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Drying Characteristics of the Borneo *Canarium odontophyllum* (Dabai) Fruit

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ABSTRACT

The quality and shelf-life of an underutilized fruits are compromised by the conventional method of drying. We therefore proposed using hot-air chamber to develop the drying curves of *Canarium odontophyllum* (Dabai) fruit. Present study provides evidence of the best mathematical model to demonstrate the drying characteristics of this indigenous fruit and thus, may generate or add to the existing database. The drying experiments were performed at three different relative humidity of 10, 20 and 30% and a constant air velocity of 1 m sec^{-1}. Drying kinetics of *C. odontophyllum* fruit were investigated and obtained. A non-linear regression procedure was used to fit three different one-term exponential models of thin layer drying models. The models were compared with experimental data of *C. odontophyllum* fruit 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 value of R^2 obtained was 0.9348, the lowest MBE value was 0.0018 and the value for RMSE was 0.0420. Page model is the best mathematical model to describe the drying behavior of *C. odontophyllum* fruit.

Keywords: Drying Kinetics, *Canarium Odontophyllum*, Dabai Fruit, Hot-Air Chamber, Mathematical Modelling

1. INTRODUCTION

Drying is one of an important post handling process of agricultural products (Fudholi *et al*., 2010). Most agricultural commodities and marine products require drying process in an effort to preserve the quality of the final product. Hot-air drying is the most frequently used dehydration operation in the food and chemical industry (Othman *et al*., 2012).

Drying kinetics is generally evaluated experimentally by measuring the weight of a drying material a function of time. Drying curves may be represented in three different types of plots, i.e. moisture content versus time, drying rate versus time and drying rate versus moisture content. Mathematical modeling of thin layer drying is important for optimum management of operating parameters and prediction performance of drying process. It is essential to set out accurate models to simulate the drying curves under different drying conditions. The description and prediction of the drying kinetics of a given material are still a weakness in the modeling of drying process. There is a great need for stable and reliable model to quantify and predict drying rates and drying times with a satisfying accuracy (Saeed *et al*., 2008).

Recently, there have been many reports on drying kinetics of agricultural fruits and vegetables. Thin-layer drying models have been used for analysis of drying of various agricultural and marine products, such as fish (Kilic, 2009), sea cucumber (Duan *et al*., 2010), spirulina (Dissa *et al*., 2010), apple (Doymaz, 2010), banana (Smitabhindu *et al*., 2008), berberis (Aghbashlo *et al*., 2008), blueberry (Vega-Galvez *et al*., 2009), carrot (Berruti *et al*., 2009), cassava (Ghaba *et al*., 2007), cocoa (Hii *et al*., 2009), pear (Guine *et al*., 2007), mango (Dissa *et al*., 2011), apricots, fig, grape and plum (Togrul and Pehlivan, 2004), tomatoes (Marfil *et al*., 2008), sweet cherry (Doymaz and Osman, 2011), chili (Artnaseaw *et al*., 2010) and red beet (Kaleta and Krzysztof, 2010). Heat pump drying was proposed to enhance the drying kinetic of salak fruit and retain a high concentration of total phenolic compounds in the fruit (Ong and Law, 2011).

Canarium odontophyllum Miq. which belongs to family Burseracea is locally known as 'dabai' in Malaysia and

'Borneo olives' in Sarawak, where it is a seasonal fruit indigenous to this part of East Malaysia. Dabai fruit is dieocious with male and female flowers borne on different trees. Dabai fruit is blue-black in colour when ripe, as shown in **Fig. 1**. It is oblong in shape and has a thin, edible skin. The flesh is either white or yellow, which covers a large three-angled seed. The flavour is unique with thick and oily texture like an avocado fruit. Recent study has shown that dabai fruit, especially the skin, is the major source of antioxidant due to its high content of phenolic compounds (Shakirin *et al*., 2010). In addition to this, dabai fruit is also a good source of unsaturated fatty acids and thus, has the potential to be developed as healthy cooking oil (Azrina *et al*., 2010). Dabai fruit is found to contain beneficial nutrients. According to Ding and Tee (2010), it has high energy (339 kkal/100 g edible portion), fat (26.2%), carbohydrate (22.1%), protein (3.8%), crude fibre (4.3%), ash (2.3%), potassium (810 mg/100 g edible portion), calcium (200 mg/100 g edible portion), magnesium (106 mg/100 g edible portion), phosphorous (65 mg/100 g edible portion) and iron (1.3 mg/100 g edible portion). To the best of our knowledge, no past research have been conducted to investigate the drying kinetics of dabai fruit in a hot-air drying. Keeping in mind the health-promoting properties and high nutritional benefits of dabai fruit, the present study was carried out to observe the effects of different relative humidities on drying characteristics of *C. odontophyllum* fruit and to select the best mathematical model to illustrate the drying behavior of this wonder fruit.

Fig. 1. *Canarium odontophylum* (dabai) fruit

Fig. 2. Hot-air chamber used for dabai fruit drying

2. MATERIALS AND METHODS

2.1. Plant Material

The fresh dabai fruits were purchased from a local market in Sarawak, Malaysia in January 2012 and stored in a ventilated packing bag at a temperature of 4°C. The initial moisture content of dabai fruit was determined by measuring its initial and final weight using the hot-air chamber at 120°C until constant weight was obtained (Meziane, 2011). The average initial moisture content of the fresh dabai fruit was obtained to be 63.33% w.b.

2.2. Drying Experiment

In this study, a hot-air chamber was used to investigate the drying kinetics of dabai fruit as shown in **Fig. 2**. The hot-air chamber (Model DY110, Angelantoni Asean Pte Ltd, Singapore) is capable of providing the desired drying air temperature in the range of -40-180°C and air relative humidity within the range of 10-98%. The drying experiments were conducted at different Relative Humidity (RH) 10, 20 and 30% and at a constant air temperature of 55°C and constant air velocity of 1 m sec^{-1}. The change of weight was recorded at every 5 min. The measurement was discontinued when the heavy weight of the material reaches a constant fixed value.

Table 1. Four types of one-term thin layer drying exponential models

Model name	Model
Newton (O'Callaghan *et al*., 1971)	MR = exp(-kt)
Page (1949)	MR = exp(-ktn)
Modified Page (Overhults *et al*., 1973)	MR = exp(-(kt)n)
Henderson-Pabis (Henderson and Pabis, 1961)	MR = a exp(-kt)

2.3. Data Analysis

Data obtained from the measurements of weight in a test before being used in the analysis of drying kinetics of materials, need to be changed 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 dabai fruit 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 Eq. 1:

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

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 is Eq. 2:

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

The moisture content dry basis is Eq. 3:

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

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 dabai fruit was chosen as the one with the highest coefficient of determination and the least root mean square error (Othman *et al*., 2012). This parameter can be calculated as follows Eq. 4 and 5:

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

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

3. RESULTS

The results of the drying kinetic curves of dabai fruit at 55oC and the relative humidity of 10, 20 and 30% are shown in **Fig. 3-6**. 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 3 and 4 respectively, showed a decrease in moisture content wet basis and dry basis of drying time at different relative humidity at 55°C. It was observed that at high relative humidity, the moisture content of dabai fruit is increased, slowing down the drying process as the drying time becomes longer.

Figure 5 showed the profile of the drying rate versus the drying time. From this graph, the drying rate was found higher at low values of relative humidity.

Figure 6 showed the characteristic drying curve obtained at different values of relative humidity.

Fitting of the four drying models has been done with the experimental data of dabai fruit at 55°C and relative humidity 10, 20 and 30%. Drying models, which were fitted with the experimental data of drying, were the Newton, Page and Henderson-Pabis model. Drying experimental data fitted the model of drying in the form of changes in moisture content versus drying time. In these drying models, changes in moisture content versus time were calculated using Excel software and constants were calculated by the 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 be the best estimate of the drying curve.

Newton's model of the relationship between the Moisture Ratio (MR) and drying time, demonstrated a curve of the exponential equation as shown in **Fig. 7-9**. These figures clearly showed k constant of 1.7745, 1.2966 and 0.9652 for relative humidity of 10, 20 and 30% respectively. Page's equation can also be written as the following Eq. 6:

$$In(-InMR) = Ink + nInt \quad (6)$$

Equation (6) is the relationship ln (-ln MR) versus t and the curve of this logarithmic equation, as shown in **Fig. 10-12**. From these figure, obtained values n constant of 1.3308, 0.9638 and 0.9142 for relative humidity of 10, 20 and 30% respectively. Henderson and Pabis (1961) equation can also be written as the following Eq. 7:

$$InMR = -kt + Ina \quad (7)$$

From equation (7), a plot of ln MR versus drying time gives a straight line with intercept ln a and slope k. Graph MR versus ln t, as shown in **Fig. 13-15**. From these figures obtained the value k constant of 2.2029, 1.1055 and 1.1055 for relative humidity of 10, 20 and 30% and the value a constant of 1.9935 for relative humidity of 30%. Results presented in **Table 3** showed that the Page drying model has the highest value of R^2 (0.9348), as well as the lowest values of MBE (0.0018) and RMSE (0.0420), compared to Newton and the Henderson-Pabis model. Accordingly, the Page model was selected as the suitable model to represent the thin layer drying behaviour of dabai slices.

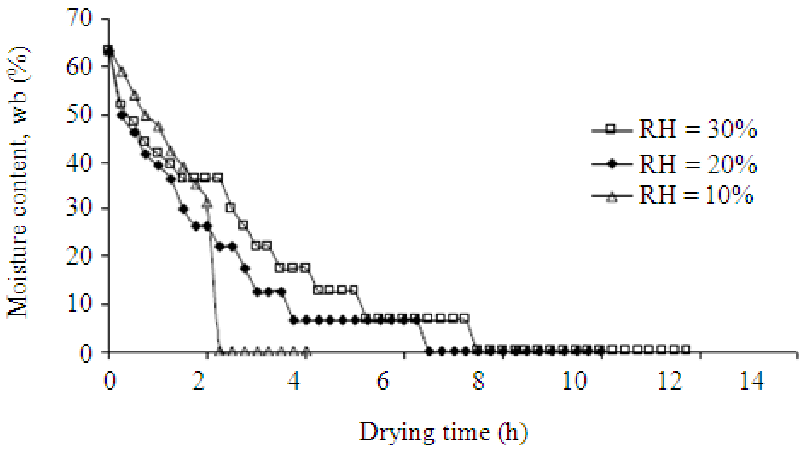

Fig. 3. Effect of drying time at 55°C and air velocity of 1 m s^{-1} on moisture content variation

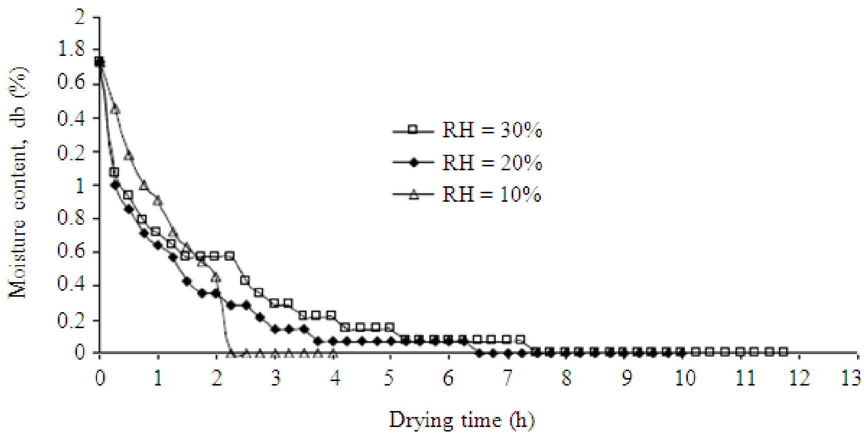

Fig. 4. Effect of drying time at 55°C and air velocity of 1 m s^{-1} on the dry basis moisture content

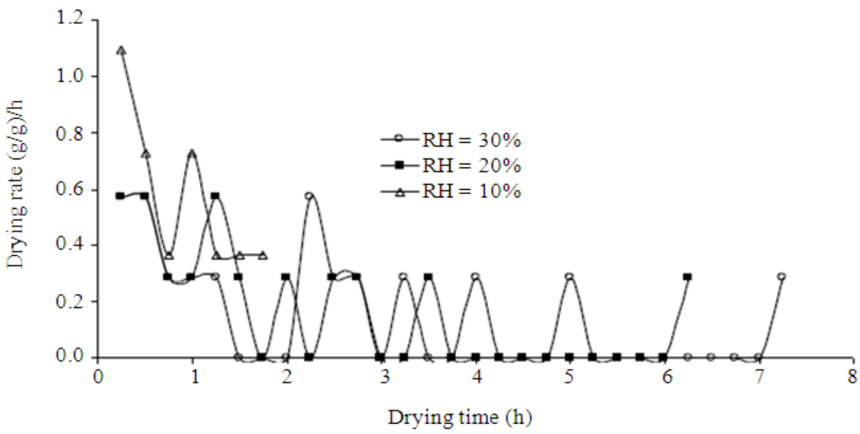

Fig. 5. Drying rate curve showing the dry basis moisture content against drying time at 55°C and air velocity of 1 m s^{-1}

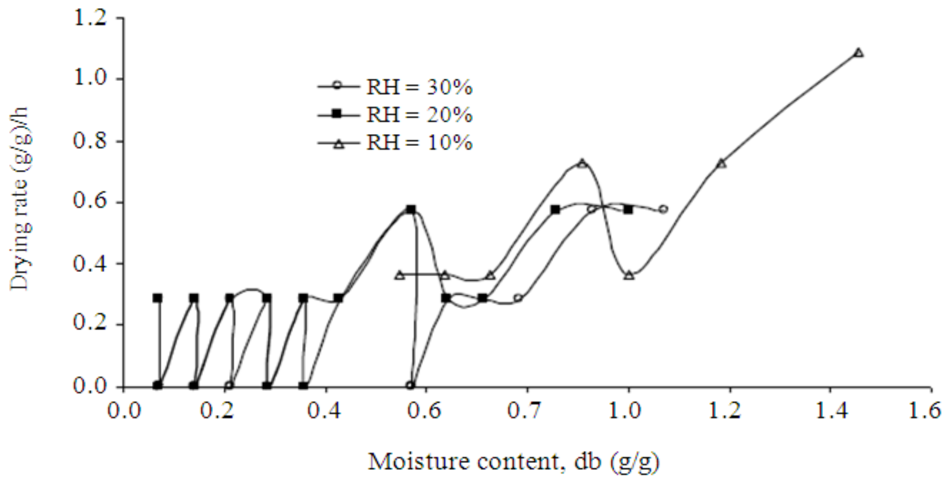

Fig. 6. Drying characteristic curve showing the dry basis moisture content against drying time at 55°C and air velocity of 1 m s^{-1}

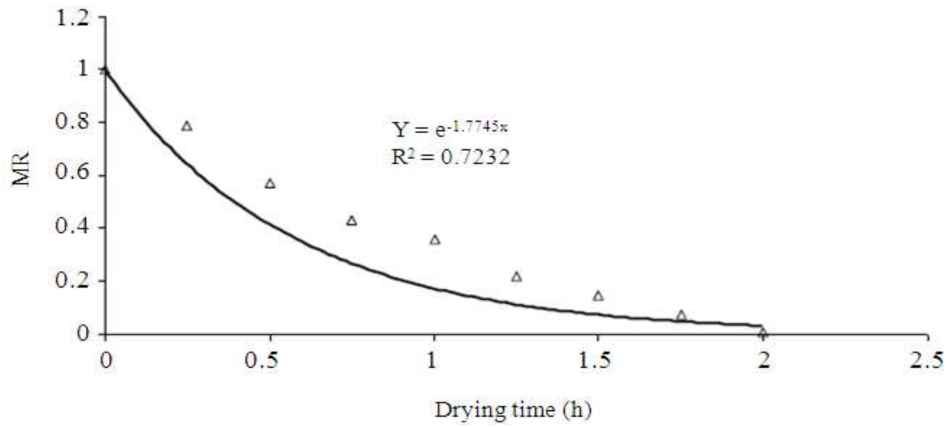

Fig. 7. Plot of MR against drying time (Newton model) at 10% RH

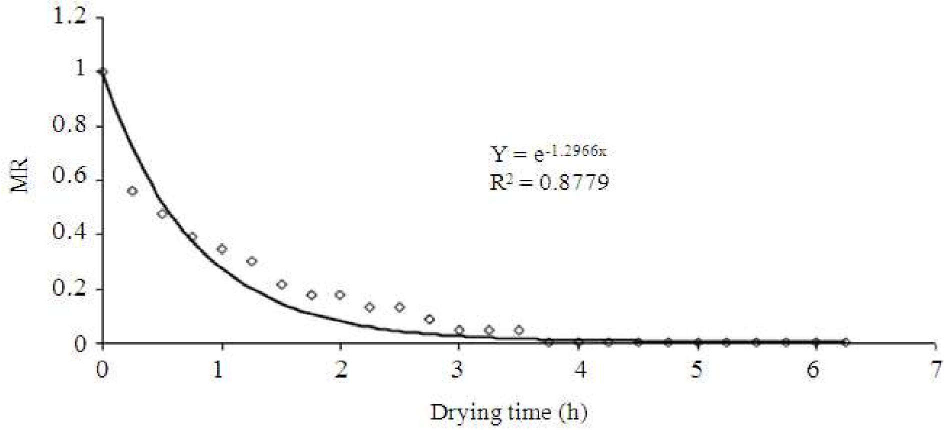

Fig. 8. Plot of MR against drying time (Newton model) at 20% RH

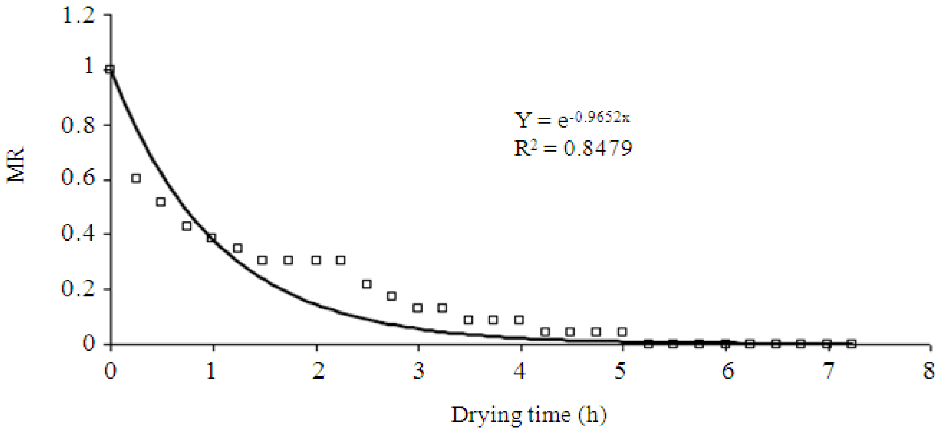

Fig. 9. Plot of MR against drying time (Newton model) at 30% RH

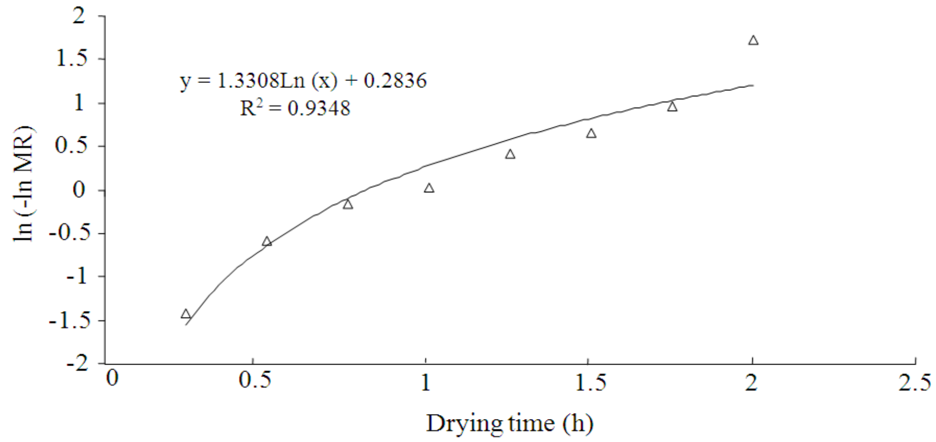

Fig. 10. Plot of ln (-ln MR) versus drying time (Page model) at 10% RH

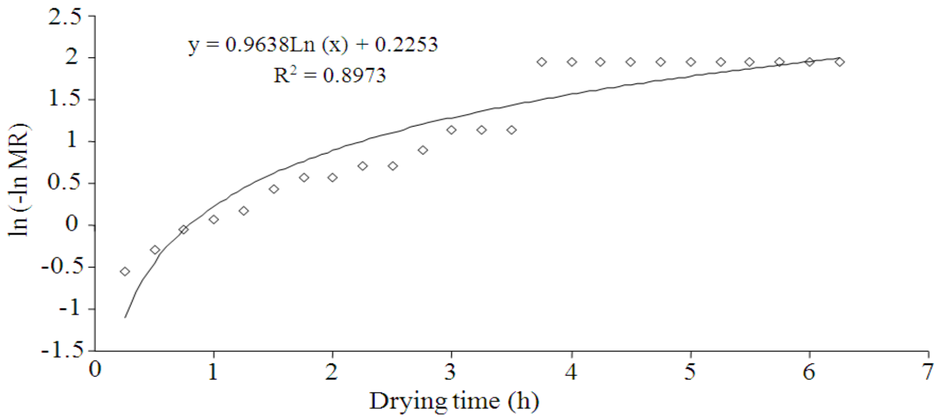

Fig. 11. Plot of ln (-ln MR) versus drying time (Page model) at 20% RH

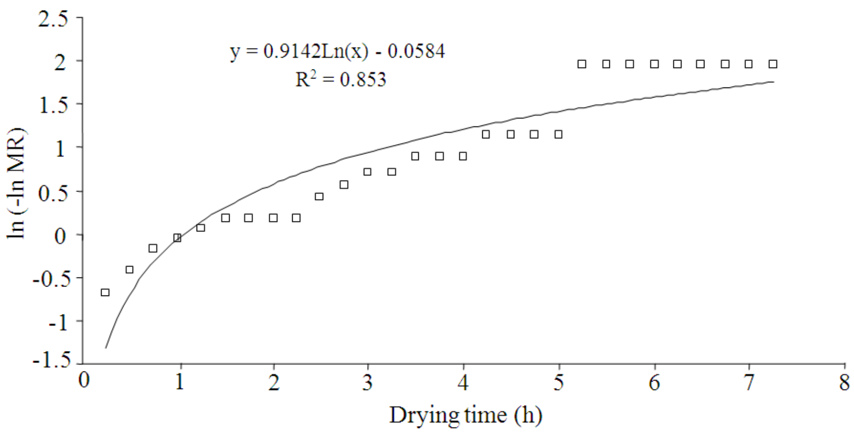

Fig. 12. Plot of ln (-ln MR) versus drying time (Page model) at 30% RH

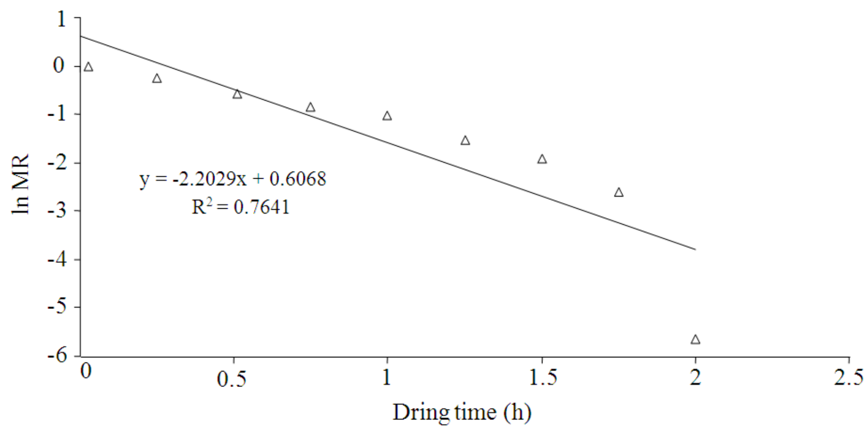

Fig. 13. Plot of ln MR versus drying time (Henderson-Pabis model) at 10% RH

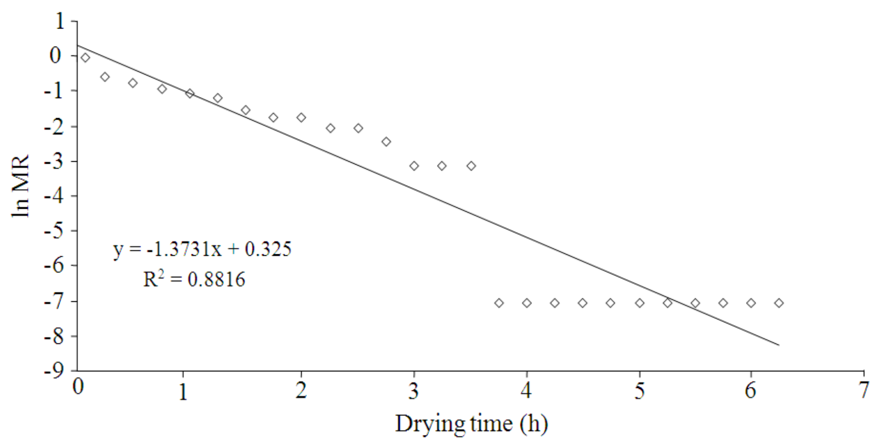

Fig. 14. Plot of ln MR versus drying time (Henderson-Pabis model) at 20% RH

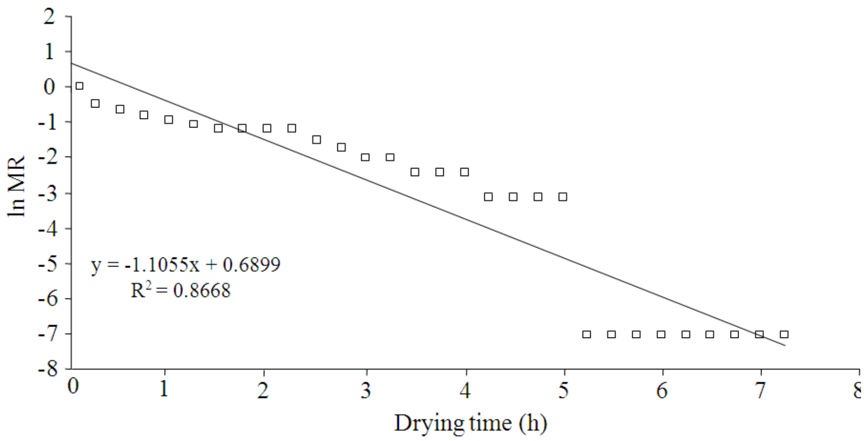

Fig. 15. Plot of ln MR versus drying time (Henderson-Pabis model) at 30% RH

Table 2. Results of non-linear regression analysis

Model name	RH (%)	Model Coefficients and Constants	R^2	RMSE	MBE
Newton	10	k = 1.7745	0.7232	0.1193	0.0142
	20	k = 1.2966	0.8779	0.0571	0.0033
	30	k = 0.9652	0.8479	0.0777	0.0060
Page	10	k = 1.3279; n = 1.3308	0.9348	0.0420	0.0018
	20	k = 1.2527; n = 0.9638	0.8973	0.0516	0.0027
	30	k = 0.9433; n = 1.9142	0.8532	0.0651	0.0042
Henderson-Pabis	10	k = 2.2029; a = 1.8346	0.7641	0.3020	0.0912
	20	k = 1.3731; a = 1.3840	0.8816	0.1266	0.0160
	30	k = 1.1055; a = 1.9935	0.8668	0.2926	0.0856

Table 3. Results of non-linear regression analysis

No. Fig.	Model name	RH (%)	Equation	Model Coefficients	R^2	RMSE	MBE
7	Newton	10	$y = e^{-1.7745x}$	k = 1.7745	0.7232	0.1193	0.0142
8	Newton	20	$y = e^{-1.2966x}$	k = 1.2966	0.8779	0.0571	0.0033
9	Newton	30	$y = e^{-0.9652x}$	k = 0.9652	0.8479	0.0777	0.006
10	Page	10	y = 1.3308ln(x) + 0.2836	k = 1.3279; n = 1.3308	0.9348	0.042	0.0018
11	Page	20	y = 0.96388ln(x) + 0.2253	k = 1.2527; n = 0.9638	0.8973	0.0516	0.0027
12	Page	30	y = 0.9142ln(x) - 0.0584	k = 0.9433; n = 1.9142	0.8532	0.0651	0.0042
13	Henderson-Pabis	10	y = -2.2029x + 0.6068	k = 2.2029; a = 1.8346	0.7641	0.302	0.0912
14	Henderson-Pabis	20	y = -1.3731x + 0.325	k = 1.3731; a = 1.3840	0.8816	0.1266	0.016
15	Henderson-Pabis	30	y = -1.1055x + 0.6899	k = 1.1055; a = 1.9935	0.8668	0.2926	0.0856

4. DISCUSSION

This study demonstrated that the higher the relative humidity, the longer was the drying process of dabai fruit due to the increased moisture content of dabai fruit. 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 experimental data reported for drying of tomato (Taheri-Garavand *et al*., 2011). The drying rate versus the drying time indicated that the time required to dry the material up to equilibrium moisture content is shorter.

According to the results of this study, the Page model was selected as the suitable model to represent the thin layer drying behaviour of dabai fruit. This is in accordance with Fudholi *et al*. (2010) that Page model was shown to be a better fit to drying seaweed among other one-term exponential model thin layer drying models. Azoubel *et al.*

(2010) reported that Page model clearly improved the simulation in comparison with the results obtained using the diffusion model, having the best fit to the experimental data, with calculated average error ranging from 1.89 to 12.76% and R^2 values greater than 0.99. Page model showed a better fit than other models by simulating accurately the drying curves of chili pepper (Tunde-Akintunde, 2011), rapeseed (Duc *et al*., 2011) okra (Doymaz, 2005) and kiwi (Simal *et al*., 2005) among others. On the other hand, as far as the drying behavior of lemon grass is concerned, the Newton model showed a better fit to the experimental data among other semi-theoretical models (Ibrahim *et al*., 2009).

5. CONCLUSION

Drying using a hot-air chamber was tested on samples of dabai fruit (*Canarium odontophyllum*). Drying kinetic curves of drying dabai fruit demonstrated that drying at 55°C and relative humidity of 10% were the optimum values for drying dabai fruit, with the appropriate equations using the Page model with drying equation $MR = \exp(-1.3279t^{1.3308})$ that produced 93.5% accuracy. According to the results which showed the highest average values of R^2 and the lowest average values of MBE and RMSE, it can be stated that the Page model could describe the drying characteristics of dabai fruit in the drying process at a temperature of 55°C and relative humidity of 10% and air velocity of 1 m sec^{-1}. However, further studies are necessary to correlate the drying kinetics with quality of dabai fruit in view of its retention of antioxidant phytochemicals and lipid composition.

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