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Modeling of thin layer drying characteristics of *"Xiem"* banana peel cultivated at U Minh district, Ca Mau province, Vietnam

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Abstract

In Vietnam, banana peels have been discarded as waste which is a potential source of raw material for food and other bioprocessing industries. Drying the peel offers opportunities for value addition into novel products, thus reducing waste from the fruit processing operations. This study presented the mathematical models of the thin-layer drying behaviour of banana peels using three air temperatures (60°C, 70°C and 80°C). The effect of drying temperature on the reduction of moisture content and drying rate of the banana peel was evaluated. A total of eight commonly drying models were used for choosing the best fitness model for describing the oven drying process. The effective moisture diffusivity and activation energy were calculated using Fick's diffusion equation. The obtained results showed that increasing drying temperature accelerate the drying process, as well as, increasing drying rate and effective diffusivity. The goodness of fit tests base on the criterion indicated that the Page model gave the best fit to experimental results. The effective diffusivity varied from 2.29×10^{-8} – 3.25×10^{-8} m^2/s. Effective diffusivity was satisfactorily by an Arrhenius relationship with activation energy within the 60-80°C temperature range. The obtained activation energy was 16.98 kJ/mol with a high coefficient of determination (R^2 = 0.903).

1. Introduction

In recent years, fruit and vegetable by-products constitute a big and very problematic portion of these by-products because of their high specific volume and moisture content. The peels/seeds from fruit and vegetable are regarded as wastes. By using appropriate processing techniques, these wastes could be used to make valuable by-products (Schieber *et al.*, 2001). Based on the 3R (reduce, reuse and recycle) principle, these materials cannot be regarded as wastes but they can become an additional valuable resource to augment existing natural materials. For economic purposes, taking advantage of by-products to process food products is more valuable, rather than their discharge to the environment which causes detrimental environmental effects.

Bananas (*Musa* sp.) are one of the most common and important tropical fruits consumed worldwide. Moreover, it is generally grown in all types of land available in Vietnam which turns it as an important economic crop. Nutritionally, bananas contain many important nutritional compounds as available carbohydrates which provide energy, vitamins B and C, and significant amounts of potassium and magnesium and amino acids. Banana peels account for only 30% of the total fruit weight and have 20% dry matter, however, in the food processing industry, a large amount of banana peels has been discarded as waste into the environment and have a negative impact on the surrounding living place (Shadma *et al.*, 2014). This resulted in a hundred tons of waste from banana peels generated each day and this amount tends to increase annually. However, it contains minerals, various amino acids, antioxidant compounds and also contains a significant amount of carbohydrates, proteins, and fiber, making it an ideal substrate for the production of value-added product (Aghbashlo *et al.*, 2008; Demir *et al.,* 2004). In some recent research, extracts of the banana peel possess potential antimicrobial activity against several microorganisms likely *Staphylococcus aureus, Streptococcus pyogenes, Enterobacter aerogenes, Escherichia coli* (Chabuck *et al.,* 2013). So, the problem can be recovered by utilizing its high-added value compounds from these materials, including the antioxidant compound and the dietary fibre fraction that have a great potential in the preparation of functional

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foods (Wachirasiri *et al.*, 2009). Banana peel can be used to make noodles by partial substitution of wheat flour with banana peel flour. With a high amount of dietary fibre, the banana peel has the potential to slow the rate of starch hydrolysis in yellow noodles (Ramli *et al*., 2009).

Several technological treatments are applied to utilize the waste from these peels, drying is one of the best and fast ways to generate a value add product, which could be an initial treatment process to solve a large amount of these peels. Drying not only extends the life of raw materials with a high moisture content but also can minimize the costs of handling and distribution (Chen and Mujumdar, 2009). In the principle of drying operation, the heat and mass transfer processes occur simultaneously where heat penetrates the food product and causes the transfer of moisture from within the food to its surface with subsequent evaporation to the air stream as vapour. Mathematical modelling of the thin layer drying process is important for managing operating conditions during the drying process and for predicting the performance of a drying process of the product. Oven drying is an economically feasible method of drying and is convenient for plant material (Chen and Mujumdar, 2009). In view of the health-promoting properties and high nutritional benefits of banana peel, the current study was conducted to obtain the effect of various temperatures (60-80°C) on drying characteristics of banana peel and to select the best mathematical model in achieving the drying behaviour of the peel.

2. Materials and methods

2.1 Sample preparation

Bananas at the colour index of 1 (mature green) according to the CSIRO banana ripening guide were purchased from U Minh district, Ca Mau province, Vietnam. The fruits were thoroughly washed with tap water to remove adhered earth and foreign materials and then, separated into pulp and peel. The fresh banana peel was cut in the dimension of 118±1.0 mm (length), 10±0.1 mm (width) and 2.0±0.1 mm (thickness) were used. Then, they were soaked in sodium metabisulfite solution (500 ppm) and were spread into stainless steel trays. Before starting the drying experiment, the initial moisture content was measured using a modified AOAC method 925.45 (2005). All the drying tests were run two times in triplicates at each temperature and averages were reported.

Three different temperature levels (60, 70 and 80°C) were used and the oven dryer (Model SIBATA SD-60, Japan) was operated at an air velocity of 1.0 m/s, parallel to the drying surface of the sample. Weight change was recorded by a digital balance (Ohaus, SR series, America, d = 0.001) at an hourly interval during drying. Peels were dried until equilibrium was reached.

2.2 Mathematical modelling of banana peel

The moisture ratio (MR) of banana peels during the drying process was obtained following Equation 1.

$$\mathrm{MR} = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

Where M_t, M_o and M_e are moisture content at each measurement time, initial moisture content, and equilibrium moisture content (kg water/kg dry matter) respectively. However, the drying varied continuously during the drying experiments, the relative moisture content of drying air is simplified into Equation 2 (Akpinar *et al.,* 2003):

$$\mathrm{MR} = \frac{M_t}{M_0} \tag{2}$$

Several researchers have predicted semi-theoretical and empirical models describing the kinetic behaviour of the thin-layer drying process. Eight thin-layer drying models were fitted to the drying curves so as to select the best model suitable for describing the drying curve of banana peels (Erbay and Icier, 2009). The models are presented in Table 1.

2.3 Nonlinear regression analysis

Nonlinear regression analysis was used to evaluate the parameters of the selected model using the statistical software Statgraphics Centurion XV.I (USA). As a primary criterion to select the best equation, the root mean square error (RMSE), coefficient of determination (R^2) and chi-square (χ^2) were determined and used as the primary criterion to select the best equation to account for variation in the drying curves of the dried samples (Ertekin and Yaldiz, 2004). The highest values of R^2 and the lowest values of χ^2 and RMSE values were used to determine the best fit. These statistical values can be calculated as following Equation 3-5, respectively.

Table 1. Selected thin layer drying models for describing the drying characteristic of purple shallot

Models	Equation	Models	Equation
Lewis	$\mathrm{MR} = e^{(-kt)}$	Logarithmic	$\mathrm{MR} = ae^{(-kt)} + c$
Henderson and Pabis	$\mathrm{MR} = ae^{(-kt)}$	Midilli	$\mathrm{MR} = ae^{(-kt)} + bt$
Page	$\mathrm{MR} = e^{(-k(t)^n)}$	Two-term exponential	$MR = ae^{(-kt)} + (1-a)e^{(-kat)}$
Wang and Smith	$\mathrm{MR} = 1 + at + bt^2$	Two-term	$\mathrm{MR} = ae^{(-k_1 t)} + be^{(-k_2 t)}$

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$$R^2 = \frac{N\sum_{i=1}^{N} MR_{pre,i}MR_{exp,i} - \sum_{i=1}^{N} MR_{pre,i}\sum_{i=1}^{N} MR_{exp,i}}{\sqrt{\left(N\sum_{i=1}^{N} MR_{pre,i}^2 - \left(\sum_{i=1}^{N} MR_{pre,i}\right)^2\right)\left(\sum_{i=1}^{N} MR_{exp,i}^2 - \left(\sum_{i=1}^{N} MR_{exp,i}\right)^2\right)}} \quad (3)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{1/2} \quad (4)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N-n} \quad (5)$$

where $MR_{exp,i}$ and $MR_{pre,i}$ is the experimental and predicted moisture ratio at observation i; N is the number of the experimental data points, and n is the number of constants in the model.

2.4 Determination of the effective moisture diffusivity (Deff)

Diffusivities are typically determined by plotting experimental drying data in terms of ln MR versus drying time (t), because the plot gives a straight line with a slope as follows Equation 6.

$$Slope = \frac{\pi^2 D_{eff}}{4L^2} \quad (6)$$

where t is the time (s), D_{eff} is the effective diffusivity (m^2/s) and L is the thickness of samples (m).

The relationship between effective diffusivity and drying temperature can be predicted appropriately using the Arrhenius equation (Akpinar *et al.*, 2003). The activation (E_a) can be determined using Equation 7.

$$D_{eff} = D_0 \exp\left(\frac{-Ea}{RT}\right) \quad (7)$$

where D_o is is the pre-exponential factor of the Arrhenius equation (m^2/s), E_a is the activation energy in KJ/mol, T is the absolute drying air temperature (K) and R is the universal gas constant (8.314 J/mol.K).

3. Results and discussion

3.1 Drying characteristics

The moisture content (% dry weight basis, (% dwb)) were calculated from the change in the sample's weight during the drying process, which occurred in each consecutive time interval. A single layer of banana peel samples was dried in the hot air oven drier at the temperature of 60, 70 and 80°C. Figure 1 shows the graph of moisture content versus time for banana peels samples. As shown, the average initial moisture content of banana peel was 1122.358±2.539 (% dwb) and drying time for all the samples ranged between 4 and 6 hours. The samples had a thickness of approximately 2 mm were dried to the final moisture content of 7.68, 7.37 and 7.56 (% dwb) using an oven drier at 60, 70 and 80°C, respectively. The temperature of 80°C required a shorter drying time in comparison with 60°C. In other words, the time of drying was reduced to approximately 33% for 80°C in comparison with 60°C. The drying time decreased as the drying temperature increased because of the relatively higher resistance to moisture movement at low temperatures than at higher ones. According to Kaya *et al.* (2007), the resistance of the food structure is known to decrease the drying rate, which resulted in the increased drying time of 60 and 70°C. Moreover, increasing the temperature of drying decreased the total time of drying as the heat transfer was increased due to the increasing temperature, in other words, drying at a higher temperature implies a larger driving force for heat transfer (Kaya *et al.,* 2007).

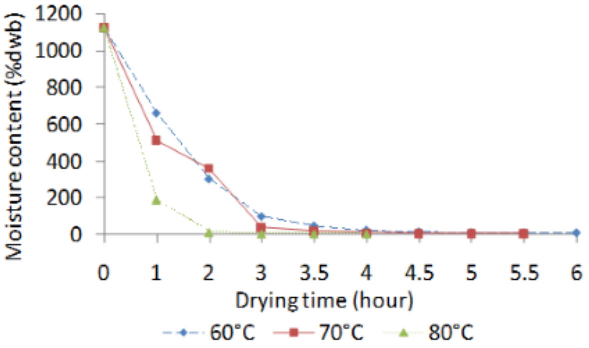

Figure 1. Drying curves of banana peels at different temperatures

The moisture content of the samples decreased at temperatures of 60, 70 and 80°C with a variation drying rate which exhibits a falling rate of drying which is the main drying mechanism in controlling the water evaporation rate. The higher drying time required to remove the moisture content in the banana peels could be a result of the slow diffusion process. Moreover, a decrease in the drying time as the temperature increases is attributed to the increased thermal energy, which increases the rate of water molecules that transfer in the food matrix (Maskan *et al.,* 2002). This result correlates with previous studies reported for various food materials such as Vietnamese shallot (Thuy *et al.*, 2020), culinary banana slices (Khawas *et al.,* 2014), and India blanched banana peel (Kumar, 2015). Figure 2 illustrates the changes in moisture ratio against drying time of banana peels at three different oven-drying temperatures. The drying rate decreased continuously during the drying period. The continuous decrease in moisture ratio indicates that diffusion has governed the internal mass

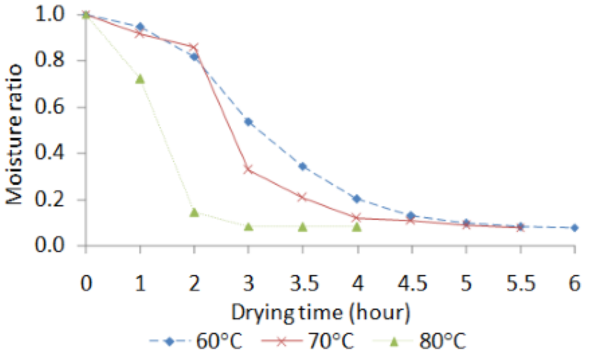

Figure 2. Drying characteristic curve of banana peels at different temperatures

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Table 2. Thin-layer models applied to the drying curves at different drying temperatures

Model	Temperature (°C)	Model constants	RSME	R^2 (%)	χ^2
Lewis					
	60	k = 0.3025	0.1468	99.00	0.0239
	70	k = 0.3454	0.1669	82.13	0.0310
	80	k = 0.6490	0.1099	92.64	0.0134
Logarithmic					
	60	a = 2.1152; k = 0.1230; c = -0.9987	0.1035	94.05	0.0153
	70	a = 2.7990; k = 0.0927; c = -1.7046	0.1389	90.72	0.0275
	80	a = 1.1681; k = 0.5146; c = -0.1281	0.1300	93.82	0.0242
Wang and Sign					
	60	a = -0.1710; b = -0.000097	0.1015	93.46	0.0129
	70	a = -0.2053; b = 0.0034	0.1350	89.76	0.0228
	80	a = -0.5054; b = 0.0679	0.0995	95.18	0.0124
Henderson and Pabis					
	60	a = 1.1548; k = 0.3422	0.1410	87.38	0.0249
	70	a = 1.1469; k = 0.3863	0.1661	84.51	0.0345
	80	a = 1.0518; k = 0.6735	0.1198	93.01	0.0179
Midilli					
	60	a = 1.087; k = 0.1010; c = -0.0981	0.1009	94.35	0.0145
	70	a = 1.090; k = 0.1521; c = 0.0911	0.1397	90.61	0.0279
	80	a = 1.041; k = 0.5731; c = -0.0205	0.1318	93.66	0.0248
Two-term					
	60	a = 0.096; b = 0.248; k_1 = 0.344; k_2 = 0.336	0.1628	87.38	0.0442
	70	a = 0.877; b = 0.268; k_1 = 0.382; k_2 = 0.396	0.1966	84.51	0.0644
	80	a = 0.957; b = 0.094; k_1 = 0.671; k_2 = 0.688	0.1694	93.00	0.0487
Two-term exponential					
	60	a = 2.4251; k = 0.5499	0.0712	96.79	0.0063
	70	a = 0.9826; k = 0.3460	0.1784	82.13	0.0398
	80	a = 0.9999; k = 0.6461	0.1229	92.64	0.0189
Page					
	60	k = 0.0386; n = 2.6074	0.0375	98.89	0.0018
	70	k = 0.0329; n = 3.0390	0.0740	96.16	0.0068
	80	k = 0.3385; n = 2.4228	0.0786	94.12	0.0077

transfer. A higher drying air temperature decreased the moisture ratio faster due to the increase in air heat supply rate to banana peel and the acceleration of moisture migration (Demir *et al.,* 2004).

3.2 Modelling of drying curves

The data of moisture content obtained from the drying process of banana peels at three levels of air-drying temperature was calculated to moisture ratio and was fitted to eight thin-layer drying models. The achieved results are presented in Table 2 along with the statistical analysis of the model included the coefficient of correlation, the root mean square error and Chi-square. According to Demir *et al.* (2004) reported that the best model to explain the thin layer drying characteristic of the banana peel was chosen based on some selection criteria's as the highest correlation coefficient (R^2), least of the root mean square error (RMSE) and least of the reduced χ^2 values (Demir *et al.*, 2004). As shown in Table 2, the values of the R^2 , RMSE and χ^2 for eight drying models and three levels of drying temperatures (60-80°C) ranged from 81.13 to 99.00%, 0.0375 to 0.1966 and 0.0018 to 0.0644, respectively. Based on these results, the model that best fit the experimental data using the previously stated criterion for drying at 60°C was the Lewis model whereas that at 70 and 80°C was the Page model. However, when the sample was dried at 60°C, the result of the correlation coefficient of the Lewis model is not significantly different in comparison with the Page model. According to these results, the best fitness model to predict the thin-layer drying behaviour of the "Xiem" banana peel was the Page model. Figure 3 shows conformity between the experimental and predicted moisture ratio values as they both laid around straight for the Page model with the high correlation coefficient (0.983). The moisture ratio of the banana peels at different stages of drying could be predicted successfully using the following Equation 8-10.

$$\text{For drying at } 60^{o}\text{C: } MR = \exp(-0.0386t^{2.6074}), \quad (8)$$
$$R^2 = 98.89, \text{ RMSE} = 0.0375, \chi^2 = 0.0018$$

$$\text{For drying at } 70^{o}\text{C: } MR = \exp(-0.0329t^{3.0390}), \quad (9)$$
$$R^2 = 96.16, \text{ RMSE} = 0.0740, \chi^2 = 0.0068$$

$$\text{For drying at } 80^{o}\text{C: } MR = \exp(-0.3385t^{2.4228}), \quad (10)$$
$$R^2 = 94.12, \text{ RMSE} = 0.0786, \chi^2 = 0.0077$$

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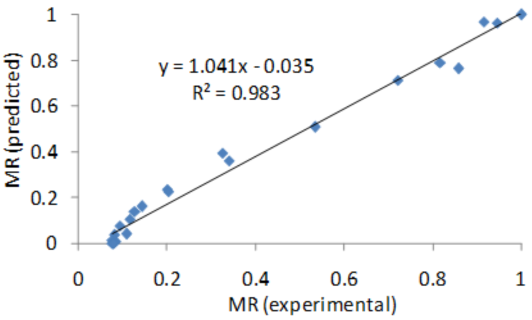

Figure 3. Plot of experimental moisture against predicted moisture ratio by Page model

3.3 The effective moisture diffusivity

Analysis of the falling rate period was performed to understand the drying kinetics and to determine the effective moisture diffusivity (D_{eff}) by slope method and this reviews that the mass transfer during drying operations is controlled by internal diffusion (Babalis and Belessiotis, 2004). The obtained result revealed that drying at 60°C had the lowest D_{eff} value of 2.29×10^{-8} while drying at 80°C had the highest value of D_{eff} (3.25×10^{-8}). In general, D_{eff} increases with an increase in drying temperature, thus temperature has a positive influence on moisture diffusivity. This variation in values could be attributed to a difference in location and growth condition, levels of maturity, drying equipment and other parameters that cannot be controlled. The study of Doymaz (2010) also reported an increase in moisture diffusivity of banana (*Cavendish*) slices with an increased drying temperature.

3.4 Activation energy

The activation energy which is the minimum energy required to initiate moisture diffusion from the food products is obtained by the Arrhenius equation for the banana peels drying data at various air-drying temperatures. Plotting the graph of In D_{eff} against the inverse of absolute temperature as revealed in Figure 4 shows a slightly high correlation of 0.903 indicating a good fit. The value of the activation energy obtained in this study was 16.98 kJ/mol. The value obtained is however lower when compared with the value reported by Doymaz (2010) for banana slices. The differences observed could be related to a higher temperature (i.e. 60 –85°C) used in their study.

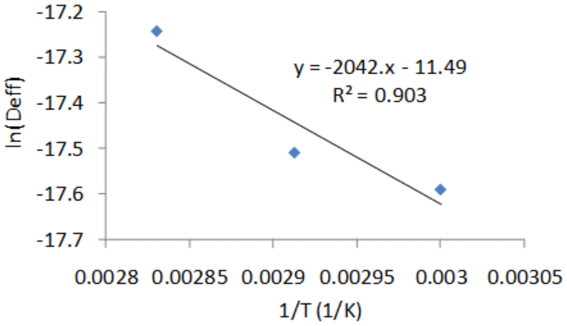

Figure 4. Arrhenius type relationship between effective moisture diffusivity and temperature

4. Conclusion

Drying kinetics curves of drying banana peel demonstrated that drying at 60-80°C were the optimum values for drying banana peel with the appropriate equations using the Page model. The research was initially carried out to solve the great amount of banana peels released into the environment. Moreover, the obtained banana peel powder from this research would be possible to utilize as a functional ingredient in starch-rich products such as noodles or nutritional powder.

Conflict of interest

The authors declare no conflict of interest.

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