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Research Article

Mathematical Modeling of Belimbing Dayak Fruit (*Baccaurea angulata*) Influence of Different Drying Air Temperature

[1]Ahmad Fudholi, [1]Chan Hoy Yen, [2]Habibis Saleh, [3]Dayang Fredalina Basri, [1]Mohd Hafidz Ruslan, [4]Rado Yendra, [4]Ari Pani Desvina, [4]Rahmadeni and [1]Kamaruzzaman Sopian
[1]Solar Energy Research Institute,
[2]School of Mathematical Sciences, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia
[3]School of Diagnostic and Applied Health Sciences, Faculty of Health Sciences, University Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz, 50300 Kuala Lumpur, Malaysia
[4]Department of Mathematics, Faculty of Science and Technology, Universitas Islam Sultan Syarif Kasim (UIN Suska), 28293 Pekanbaru, Riau, Indonesia

Abstract: Drying using a hot air chamber was tested on samples of belimbing dayak fruit (*Baccaurea angulata*). The drying experiments were performed at various air temperature drying (40 to 50°C). Drying kinetics of belimbing dayak fruit were investigated and obtained. Ten drying models were compared with experiments data belimbing dayak fruit drying. A new model was introduced, which is an offset linear logarithmic (offset modified Page model). The fit quality of the models was evaluated using the coefficient of determination (R^2), Root Mean Square Error (RMSE) and Sum of Squared Absolute Error (SSAE). The result showed that the new model was comparable with two or three-term exponential drying models.

Keywords: *B. angulata*, belimbing dayak, drying kinetics, drying modeling, hot air chamber

INTRODUCTION

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. Several thin-layer drying model available in the literature for explaining drying of various agricultural and marine products have been used by Taheri-Garavand *et al*. (2011) for tomato, Gorjian *et al*. (2011) for barberry, Tahmasebi *et al*. (2011) for quercus, Kilic (2009) for fish, Daun *et al*. (2010) for sea cucumbar, Dissa *et al*. (2010) for spirulina and Fudholi *et al*. (2014b, 2012a, b) for seaweeds. 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, d, e, 2011), 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 drying air temperature on drying characteristics of belimbing dayak fruit. Also, ten drying models are evaluated with experiment's data to select to best describe the drying behavior of belimbing dayak fruit.

MATERIALS AND METHODS

In this study, a hot air chamber was used to investigate the drying kinetics of belimbing dayak 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 to 180°C and air relative humidity in the range of 10 to 98%. The drying experiments were conducted at drying air temperature 40, 45 and 50°C and at a constant relative humidity of 20% 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

Corresponding Author: Ahmad Fudholi, Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia

Fig. 1: Photograph of the belimbing dayak fruit in a hot air chamber

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 belimbing dayak 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:

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

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. The moisture content wet basis:

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

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, Sum of Squared Absolute Error (SSAE) 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 belimbing dayak fruit was chosen as the one with the highest coefficient of determination and the least RMSE and SSAE.

RESULTS AND DISCUSSION

Fitting of the ten drying models has been done with the experimental data of belimbing dayak at relative humidity 20% and drying air temperature 40, 45 and 50°C, respectively and constant air velocity of 1 m/s. The drying experimental data fitted the model of drying in the form of MR versus drying time. 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 RMSE and SSAE was selected to better estimate the drying curve.

Table 1: Several the exponential model thin layer drying models (Fudholi *et al*., 2012a, b; Othman *et al*., 2012)

No.	Model name	Model
1	Newton	MR = exp(-kt)
2	Page	MR = exp(-ktn)
3	Modified Page	MR = exp(-(kt)n)
4	Henderson and Pabis	MR = a exp(-kt)
5	Logarithmic	MR = a exp(-kt) + c
6	Two term	MR = a exp(-k0t) + b exp(-k1t)
7	Diffusion approach	MR = a exp(-kt) + (1-a) exp(-kbt)
8	Modified Henderson and Pabis	MR = a exp(-kt) + b exp(-gt) + c exp(-ht)
9	Midilli *et al*. (2002)	MR = a exp(-ktn) + bt
10	Offset modified Page (New model)	MR = exp(-(kt)n) + (a-1)tn

Table 2: Results of non-linear regression analysis for RH = 20%

No.	Model name	T (°C)	Model coefficients and constants	R2	RMSE	SSAE
1	Newton	40	k = 3.6519252021642046E-01	0.999133713913	0.00767743327375	3.6544648637141203E-03
		45	k = 4.6874679369279909E-01	0.99936354508	0.00610593411597	2.1623810228574539E-03
		50	k = 6.4601656722745826E-01	0.998271147389	0.0103545372761	4.8247398991086337E-03
2	Page	40	k = 3.6158815707079406E-01 n = 1.0079624221207868E+00	0.999138566704	0.00760549434936	3.5862997464887959E-03
		45	k = 4.6397605203302139E-01 n = 1.0104113512820283E+00	0.999393067765	0.00598053578515	2.0744748800935312E-03
		50	k = 6.2302500308801889E-01 n = 1.0557283118431799E+00	0.998903115585	0.00820320909216	3.0281687734341148E-03
3	Modified Page	40	k = 3.6450550748505173E-01 n = 1.0079624236182905E+00	0.999138566702	0.00760549434936	3.5862997464887964E-03
		45	k = 4.6766193107073750E-01 n = 1.0104113519279354E+00	0.999393067764	0.00598053578515	2.0744748800935312E-03
		50	k = 6.3878224078363854E-01 n = 1.0557283121258991E+00	0.998903115584	0.00820320909216	3.0281687734341175E-03
4	Henderson and Pabis	40	a = 9.9711460489283688E-01 k = 3.6415117232707594E-01	0.99913813772	0.00764852426078	3.6269952487979662E-03

Table 2: Continue

		45	a = 1.0028178692527017E+00 k = 4.7005768827536826E-01	0.999369561886	0.00607588014198	2.1411465309814884E-03
		50	a = 1.0268563653107068E+00 k = 6.6296385018725745E-01	0.998836834627	0.00858226865814	3.3144900894198749E-03
5	Logarithmic	40	a = 9.9869237146617662E-01 c = -6.2622005055990408E-03 k = 3.5595704787741977E-01	0.999271342876	0.00678661298172	2.8556031773464673E-03
		45	a = 1.0026984214869774E+00 c = 4.9226846314707941E-04 k = 4.7091405927438246E-01	0.999370574967	0.0060674073001	2.1351790180291512E-03
		50	a = 1.0278685132763403E+00 c = -3.2972880753942323E-03 k = 6.5524664696278834E-01	0.998880732174	0.00828220953256	3.0867747633537578E-03
6	Two term	40	a = 9.9586329413219110E-01 b = 4.1367043601478332E-03 k0 = 3.6370001716107592E-01 k1 = 1.0536598842181731E+02	0.999144327996	0.00763592727202	3.6150578888226089E-03
		45	a = -2.8463795234490781E-02 b = 1.0253083605983011E+00 k0 = 1.4979613842679367E+00 k1 = 4.7750586100976522E-01	0.999406874108	0.00592134901682	2.0336177023851272E-03
		50	a = -6.0006793356732601E-03 b = 1.0301232260189355E+00 k0 = 6.9734928099855389E-02 k1 = 6.5259875297250525E-01	0.998882251902	0.00827658565047	3.0825841513314233E-03
7	Diffusion approach	40	a = -3.2417108127763272E-03 b = -9.1963625295536815E+00 k = -3.9223968705652784E-02	0.999230286924	0.00698376620191	3.0239254025007300E-03
		45	a = 2.4328668317347518E-04 b = -2.6404175194423954E+02 k = -1.7765622670615328E-03	0.999363351557	0.00610367140424	2.1607786674329179E-03
		50	a = -5.2474073761574321E-02 b = 8.4037542751524952E-04 k = 8.0834948768909294E+02	0.999315670179	0.00651663438037	1.9109935641343243E-03
8	Modified Henderson and Pabis	40	a = -5.3757887135151748E+01 b = -5.1870860050369618E+00 c = 5.9933678994272498E+01 g = 4.3836148405386077E-01 h = 4.3694651244441429E-01 k = 4.3843739424056349E-01	0.999211469442	0.00712055484161	3.1435426776499288E-03
		45	a = 2.8706385660920333E+01 b = 1.2057458173265395E-01 c = -2.7831418163973872E+01 g = 2.8219471396265816E-01 h = 6.5990541251091195E-01 k = 6.5401349680082088E-01	0.99944405012	0.0057043828393	1.8873190474865931E-03
		50	a = 6.4860793956884578E+01 b = 9.4792204939088576E-01 c = -6.4810285870797543E+01 g = 6.4083780852479721E-01 h = 2.8291932693596511E+00 k = 2.8219523854168163E+00	0.999550781081	0.00549871403221	1.3606135203629232E-03
9	(Midilli *et al*., 2002)	40	a = 9.9149788108137304E-01 b = -4.1830307008033864E-04 k = 3.5643908875941549E-01 n = 1.0058586491351291E+00	0.99926445187	0.00681876720101	2.8827263407750080E-03
		45	a = 9.9685711249166264E-01 b = 1.3309638916394968E-04 k = 4.6004773940224214E-01 n = 1.0180771943806679E+00	0.999404730287	0.00590163067453	2.0200961878735998E-03
		50	a = 1.0147590908881088E+00 b = -1.6638428827778074E-04 k = 6.3975706767347851E-01 n = 1.0344675105890260E+00	0.999011413205	0.00778599826402	2.7279796035293452E-03
10	Offset modified Page (Fudholi *et al*., 2012a, b)	40	a = 9.9952058907844310E-01 k = 3.6228115582137405E-01 n = 9.9342455922597273E-01	0.999237876391	0.00694615805452	2.9914449265354462E-03
		45	a = 1.0001160578719643E+00 k = 4.6821973865239491E-01 n = 1.0137016306794022E+00	0.999400409158	0.0059219425225	2.0340253879066691E-03
		50	a = 9.9989511482071780E-01 k = 6.3825456758962584E-01 n = 1.0534769661775998E+00	0.998916865443	0.00817599828232	3.0081126560628640E-03

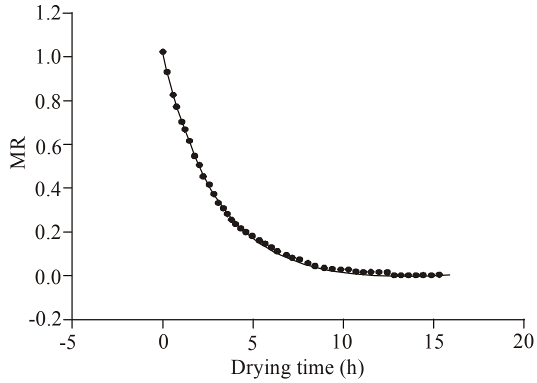

Fig. 2: Plot of MR versus drying time (h) of offset modified page (new model) model at 20% RH and T = 40°C

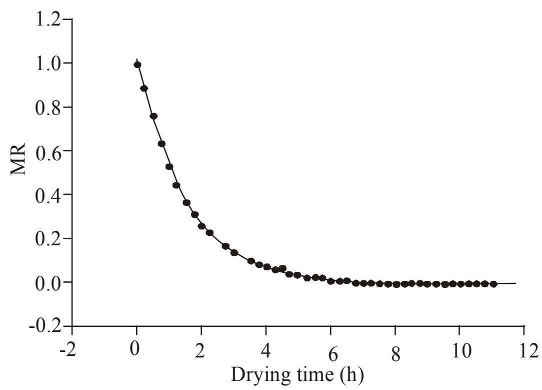

Fig. 3: Plot of MR versus drying time (h) of offset modified page (new model) model at 20% RH and T = 50°C

Non-linear regression analysis was performed using data fitting online. The statistical parameter estimations showed that R^2 and SSAE values ranged from 0.9983 to 0.9995 and 1.3606E-03 to 4.8247E-03, respectively, as shown in Table 2. The model that best described the thin layer drying kinetics is the one that gives the highest R^2 and the lowest RMSE and SSAE values. Based on these criteria, the new model (offset modified Page) was comparable with two or three-term exponential drying models. Figure 2 and 3 show plot of MR versus drying time (h) of offset modified Page (new model) model for air temperature of 40°C and 50°C respectively.

CONCLUSION

Drying using a hot air chamber was tested on samples of belimbing dayak. The drying experiments were conducted at drying air temperature 40, 45 and 50°C and at a constant relative humidity of 20% and constant air velocity of 1 m/s. A new model was introduced, which is an offset linear logarithmic (offset modified Page model). The fit quality of the models was evaluated using the coefficient of determination (R^2), Root Mean Square Error (RMSE) and Sum of Squared Absolute Error (SSAE). The result showed that the new model was comparable with two or three-term exponential drying models.

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