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A Preliminary Study: Kinetic Model of Drying Process of Pumpkins (*Cucurbita Moschata*) in a Convective Hot Air Dryer

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Abstract

Drying of pumpkin (*Cucurbita moschata*) was investigated experimentally using a hot air convective dryer. 30 samples of pumpkin with thickness of 2 mm and 4 mm were subjected to 11 hours drying at temperatures 50 °C, 60 °C and 70 °C respectively. The drying data were fitted to the Moisture Ratio (*MR*) models, which produced $MR = aexp^{-kt}$ as the model of prediction. Selection of the best model was investigated using statistical analysis of variance, carried out via SPSS 17.0. Lewis, Henderson and Pabis models gave the best prediction with *R* (97.1%), R^2 (94.2%), *SSE* (0.577) and *R* (95.7%), R^2 (91.6%), *SSE* (0.703) respectively.

Keywords: Pumpkin; convective drying; thin layer drying; drying kinetics; modeling; SPSS

1. Introduction

Pumpkin (*Curcurbita moschata*) is extensively used as vegetable processed food and stock feed in different part of the world. Although very little information is available about the production statistics of pumpkin, the average yield of fruit is reported to be 25000 kg/ha (Choudhary et al., 2001).The major pumpkin producing states

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in Malaysia are Terengganu, Kelantan, Perak and Kedah (MARDI, 2007). Pumpkin is rich in carotene, vitamins, minerals, dietary fibre and pectin (Djutin, 1991).

Drying is one of the oldest and commonly used methods for food preservation. In most of the tropical countries, natural sun is one of the most common ways to conserve agricultural products (Alonge and Onwude, 2013). This involves the spreading of the commodity in the sun on a suitable surface, hanging of commodity on buildings or drying on the stalk by standing in bundies (Alonge and Onwude, 2013). Kiranoudis et al. (1997) analysed the moisture removal of four fruits (namely, apple, pear, kiwi and banana) using hot air dryer and found out the drying process was greatly affected by the drying air conditions as well as the characteristic dimension of the material.

The knowledge of temperature and moisture distribution in the product is essential for process design and quality control. Many mathematical models have been used to describe drying process, yet with limited information on the drying kinetics. All parameters used in simulation models are directly related to the drying conditions. Furthermore, the drying condition can be directly related to the drying time and energy demand (Babalis and Belessiotis, 2004). To describe the convective drying process, a mathematical model is normally used. In this article, several empirical models were selected to simulate experiments of thin layer drying accomplished with whole pumpkin at temperatures of 50, 60 and 70 °C and thickness of 2 mm and 4 mm. The outcome of this research will help in the design of more efficient convective hot air dryers, improve drying processes of pumpkin and reduce time loss during drying.

2. Materials and methods

2.1. Equipment set-up

The dryer consisted of three basic units; a fan provided the desired drying air velocity, electrical heaters that were used to control the temperature of drying air and a drying chamber. The drying chamber was about 40 cm long, 30 cm width and 30 cm high and was made from galvanized metal sheet of 1.5 mm thickness. The design consisted of a single door on one side of the walls in order to allow the insertion or removal of the drying tray. Air was forced through the dryer using an axial flow blower and the velocity of air was controlled by use of an air control valve.

2.2. Samples

The pumpkin used in this study was *Cucurbita moschata* variety which is the most cultivated and consumed pumpkin in Malaysia. Before the drying process commenced, samples were cleaned, peeled and sliced into cubes of 2 x 2 cm with different thickness i.e. 2 mm and 4 mm. The samples were dried at 50 °C, 60 °C and 70 °C for 11 hours and data collection was conducted for every 1 hour interval. The number of samples for each thickness and temperature were $n = 30$ to make a total number of samples $n=180$.

2.3. Moisture content determination

The initial and final moisture contents (*MC*) of the pumpkin were determined at 70 °C during 48 hours with the oven method (Oje et al., 1999). In this method, the initial weight of each sample was obtained (w_1) and the final weight (w_2) was obtained after the samples were dried at 70 °C. Mathematically:

$$MC \text{ (Wet basis)} = \frac{w_1 - w_2}{w_1} \times \frac{100}{1} \quad (1)$$

2.4. Mathematical modeling

Using an exponential trendline and by forcing the intercept to be equal to the initial dry basis moisture of the pumpkin sample provided an equation as follows:

$$M = M_o \, exp^{-k\,t} \quad (2)$$

To compare the drying of pumpkin samples with different initial moisture contents, moisture ratios were calculated based on the wet basis moisture at any time, *t*.

$$\text{Moisture Ratio } (MR) = \frac{M - M_e}{M_o - M_e} \quad (3)$$

$$\text{Also } M = \left[\frac{(M_o + 1)\, w_2}{w_1}\right] - 1 \quad (4)$$

where;
M = Wet basis moisture content at any time t
M_o = initial wet basis moisture content of sample
M_e = Equilibrium moisture content
w_1 = initial sample weight
w_2 = Weight of sample at any time t
k = drying rate coefficient (reciprocal hours)
t = time (hours)

The values of M_e are relatively little compared to those of M or M_o, the error involved in the simplification is negligible (Aghbashlo et al., 2008), thus moisture ratio was calculated as:

$$\text{Moisture Ratio } (MR) = \frac{M}{M_o} \quad (5)$$

Through this approach, the exponential trendline described in Eq. (3) would become;

$$\text{Moisture Ratio} = M / Mo = exp^{-k\,t} \quad (6)$$

$$\text{Drying rate, } \frac{\partial M}{\partial t} = a exp^{-kt} \quad (7)$$

2.5. Data analysis

The statistical design was completely randomized in a factorial 2 × 4 arrangement (thickness x temperature × time x Moisture Ratio) with two replicates, which total 32 experimental units. The experimental data for the moisture ratio and drying time variables from convective drying were fitted into 3 known drying models (Table 1) using non-linear regression analysis tool in *SPSS 17.0* Statistical Software.

Table 1. Thin layer curve models.

Model no.	Model name	Model	Reference
1	Lewis	$MR=exp^{(-kt)}$	Kaleta and Go´rnicki (2010)
2	Henderson & Pabis	$MR=aexp^{(-kt)}$	Diamante et al. (2010)
3	Page	$MR=exp^{(-ktn)}$	Diamante et al. (2010)

The quantity *R*, called the *correlation coefficient*, measures the strength and the direction of a relationship between two variables (Draper and Smith, 1998). The mathematical formula for computing *R* is:

$$R = \frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{MR_{\exp,i} = \overline{MR}_{pre,i}}{S_{MRpre}}\right)\left(\frac{MR_{\exp} - \overline{MR}_{\exp}}{S_{M\,\mathrm{Re}xp}}\right) \tag{8}$$

R-squared (R^2) is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression. The definition of *R*-squared is fairly straight-forward; it is the percentage of the response variable variation that is explained by a linear model. The higher the *R*-squared, the better the model fits the data (Draper and Smith, 1998). This is computed mathematically as:

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2}{\sum_{i-1}^{N}(MR_{pre} - MR_{\exp,i})^2}\right] \tag{9}$$

SSE also known as Error sum of squares, is the sum of the squared differences between each observation and its group's mean. It can be used as a measure of variation within a cluster. If all cases within a cluster are identical the *SSE* would then be equal to 0. Mathematically, it can be written as:

$$SSE = \left[\frac{\sum_{i=1}^{N}(MR_{\exp,i} - MR_{pre,i})^2}{N}\right] \tag{10}$$

In the above equations $MRpre,i$ is the *ith* predicted moisture ratio, $MRexp,i$ is the *i*th experimental moisture ratio, S_{MRpre} is the predicted sum of square, S_{MRexp} is the experimental sum of square while N is number of observations and m is number of constants.

3. Results and discussion

The study consisted of two stages, the first of which was designed to assess the effect of temperature and thickness on the drying kinetics of pumpkin. The second stage of analysis was employed to verify whether the model listed in Table 1 can be considered applicable to describe the experimental drying curves of the product under the examined conditions.

Table 2 shows the result of non-linear regression analysis carried out on the experimental data. The analysis was carried out at temperatures 50°C, 60°C and 70°C at different thickness level of 2 mm and 4 mm respectively. Plotting exponential trendlines for each of the experimental data of moisture ratio against time gives the values of *a* (constant), *k* (drying rate coefficient) and the values of *R*, R^2 and *SSE*. The values when fitted into Eq. (6) gave the experimental model.

Table 2. Statistical result for our experimental model.

	2mm			4mm		
$MR=a\exp^{-kt}$	50°C	60°C	70°C	50°C	60°C	70°C
A	2.29	2.690	2.443	2.610	1.918	1.261
K	0.665	0.602	0.725	0.786	0.826	0.738
R	0.93	0.913	0.838	0.984	0.976	0.976
R^2	0.866	0.833	0.702	0.969	0.953	0.953
SSE	0.915	0.944	1.649	0.490	0.643	0.572

3.1. Effect of drying temperature on moisture ratio (MR)

Figs. 1 and 2 shows the effect of drying air temperature on the reduction of *MR* as a function of time with a decrease in the moisture content from 57.7% to 9.2% at 50 °C, 80.5 to 0.1% at 60^{o}C and 82.4 to 0.8% at 70 °C all in wet basis. The results show that the rate of reduction in moisture content increased considerably with rising air temperature. The drying time to reach an MR of 0.15 for 50 °C was 300 min, while 60 °C required 200 min and 70 °C requires 170 min *i.e.*, the drying time was reduced to two-third with a 10 °C increase in temperature. Also, it can be observed that there is no constant rate drying period in the drying of pumpkins slices, and all the drying process are seen to occur in the falling rate period. This behavior is in accordance with findings reported in the literature for the drying of some medicinal and aromatic plants, including pumpkin (Akpinar et al., 2003), mint (Lebert et al., 1992), *Taxus* clippings (Hansen et al., 1993), black tea (Temple and Van Boxtel, 1999), bay leaves (Demir et al., 2004), and dill and parsley leaves (Doymaz, 2006).

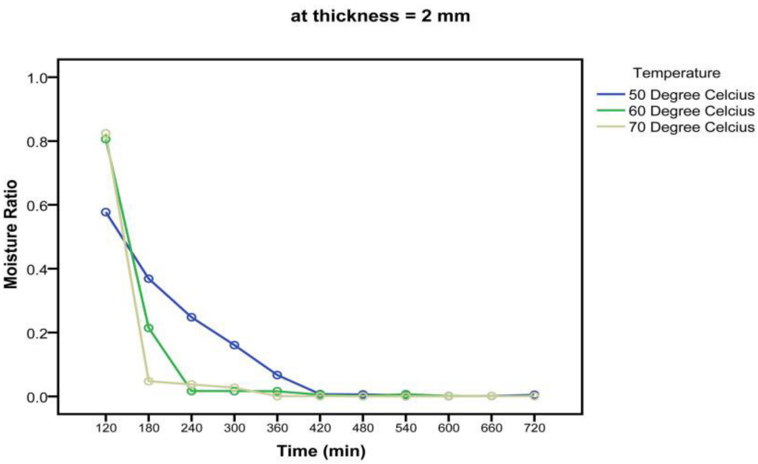

Fig. 1. Effect of temperature on the moisture ratio of the pumpkin at 2 mm thickness.

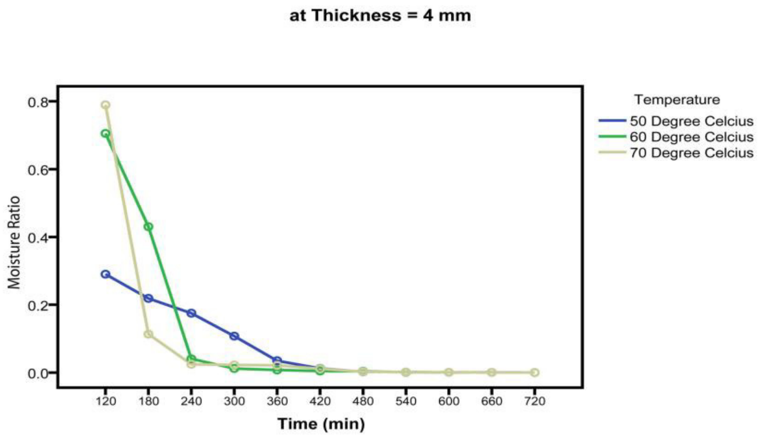

Fig. 2. Effect of temperature on the moisture ratio of the pumpkin at 4 mm thickness.

3.2. Effect of thickness on moisture ratio

Figs. 3 to 5, represents the moisture ratio versus drying time. It is clearly evident that the moisture ratio decreased continuously with drying time. The change in moisture content of sample versus drying time, for various sample thicknesses at a drying temperature of 50 °C, is shown in Fig. 3. It was also found that greater sample thickness required a longer drying time due to the increased distance travelled by moisture to the surface. Similar trends were also observed at drying temperatures of 60 °C and 70 °C.

Also from Fig. 5, it can be seen that there is little or no difference between 2 mm and 4 mm thickness at temperature of 70°C. MR was highest at 50 °C for drying pumpkin 4 mm thick, and lowest at 70 °C for drying pumpkin 2 mm thick. The increase in the moisture ratio at a lower thickness is due the movement of air on the surface of the pumpkin layer which is faster at a smaller surface area than a larger surface area. It can be said that at a higher drying temperature, thickness has no much effect on the drying rate.

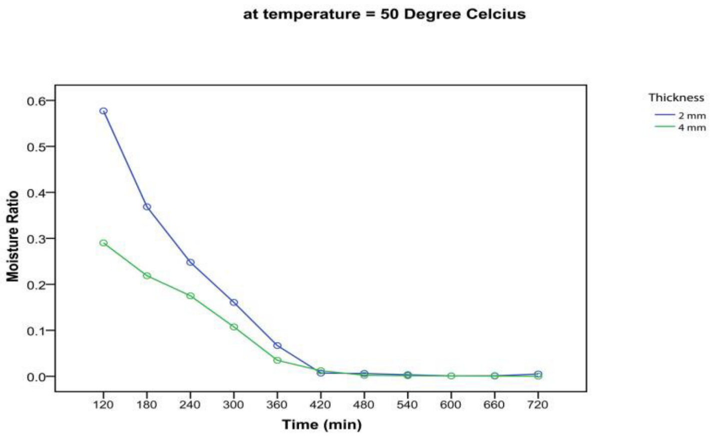

Fig. 3. Effect of pumpkin thickness on the moisture ratio of the pumpkin during drying at 50 °C.

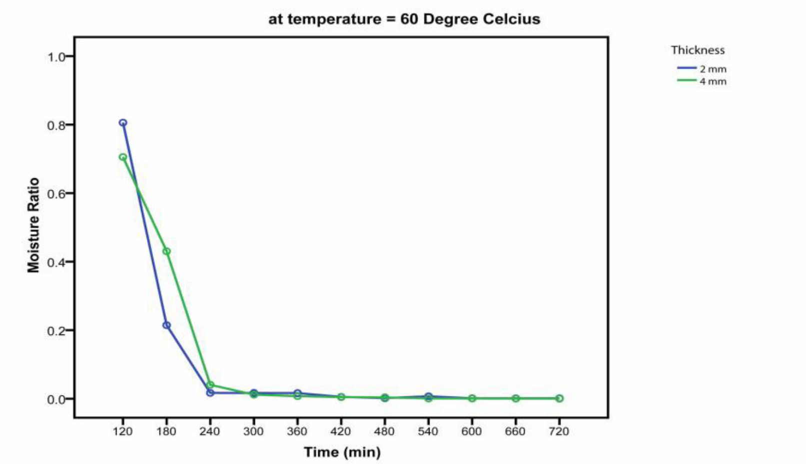

Fig. 4. Effect of pumpkin thickness on the moisture ratio of the pumpkin during drying at 60 °C.

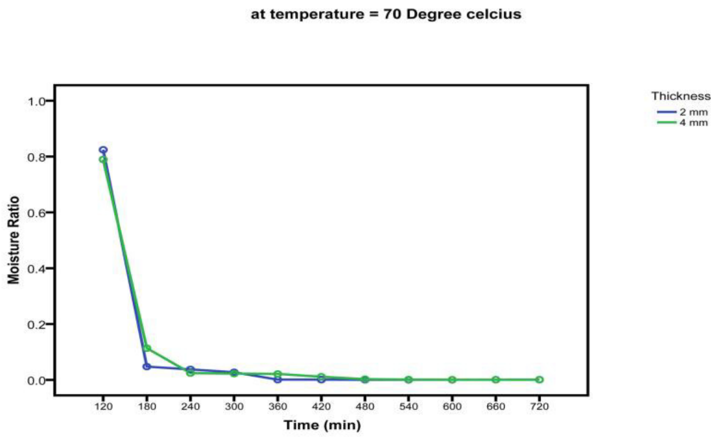

Fig. 5. Effect of pumpkin thickness on the moisture ratio of the pumpkin during drying at 70 °C.

3.3 Comparison between the drying models

Table 3 shows the results of fitting the experimental data to the drying models listed in Table 1. It is observed that model 1 and 2 were the most suitable. The suitability of the Lewis model and Henderson and Pabis model to describe the phenomenon studied was evaluated using the calculation of the following statistical parameters according to the following criteria: correlation coefficient (R) greater than 95%, coefficient of determination (R^2) greater than 90% and Standard square estimate error (SSE) less than 1.0 using Eqs. (8) to (10). The best-fitting model for pumpkin (*Cucurbita moschata)* is the Lewis Model with R (97.1%), R^2 (94%) and SSE (0.577). Fig. 6 shows the behavior of the different models on the drying curve. It can also be seen that the graph of *Henderson and Pabis* model (R = 95.7%, R^2 = 91.6% and SSE = 0.703) is close to that of the experimental model. The statistical values of the models are as tabulated in Table 3. Hence, *Lewis* model gives accurate prediction of the effect of temperature and thickness on the moisture ratio of pumpkin, the *Henderson and Pabis* model gives a better relationship between the experimental data and the predicted data.

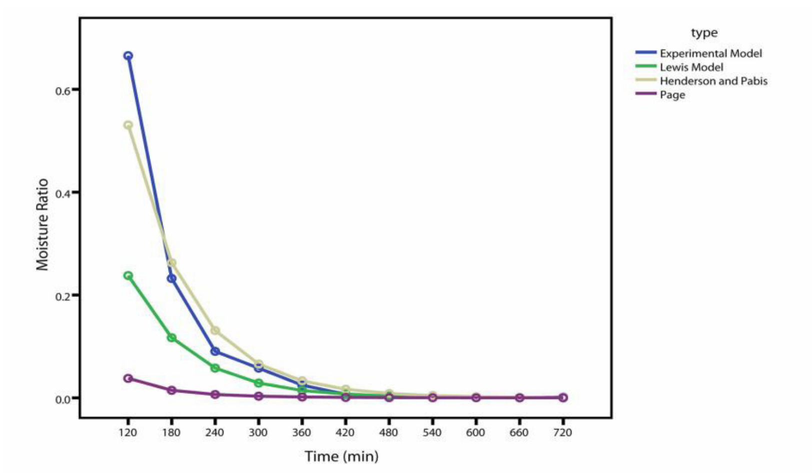

Fig. 6. Behaviour of different models on drying curves.

Table 3. Statistical result of the selected models.

Model Name	*R*	R^2	*SSE*	*A*	*K*	*N*
Lewis	0.971	0.942	0.577	1.00	0.724	
Henderson and Pabis	0.957	0.916	0.703	2.136	0.724	
Page	0.812	0.659	2.215	-	0.125	0.960

4. Conclusions

The effect of temperature and thickness on the drying kinetics of pumpkin was investigated. An increase in temperature resulted in a corresponding decrease in the drying time of pumpkin and a decrease in the thickness resulted to a decrease in the drying time and an increase in the moisture ratio.

In order to explain the drying behavior of pumpkin *(Cucurbita Moschata)*, 3 drying kinetics models were applied and fitted to the experimental data. According to the statistical analysis applied to all models, it can be concluded that among these models, Lewis and Henderson and Pabis gave the best results. Lewis model gave a better prediction on the effect of temperature and thickness on drying rate of pumpkin, while Henderson and Pabis model predicted the best relationship between the experimental data and the predicted data. Hence, both Lewis model and Henderson and Pabis were found to produce accurate predictions of the drying curves of Pumpkin.

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