Drying Kinetics of Malaysian *Canarium odontophyllum* (Dabai) fruit

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Abstract: Drying method using a hot air chamber was tested on samples of dabai (*Canarium odontophyllum*) fruit. The drying experiments were performed at three different relative humidity of 10%, 20% and 30% and a constant air velocity of 1 m/s. 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 values of R^2 (0.9348), the lowest MBE (0.0018) and RMSE (0.0420) indicated that the 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 [1]. 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 [2].

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 [3-6]. Fudholi et al. [7] reported the effects of drying air temperature and humidity on the drying kinetics of seaweed *Gracilaria cangii*. The drying kinetics of *G. cangii* was studied using solar drying system [8] whereas hot air chamber was used to determine the drying kinetics of brown seaweed *Eucheuma cottonii* [9]. 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 [10].

Dabai (*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 is dieocious with male and female flowers borne on different trees. Dabai fruits are blue-black in colour when ripe. They are oblong in shape and have a thin, edible skin. The flesh is either white or yellow which covers a large three-angled seed. The flavour taste unique with thick and oily texture like an avocado fruit. Recent study has showed that dabai fruit, especially the skin, is the major source of antioxidant due to its high content of phenolic compounds [11]. 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 [12]. To the best of our knowledge, no past researches 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 humidity on drying characteristics of *C. odontophyllum* fruit and to select the best mathematical model to illustrate the drying behavior of this wonder fruit.

2 Material and Methods

The fresh dabai fruits were purchased from a local market in Miri, Sarawak (Malaysia) in January 2012 and stored in 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 [13]. The average initial moisture content of the fresh dabai fruit was obtained to be 63.33% w.b.

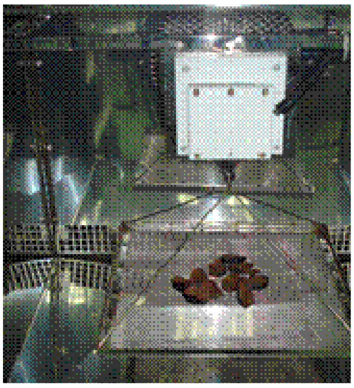

Fig. 1 Photograph of the dabai fruit in a hot air chamber

In this study, a hot air chamber was used to investigate the drying kinetics of dabai fruit 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 °C to 180°C and air relative humidity in the range of 10% to 98%. The drying experiments were conducted at three different relative humidity (RH) 10%, 20% and 30% and at a constant air temperature of 55°C and constant air velocity of 1 m/s. The change of weight was recorded at every 5 mins. 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 dabai fruit were fitted to the exponential model thin layer drying models as shown in Table 1 by using non-linear regression analysis.

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

No.	Model name	Model
1	Newton [14]	$MR = \exp(-kt)$
2	Page [15]	$MR = \exp(-kt^n)$
3	Modified Page [16]	$MR = \exp(-(kt)^n)$
4	Henderson and Pabis [17]	$MR = a \exp(-kt)$

The moisture ratio (MR) can be calculated as

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

where,
Me = Equilibrium moisture content
Mo = 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

$$M = \frac{w(t) - d}{w} x100\% \quad (2)$$

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 dabai fruit was chosen as the one with the highest coefficient of determination and the least root mean square error [18]. This parameter can be calculated as follow:

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

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

3 Results and Discussion

The results of the drying kinetic curves of dabai fruit at 55°C and the relative humidity of 10, 20 and 30% are shown in Fig. 2 to Fig. 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).

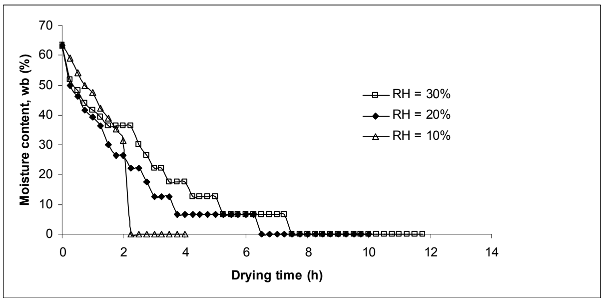

Fig.2. Moisture content variation with drying time at 55°C and air velocity of 1 m/s

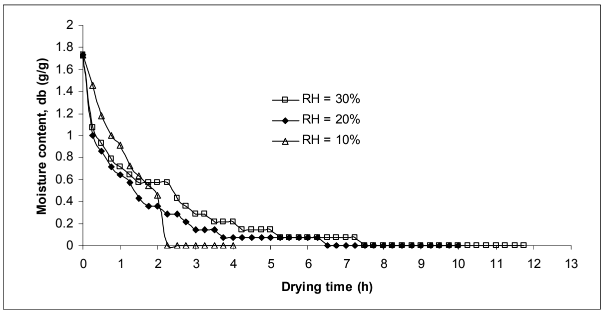

Fig. 3. Drying curve: dry basis moisture content versus drying time at 55°C and air velocity of 1 m/s

Fig. 2 and Fig. 3 respectively, showed a decrease in moisture content wet basis and dry basis of drying time at three 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. 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 [4].

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

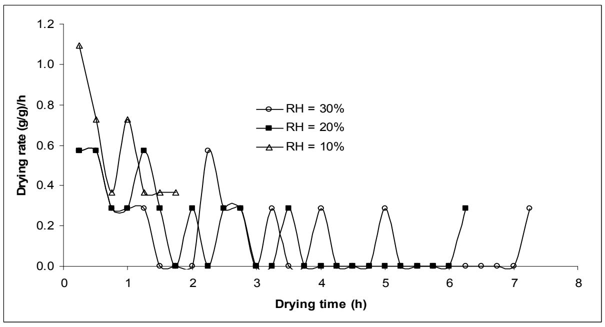

Fig. 4. Drying rate curves: dry basis moisture content versus drying time at 55 °C and air velocity of 1 m/s

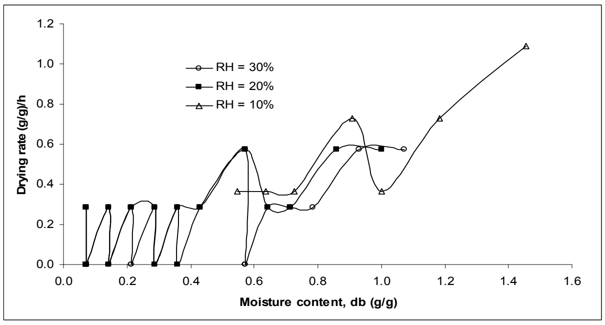

Fig. 5. Drying characteristic curves: a dry basis moisture content versus drying time at 55°C and air velocity of 1 m/s

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 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. In this 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.

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 and 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

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

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

From equation 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 = 1.1055 and the value of a = 1.9935. Results presented in Table 2 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'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 dabai slices. This is in accordance with Fudholi et al. [7-9] that Page model was shown to be a better fit to drying seaweed among other one-term exponential model thin layer drying models. On the other hand, as far as the drying behavior of lemon grass is concerned, the Newton model was showed a better fit to the experimental data among other semi-theoretical models [19].

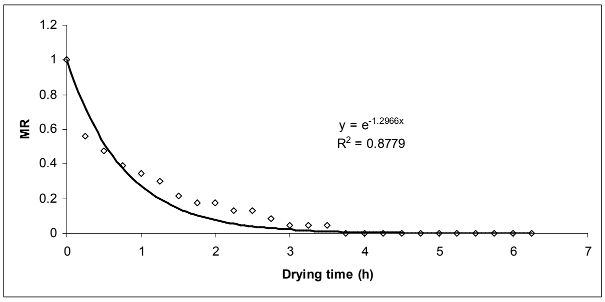

Fig. 6. Plot of MR versus drying time (Newton's model) at 20% RH

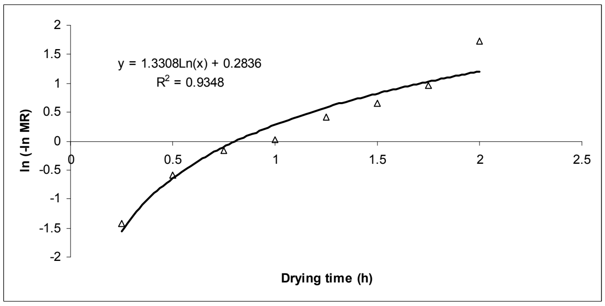

Fig. 7. Plot of ln (-ln MR) versus drying time (Page's model) at 10% RH

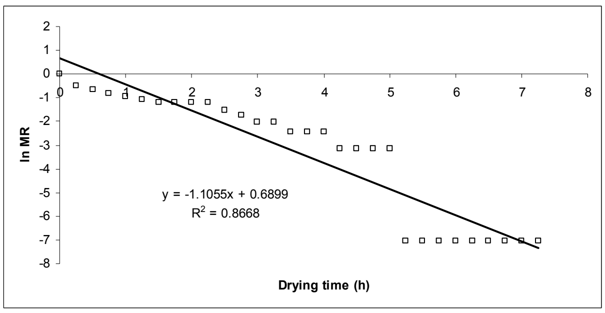

Fig. 8. Plot of ln MR versus drying time (Henderson and Pabis model) at 30% RH

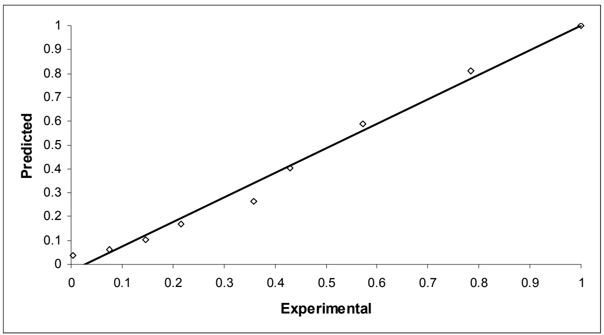

Fig.9. Comparison of experimental MR with predicted MR from Page model at 10% RH

4 Conclusion

Drying using a hot air chamber was tested on samples of dabai fruit (*Canarium odontophyllum*). Drying kinetics 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 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, therefore 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/s. However, further studies is 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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References

[1] A. Fudholi, K. Sopian, M. H. Ruslan, M.A. Alghoul, and M. Y. Sulaiman, "Review of solar dryers for agricultural and marine products," *Renewable & Sustainable Energy Review*, vol. 14, pp. 1-30, 2010.

[2] A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K. Sopian, "Techno-economic analysis of solar drying system for seaweed in Malaysia," in *Proc. of the 7th IASME/WSEAS Int. Conf. on Energy, Environment, Ecosystems and Sustainable Development (EEESD,11),* France, 2011.

[3] A. Mohammadi, S. Rafiee, A. Keyhani and Z. Emam-Djomeh. 2008. Estimation of Thin-layer Drying Characteristics of Kiwifruit (cv. Hayward) with Use of Page's Model. American-Eurasian J. Agric. & Environ. Sci., 3(5) : 802-805.

[4] A.Taheri-Garavand. S. Rafiee and A. Keyhani. 2011. Mathematical Modeling of Thin Layer Drying Kinetics of Tomato Influence of Air Dryer Conditions. International Transaction Journal of Engineering, Management & Applied Sciences & Technologies 2 (2) : 147-160.

[5] S. Gorjian, T. Tavakkoli Hashjin, M.H. Khoshtaghaza and A.M. Nikbakht. 2011. Drying Kinetics and Quality of Barberry in a Thin Layer Dryer. J. Agr. Sci. Tech. 13 : 303-314.

[6] M. Tahmasebi, T. Tavakkoli Hashjin, M.H. Khoshtaghaza and A.M. Nikbakht. 2011. Evaluation of Thin-Layer Drying Models for Simulation of Drying Kinetics of Quercus (*Quercus persica* and *Quercus libani*). J. Agr. Sci. Tech. 13 : 155-163.

[7] A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K. Sopian, "The effects of drying air temperature and humidity on drying kinetics of seaweed", in *Recent Research in Geography, Geology, Energy, Environment and Biomedicine,* Corfu, 2011, pp. 129-133.

[8] A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K. Sopian, "Design and testing of solar dryer for drying kinetics of seaweed in Malaysia," in *Recent Research in Geography, Geology, Energy, Environment and Biomedicine,* Corfu, 2011, pp. 119-124.

[9] A. Fudholi, M. H. Ruslan, L.C. Haw, S. Mat, M. Y. Othman, A. Zaharim and K. Sopian, "Mathematical modeling of Brown Seaweed Drying Curves", in *9th WSEAS Int. Conf. on Fluid Mechanics (FLUIDS'12),* USA, 2012.

[10] S. P. Ong and C.L. Law. 2011. Drying Kinetics and Antioxidant Phytochemicals Retention of Salak Fruit under Different Drying and Pretreatment Conditions. Drying Technology, 29 : 429 – 441.

[11] F.H. Shakirin, K.N. Prasad, I. Amin, C. Y. Lau, and A. Azrina. 2010. Antioxidant capacity of underutilized Malaysian *Canarium odontophyllum* (dabai) Miq. fruit. Journal of Food Composition and Analysis, 23 (8) : 777-781.

[12] A. Azrina, K.N. Prasad, H.E. Khoo, A.A. Nurnadia and M. Alina. 2010. Comparison of fatty acids, vitamin E and physicochemical properties of *Canarium odontophyllum* Miq. (dabai), olive and palm oils. Journal of Food Composition and Analysis, 23 : 772-776.

[13] S. Meziane "Drying kinetics of olive pomace in a fluidized bed dryer". *Energy Conversion and Management*, vol. 52, pp. 1644-1649, 2011.

[14] J. R. O'Callaghan, D.J. Menzies and P.H. Bailey. 1971. Digital simulation of agricultural dryer performance. J. Agric. Eng. Res. 16 : 223-244.

[15] G.E. Page. 1949. Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin Layers, MSc Thesis, Purdue University, West Lafayette, Indiana.

[16] D.D. Overhults, G.M. White, M.E. Hamilton and I.J. Ross. 1973. Drying soybeans with heated air. Trans. ASAE., 16 : 195-200.

[17] S.M. Henderson and S. Pabis. 1961. Grain Drying Theory : 1. Temperature Affection Drying Coefficient. J. Agric. Eng. Res. 6: 169-170.

[18] M. Y. Othman, A. Fudholi, K. Sopian, M. H. Ruslan, and M. Yahya, "Analisis Kinetik Pengeringan Rumpai Laut *Gracilaria cangii* Menggunakan Sistem Pengering Suria (Drying Kinetics Analysis of Seaweed *Gracilaria cangii* using Solar Drying System)" *Sains Malaysiana*, vol. 41, no. 2, pp. 245-252, 2012.

[19] M. Ibrahim. K. Sopian and W.R.W. Daud. 2009. Study of the drying Kinetics of lemon Grass, American Journal of Applied Sciences 6(6) : 1070-1075.