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Research Article

Drying Kinetics and Drying Models of Terong Dayak (*Solanum lasiocarpum)*

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Abstract: Drying using a hot air chamber was tested on samples of terong dayak (*Solanum lasiocarpum*). Drying kinetics curves of drying *S. lasiocarpum* demonstrated that drying at 55°C and relative humidity of 10% were the optimum values for drying *S. lasiocarpum*, with the appropriate equations using the Page's model drying equation $MR = \exp(-0.5494t^{1.4052})$ that produced 96.8% accuracy. According to the results which showed the highest average values of R^2 and the lowest average values of MBE and RMSE, therefore it can be stated that the Page model could describe the drying characteristics of *S. lasiocarpum* in the drying process at a temperature of 55°C and relative humidity of 10%.

Keywords: Drying kinetics, drying modeling, hot air chamber, *S. lasiocarpum*, terong dayak

INTRODUCTION

Most agricultural and marine commodities require drying process in an effort to preserve the quality of the final product. Drying is a traditional method that has been used for many centuries to preserve agricultural and marine products (Fudholi *et al*., 2015, 2014a). The quality of the products depends on many factors including the drying temperature, relative humidity and duration of drying time (Fudholi *et al*., 2010). Hot air drying is the most frequently used dehydration operation in the food industry. Recently, there have been many reports on drying kinetics of agricultural fruits and vegetables. Thin-layer drying models also have been widely used for analysis of drying of various agricultural products, such as tomato (Taheri-Garavand *et al*., 2011), barberry (Gorjian *et al*., 2011), quercus (Tahmasebi *et al*., 2011), fish (Kilic, 2009), sea cucumbar (Daun *et al*., 2010), spirulina (Dissa *et al*., 2010) and seaweeds (Fudholi *et al*. 2014b; 2012a, 2012b).

Three different one-term exponential drying models were compared with experiment data. An excel software was used in the analysis of raw data obtained from the drying experiment. The values of the parameters a, n and k for the models were determined using a plot of curve drying models (Basri *et al*., 2012a, 2012b, 2012c; Fudholi *et al*., 2013, 2012c, 2012d, 2012e, 2011; Othman *et al*., 2012), which the model Page model has been reported to exhibit a better fit than other one-term exponential model thin layer drying models in accurately simulating the drying curves.

The objectives of this study are to observe the effects of different relative humidity on drying characteristics of *S. lasiocarpum* and to propose mathematical model for drying curves on drying behavior of *S. lasiocarpum*.

MATERIALS AND METHODS

The fresh *S. lasiocarpum* were purchased from a local market in Miri, Sarawak (Malaysia) in September 2012 and stored in ventilated packing bag at a temperature of 4°C. The initial moisture content of *S. lasiocarpum* was determined by measuring its initial and final weight using the hot air chamber at 120°C until constant weight was obtained. The average initial moisture content of the fresh *S. lasiocarpum* was obtained to be 90.54% w.b.

The experiments are carried out at the Solar Energy Laboratory in Physics Department, Universiti Kebangsaan Malaysia. In this study, a hot air chamber

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Fig. 1: Photograph of the *S. lasiocarpum* in a hot air chamber

Table 1: One-term exponential models thin layer drying models

No.	Model name	Model
1	Newton	MR = exp(-kt)
2	Page	MR = exp(-kt^n)
3	Henderson and Pabis	MR = a exp(-kt)

was used to investigate the drying kinetics of *S. lasiocarpum*, as shown in Fig. 1. The hot air chamber (Model DY110, Angelantoni Asean Pte Ltd, Singapore) is capable of providing the desired drying air temperature in the range of -40 to 180°C and air relative humidity in the range of 10 to 98%. *S. lasiocarpum* after been cleaned was inserted into the chamber. The drying experiments were conducted at Relative Humidity (RH) of 10, 20 and 30% and at drying air temperature 55^{o}C and constant air velocity of 1 m/s. The change of weight was recorded at every 5 min. Measurement was discontinued when the heavy weight of the material reaches a constant fixed value. Data obtained from the measurements of weight in a test prior to being used for the analysis of drying kinetics of materials need to be changed first in the form of moisture content data. The moisture content was expressed as a percentage wet basis and then converted to gram water per gram dry matter. The experimental drying data for *S. lasiocarpum* were fitted to the exponential model thin layer drying models as shown in Table 1 by using non-linear regression analysis.
The Moisture Ratio (MR) can be calculated as:

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

where,
M_e = Equilibrium moisture content
M_0 = Initial moisture content

The moisture content of Materials (M) can be calculated using two methods on the basis of either wet or dry basis using the following equation.
The moisture content wet basis:

$$M = \frac{w(t) - d}{w} \times 100\,\% \quad (2)$$

The moisture content dry basis:

$$X = \frac{w(t) - d}{d} \quad (3)$$

where,
w(t) = Mass of wet materials at instant t
d = Mass of dry materials

The coefficient of determination (R^2) was one of the primary criteria to select the best model to compare with the experimental data. In addition to R^2, Mean Bias Error (MBE) and Root Mean Square Error (RMSE) were also used to compare the relative goodness of the fit. The best model describing the drying behavior of *S. lasiocarpum* was chosen as the one with the highest coefficient of determination and the least root mean square error (Fudholi *et al*., 2014b, 2013). This parameter can be calculated as follow:

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

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

RESULTS AND DISCUSSION

The results of the drying kinetic curves of *S. lasiocarpum* at drying temperature of 55^{o}C and the relative humidity of 10, 20 and 30% are shown in Fig. 2 to 5. It consists of three curves namely the drying curve, the drying rate curve and the characteristic drying curve. Drying curve showed the profile change in moisture content (X) versus drying time (t). Drying rate curve illustrated the drying rate profile (dX/dt) versus drying time (t). Drying characteristic curves displayed the drying rate profile (dX/dt) versus moisture content dry basis (X).

Figure 2 and 3 showed a decrease in moisture content wet basis and dry basis of drying time at different relative humidity at temperature 55^{o}C, respectively. From these graphs, it shows that at high relative humidity, the moisture content of *S. lasiocarpum* is increased, slowing down the drying process as the drying time becomes longer. In contrast, by decreasing air relative humidity, increasing the moisture content caused a reduction in drying time rapidly. This observation is in agreement with other finding reported for drying of tomato (Taheri-Garavand *et al*., 2011).

Figure 4 showed the profile of the drying rate versus drying time. From this graph, the drying rate was found higher at high temperature. This means that the time required to dry the material to reach equilibrium moisture content is shorter. Figure 5 showed the characteristic drying curve obtained at different relative humidity.

Fitting of the three drying models has been done with the experimental data of *S. lasiocarpum* at drying temperature of 55^{o}C and the relative humidity of 10%, 20% and 30%. Drying models which were fitted with the experimental data of drying were the Newton

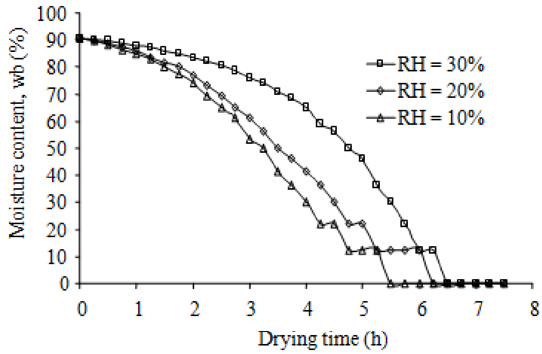

Fig. 2: Moisture content variation with drying time at 55°C

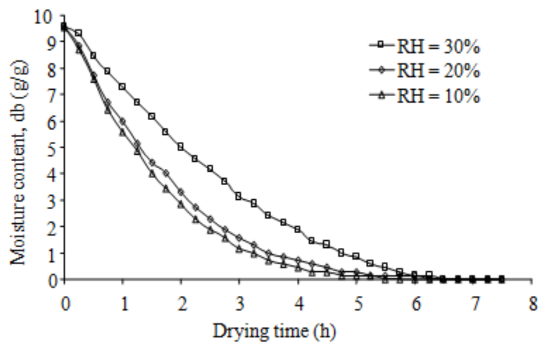

Fig. 3: Drying curve: Dry basis moisture content versus drying time at 55°C

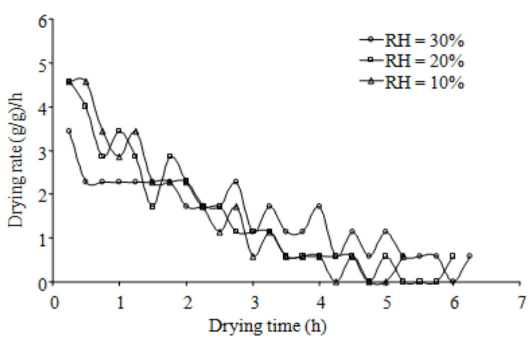

Fig. 4: Drying rate curves: Dry basis moisture content versus drying time at 55°C

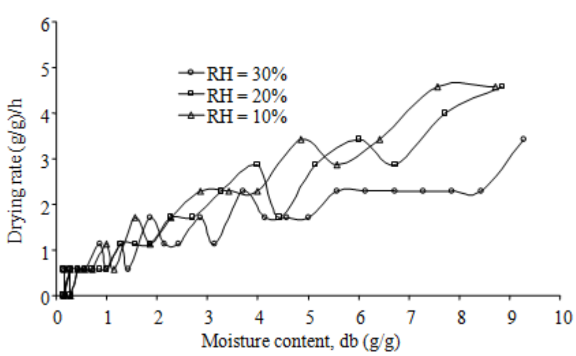

Fig. 5: Drying characteristic curves: A dry basis moisture content versus drying time at 55°C

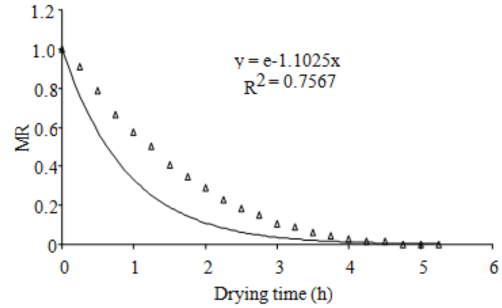

Fig. 6: Plot of MR versus drying time (Newton's model) at 10% RH

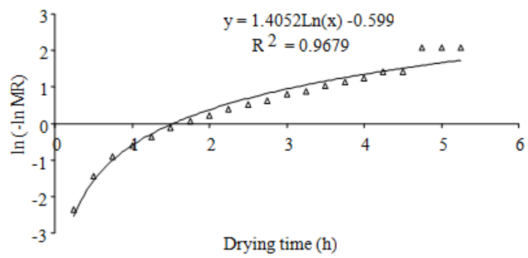

Fig. 7: Plot of ln (-ln MR) versus drying time (Page's model) at 10% RH

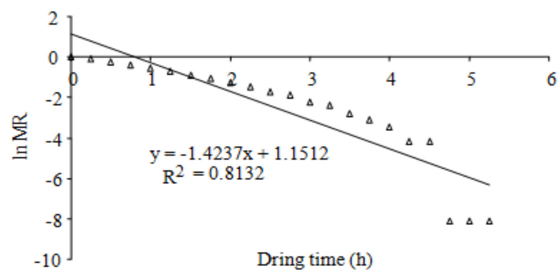

Fig. 8: Plot of ln MR versus drying time (Henderson and Pabis model) at 10% RH

model, Page model and Henderson and Pabis model. Drying experimental data fitted the model of drying in the form of changes in moisture content versus drying time (Fig. 6). In these drying models, changes in moisture content versus time were calculated using Excel software and constants were calculated by graphical method. The results that fitted with the drying models with experimental data were listed in Table 2. This table showed a constant drying and precision fit for each model of drying. The one with the highest R^2 and the lowest MBE and RMSE was selected to better estimate the drying curve. Page equation can also be written as the following equation:

$$\ln(-\ln MR) = \ln k + n \ln t \quad (6)$$

Equation 6 is the relationship ln (-ln MR) versus t, is the curve of the logarithmic equation, as shown in Fig. 7. Henderson and Pabis equation can also be written as the following equation:

Table 2: Results of non-linear regression analysis

Model name	RH (%)	Model coefficients and constants	R^2	RMSE	MBE
Newton	10	k = 1.1025	0.7567	0.1380	0.0190
	20	k = 1.0168	0.7627	0.1409	0.0198
	30	k = 0.6843	0.6254	0.1720	0.0296
Page	10	k = 0.5494; n = 1.4052	0.9679	0.0286	0.0008
	20	k = 0.4736; n = 1.4135	0.9675	0.0298	0.0009
	30	k = 0.2556; n = 1.5122	0.9601	0.0390	0.0015
Henderson and Pabis	10	k = 1.4237; a = 3.162	0.8132	0.5733	0.3287
	20	k = 1.3178; a = 3.4182	0.8211	0.6207	0.3852
	30	k = 0.9331; a = 2.8792	0.6923	0.5129	0.2631

$$\ln MR = -kt + \ln a \quad (7)$$

From Eq. 7, a plot of ln MR versus drying time gives a straight line with intercept = ln a and slope = k.

Graf MR versus ln t, as shown in Fig. 8, obtained the value k = 1.4237 and the value of a = 3.1620. Results presented in Table 2 showed that the Page drying model has the highest value of R^2 (0.9679), as well as the lowest values of MBE (0.0008) and RMSE (0.0286), compared to Newton's model and Henderson and Pabis model. Accordingly, the Page model was selected as the suitable model to represent the thin layer drying behaviour of *S. lasiocarpum*. The model Page model has been reported to exhibit a better fit than other one-term exponential model thin layer drying models in accurately simulating the drying curves of seaweed and chili (Fudholi *et al*., 2014b, 2013).

CONCLUSION

Drying using a hot air chamber was tested on samples of terong dayak (*Solanum lasiocarpum*). The drying experiments were performed at relative humidity of 10, 20 and 30% and a constant air velocity of 1 m/s. Drying kinetics of *S. lasiocarpum* were investigated and obtained. A non-linear regression procedure was used to fit three drying models of thin layer drying models. The models were compared with experimental data of *S. lasiocarpum* drying at air temperature of 55°C. The fit quality of the models was evaluated using the coefficient of determination (R^2), Mean Bias Error (MBE) and Root Mean Square Error (RMSE). The highest values of R^2 (0.9679)**,** the lowest MBE (0.0008) and RMSE (0.0286) indicated that the Page model is the best mathematical model to describe the drying behavior of *S. lasiocarpum*.

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