus carota L.), and chayote (Sechium edule) skins submitted to drying at

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temperatures of 40, 50, 60, and 70°C.

Materials and Methods

Potato, carrot, and chayote skins resulted from the processing of vegetables to obtain soup from the Social Assistance Program Chico Xavier in Santa Helena de Goiás, GO. First, the peels were removed and packed in an isothermal box with ice for transport to the Animal Origin Products Laboratory at the Instituto Federal Goiano - Campus Rio Verde. Then peels were washed in running water to remove dirt and unwanted parts and sanitized in hypochlorite solution at ten ppm/15 min. After this step, they were cut into 2 cm lengths.

Drying was performed on samples of 150 grams of peels in triplicate for each product, and 40, 50, 60, and 70 °C using greenhouses with forced air ventilation as drying temperatures (Marconi MA-035, Piracicaba, SP, Brazil). Weighings were performed every 30 minutes until constant mass to determine the end of the drying.

The reduction in moisture content during drying used the gravimetric method (loss of mass), knowing the initial moisture content of the product until reaching constant mass. The mass reduction during drying was monitored using a scale (SHIMADZU-BL3200H) with a resolution of 0.01 grams.

After drying, the peels were ground in a DIOGOMAQ® multipurpose grinder to obtain the flour, packed in transparent polyethylene packaging, sealed, and stored in desiccators for further analysis.

Determining the caloric values of the flours in the peels were done by direct calorimetry in a bomb calorimeter. Analysis weighed 1 gram of sample in a combustion chamber with oxygen under pressure to compare the sample's combustion heat with the benzoic acid standard (Tannus et al., 2001).

The research used the quantitative method nº 920.87 of the AOAC International in a micro-Kjeldahl distiller (Tecnal□/TE-0363) to determine the crude protein content. From the total nitrogen content, a conversion factor of 5.75 was used for vegetable proteins (AOAC, 2000).

A continuous extraction methodology was used in a Soxhlet-type apparatus to determine the ether extract. Organic solvent hexane P.A. during 8 hours of extraction, according to method nº 925.38 of the AOAC International (AOAC, 2000).

The instrumental color parameters were analyzed in a Hunter Lab Colorimeter, model Color Flex EZ. Results expressed in L*, a*, and b*, with L* values (brightness or brightness) ranging from black (0) to white (100), chroma values a* from green (-60) to red (+60) and those of chroma b* from blue (-60) to yellow (+60), according to Paucar-Menacho et al. (2008). The cylindrical coordinates were also determined, according to the HSB model: Chroma color saturation (Equation 1) and Hue chromatic hue (Equation 2) (ABNT, 1992).

$$C^* = \sqrt{a^2+b^2} \quad (1)$$

$$h° = \arctan(^{b^*/a^*}) \quad (2)$$

Where:

C* = Chroma (Dimensionless);

a* e b* = Chromaticity (Dimensionless);

h = Hue (°).

The study determined the moisture content ratios of potato, carrot, and chayote residues during drying using the expression below:

$$RX = \frac{X-X_e}{X_i-X_e} \quad (3)$$

Where:

RX = product moisture content ratio, dimensionless;

X = product moisture content (b.s.);

X_i = initial moisture content of the product (b.s.);

X_e = product balance moisture content (b.s.).

The experiments used a completely randomized design, and we applied different drying temperatures as treatments. Means were compared by Tukey's test at 5% significance.

The mathematical models used to represent the drying of vegetable products are presented in (**Table 1**), which were adjusted to the experimental drying data.

The mathematical models were adjusted through non-linear regression analysis using the Gauss-Newton method for the degree of adjustment, considering the magnitude of the coefficient of determination (R^2), the Chi-square test (χ^2), the mean error relative (P) and the standard deviation of the estimate (SE).

Results and Discussion

English Potato Skins

With increasing temperature, the protein content was higher (Table 1). In this study, the protein content ranged from 10.42 to 12.39%, similar to those obtained by Rosa et al. (2017) (11.51%) for oven-dried potato flour at 65 °C.

As the potato skins' drying temperature increased, the ether extract's value decreased, with the lowest value of 0.011% at 70 °C. The instrumental color parameters in the potato peel flour varied with different temperatures. The production of darker flours occurred due to enzymatic oxidation at 40° C and 50 ° C. According to Oliveira (2008), enzymatic inactivation of PPO by heating is possible by applying temperatures above 50 °C.

Table 1. Mathematical models used to predict the drying of plant products		
Model Designation	Model	
$RX = 1+a.t+b.t^2$	Wang and Singh	(4)
$RX = a.\exp -k.t+1 - a \exp -k_1.t$	Verma	(5)
$RX = \exp -a-a^2+4.b.t^{0.5}/2.b$	Thompson	(6)
$RX = \exp - k.t^n$	Page	(7)
$RX = \exp -k.t$	Newton	(8)
$RX = a. \exp - k.t^n+b.t$	Midilli	(9)
$RX = a. \exp - k.t+c$	Logarítmico	(10)
$RX = a. \exp - k.t$	Henderson and Pabis	(11)
$RX = a. \exp - k.t +1-a\exp - k.a.t$	Two Terms Exponential	(12)
$RX = a. \exp -k_0.t+b \exp - k_1.t$	Two Terms	(13)
$RX = a.\exp - k.t+1-a \exp - k.b.t$	Diffusion Approach	(14)
t: drying time, h; k, ko, k1: drying constants, h-1; and a, b, c, n: model parameters		

Protein values were lower at temperatures of 40 and 50 °C, where the exposure period in the oven was more extended. For Tattini Junior et al. (2006), exposure time and temperature can cause damage to dehydrated products, such as loss of volatiles, thermal decomposition, enzymatic actions, and protein denaturation in the drying process at high temperatures. Still, below 100°C, drying occurs more quickly, preserving the nutritional characteristics.

For temperatures 60 and 70 °C, the lipid contents were lower. According to Elias et al. (2008), increasing the drying temperature reduces the lipid content.

Similar values were found by Fernandes et al. (2008), who analyzed potato peel flour dried at 55 °C, with the following results: L* 59.52, a* 5.00, and b* 14.68. In the analysis of the caloric value of the potato peel flour, the results increased according to the temperature, being obtained at temperatures of 60 and 70 °C, 3818 kcal, and 3819.67 kcal, respectively.

Stork et al. (2013) analyzed the nutritional composition of leaves, stems, bark, and vegetable seeds for use in food. Due to low-calorie levels, the tests demonstrated that adding them to different dishes would not significantly boost their energy value. In addition, cultivation type and drying temperature affect the calorie content in flour.

In (**Figure 1**), it is possible to observe the drying time of the potato skin in hours and the ratios of the moisture content (decimal) (RX) for the drying temperatures of 40, 50, 60, and 70 °C.

The experiment observed that the different temperatures influenced the product's water loss. For example, the researchers determined that drying potato skin at a temperature of 40°C took 9 hours; for a temperature of 50 °C, it took 5.5 hours; for a temperature

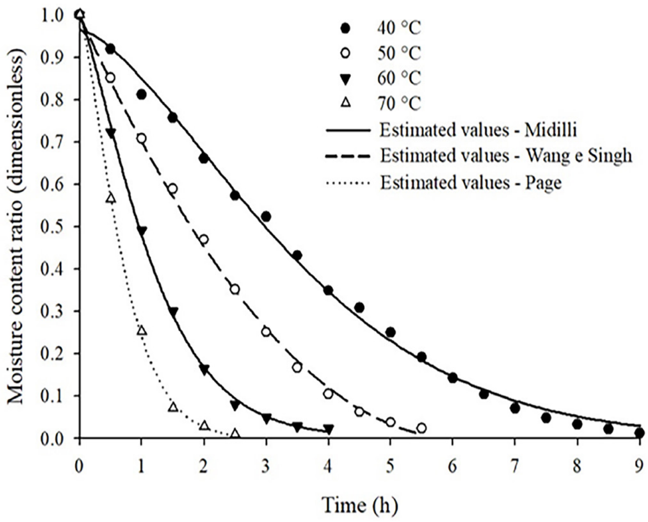

Figure 1. Moisture content ratio of potato peel over drying time at temperatures of 40, 50, 60, and 70 °C.

of 60 °C, 4 hours and for a temperature of 70°C, 2.7 hours.

Sousa et al. (2011) report that increasing the temperature of the drying air causes a higher rate of water removal from the product due to the more significant moisture gradient between the product and air, decreasing the time required to reduce the moisture content to the value desired (0.15 dry base, d.b.).

(**Table 2**) presents the values for the Chi-square test (χ^2) and estimated average error (SE) calculated for the 11 models used in the representation of the drying kinetics of potato skins.

Regarding the estimated mean error (SE) and Chi-square (χ^2) analysis, the Wang and Singh, Midilli, and logarithmic models obtained lower values than the others.

Mean estimated error (SE) and Chi-square (χ^2) values alone cannot determine the model's effectiveness. (**Table 3**) displays the results of a comprehensive evaluation of the best model, which involved analyzing

Table 2. Mean values and standard error of protein (%), ether extract (%), instrumental parameters of color, and caloric value (kg) of dry potato residue

Variables	Temperature (°C)			
	40	50	60	70
Protein	10.42 ± 0.026[b]	11.18 ± 0.020[b]	12.39 ± 0.027[a]	12.37 ± 0.004[a]
Ether extract	0.020 ± 0.000[a]	0.018 ± 0.000[ab]	0.013 ± 0.346[b]	0.011 ± 0.000[b]
L*	55.63 ± 0.017[b]	52.24 ± 0.028[c]	58.18 ± 0.013[a]	57.66 ± 0.011[a]
a*	4.68 ± 0.111[b]	4.56 ± 0.039[b]	5.87 ± 0.077[a]	4.96 ± 0.084[b]
b*	15.43 ± 0.066[c]	14.65 ± 0.016[c]	20.82 ± 0.052[a]	16.92 ± 0.067[b]
Chroma	16.12 ± 0.070[c]	15.34 ± 0.018[c]	21.64 ± 0.053[a]	17.63 ± 0.068[b]
Hue	73.16 ± 0.009[bc]	72.70 ± 0.005[c]	74.26 ± 0.005[a]	73.69 ± 0.004a[b]
Caloric value	3712.67 ± 0.003[c]	3778.67 ± 0.00[b]	3818.00 ± 0.00[a]	3819.67 ± 0.00[a]

According to Tukey's test, different letters on the line differ at the 5% significance level.

Table 3. Values for the Chi-square test (χ^2, x 10^{-3} decimal) and estimated mean error (SE, decimal) calculated for the eleven models used to represent the drying kinetics of potato skins

Model	40 °C		50 °C		60 °C		70 °C	
	SE	χ²	SE	χ²	SE	χ²	SE	χ²
Wang and Singh	0.0146	0.000212	0.0125	0.000157	0.0167	0.000278	0.0216	0.000467
Verma	0.0205	0.000420	0.0232	0.000536	0.0269	0.000723	0.0320	0.001021
Thompson	0.0643	0.004135	0.0608	0.003692	0.0406	0.001647	0.0470	0.002205
Page	0.0229	0.000523	0.0209	0.000438	0.0103	0.000106	0.0096	0.000092
Newton	0.0624	0.003891	0.0579	0.003356	0.0380	0.001440	0.0420	0.001764
Midilli	0.0137	0.000187	0.0155	0.000239	0.0119	0.000143	0.0135	0.000181
Logarithmic	0.0197	0.000388	0.0234	0.000546	0.0288	0.000831	0.0357	0.001276
Henderson and Pabis	0.0558	0.003111	0.0545	0.002973	0.0376	0.001413	0.0457	0.002086
Two Terms Exponential	0.0643	0.004134	0.0608	0.003691	0.0406	0.001646	0.0470	0.002205
Two Terms	0.0596	0.003556	0.0230	0.000529	0.0280	0.000781	0.0384	0.001472
Diffusion Approach	0.0205	0.000420	0.0232	0.000536	0.0269	0.000723	0.0320	0.001021

the coefficient of determination (R^2) and mean relative error (P).

The mean relative error values indicate deviation of the observed values concerning the curve estimated by the model (Kashaninejad et al., 2007). Mohapatra and Rao (2005) consider models with inappropriate relative average error values when higher than 10%.

The study analyzed the models at all temperatures and found coefficients (R^2) ranging from 96.28% to 99.92%. Analysis of the models at all temperatures found coefficients (R^2) ranging from 96.28% to 99.92%. According to Madamba et al. (2007), these results adequately represent the phenomenon under study in which the R^2 values are greater than 95%. Regarding the mean relative error (P), researchers observed that Wang and Singh (50 °C), Page (60 °C and 70 °C), and Midilli (40 °C and 60 °C) presented values below 10%, highlighting them as the most suitable models for representing the drying phenomenon.

The models considered satisfactory were those of Wang and Singh (50 °C), Page (60 °C and 70 °C), and Midilli (40 °C and 60 °C). These models showed R^2 values above 99.85% and P values below 10%. Thus, through the joint analysis of the statistical parameters (R^2, P, SE, and $\chi 2$), these models showed a better adjustment to the drying process, with the model being the Midilli model selected for temperatures 40 and 60 °C. Therefore, the selection process for the models opted for Wang and Singh for temperatures of 50 °C and the Page model for 70 °C.

Carrot Peels

(**Table 4**) shows the values of protein, ether extract, L*, a*, b*, Chroma, Hue, and caloric value of carrot peels dried at temperatures of 40 °C, 50 °C, 60 °C, and 70 °C.

When drying carrot peels at a temperature of 70 °C, flours with a higher protein content of 11.82% were obtained compared to temperatures of 40 °C, 50 °C and 60 °C.

The values of the ether extract at temperatures of 40 °C and 50 °C were higher (0.016 g and 0.022 g) compared to temperatures of 60 °C (0.13 g) and 70 °C (0.10 g).

The flours were lighter in the color analysis of the carrot peel flour at 70 °C. (L* 54.18). Analyzing b* at temperatures 40 °C and 60 °C differed; at 70 °C, the value was lower, indicating a yellow hue. The carrot peel flours presented opaque (Chroma 29.37) and reddish (Hue 66.60) tones according to the increase in temperature.

In the calorimetry of carrot peel flours, the values also increased with increasing temperature. Souza et al.

Table 4. Mean values and standard error of protein (%), ether extract (%), instrumental parameters of color, and caloric value (kg) of carrot dry residue

Variables	Drying temperature (°C)			
	40	50	60	70
Protein	6.31 ± 0.04[c]	6.70 ± 0.02[c]	7.49 ± 0.03[b]	11.82 ± 0.01[a]
Ether extract	0.016 ± 0.001[ab]	0.022 ± 0.22[a]	0.013 ± 0.43[b]	0.010 ± 0.00[b]
L*	48.24 ± 0.01[b]	44.73 ± 0.04[c]	44.67 ± 0.03[c]	54.18 ± 0.02[a]
a*	16.57 ± 0.07[a]	15.02 ± 0.07[b]	12.04 ± 0.03[c]	11.64 ± 0.02[c]
b*	28.60 ± 0.02[b]	30.99 ± 0.03[a]	28.85 ± 0.01 [b]	26.95 ± 0.05[c]
Chroma	33.06 ± 0.03[b]	34.46 ± 0.02[a]	31.26 ± 0.01[c]	29.37 ± 0.05[d]
Hue	59.95 ± 0.22[c]	64.14 ± 0.03[b]	67.35 ± 0.00[b]	66.60 ± 0.01[a]
Caloric value	3406.00 ± 0.02 [c]	3386.00 ± 0.00[d]	3449.33 ± 0.00[b]	3518.67 ± 0.00[a]

According to Tukey's test, different letters on the line differ at the 5% significance level.

(2007) demonstrated that carrot peels have flours with fewer calories, precisely 42 kcal per 100 g. The authors suggest that the type of equipment, handling, and quality of the carrot influence the amount of nutrients in the flour.

In (**Figure 2**), it is possible to observe the drying time of the carrot peel in hours and the ratios of the moisture content (decimal) (RX) for the drying temperatures of 40, 50, 60, and 70 °C.

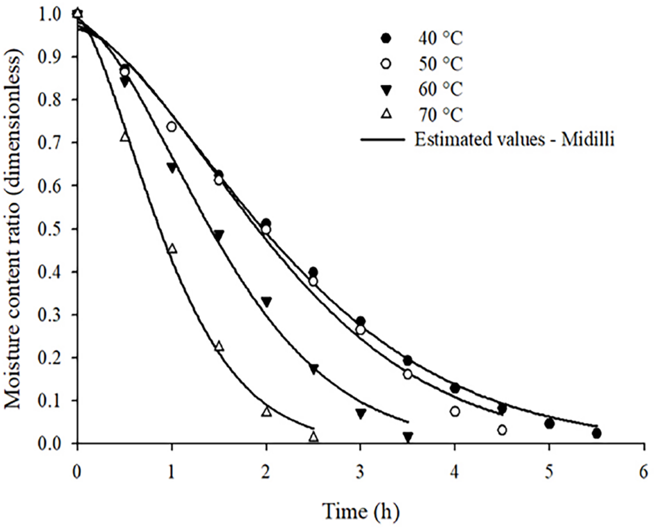

Figure 2. Moisture content ratio of carrot peel over drying time at temperatures of 40, 50, 60, and 70 °C.

In the same way, as it occurred in the potato peel, the different temperatures influenced the water loss in the carrot peel. Considering the time spent, results demonstrate that drying the carrot peel at 40 °C took 5.5 hours; for a temperature of 50 °C, it took 4.8 hours; for a temperature of 60 °C, 3.5 hours; and at a temperature of 70 °C, 2.5 hours.

(**Table 5**) presents the values for the Chi-square test (χ^2) and estimated average error (SE) calculated for the 11 models used in the representation of the drying kinetics of carrot peel.

Regarding the estimated average error (SE) and Chi-square (χ^2) analysis, the Wang, Singh, and Midilli models obtained lower values at all temperatures than the other models.

It is observed in (**Table 6**) that the models adjusted for all temperatures, presenting coefficients (R^2) between 95.71% and 99.84%, except for the temperature of 50 °C. In the mean relative error (P) values, results demonstrate that the Midilli model presented values lower than 10%, thus standing out as the adequate model to represent the drying phenomenon of the carrot peel.

Chayote peel

The values of protein, ether extract, L*, a*, b*, Chroma, Hue, and caloric value of chayote peel flours dried at temperatures of 40 °C, 50 °C, 60 °C, and 70 °C are shown in (**Table 7**). Chayote flour at 70 °C had 11.79% protein, the lowest value observed at all evaluated temperatures, possibly due to protein denaturation. Cristo et al. (2015), when studying chayote peel flour dried at 60 °C, obtained similar values (12.51%).

The ether extract values in the chayote peel flour did not differ for the different temperatures, maintaining the result at 0.01%. However, flours with higher amounts of ether extract were observed by Cristo et al. (2015) when analyzing chayote peel flour dried at 60 °C, which obtained values around 0.7%.

The temperature influenced the luminosity of the chayote peel flours, with lower luminosity obtained at 70 °C (L* 48.63). The Maillard reaction may have occurred due to sugars and proteins in the peel. According to Moser et al. (1995), at temperatures above 55 °C, non-enzymatic browning reactions (such as the Maillard reaction) are favorable, especially after 70 °C.

Higher temperatures (70 °C) resulted in flours with lower caloric value, similar to the study by Stork et al. (2013). When studying vegetable peels, the authors found 18.1 kcal in the chayote peel, popularly considered a nutrient-free food. However, in this study, it was observed that the chayote peel is nutritionally rich.

(**Figure 3**) shows the chayote peel drying time in hours and the moisture content ratios (decimal) (R^X) for

Table 5. Values for the Chi-square test (χ^2, x 10^{-3} decimal) and estimated mean error (SE, decimal) calculated for the eleven models used to represent the drying kinetics of carrot peel

Model	40 °C		50 °C		60 °C		70 °C	
	SE	χ^2	SE	χ^2	SE	χ^2	SE	χ^2
Wang and Singh	0.0176	0.000310	0.0131	11.324	0.0150	4.495	0.0184	25.312
Verma	0.0246	0.000605	0.0152	12.509	0.0172	4.789	0.0305	42.555
Thompson	0.0690	0.004754	0.0814	63.554	0.0828	33.365	0.0789	127.291
Page	0.0226	0.000512	0.0336	23.336	0.0269	10.668	0.0249	36.431
Newton	0.0657	0.004321	0.0767	63.551	0.0756	33.362	0.0706	127.319
Midilli	0.0155	0.000239	0.0134	9.300	0.0118	2.672	0.0078	5.205
Logarithmic	0.0240	0.000576	0.0150	12.225	0.0161	4.544	0.0312	43.842
Henderson and Pabis	0.0614	0.003771	0.0741	57.434	0.0754	30.910	0.0751	120.585
Two terms Exponential	0.0689	0.004753	0.0814	63.551	0.0828	33.363	0.0348	60.124
Two terms	0.0242	0.000584	0.0159	11.927	0.0184	4.451	0.0360	40.824
Diffusion Approach	0.0246	0.000605	0.0152	12.509	0.0172	4.789	0.0305	42.555

Table 6. Coefficients of determination (R^2, %) and mean relative error (P, %) for the analyzed models during drying of carrot peel at different temperatures (°C)

Model	40 °C		50 °C		60 °C		70 °C	
	P	R^2	P	R^2	P	R^2	P	R^2
Wang and Singh	12.650	99.75	11.324	99.87	4.495	99.84	25.312	99.82
Verma	19.771	99.57	12.509	99.84	4.789	99.83	42.555	99.63
Thompson	60.845	96.21	63.554	94.83	33.365	95.14	127.291	96.67
Page	15.586	99.59	23.336	99.12	10.668	99.49	36.431	99.67
Newton	60.845	96.21	63.551	94.83	33.362	95.14	127.319	96.67
Midilli	8.564	99.85	9.300	99.89	2.672	99.94	5.205	99.98
Logarithmic	19.147	99.59	12.225	99.85	4.544	99.85	43.842	99.61
Henderson and Pabis	53.362	96.99	57.434	95.71	30.910	95.96	120.585	96.99
Two terms Exponential	60.845	96.21	63.551	94.83	33.363	95.14	60.124	99.35
Two terms	17.854	99.63	11.927	99.85	4.451	99.86	40.824	99.65
Diffusal Approach	19.771	99.57	12.509	99.84	4.789	99.83	42.555	99.63

Table 7. Mean values and standard error of protein (%), ether extract (%), instrumental parameters of color, and caloric value (kg) of chayote dry residue

Variables	Drying temperature (°C)			
	40	50	60	70
Protein	14.73 ± 0.013 ^{a}	16.03 ± 0.029^a	15.13 ± 0.004^a	11.79 ± 0.030^a
Ether extract	0.01 ± 0.000^a	0.01 ± 0.000^a	0.01 ± 0.001^a	0.01 ± 0.001^a
L*	51.16 ± 0.011^a	47.72 ± 0.014^b	41.83 ± 0.016^c	48.63 ± 0.073^b
a*	-4.92 ± 0.045^c	-5.26 ± 0.080^c	-1.93 ± 0.286^b	0.08 ± 31.569^a
b*	22.90 ± 0.02^b	20.22 ± 0.02^c	22.11 ± 0.02^b	25.85 ± 0.07^a
Chroma	23.43 ± 0.015^b	20.90 ± 0.022^c	22.10 ± 0.022^b	25.97 ± 0.071^a
Hue	-77.87 ± 0.009^b	-75.44 ± 0.014^b	-85.02 ± 0.016^b	29.48 ± 2.868^a
Caloric Value	3726.00 ± 0.003^b	3771.67 ± 0.003^a	3711.00 ± 0.007^c	3727.00 ± 0.002^c

According to Tukey's test, different letters on the line differ at the 5% significance level.

the drying temperatures of 40, 50, 60, and 70 °C.

The different temperatures influenced the water loss of the product. Considering the time spent, results demonstrated that drying the chayote peel at 40 °C took 9.6 hours, 6.5 hours for a temperature of 50 °C, 4.5 hours at 60 °C, and 3 hours at 70 °C. Baptestini et al. (2015), when studying soursop foam drying, found that from the increase in air temperature, there was a reduction in the drying time of soursop foams. The model to determine the binomial critical moisture content and critical time and the Midili fit well to the soursop foam drying experimental data.

(**Table 8**) presents the values for the Chi-square test (χ^2) and estimated average error (SE) calculated for the 11 models used to represent chayote peel drying kinetics.

Regarding the estimated mean error (SE) and Chi-square ($\chi2$) analysis, the Midilli model obtained the lowest values compared to the others.

It is observed in (**Table 9**) that the models adjusted for all temperatures, presenting coefficients (R^2) between 97.94% and 99.99%. According to Madamba et al. (2007), these results adequately represent the phenomenon under study in which the R^2 values are greater than 95%.

Table 8. Values for the Chi-square test (χ^2, x 10^{-3} decimal) and estimated average error (SE, decimal) calculated for the eleven models used to represent chayote peel drying kinetics

Model	40 °C		50 °C		60 °C		70 °C	
	SE	χ^2	SE	χ^2	SE	χ^2	SE	χ^2
Wang and Singh	0.0121	14.229	0.0351	92,901	0.0044	2.368	0.0111	16.131
Verma	0.0277	29.593	0.0284	51,897	0.0178	16.160	0.0192	19.546
Thompson	0.0473	48.476	0.0400	55,854	0.0515	53.454	0.0420	49.148
Page	0.0117	7.413	0.0053	12.922	0.0175	15.434	0.0086	9.206
Newton	0.0460	48.475	0.0384	55,854	0.0482	53.449	0.0384	49.138
Midilli	0.0108	7.628	0.0051	5.731	0.0122	9.323	0.0075	6.528
Logarithmic	0.0273	28.856	0.0291	50.613	0.0189	17.260	0.0216	22.235
Henderson and Pabis	0.0403	39.418	0.0352	46.173	0.0474	48.876	0.0397	46.022
Two terms Exponential	0.0473	48.476	0.0400	55.858	0.0515	53.448	0.0420	49.146
Two terms	0.0253	25.859	0.0266	46.133	0.0221	19.126	0.0212	18.657
Diffusal Approach	0.0277	29.593	0.0284	51.898	0.0178	16.160	0.0192	19.546

Table 9. Determination coefficients (R^2, %) and mean relative error (P, %) for the analyzed models, during chayote peel drying at different temperatures (°C)

Model	40 °C		50 °C		60 °C		70 °C	
	P	R^2	P	R^2	P	R^2	P	R^2
Wang and Singh	14.229	99.86	92.901	98.95	2.368	99.99	16.131	99.92
Verma	29.593	99.33	51.897	99.36	16.160	99.80	19.546	99.82
Thompson	48.476	97.94	55.854	98.63	53.454	98.07	49.148	98.91
Page	7.413	99.87	12.922	99.98	15.434	99.78	9.206	99.95
Newton	48.475	97.94	55.854	98.63	53.449	98.07	49.138	98.91
Midilli	7.628	99.90	5.731	99.98	9.323	99.92	6.528	99.98
Logarithmic	28.856	99.35	50.613	99.34	17.260	99.78	22.235	99.77
Henderson and Pabis	39.418	98.50	46.173	98.94	48.876	98.37	46.022	99.03
Two terms Exponential	48.476	97.94	55.858	98.63	53.448	98.07	49.146	98.91

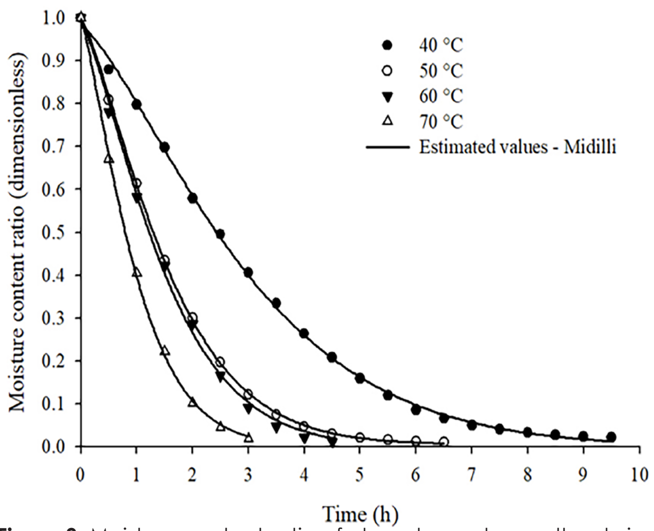

Figure 3. Moisture content ratio of chayote peels over the drying time at temperatures of 40, 50, 60, and 70 °C.

From the average relative error (P), it was observed that the Midilli model presented values below 10%, thus standing out as the most suitable model for representing the chayote peel drying phenomenon.

Determined equations for the different products

The model considered satisfactory in all temperature conditions evaluated was the Midilli model. This model presents R^2 values above 99.90% and P values below 10%. Thus, through the joint analysis of the statistical parameters (R^2, P, SE, and χ^2), the model better adjusted the drying process. In general, analyses of flours from potato, carrot, and chayote skins presented promising results compared to other literature.

(**Table 10**) shows the equations determined to estimate potato, carrot, and chayote skins drying under the different temperature conditions tested.

Table 10. Equations determined to predict drying of potato, carrot, and chayote skins at different temperatures (°C)

English potato	
Temperature (°C)	Equation
40	$RX = 0.9868.exp-0.1514.t^{1.2902}-0.0101t$
50	$RX= 1-0.3267.t+0.0267.t^2$
60	$RX=0.9959.exp-0.7344t^{1.2830}+0.0009.t$
70	$RX= 1-0.3267.t+0.0267.t^2$
Carrot	
Temperature (°C)	Equation
40	$RX=0.9877.exp-0.2551.t^{1.3322} - 0.0134.t$
50	$RX= 0.9941.exp-0.2265.t^{1.2074} - 0.0519.t$
60	$RX= 1.0009.exp-0.3206.t^{1.2517} - 0.0709.t$
70	$RX= 0.9997.exp-0.5277.t^{0.8449} - 1.02517.t$
Chayote	
Temperature (°C)	Equation
40	$RX= 0.9799.exp-0.2007.t^{1.3614} - 0.0001.t$
50	$RX= 0.9957.exp-0.4908.t^{1.3173} - 0.0008.t$
60	$RX= 0.9962.exp-0.5140.t^{1.2083} - 0.0133.t$
70	$RX= 0.9989.exp-0.9035.t^{1.2230} - 0.0061.t$

Conclusion

Flours obtained at higher temperatures showed satisfactory results, allowing their use to obtain flours in shorter times, accelerating the process without impairing their nutritional quality.

Among the models studied for potato skins, the models by Wang and Singh, Midilli, and Logarithmic were the most adequate. As for chayote and carrot peels, the Midilli model is the most appropriate.

By determining the equations as performed in this study, the drying process can be optimized for potato, carrot, and chayote skins. In this way, the research facilitates and encourages the use of vegetable residues in food preparations, presenting themselves as excellent nutritional sources and adding flavor and texture to food.

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