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Kinetics of Drying and Physical-Chemical Quality of Peach cv. Hubimel

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Abstract

The objective of this study was to perform the kinetics of peach drying and to adjust the experimental data obtained to empirical and diffusive mathematical models to evaluate the effect of temperature on the physical-chemical quality of the final product. The drying experiments were performed in an air circulation dryer with a velocity of 1.5 m s^{-1}, the drying kinetics were performed at temperatures of 60, 70 and 80 °C. Among the mathematical models applied, the Page model was the one that best fit the experimental data, because it presents greater efficiency in the description of the drying process. The decrease in the drying rate from the initial time to the end of the process was observed, increasing the temperature of the air caused a reduction in the drying time. It was verified through the analytical solution of the diffusion equation with infinite wall geometry that the increase of the drying temperature caused the increase of the diffusivity and convective coefficient of heat transfer. Through the Biot number, it can be stated that the first-type boundary condition would also describe the process satisfactorily. The fresh peach slices present high water content and water activity and the drying effect caused significant differences in all physical-chemical parameters analyzed.

Keywords: dehydration, *Prunus persica* L., mathematical models

1. Introduction

Peach (*Prunus persica* L.) is one of the most important fruits of the human diet, due to its unique flavor and high amount of nutrients present in its composition. However, peach fruits are highly perishable and exhibit rapid deterioration when stored at room temperature (Huan et al., 2019). According to Sun et al. (2019) peaches are usually harvested during the summer, a period that is characterized by a hot and humid climate, a fact that contributes to the greater susceptibility of the fruit to deterioration by microorganisms in the post-harvest period. Three to five days storage at room temperature would result in rapid changes in taste and texture.

Due to their high perishability, peaches must be submitted to food preservation techniques such as drying, which according to Defraeyer and Radu (2018) is a fundamental technology for their preservation, because when drying, the availability of this fruit is increased outside its season and its nutritional content is assured, as well as reducing post-harvest waste.

Conservation by drying is based on the fact that microorganisms, enzymes and the metabolic mechanism all require water for their activities. By reducing the amount of water available, water activity and the rate of chemical reactions are reduced and, as a consequence, the development of microorganisms is reduced, giving the product a higher quality for a longer period of time, thus, shelf life (Oliveira et al., 2015).

According to Santos et al. (2019) the drying of agricultural products can be described by several theoretical, semiteoric and empirical mathematical models that can be used later in equipment designs. Considering the diversity of biological structures involved in the transfer of heat and mass, and the observed effects on each product. Information about the conditions with which the product loses moisture is an issue that can be solved by incorporating widely used mathematical models (Leite et al., 2019).

Thus, the drying process for the peach emerges as an alternative to increase its post-harvest life, as it provides reduction in the amount of water, resulting in longer shelf life with decreased microbial activity. The objective of this study was to carry out the kinetics of drying peaches at temperatures of 60, 70 and 80 °C and to adjust the experimental data obtained to empirical and diffusive mathematical models, to evaluate the effect of temperature on physico-chemical quality of the final product.

2. Material and Methods

The peaches cv. Hubimel was acquired in the local commerce of the city of Campina Grande, Paraiba, Brazil. The samples of ripe stages and auverege size were selected, sanitized and cut manually in slices (0.6 mm), with the help of a domestic knife and caliper. The work was developed at the Food Drying Laboratory of the Federal University of Campina Grande.

2.1 Kinetics of Drying

The kinetics of drying were carried out in an air circulation oven with an air velocity of 1.5 m s^{-1} at temperatures of 60, 70 and 80 °C (Tecnal brand TE-394/4). The peach slices with a thickness of 0.6 mm were evenly distributed in trays. The experimental data were expressed in terms of the water content ratio (X* given by the relationship between the water content differences in time, t, and equilibrium water content (X (t) – X eq) of initial and equilibrium water (Xi-Xeq). As described in Equation (1):

$$X^*(t) = \frac{X(t) - X_{eq}}{X_i - X_{eq}} \tag{1}$$

Where, X^* = ratio of water content (dimensionless); X_{eq} = equilibrium water content (dry basis); $X(t)$ = water content (dry basis); X_i = initial water content (dry basis).

The empirical functions f (t, a, b) presented in Table 1 were fitted to the experimental data sets, using nonlinear regression using the LAB Fit Curve Adjustment Software (W. P. Silva & C. M. D. P. S. Silva, 2008). From the models presented in Table 1, the mathematical expressions for drying rate versus time are expressed as shown in Table 2. The results of the empirical models were evaluated using the chi-square, χ^2 and coefficient of determination, R^2 (Bevington and Robinson, 1992; Da Silva et al., 2008; Taylor, 1997; Silva et al., 2014).

Table 1. Empirical models to describe drying kinetics

Model Name	Empirical expression	Reference
Page	$X^* = e^{-at^b}$	Diamante et al. (2010)
Lewis	$X^* = e^{-at}$	Kaleta and Górnicki (2010)
Peleg	$X^* = t(a + bt)$	Mercali et al. (2010)
Handerson and Pabis	$X^* = ae^{-bt}$	Diamante et al. (2010)

Table 2. Drying rate expressions obtained through the empirical models

Model Name	Drying rate
Page	$\mathrm{d}X^*/\mathrm{d}t = -abe^{b-1}e^{-at^b}$
Lewis	$\mathrm{d}X^*/\mathrm{d}t = ae^{-at}$
Peleg	$\mathrm{d}X^*/\mathrm{d}t = \mathrm{a(a + bt)}^2$
Handerson and Pabis	$\mathrm{d}X^*/\mathrm{d}t = abe^{-bt}$

2.2 Analytical Solution of the Diffusion Equation

The average moisture content of the solid with infinite wall geometry at time t is given by

$$X^*(t) = \sum_{n=1}^{16} B_n \exp\left(-\mu_n^2 \frac{D}{L/2} t\right) \tag{2}$$

where, $X^*(t)$ is the moisture content at time t; X_{eq} is the moisture content for t→∞; X_i is the moisture content pa pa = 0; L is the thickness; D is the diffusivity; t is the time.

The number of terms of the summation was established with 16, instead of infinity, and the parameter Bn is given by:

$$B_n = \frac{2Bi^2}{\mu_n^2\left(Bi^2 + Bi + \mu_n^2\right)} \tag{3}$$

Given that *Bi* is the Biot number and is given by the following equation:

$$Bi = \frac{h(L/2)}{D} \tag{4}$$

Where, *h* is the convective coefficient of heat transfer; and is the characteristic equation for the infinite wall. In order to obtain the process parameters *D*, *h* and *Bi*, the optimization of the process was done according to the methodology described by Da Silva et al. (2010).

2.3 Physical-Chemical Characterization

The moisture content, total solids, ash, pH, titratable total acidity (ATT), total soluble solids (SST), ratio (SST/ATT) according to the methodology of the Institute were evaluated in triplcatas, in natura and dehydrated peaches Adolfo Lutz (Brasil, 2008). The water activity was determined in Aqualab 3TE (Decagon, Devices USA) at room temperature (25 °C). The content of vitamin C was determined by the reaction of ascorbic acid with 2.6-dichlorophenol indophenol (DCFI), according to the procedure described by Brasil (2008), and the results were expressed mg of ascorbic acid/100 g sample.

2.4 Statistical Analysis

The results of the analyzes were submitted to statistical treatment using a completely randomized design with a comparison test of means, using the software Assistat version 7.7 beta (Silva & Azevedo, 2016).

3. Results and Discussion

Table 3 shows the results obtained for the empirical models applied to the kinetics of peach drying, as well as the statistical indicators, chi-square (χ^2) and coefficient of determination (R^2).

Table 3. Results obtained for the models

Model	T (°C)	*a*	*b*	R^2	$\chi^2 \times 10^{-3}$
Page	60	0.273×10^{-2}	1.155	0.9993	1.831
	70	0.476×10^{-2}	1.086	0.9996	1.552
	80	1.269×10^{-2}	0.934	0.9996	1.234
Lewis	60	0.591×10^{-2}	-	0.9977	1.,111
	70	0.476×10^{-2}	-	0.9992	5.522
	80	0.127×10^{-2}	-	0.9993	3.947
Peleg	60	0.738×10^{-2}	-0.161×10^{-2}	0.9892	3.464
	70	1.095×10^{2}	0.8388	0.9896	42.679
	80	7.807×10^{1}	0.8753	0.9835	20.736
Handerson & Pabis	60	1.042	0.631×10^{-2}	0.9981	7.640
	70	1.028	0.750×10^{-2}	0.9943	2.126
	80	0.974	0.898×10^{-2}	0.9994	2.683

In the analysis of the statistical indicator (R^2), all models presented values above 0.980; with the lowest values of R^2 obtained for the Peleg model ($0.990 > R^2 > 0.980$) at all applied temperatures. However, only mathematical models with determination coefficients (R^2) above 0.990 were considered as good adjustments. Thus, the best Page model was fitted to the experimental data, because for all the applied temperatures, presented the highest values for this indicator.

High R^2 values were also obtained for the Lewis and Handerson and Pabis models, but according to Silva et al. (2019) for a model to adequately fit the experimental data, it is essential that besides R^2 be greater than 0.99 the chi-square χ^2 should be as low as possible. Therefore, in relation to the values of the lowest values were obtained for the page model ranging from 1.831 to 1.234×10^{-3} when there was a temperature variation of 60 to 80 °C.

It was also observed that the parameter "a" of the empirical squalls (Page and Peleg) showed a tendency to increase with increasing drying air temperature, the same parameter for the models of Handerson and Pabis and

Lewis decreased with increasing temperature. A similar pattern was observed for the parameter "b" where it increased as the temperature of the drying air increased, however, only the Page model presented different behavior. According to Moreira et al. (2018), parameter "b" is a constant of proportionality between the drying rate and the moisture ratio.

According to Zhu and Shen (2014) in evaluating the peach drying process, they observed that the change of moisture ratio with drying time at temperature ranging from 60 to 80 °C can be successfully described by the Page model. Resende et al. (2019) when studying the drying process of the seed bread, concluded that the Page model was the best fit to the experimental data. Leite et al. (2016) when applying empirical mathematical models on carambola drying kinetics, also determined that the Page model fitted more satisfactorily to the experimental data due to the higher coefficient of determination (R^2) and lower values of.

In Figure 1, the Page model can be observed as the one that best described the drying kinetics for the drying air temperatures applied.

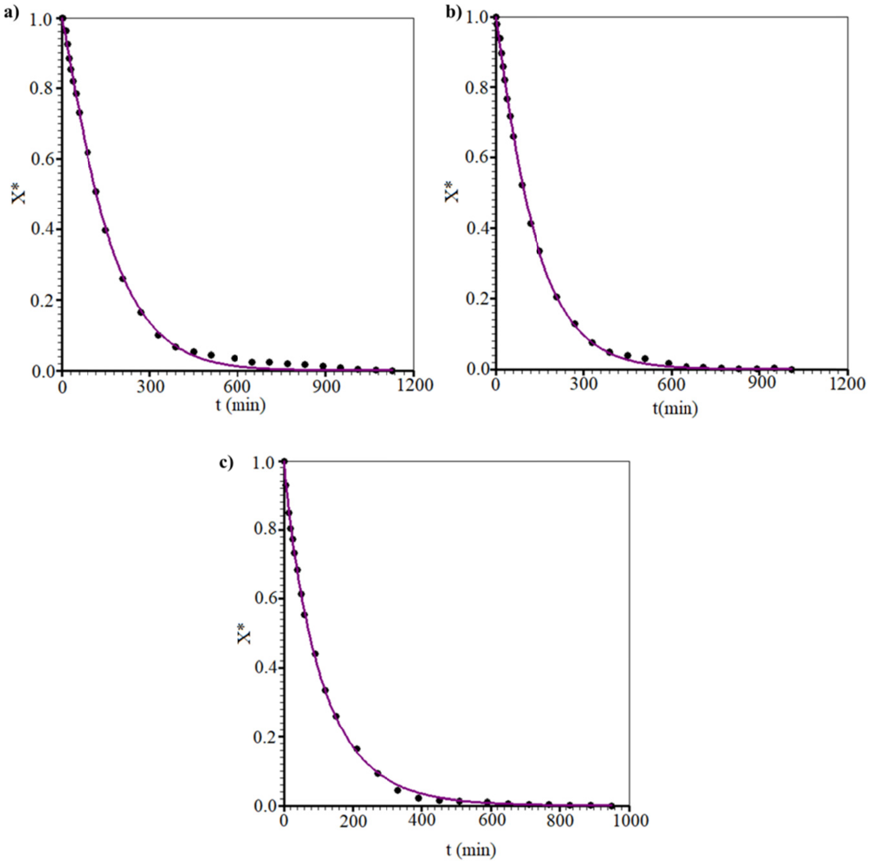

Figure 1. Drying kinetics simulations using the empirical model Page at temperature T:
a) 60 °C; b) 70 °C; c) 80 °C

Analyzing the graphs of Figure 1, it can be noted that the slices subjected to 60 °C required more time to reach equilibrium and consequently less time was required for the slices exposed to 80 °C. According to Santos et al. (2019) this phenomenon is due to the fact that at higher temperatures the kinetic energy of the water molecules is accelerated due to the higher heating energy (Deng et al., 2017; Aral & Beşe, 2016; Santos et al., 2014).

Figure 2 shows the curves representing the drying rates at all applied temperatures (60, 70 and 80 °C) due to the moisture content of the product, in which it was observed that the drying rate is proportional to the ratio of moisture. Therefore, the decrease of the drying rate ($-dX^*/dt$) from the initial time to the end of the process, which occurs when the drying rate has a null value, is shown to have been reached, showing that an equilibrium condition was reached. Moreira et al. (2018) in their studies on drying Kiwi slices, also found higher values of drying rate during the initial instants of the process, in which the product had higher values of moisture ratio.

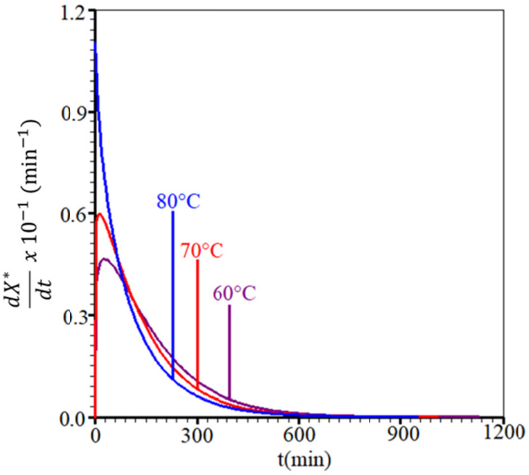

Figure 2. Drying rate calculated using the expression obtained through the Page model for temperatures of 60, 70 and 80 °C

In Table 4, the values for effective diffusivity (Def), convective coefficient of heat transfer (h) and number of Biot (Bi) obtained in the drying of peach slices at different temperatures are described.

Table 4. Results obtained by analytical solution for drying the peach slices

Temperature (°C)	$D_{ef} \times 10^{12}$ (m^2 min^{-1})	h × 10^6 (m min^{-1})	*Bi*
60	2.27	1.51	200
70	2.44	1.63	200
80	2.69	1.79	200

The addition of the drying air temperature provided the increase of the Def, presenting a variation of (2.27 to 2.69 × 10^{-12} m^2 min^{-1}). Santos et al. (2019) in studies with acuri slices, obtained diffusivity ranging from 3.28 to 5.53 × 10^{-11} m^2 s^{-1} when the drying temperature ranged from 60 to 90 °C. The increase in def indicates greater ease of mass transfer in the product, a fact that occurs due to the increase of the temperature applied in the process, which causes more agitation of the molecules and consequently the increase of the vapor pressure in the product. The increase in the values of Def is also associated with the change in the viscosity of the water present in the product, because with the increase in temperature the viscosity decreases and consequently favors the exit of the fluid from the interior of the product to the external environment (Lisbôa et al., 2015; Aral & Bese, 2016).

Regarding the convective coefficient of heat transfer, proportionality was observed in relation to the increase of the temperature of the drying air, presenting a variation of 1.51 to 1.79 × 10^{-6} m min^{-1}. It can be affirmed that, among the temperatures applied in the process, the temperature of 80 ºC allows a greater amount of heat transferred to the product. No correlation was observed between the number of Biot (Bi) and the temperature of the drying air, because in all applied treatments Bi presented a value corresponding to 200. This high value indicates that the first type contour condition would also describe the process of drying peach slices satisfactorily. Bi is a admensional number that correlates internal wicking rate with the rate of external convection and is capable of displaying the internal resistance of the product to heat and mass transfer process (Giner et al., 2010; Bezerra et al., 2015).

The nutritional quality of a product can be represented by its initial composition. It is necessary to determine its composition to judge the effect of process variables on the final product, in this way in Table 5 are expressed the values obtained for the peach *in natura*.

Table 5. Physical-chemical characterization of peach *in natura*

Parameters	*In natura*
Moisture content (% w.b)[1]	89.66±0.36
Total Solids (%)	10.34±0.36
Water activity (a_w)	0.946±0.25
pH	6.66±0.14
Titratable total acidity-ATT (% citric acid)	0.47±0.05
Total Soluble Solid-SST (°Brix)	12.5±0.19
Ratio (SST/ATT)	26.60±0.61
Vitamin C (mg of ascorbic acid 100 g^{-1} sample)	88.63±0.64
Ashes (%)	0.59±0.02

Note. [1] wet basis.

The physical-chemical analysis performed on the fresh peach shows that it is a fruit of high content and activity of water, with total solids content of 10.34%. Such conditions are related to the stability of the fruits, since the greater water content leads to the proliferation of deteriorating microorganisms. Such values of water content and activity are close to those found by Dermesonlouoglou et al. (2019), whose values were 87.99% and 0.9815, respectively.

The pH, titratable acidity, total soluble solids and found ratio, reveal that the fruit has characteristic little acid, sensory sweetened, primarily due to higher levels of total sugars, which provides sensory characteristics preferred for direct consumption and industrialization (Goncalves et al., 2017). Lower pH values were found by Dermesonlouoglou et al. (2019) and Ullah et al. (2016), with values of 3.7 and 3.57, respectively. The same was observed for the vitamin C content, in which the values found were higher than those presented by Mir et al. (2018), whose initial value was 10 mg of ascorbic acid 100 g^{-1} sample, to cultivar Shan-e-Punjab. However, Sousa et al. (2018), found values close to those found in this work, pH and vitamin C of 6.7 and 110 mg of ascorbic acid 100 g^{-1} sample, respectively, for the cultivar Rubimel. The results show that the variation between the physical-chemical characteristics found in this work and those observed in the mentioned literature may be due to the differences between the cultivars, stage of maturation, system and place of production.

The average ash content of fresh fruit is similar to that presented in the Brazilian Table of Food Composition (Taco, 2011), whose value is 0.5% for aurora peach.

All the physical-chemical parameters analyzed for the dried peach (Table 6) were statistically significant ($p > 0.05$), for the effect of drying temperatures. The moisture content was lower when there was an increase in the drying temperature (80 °C), being inversely proportional to the concentration of total solids. Showing greater efficiency of the drying process at the temperature of 80 °C. Second Ferrão et al. (2019) drying causes chances in taste, colour and texture that results in unique properties. However, relatively rigid and permanent cell distortions are common in dehydrated products, which impart an aspect of surface wrinkling, of varying degrees (Fagundes et al., 2005).

This behavior was verified by the parameter of water activity (a_w), which ranged from 0.409 to 0.358, at temperatures of 60 ° C and 80 °C, respectively. These values are consistent with the data presented by Zhang et al. (2017), who found values of water activity ranging from 0.327 to 0.376, for drying of cylinders of peaches affected by osmotic pretreatment.

Table 6. Physical-chemical characterization of dehydrated peach slices

Parameters	Convective drying		
	60 °C	70 °C	80 °C
Moisture content (%d.b)[1]	11.0^a	10.03^b	9.22^c
Total Solids (%)	89.0^c	89.97^b	90.78^a
Water activity	0.409^a	0.379^b	0.358^c
pH	6.52^a	6.43^b	6.32^c
Titratable total acidity (% Citric acid)	1.26^c	1.59^b	1.82^a
Total Soluble Solid (°Brix)	13.0^b	13.67^a	14.17^a
Ratio (SST/ATT)	10.32^a	8.61^b	7.78^c
Vitamin C (mg of ascorbic acid/100g sample)	70.85^a	64.42^b	51.45^c
Ashes (%)	0.66^b	0.71^a	0.72^a

Note. [1] dry base; Letter superscripts equal in the same line do not present significant difference at the 5% probability level.

The pH decreased in the drying process and the temperature increased. Inversely proportional to pH, the titratable acidity increased, ranging from 1.26 to 1.82% citric acid, at temperatures of 60 °C and 80 °C, respectively. The titratable acidity data are consistent with those reported by Zhang et al. (2017), in the study with peach jiubao.

The total soluble solids content increased up to 1.67 °Brix when compared to the fresh slices (Table 5) in relation to the dehydrated slices, with the increase of the drying temperature. This behavior results from the lower water content, and the solids concentration. The ratio ratio (SST/ATT) decreased compared to fresh fruit. The decrease in the ratio ratio is due to the increase of the acidity after the dehydration process, at the temperatures analyzed. According to Brasil (1996), this relationship is used as an indication of the degree of maturation of the fruit, evidencing the predominant flavor in the same, whether sweet or acid, or if there is a balance between them.

Vitamin C, considerably reduced at temperatures of 60 and 80 °C, expected result, since the drying conditions of the peach slices greatly affect the retention of vitamin C in the dehydrated product. According to Shewale and Hebbar (2017), the degradation of ascorbic acid depends on several factors, which include oxygen, metal ion catalysis, light, temperature and moisture content. The retention of vitamin C was higher than the values found in studies of drying kiwi slices (Pham et al., 2018), and dried apples by different processes (Shewale & Hebbar, 2017), which observed a mean loss of 56.23% of vitamin C, compared to dried fruit, for the conventional hot air drying system.

The temperature of 60 °C was considered to be more suitable for the drying of peach slices, since the treatment allowed the better preservation of vitamin C of the product when compared to the other samples that presented greater degradation of vitamin c.

The ash content increased in proportion to the increase in the drying temperature, since, with increasing temperature, the efficiency of the fruit dehydration process increased. The values obtained in the present study are within the range suggested by the Adolfo Luttz Institute (Brasil, 2008), which suggests the ash content in foods, such as dehydrated fruits varying from 0.3 to 2.1%.

4. Conclusion

The Page model was the one that best described the drying process of the peach because it had the largest R2 and the smallest. There was a decrease in the drying rate from the initial time to the end of the process. The analytical solution of the diffusion equation with infinite wall geometry showed increased diffusivity and convective coefficient of heat transfer with increasing drying temperature. The Biot number indicated that the first-type contour condition would also satisfactorily describe the process. The fresh peach showed high content and water activity and the addition of drying air temperature caused an increase in the total soluble solids content, ash content and acidity. However there was reduction in water content, water activity, vitamin C and pH.

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