Investigation of Mathematical Modeling for Banana Slices Drying using Hot Air Technique

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Received: 2 January 2020; Revised: 7 April 2020; Accepted: 17 April 2020; Available online: 5 June 2020

Abstract

The parameter models of banana slices drying are very important for predicting to approximate the mathematical. This paper demonstrates the drying kinetics with mathematical modeling of banana slices drying using hot air technique. The banana slices were dried the temperature about of 60-70°C and 0.8 m/s for the hot air velocity. The parameters were studied the banana slices thickness of 2-6 mm and 300% db for initial moisture content. An experimental result was presented in terms of moisture content and shrinkage. The drying time was revealed about of 180-220 minutes which the temperature affected the moisture content and shrinkage of banana slices. The moisture diffusivities were presented of $1.42-13.5\times10^{-10}$ m^2/s. In addition, the moisture ratio was applied to generate the drying models of banana slices which the Page model to be the best model.

Keywords: banana slices, drying kinetics, drying model, hot air

Introduction

Fresh bananas are highly nutritious, such as consisting of water, flour, protein, fat, fiber, and vitamins. In addition, there are other substances, such as enzymes, pectin, and tannins (Dehsheikh & Dinani, 2019). Fresh banana are used as medicine by drying and grinding, mixed with water or honey to prevent and treat stomach ulcers; in addition, that also have anti-fungal and bacterial effects (Swasdisevi, Devahastin, Sa-Adchom, & Soponronnarit, 2009).

Fresh bananas contain 70%wb-80%wb of moisture, and therefore very susceptible to post-harvest losses. Quality of banana powder depends on the moisture content and ripeness of bananas. Therefore, fresh bananas must be dried in order to reduce the moisture to below 5%wb before making to the powder. Initial moisture content can be reduced by drying with sunlight for 3 to 4 days while drying with sunlight it may be contaminated with dust, dirt, and rain; in addition, they also take a long time to dry. It was affected to the operating cost, drying time, and quality of products (Dongbang, 2013).

The method for drying involve the transfer of heat into the product based on radiation, conduction and convection (Ramaswamy & Marcotte, 2005) with different applications: cooking (Kor & Icier, 2016), drying (Lin, Lee, Tsen, & King, 2007), heating (Sakai & Hanzawa, 1994), and pasteurization (Mao, Oshima, Yamanaka, Fukuoka, & Sakai, 2011). Moreover, the convective drying with combined application of ultrasonic and Carboxymethyl cellulose coating were effective approach to improve the banana slices quality. The increasing of ultrasonic power for the banana slices drying is effect to decrease of the drying time, energy consumptions, shrinkage, shear stress and the total color change of product. In addition, changing the coating ratio of

Carboxymethyl cellulose from 1:2 to 1:4 was reduced the shrinkage, shear stress, and color change of product as well as. (Dehsheikh & Dinani, 2019)

Thus,this work for the drying kinetics with mathematical modeling is necessary of study to predict the specific process on the banana slices drying. The study aims are (i) to experimentthe drying kinetics of banana slices using the hotair technique and (ii) to investigate the mathematical of drying models.

Materials and Methods

Materials preparation

The banana in Thai called Kluai namwa: scientific name Musa sapientum L was sliced as shown in Figure 1 to be the sample for drying. This work, an experiment was repeated of three times for one sample of data. It was peeled and sliced to the normally thickness of 2, 4, and 6 mm with error ± 0.5 mm after that the samples were placed at the steel tray of dryer.

Figure 1 Banana slices for drying

Moisture content

The initial moisture content was calculated as a percentage of wet weight (wet basis: wb) or dry matter (dry basis: db). The market price is usually based on wet basis; on the other hand, the dry basis moisture contents are used in many engineering calculations (Brooker, Bakker-Arkema, &Hall, 1974). The initial moisture contents of banana slices are calculated as follows:

$$M_{i,w} = \frac{w-d}{w}(100\%) \quad (1)$$

$$M_{i,d} = \frac{w-d}{d}(100\%) \quad (2)$$

where w was wet weight, d was dry weitht, and M_i is initial moisture content which can be calculated with the Equation (1) or (2), while the moisture content at various time: M_t can be calculated with Equation (3).

$$M_t = 100 - \frac{w_i}{w_t}(100 - M_i) \quad (3)$$

where w_i is initial weight, w_t is weight various times during drying, and M_i is initial moisture content.

Experimental set-up

An apparatus for this study as schematic diagram can be found the Figure 2. They consist of electric heater for heating the drying air that was installed inside the chamber. The fan was used for circulating the drying air inside the chamber. The air temperature was adjusted by using the PID controller with an accuracy of ±0.5% and was measured by using the type K thermocouples with an accuracy of ±0.75%. During experiment, the weights loss from drying processes were recorded by using the balance meter that was installed at under the drying chamber.

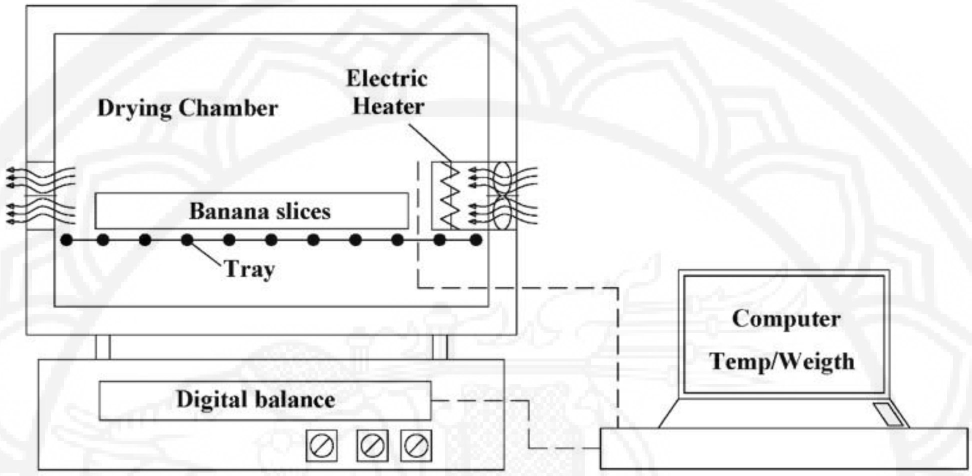

Figure 2 Schematic diagram of apparatus using hot air technique

Drying method

An electric heater was adjusted for drying at air temperatures of 60, 65 and 70°C. The air velocity of 0.8 m/s was used, as well as the fish drying due to product have a similar soft (Dongbang & Matthujak, 2013). The samples were weighted by electric balance which called an initial weight. While drying, the weight at various times was recorded every 10 min by using a digital balance (OHAUS, PA512, USA) with an accuracy of ±0.01 g. The banana slices were dried from the initial moisture content of 300 ± 5%db down to moisture of 5 ± 1 % db.

Moisture diffusivity

The moisture diffusivity inside the banana slices were investigated by using the Fickian's second law as Equation (4) with assumptions: the moisture is transferred from inside to the surface; in addition, the physical properties of all banana slices constant with time (Crank, 1975).

$$\frac{\partial M}{\partial t} = D\nabla^2 M \quad (4)$$

The solution of Equation (4) for an infinite slab was presented by using Equation (5) as follows:

$$\mathrm{MR} = \frac{\mathrm{M_t - M_e}}{\mathrm{M_i - M_e}} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left[\frac{-(2n+1)^2\pi^2}{4}\mathrm{X}^2\right] \quad (5)$$

where, D was the moisture diffusivity, $L$was the layter of banana slices, M_{e} was the equilibrium moisture content, MR was the dimensionless moisture ratio, M_{i} was the initial moisture content, and M_{t} was the moisture content various times. Since the values of M_{e} are relatively small compared with M_{i} and M_{t} (Dongbang & Pirompugd, 2015) so the empirical moisture ratio can be calculated as follows:

$$MR = \frac{M_t}{M_i} \tag{6}$$

Equation (6) was formed in logarithmic as follows.

$$\ln MR = \left(ln\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D}{L^2}\right)t \tag{7}$$

Statistical Analysis

The drying models were calculated the parameters of banana slices drying as follows:

Newton Model (Ayensu, 1997)

$$MR = exp(-kt) \tag{8}$$

Page Model (Page, 1949)

$$MR = exp(-kt^n) \tag{9}$$

Henderson and Pabis (Westerman, White, & Ross, 1973)

$$MR = Aexp(-kt) \tag{10}$$

Logarithmic (Toğrul & Pehlivan, 2002)

$$MR = Aexp(-kt) + B \tag{11}$$

Where MR was the moisture ratio, A, B, k, and n were the parameter constants and t was the drying time in minutes.

The values of Chi-square (χ^2), root mean square error ($RMSE$) and coefficient of determination $\left(R^2\right)$ were used for identifying the best models. These are used to compare between the experimental moisture ratios $\left(MR_{exp,i}\right)$ and the predicted moisture ratios $\left(MR_{pre,i}\right)$ by using the SPSS Program based on equation as follows:

$$\chi^2 = \sum_{i=1}^{k}\frac{\left(MR_{exp,i} - MR_{pre,i}\right)^2}{MR_{pre,i}} = \sum_{i=1}^{k}\frac{\left(MR_{exp,i}\right)^2}{MR_{pre,i}} - N \tag{12}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{k}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]^{1/2} \tag{13}$$

Equation (12) under Pearson Chi-Square, N was the number of observation and k was the random sample from a population. Analysis of variance was carried out to find the relation of moisture ratio of drying banana slices. Equation (13) variables observed over n times, was computed for n different predictions.

Shrinkage

The banana slices can be shrinkage after drying (Koua, Koffi, & Gbaha, 2019; Dehsheikh & Dinani, 2019) that affected by the cellular structure and mechanical properties of products (Khan, Nagy, & Karim, 2018). In addition, the drying conditions were affected the magnitude of shrinkage strongly (Khan & Karim, 2017) that can be calculated by using the following equation:

$$Shrinkage = \left(\frac{V_i - V}{V_i}\right) 100\% \qquad (14)$$

where V_i is initial volume and V is volume after drying.

Results and discussion

Drying kinetics

The moisture ratio(MR) were calculated by using the experimental data and plotted versus drying time as shown in Figure 3 under the three levels of drying temperature (60°C, 65°C,70°C) and three-layer heights (2, 4, 6 mm).

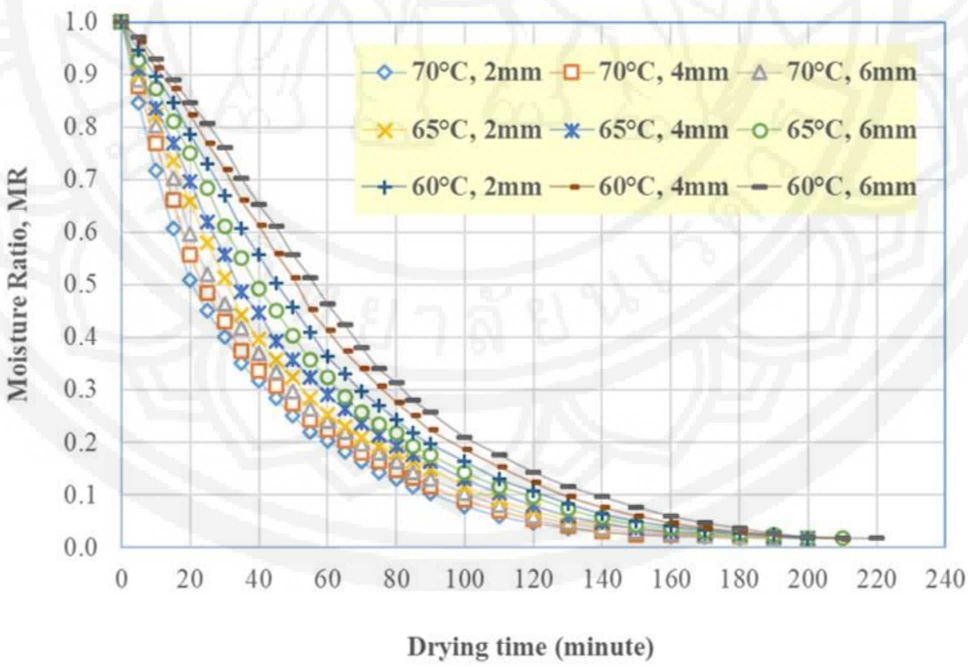

Figure 3 The experimental results of banana slices with nine conditions

The drying times for dehumidifying the banana sliced from 300% db down to 5% db ranged from 180 to 220 minute. After moisture content was targeted after that will be dried with sun until the moisture content closely to storage safety. The results found that the heat was mainly supplied to the surface of the banana slices by hot air. The latent heat was intensified while the evaporation from the banana slices was improved which has been similarly reported for other moist materials, i.e., anchovy (Dongbang& Matthujak, 2013), paddy (Sujumnong, Dongbang, & Trirattanasirichai, 2005) and chilies (Dongbang, Pirompugd, & Triratanasirichai, 2010). Layer of banana slices also affected the drying time because the abundance of free water on the surface contributed to the moisture liberation (Dehsheikh & Dinani, 2019). However, the thick layer had difficulty expelling water later, when the banana slices surface become harder due to shrinkage (Dongbang & Matthujak, 2013). The layer height of 2 mm is accepable under lowest shrinkage and the shortest time for drying. They are the good physical properties that can be mixed with water; in addition, they are suitable for making the powder.

Parameters of drying models

The relation of moisture ratio (MR) and drying time t from 60°C, 65°C and 70°C were shown in Table 1 found that the lowest value of χ^2 and $RSME$ were obtained with the Page model.

Table 1 Parameters of drying models for banana slices

Conditions	Banana slices = 2 mm			Banana slices = 4 mm			Banana slices = 6 mm		
	60°C	**65°C**	**70°C**	**60°C**	**65°C**	**70°C**	**60°C**	**65°C**	**70°C**
Newton model: $MR = exp(-kt)$									
k	0.0165	0.0222	0.0286	0.0149	0.0202	0.0261	0.0136	0.0183	0.0240
χ^2	0.0603	0.0046	0.0230	0.0932	0.0064	0.0131	0.1333	0.0242	0.0061
$RSME$	0.0195	0.0039	0.0095	0.0292	0.0036	0.0077	0.0402	0.0107	0.0041
Page model: $MR = exp(-kt^n)$									
k	0.0058	0.0209	0.0480	0.0039	0.0156	0.0361	0.0027	0.0100	0.0286
n	1.2521	1.0147	0.8611	1.3146	1.0648	0.9152	1.3752	1.1473	0.9550
χ^2	0.0402	0.0031	0.0153	0.0621	0.0042	0.0087	0.0888	0.0161	0.0041
$RSME$	0.0012	0.0029	0.0018	0.0016	0.0014	0.0037	0.0023	0.0020	0.0027
Henderson and Pabis model: $MR = Aexp(-kt)$									
A	1.0757	0.0225	0.0271	0.0164	0.0207	0.0255	0.0151	0.0192	0.0238
k	0.0178	1.0111	0.9543	1.0888	1.0239	0.9786	1.1039	1.0491	0.9919
χ^2	0.0804	0.0062	0.0307	0.1242	0.0085	0.0174	0.1777	0.0322	0.0082
$RSME$	0.0211	0.0027	0.0108	0.0339	0.0026	0.0076	0.0474	0.0087	0.0039
Logarithmic model: $MR = Aexp(-kt) + B$									
A	1.1103	1.0082	0.9432	1.1387	1.0278	0.9698	1.1675	1.0601	0.9853
B	0.0528	0.0054	0.0277	0.0736	0.0070	0.0203	0.0916	0.0187	0.0143
k	0.0157	0.0228	0.0299	0.0139	0.0203	0.0273	0.0124	0.0183	0.0249
χ^2	0.1005	0.0077	0.0384	0.1553	0.0107	0.0218	0.2221	0.0403	0.0103
$RSME$	0.0130	0.0026	0.0063	0.0195	0.0024	0.0051	0.0268	0.0071	0.0027

Moisture diffusivity

Moisture diffusivity (D) was determined as Equation (7), i.e., the slopes derived from the linear regression of lnMR against drying time (t). The results found that the moisture diffusivity of banana slices ranged from

1.42 to 13.5×10^{-10} m^2/s under the drying temperature from 60°C to 70°C. The values of D at thickness of 2 - 6 mm were fitted with the drying air temperature on equation as follows:

At thickness of 2 mm, R^2 = 0.997

$$D = 110.14 + 4.212T + 0.041T^2 \quad (15)$$

At thickness of 4 mm, R^2 = 0.999

$$D = 153.78 + 5.682T + 0.052T^2 \quad (16)$$

At thickness of 6 mm, R^2 = 0.998

$$D = 156.58 + 5.824T + 0.054T^2 \quad (17)$$

Where R^2 is the coefficient of determination, T is the drying temperature

Shrinkage

The shrinkage was increased relation with the drying temperature was increased as shown in Figure 4. In addition, the thickness of banana slices were increased which effect to shrinkage more than ever significant by comparing the temperature as same value. Due to during banana slices drying, the microstructural stress was affected by the moisture and temperature (Khan & Karim, 2017), while the microstructural stress leaded to deformation that can be referred as shrinkage of banana slices. Its tissue was constantly emptied and air-filled (Khan, Wellard, Nagy, Joardder, & Karim, 2016), the exterior skin structure collapse leads to shrinkage (Panyawong & Devahastin, 2007).

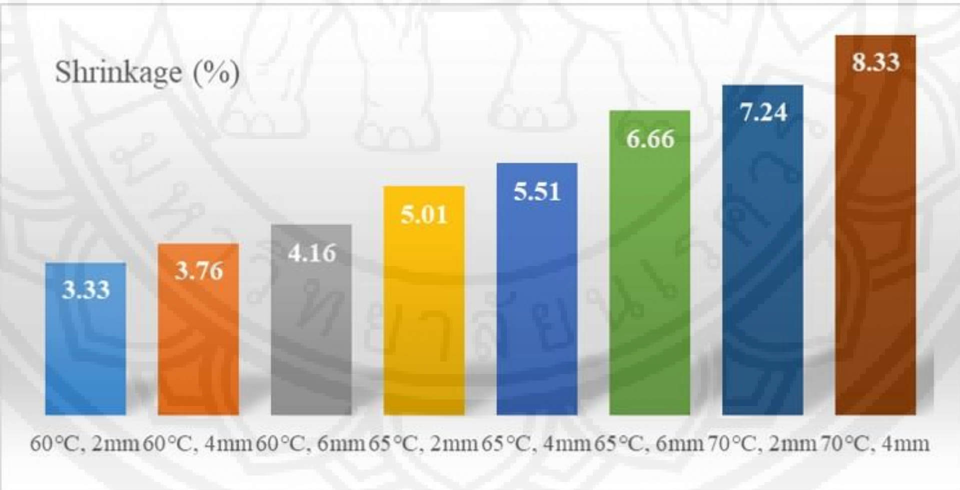

Figure 4 Shrinkage of banana slices after drying each condition

Conclusion

The results found that the drying kinetics related with air temperature and thickness of banana slices. The moisture ratio curves provide evidence that moisture diffusivity predominates in the drying mechanism. They were fitted to various drying models for calculating the parameters; in addition, the moisture diffusivity was investigated found that the Page model can be adequately described the drying kinetics while the moisture diffusivity was found at $1.42\text{-}13.5\times10^{-10}$ m^2/s.

Acknowledgments

The authors are grateful for the support from the faculty of engineering, Burapha University, Thailand.

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