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Drying kinetics and the effect of blanching pretreatment in the physical characteristics of the dehydrated banana

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ABSTRACT

The aim of this study was to evaluate and select the drying kinetic model of thin-layer drying of banana slices and the effect of blanching pretreatment on color. In order, 16 semi-theoretical and/or empirical models were applied to the experimental data and compared according their coefficients of determination (R^2), sum squared errors (SSE), and root mean square error (RMSE), which were predicted by non-linear regression analysis. The drying kinetics of banana slices were obtained at 50 °C, 60 °C and 70 °C for 630 min. The thermal blanching treatment effect was carried out on samples subjected to drying at 50 and 60 °C. Chromatic characterization and shrinkage analysis were performed. Among the thin-layer drying models considered to determine the kinetic drying parameters, the semi-theorical Two-term model gave the best fit for all drying conditions. Effective moisture diffusivity varied from 8.25×10^{-11} m^2s^{-1} to 2.26×10^{-10} m^2s^{-1} over the temperature range of the study. The increase in temperature led to a 60% average volume reduction. For color, the parameters L* and b* decreased, and a* increased with the temperature increase, and samples blanched and dried at 50 °C were similar to the fresh sample for lightness.

Keywords: *Musa acuminata*, dehydration, drying models.

INTRODUCTION

Banana (*Musa acuminata*) is a low-cost tropical fruit with high nutritional value. The fruit is compound majoritarily in carbohydrates, potassium, vitamins B, and C (MOHAPATRA et al., 2010). In 2018, Brazilian annual production was about 7 million tons, thus Brazil is the fourth largest banana producer in the world (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2020). Banana can be consumed fresh, fried, baked, homemade sweet, dried or in industrialized products and this application range makes this fruit one of the most consumed in the world (AURORE et al., 2009; QAMAR and SHAIKH, 2018). Bananas are usually consumed fresh, but the quality of this raw material may deteriorate rapidly after harvesting, with a loss of around 50% over its initial production (QAMAR and SHAIKH, 2018). This loss is related to fruit processing in the stages between producer and consumer, which can occur due to lack of appropriate post-harvest, storage, and transport technology (HAILU et al., 2013).

Bananas deteriorate rapidly due to their high water activity (0.90), which decreases the shelf life and marketability of fresh bananas once ripened (ZABALAGA et al., 2016). Thus, drying is one of the most widely used processes for fruit preservation (OWUNDE et al., 2016; CASTRO et al., 2018). Drying is defined as a simultaneous phenomenon of mass and heat transfer between the water in the product and air (CACCAVALE et al., 2016), this process, under controlled temperature and humidity conditions, is considered an effective method of prolonging the shelf life of the raw material, decreasing the initial moisture content to a safe limit, and guaranteeing high product quality during long-term storage (PROIETTI et al., 2018). This process decreases water activity in the fruit, thus minimizing physical and chemical changes during storage, and inhibits the occurrence of biochemical reactions, enzymatic reactions responsible for deterioration, and the growth of microorganisms, allowing greater fruit preservation and, consequently, increasing the product’s shelf life (OMOLOLA, et al., 2017; CACCAVALE et al., 2016).

In the course of drying, characteristic darkening of the raw material may occur, possibly due to solute concentrations and the Maillard reaction, making it necessary to apply a method such as blanching. In addition, volume shrinkage may occur because of microstructural changes in the fresh material, such as an increase in cavities caused by moisture removal (SARPONG et al., 2018).

The study of drying kinetics of agricultural materials is important for improving dryer efficiency, reducing operating costs, and increasing dehydrated product quality (PROIETTI et al., 2018; CASTRO et al., 2018). Thus, the use of drying kinetics models is indispensable to the estimation of the time required to reduce the moisture content of the final product under different drying conditions and contributes to improved processing efficiency. In addition, the energy required for material drying is determined (ONWUDE et al., 2016; CASTRO et al., 2018).

The most widely used theory to explain the mechanism of water removal from material to be dehydrated is diffusion along a concentration gradient (DHANUSHKODI et al., 2017). Thus, the diffusion equation is used by many authors to describe the drying behavior of agricultural products such as banana (OMOLA et al., 2015; Da SILVA et al., 2015), mango waste (WILKINS et al., 2018); cassava pulp (CHARMONGKOLPRADIT et al., 2017); cashew (DHANUSHKODI et al., 2017); and pear (PROIETTI et al., 2018). The drying process can be predicted by using an appropriate thin-layer model. Thin-layer drying means placing a layer of particles, samples, or slices in contact with hot air (ONWUDE et al., 2016; CASTRO et al., 2018). Thin-layer models can describe the drying phenomenon in agricultural products; these models are classified as theoretical, semi-theoretical, and empirical (ASHTIANI et al., 2017).

The main difference between of the three model classifications is that the theoretical model considers that mass transfer between the product and air is mainly controlled by internal resistance, while the other two classes of model consider only external resistance (CASTRO et al., 2018). The most used theoretical model is Fick´s second law of diffusion (ONWUDE et al., 2016). Semi-theoretical models are derived from the general solution of Fick’s second law of diffusion or its simplified variation of Newton’s law of cooling. The most often used among thin-layer drying semi-theoretical models are the Newton model, Henderson and Pabis model, Modified Henderson and Pabis model, Page model, Modified Page model, Two-term model, exponential Two-term model, Midilli-Kucuk model, logarithmic model and Verma et al. Model (ASHTIANI et al., 2017). The empirical models are derived from experimental data on the relation between moisture content and time and have no physical implications for the drying process (ONWUDE et al., 2016).

The aim of this work was to examine the drying kinetics of banana, determine the mathematical drying model that best describes the drying behavior of bananas, and evaluate the effect of blanching treatment on color and drying temperature on shrinkage.

MATERIAL AND METHODS

Material Preparation

Bananas (*Musa acuminata*), subgroup Cavendish, with commercial origin from the producers of the Massaranduba, Santa Catarina, Brazil, were purchased from a local supermarket of Umuarama, Paraná, Brazil. The fruits were visually selected for integrity and degree of ripeness close to 5, following a scale from 1 to 7 (PBMH e PIF, 2006). The fruits were washed with drinking water, peeled, and sliced to a thickness of 5 mm.

Drying Kinetics

Experiments on the drying kinetics of banana by forced convection were performed in triplicate by using a circulating oven (MARCONI Model MA035). Banana slices were identified, weighted on an analytical balance (MARTE Model UX420H), placed in a metal basket, and sent to the oven. Drying experiments were carried out at air temperatures of 50, 60, and 70 °C. Bananas must be dried using a maximum temperature of 70 °C to keep acceptable quality in nutritional terms (FARIA et al., 2020).

The samples were weighed every 15 min during the first 60 min of drying and every 30 min for 570 minutes of drying. The drying period was standardized for the three different temperatures. Humidity of the samples was carried out in an oven (Logen Scientific, Model SP – 1.0) at 105 °C until they reached a constant weight (AOAC, 1995).

Blanching

Banana slices subjected to the thermal blanching treatment were submerged in boiling water at 100 °C for 1 minute and then submerged in cold water at 0 °C for 30 seconds for enzymatic inactivation of the raw material. Then, the samples were dried at 50 °C and 60 °C for a period of 630 min. Above 65 °C, starch would undergo gelatinization accompanied by swelling which would decrease the porosity and then slow down the moisture transfer rate. (DEMIREL and TUHAN, 2003). Humidity was determined as described for drying kinetics above.

Mathematical Modeling of Drying Curves

The experimental drying data were fitted to the 15 mathematical thin-layer drying models listed in Table 1, to determine the model that best describes the drying curve.

Table 1 –Thin layer drying models applied to drying curves.

Model name	Equation	Reference
Newton	$MR = exp(-kt)$	ERTEKIN and FIRAT, 2017
Page	$MR = exp(-kt)^n$	JUNIOR; SANTOS; SOUZA, 2018
Modified Page II	$MR = \exp[-(kt)^n]$	ERTEKIN and FIRAT, 2017
Modified Page III	$MR = k\exp(-t/d^2)^n$	ERTEKIN and FIRAT, 2017
Henderson e Pabis	$MR = a\ exp\ (-kt^n)$	KUMAR and SAXENA, 2016
Modified Henderson and Pabis	$MR = a\ exp\ (-kt) + b\ exp\ (-gt) + c\ exp\ (-ht)$	ONWUDE et al., 2016
Midili and others	$MR = a\ exp\ (-kt) + bt$	ONWUDE et al., 2016
Logarithmic	$MR = a\ exp\ (-kt) + c$	ASHTIANI et al., 2017
Two-term	$MR = a\ exp\ (-k_1t) + b\ exp\ (-k_2t)$	MAHJOORIAN et al., 2017
Hii and others	$MR = a\ exp\ (-k_1t^n) + b\ exp\ (-k_2t^n)$	ONWUDE et al., 2016
Wang and Singh	$MR = 1 + at + bt^2$	OMOLA et al., 2015
Diamante and others	$ln(-ln(MR)) = a + b(lnt) + c(lnt)^2$	DIAMANTE et al., 2010
Weibull	$MR = a - b\ exp\ (-k_0t^n)$	ONWUDE et al., 2016
Silva and others	$MR = exp\ (-at - b\sqrt{t})$	ONWUDE et al., 2016
Peleg	$MR = 1 - t/(a + bt)$	Da SILVA et al., 2015

MR – Moisture ratio; k – Drying constant (min-1); t – Time (min); a, b, c, d e n – Model constant.

Source: Elaborated by the author (2020).

The moisture ratio of banana was calculated using the Equation 1

$$MR = \frac{(M - M_e)}{(M_0 - M_e)} \tag{1}$$

where MR is the moisture rate, M is the moisture content at any given instant in % dry base (db), Me is the equilibrium moisture content in % db, Mo is the initial moisture content in % db. To determine the equilibrium water content, the samples were kept in the dryers until they reached a constant weight.

The model parameters were determined by nonlinear regression analysis with the software MATLAB version 9.2. Different drying models were compared according to their coefficients of determination (R^2), sum squared errors (SSE), and root mean square error (RMSE) to determine the best fit (ERTEKIN e FIRAT, 2017). These critical parameters were calculated by using Equation 2, 3 and 4.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} \left(MR_{exp} - MR_{pred}\right)^2}{\sum_{i=1}^{n} \left(MR_{exp} - \overline{MR}_{exp}\right)^2} \tag{2}$$

$$SSE = \sum_{i-n}^{n} \left(\mathrm{MR}_{exp} - \mathrm{MR}_{pred}\right)^2 \tag{3}$$

$$RMSE = \sqrt{\frac{\sum(\mathrm{MR}_{exp} - MR_{pre})^2}{n}} \tag{4}$$

where, MR_{exp} is the experimentally observed moisture ratio, MR_{pre} is the predicted moisture ratio, $\overline{MR}_{exp}$ is the average experimental MR and n is the number of experimental observations. The lowest SSE and RMSE values and the R^2 value closer unit one (1) indicate a good fit of the model to the experimental data.

Effective Diffusion Coefficients

The effective diffusion coefficients of moisture (D_{eff}) were determined according to Fick's Second Law applied to an infinite slab. The diffusion model has been applied to the drying of agricultural products in the falling rate period (ONWUDE et al., 2016). Therefore, the analytical solution of the following diffusion equation (Equation 5) was described by Crank (1975).

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left[\frac{-(2n+1)^2 . \pi^2 . D_{eff}}{4L^2} t\right] \tag{5}$$

where D_{eff} is the effective diffusion coefficient of moisture (m^2s^{-1}); L is the thickness of the fresh samples (m); t is time (s); and n is the number of terms of the series.

Effective diffusion coefficients were calculated from the experimental data according to Equation 5 using Statistica® 8.0 software, which uses the least square estimation method to perform the calculations. The least square estimation method aims to minimize the sum of the squared deviations of the values observed for the dependent variable from those predicted by the model. A convergence criterion of 1×10^{-6} was used, and the estimated parameters (D_{eff}) and standard errors were displayed on a spreadsheet.

Five terms were used in the calculations of moisture diffusivity, i.e., n = 5 in Equation 5.

Color Measurements

Chromatic characterization was performed for samples submitted to kinetic analysis at 50 °C, 60 °C, and 70 °C before and after drying. To evaluate the effect of blanching on the color of the samples, temperatures of 50 °C and 60 °C were selected and the results compared with those of fresh samples after 10 hours and 30 minutes of drying for the different ranges of temperature.

Color parameters were determined by using the Minolta CR-400 colorimeter (Konica Minolta Inc., Japan), and the results were expressed in accordance with the CIELab color space. The analyzed parameters were L* (L = 0 (black) and L = 100 (white)), a* (– a = greenness and + a = redness), b* (– b = blueness and + b = yellowness). Color coordinates were measured at five points on the surface in a reflectance regime calibrated to daylight (JAISWAL et al., 2014).

Chroma (C*) and angle hue (° h) describe the relationship between the values a* and b* that indicate the actual color and saturation of the object to be analyzed, respectively (HARDER, CANNIATTI-BRAZACA; ARTHUR, 2007). Equations 6 and 7 were used to determine the C* and ° h of banana samples.

$$C^* = \left[a^{*2} + b^{*2}\right]^{\frac{1}{2}} \tag{6}$$

$$°h = arctang\left(\frac{b^*}{a^*}\right) \tag{7}$$

For a* and/or b* parameters with negative values, Equation 8 was used to determine the hue angle of the banana samples.

$$°h = 180 + arctang\left(\frac{b^*}{a^*}\right) \qquad (8)$$

Shrinkage Measurements

A shrinkage analysis was performed by measuring the diameter at three different points and the thickness of the banana slices in the native form and after 10 hours and 30 minutes of drying as indicated. Diameter values were obtained with calipers. To determine the shrinkage of banana samples after drying kinetics, the sample volume was calculated through Equation 9, where L is the thickness and the radius of the banana slice in centimeters (LEITE et al., 2015).

$$V = L\pi r^2 \qquad (9)$$

Statistical Analysis

All analyses were performed in triplicate. The results were evaluated by analysis of variance (ANOVA) using the Tukey test with a significance level of 5% ($\alpha = 0.05$), with the aid of Statistica® 8.0 software.

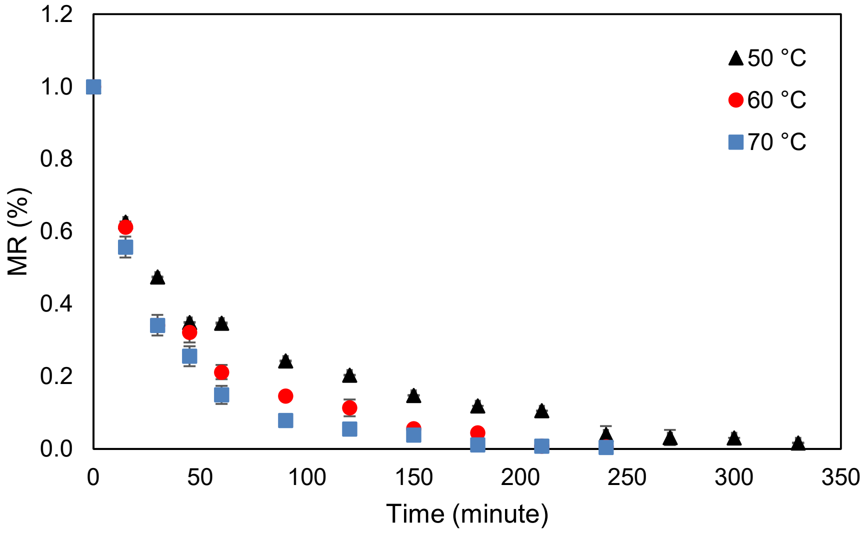
RESULTS AND DISCUSSION

Drying curves

The initial moisture content of fresh banana was 76.65% ± 0.89. In reports in the literature, the moisture content of fresh banana varies in the range of 76%–78% (ROMANO et al., 2008; KATEKAWA e SILVA, 2007). The pulp moisture content of the pulp increases during the ripening process due to the breakdown of starch into smaller carbohydrates, thus moisture migration from the shell to the pulp occurs (MOHAPRATA et al., 2010; YAP et al., 2017).

Moisture content data for different drying conditions were converted to moisture ratios (MR). This is because MR curves better explain the drying behavior of products than moisture content curves, as the starting MR for all experiments was set at one. Thus, the drying curves were plotted for banana slices of the yellow Cavendish variety at temperatures of 50, 60, and 70 °C, as shown in Figure 1.

Figure 1 - Moisture ratio (MR) for banana slice as a function of time at (▲) 50, (●) 60, and (■) 70 °C.



Source: Elaborated by the author (2020).

The drying curves were characteristic of fruits and vegetables, since the drying rate interval was not constant on the drying curves. On the other hand, the curves showed that the drying process occurred during the falling rate period for all conditions tested. This shows that moisture removal from samples was faster during the early stages of the drying process, which decreases as the drying time increases. MR continued to decrease during drying. From the decreasing MR values, it can be concluded that diffusion probably controls internal moisture transfer. This suggests that internal diffusion was the mechanism for controlling mass transfer of samples (ONWUNDE et al., 2016). Food drying may allow for this internal control, mainly due to its complex structure and composition (MUSIELAK et al., 2016). Similar results were reported by ASHTIANI et al. (2017) for peppermint leaves, La Fuente et al. (2017) for banana, Kumar and Saxena (2016) for banana peel and Costa et al. (2019) for patawa pulp.

The time required for the drying process is determined when the steady state is reached. As shown in Figure 3, the drying time decreased with increasing temperature, since at 50 °C, 60 °C, and 70 °C, the samples reached steady state at times of 360, 210, and 180 minutes, respectively. At 70 °C, there was an increase in transfer of energy in the samples, halving the time required for the drying process to reach equilibrium, relative to a temperature of 50 °C. Increasing the temperature increases the heat transfer rate; in turn, the water molecules move faster, and the result is acceleration of moisture removal from the samples (GUINÉ et al., 2019). A decrease in drying time with an increase in drying temperature has been reported for many food products, such as eggplant (BRASIELLO et al., 2013), cassava (CHARMONHKOLPRADIT and LUAMPON, 2017), kiwi (DIAMANTE et al. 2010), and green banana (ZABALAGA et al., 2015).

Mathematical modeling of drying curves

The drying curves in Figure 1 were adjusted by 15 thin-layer mathematical models, presented in Table 1. The results of statistical analysis of these models of banana drying are shown in Table 2. Three criteria for adequacy of the model fit, R^2, SSE, and RMSE, were used to validate the models.

Table 2 - Results of statistical analysis on thin-layer drying curve models.

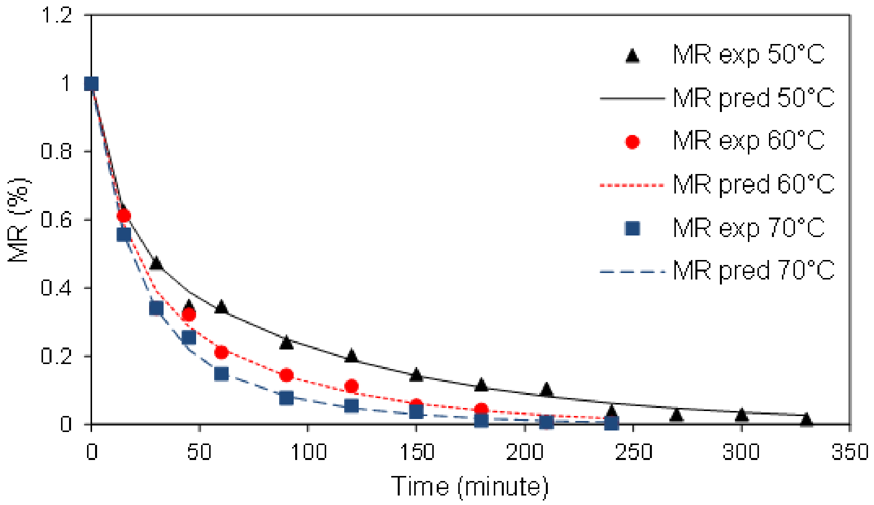
Model	Temperature (°C)	SSE	R^2	RMSE
Lewis	50	0.07037	0.9347	0.07090
	60	0.02573	0.9725	0.05073
	70	0.00771	0.9920	0.02777
Page	50	0.00654	0.9939	0.02242
	60	0.00735	0.9921	0.02858
	70	0.00112	0.9988	0.01117
Modified Page II	50	0.00654	0.9939	0.02242
	60	0.00735	0.9921	0.02858
	70	0.00123	0.9987	0.01169
Modified Page III	50	0.00653	0.9939	0.02333
	60	0.00734	0.9922	0.03029
	70	0.00112	0.9988	0.01184
Henderson and Pabis	50	0.00653	0.9929	0.02333
	60	0.00734	0.9902	0.03029
	70	0.00112	0.9985	0.01184
Modified Henderson and Pabis	50	0.00999	0.9907	0.03333
	60	0.01185	0.9873	0.04867
	70	0.00215	0.9978	0.02074
Logarithmic	50	0.03670	0.9603	0.05530
	60	0.01558	0.9834	0.04413
	70	0.00442	0.9954	0.02351
Midili	50	0.04434	0.9588	0.06079
	60	0.01918	0.9795	0.04897
	70	0.00394	0.9959	0.02219
Wang	50	0.43850	0.5930	0.18370
	60	0.28800	0.6923	0.17890
	70	0.32870	0.6569	0.19110
Two-term	50	0.00410	0.9962	0.01931
	60	0.00221	0.9976	0.01566

	70	0.00077	0.9992	0.01049
Hii	50	0.00875	0.9919	0.02959
	60	0.00536	0.9943	0.02988
	70	0.00106	0.9989	0.01327
Weibull	50	0.00421	0.9961	0.01956
	60	0.08883	0.9905	0.03562
	70	0.00128	0.9987	0.01353
Da Silva	50	0.00580	0.9946	0.02112
	60	0.00554	0.9941	0.02812
	70	0.00146	0.9985	0.01272
Peleg	50	0.00946	0.9912	0.02697
	60	0.00575	0.9939	0.02527
	70	0.00271	0.9972	0.01734
Diamante	50	0.09555	0.9816	0.09775
	60	0.14690	0.9692	0.14490
	70	0.02962	0.9938	0.06505

Source: Elaborated by the author (2020).

The evaluated models presented R^2 above 0.93, except for the Wang model. The lowest SSE and RMSE values were obtained Two term model to temperature of 70 °C, 0.00077 and 0.01049, respectively. Furthermore, Two term model also presented the lowest values of SSE and RMSE for temperatures of 50 °C and 60 °C. Although most of the models evaluated present satisfactory fit, Two term model was chosen because it presented the highest R^2 value and the lowest SSE and RMSE values. The values of R^2, SSE, and RMSE values of the Two-term model ranged from 0.9992 to 0.9962, 0.00077 to 0.00410, and 0.01049 to 0.01931, respectively. Figure 2 presents the data predicted by the model and the experimental data.

Figure 2 - Experimental and predicted total dimensionless water content temporal profiles during banana drying at different temperatures.



Source: Elaborated by the author (2020).

The Two-term model is the first two terms of the general solution of Fick's Second Law series (ERTEKIN and FIRAT, 2015). The first term describes the last part of the drying process, while the second term describes the beginning of the drying process. For fruits and vegetables with a high moisture content, this model may be suitable, as it assumes constant temperature and diffusivity during the drying process (ONWUNDE et al., 2016). The Two-term model with the best fit to the experimental data has also been applied to predict the drying behavior of green banana (ZALANGA et al., 2015), banana (OMOLOLA et al., 2015), cashew (DHANUSHKODI et al., 2017), and curcuma (LAKSHMI et al., 2019).

Table 3 shows the coefficients of the Two-term model obtained for drying banana slices at 50, 60, and 70 °C.

Table 3 - Coefficients of the Two-term model for drying banana slices.

Temperature	a	k_1	b	k_2
50 °C	0.5742	0.0092	0.4263	0.0124
60 °C	0.5262	0.0533	0.4777	0.0136
70 °C	0.6745	0.0652	0.3252	0.0160

Source: Elaborated by the author (2020).

The coefficients k_1 and k_2 of the Two-term model are the drying constants, and coefficients a and b are dimensionless empirical constants. The values of drying constants k_1 and k_2 increased as a function of the increase in drying kinetic temperature, because the higher the drying temperature, the easier it will be to lose free water, as demonstrated by Adiletta et al. (2016) for grapes and Mahjoorian et al. (2017) for kiwi slices.

The effective moisture diffusivity (D_{eff}) of foods represents their intrinsic moisture mass transfer characteristics, consisting of parameters such as liquid diffusion, molecular diffusion, hydrodynamic flow, vapor diffusion, and other mass transport mechanisms (ASHTIANI, et al., 2017). Table 4 shows the mean values obtained from the effective diffusivity coefficient (D_{eff}) obtained by applying the Fick model (Equation 5) to the banana drying experimental data for the three different temperatures.

Table 4 - Effective diffusivity coefficient at different temperatures.

Temperature (°C)	D_{eff} (m^2s^{-1})
50	$8.25x10^{-11a}$
60	$1.94x10^{-10b}$
70	$2.26x10^{-10c}$

[abc] Means followed by the same letter in the column do not differ by Tukey test (p>0,05).

Source: Elaborated by the author (2020).

The values of the diffusion coefficient were significantly different between the three evaluated temperatures, and D_{eff} was influenced by the drying air temperature, because increasing this parameter resulted in an increase of D_{eff}. Increasing the temperature raises the kinetic energy of water vapor and, therefore, water vapor diffusivity increases. This situation increases the drying rate and reduces critical moisture (BORGES et al., 2011).

For agricultural products such as dwarf banana, the effective diffusion coefficient values (D_{eff}) are within the general range of 10^{-11} to 10^{-9} m^2s^{-1} as presented by Fernando et al. (2011), who studied the dependence of the effective diffusion coefficient on the drying kinetics of banana, cassava, and pumpkin slices. These results are agreeing with those obtained by Omola et al. (2015) when studying the drying kinetics of bananas, in which the diffusivity coefficient was 1.8×10^{-11}, 1.95×10^{-11}, and 2.28×10^{-11} m^2s^{-1} at temperatures of 40, 50, and 60 °C respectively. The same behavior was observed by Martín-Goméz et al. (2019) in the drying kinetics of grapes: at the evaluated temperatures, the diffusivity coefficient increased from 8.04×10^{-12} to 3.22×10^{-11} m^2s^{-1}, when the temperature was raised from 30 to 50 °C.

Effects of drying on color and shrinkage of banana samples

Color analysis was performed on samples before and after drying kinetics (Table 5). The color properties of pretreated (blanched) samples were significantly different from those of non-blanched samples ($p < 0.05$).

Table 5 - Parameters L*, a*, b*, C*, and h° of banana samples after drying at different temperatures blanched and non-blanched.

Samples	L*	a*	b*	C*	h°
Fresh	61.38 ± 2.21^{a}	1.34 ± 0.39^{a}	28.06 ± 0.67^{a}	28.86 ± 0.97^{a}	1.52 ± 0.01^{a}
50 °C nb	50.64 ± 1.43^{b}	2.41 ± 0.02^{b}	17.37 ± 1.20^{b}	17.53 ± 1.20^{b}	1.43 ± 0.01^{b}
50 °C b	61.50 ± 0.93^{a}	2.75 ± 0.23^{c}	9.18 ± 0.17^{c}	27.00 ± 0.37^{a}	1.78 ± 0.01^{c}
60 °C nb	53.26 ± 0.61^{c}	3.03 ± 0.14^{d}	20.44 ± 0.39^{d}	20.66 ± 0.40^{c}	1.42 ± 0.01^{b}
60 °C b	42.92 ± 0.39^{d}	3.14 ± 0.10^{d}	29.75 ± 1.19^{a}	12.33 ± 1.28^{d}	1.24 ± 0.03^{d}
70 °C nb	48.40 ± 0.45^{e}	5.49 ± 0.03^{e}	18.40 ± 0.76^{b}	$19.20 \pm 0.73^{b.c}$	1.28 ± 0.01^{e}

[abcde] Means followed by the same lowercase letter in each column were not different ($p > 0.05$). h° = hue angle (°); L* = luminosity; nb = non-blanched; b = blanched.

Source: Elaborated by the author (2020).

The parameter L* decreased significantly with increasing temperature, ranging from 61.38 to 42.92. Without blanching, banana samples darkened, which corresponded to a decrease in the L value. Enzymatic and non-enzymatic browning normally occurs when agro-products are heated (Omolola et al., 2015). Samples that were blanched and subsequently dried at 50 °C were not significantly different ($p > 0.05$) from the fresh sample. Blanching inactivates the endogenous enzymes responsible for color degradation (HAILE et al., 2015).

Regarding the coordinate a*, there was a significant difference between treated and fresh samples, as well as between treatments, except for the temperature of 60 °C. A darker color with increased redness was observed when the heating power was increased. The redness phenomenon is due to the Maillard reaction, which generates the brown coloration (JIANG et al., 2013). For fresh samples and after drying at 60 °C, there was no significant difference ($p > 0.05$) with respect to the parameter b*, which consisted of a yellowish color, characteristic of the raw material. The decrease in L* and b* and increase in a* from the initial values may have been due to pigment decomposition and the formation of browning pigments or ascorbic acid browning and non-enzymatic Maillard browning (SARPONG et al., 2018). Da Silva et al. (2015) also suggested that changes in color can be related to oxidative reactions that occur during air dehydration, which is potentiated by higher temperatures and lower drying conditions. Baini and Langrish (2009) evaluated the color of bananas dried in a temperature range from 50 to 100 °C. The parameters L * and b * decreased and a* increased as the temperature increased, in close agreement with the finding of the present study. For parameter C*, no significant difference was observed between fresh samples and those dried at 50 °C with blanching. Compared with fresh samples, the C values of dried samples were reduced ($p < 0.05$).

The hue angles were found to be in the redness range. Fresh samples showed a higher shade of red color than other samples ($p < 0.05$). Samples dried at 50 °C and blanched showed a lower intensity of saturation between samples. The color of banana slices was slightly yellow before drying and became brownish after drying. The discoloration decreased with decreasing drying temperature, as reported by Thuwapanichayanan et al. (2011).

Table 6 presents the results obtained by shrinkage analysis of fresh banana samples and after drying kinetics. All samples differed with respect to the fresh sample, but there was no significant difference between banana samples after drying kinetics.

Table 6 - Volumes (cm³) obtained from fresh banana samples and after drying kinetics at different temperatures.

Samples	Volume (cm³)
Fresh	3.09 ± 0.352 [a]
50 °C	1.05 ± 0.233 [b]
60 °C	0.97 ± 0.373 [b]
70 °C	0.99 ± 0.040 [b]

[ab] Means followed by the same lowercase letter in each column were not different ($p > 0.05$).

Source: Elaborated by the author (2020).

The increase in temperature led to a 60% average volume reduction. The shrinkage value was expected due to banana being composed 80% of water associated the temperatures used in the drying process (MAHIUDDIN et al., 2018). During drying, the loss of water generates tension in the cell structure, causing it to shrink or collapse, and changes in the shape of the product may occur (MAYOR and SERENO, 2004). Faria et al. (2020), carried out drying of bananas slices in the temperature at 40, 50, 60 e 70 °C and observed that after to reach steady state there was a shrinkage in the volume of 65% in the four temperatures evaluated.

CONCLUSIONS

Drying of bananas occurred during the falling rate period, and no constant rate period of drying was observed for the present study, which implies that moisture removal from the material was governed by the phenomenon of diffusion. The drying data was fitted to 16 different models. Statistical analyses showed that the Two-term model, which had higher R^2 values and lower SSE and RMSE values, was the best model for predicting the drying characteristics of bananas. To gain a deeper insight into the mass transfer mechanism of bananas during the drying process, the effective moisture diffusivity (D_{eff}) was also determined. D_{eff} values of 8.25×10^{-11} m^2s^{-1}, 1.94×10^{-10} m^2s^{-1}, and 2.26×10^{-10} m^2s^{-1} were found at 50 °C, 60 °C, and 70 °C, respectively. The effective diffusivity coefficient is directly related to the increase in temperature. Blanching showed a positive effect on the physical properties of the samples, such as the color. Banana samples after drying kinetics showed a characteristic color (reddish). Samples that were blanched and dried at 50 ° C displayed no characteristic darkening and the volume reduction after drying was inversely proportional to the drying temperature.

Cinética de secagem e efeito do pré-tratamento de branqueamento em banana

RESUMO

O objetivo deste estudo foi estimar e selecionar o modelo cinético de secagem em camada fina de fatias de banana e o efeito de pré-tratamento de branqueamento na cor. Para isso, 16 modelos semi-teóricos e /ou empíricos foram aplicados aos dados experimentais e comparados de acordo com seus coeficientes de determinação (R^2), erros ao quadrado da soma (SSE) e erro quadrático médio da raiz (RMSE), que foram previstos por análise de regressão não linear. A cinética de secagem das fatias de banana foi obtida a 50 °C, 60 °C e 70 °C por 630 min. O tratamento térmico de branqueamento foi realizado nas amostras submetidas a secagem a 50 °C e 60 °C. Caracterização cromática e análise de encolhimento foram realizadas. Entre os modelos de secagem de camada fina considerados para determinar os parâmetros de secagem cinéticos, o modelo semi-teórico Two term apresentou o melhor ajuste para todas as condições de secagem. A difusividade efetiva da umidade variou de $8{,}25 \times 10^{-11}$ m^2s^{-1} a $2{,}26 \times 10^{-10}$ m^2s^{-1} na faixa de temperatura do estudo. O aumento da temperatura levou a uma redução de volume médio de 60%. Para a cor, os parâmetros L* e b* diminuíram e a* aumentaram em relação ao aumento da temperatura; e as amostras branqueadas e secas a 50 ° C foram semelhantes à amostra fresca para luminosidade.

Palavras-chaves: *Musa acuminata*, desidratação, modelos de secagem.

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