Solar Open Drying Kinetics Method for Drying Chilies

*AHMAD FUDHOLI, MOHD HAFIDZ RUSLAN, MOHD YUSOF OTHMAN, AZAMI ZAHARIM, KAMARUZZAMAN SOPIAN

Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor,
MALAYSIA.

*Corresponding author: fudholi.solarman@gmail.com

Abstract: This study was conducted to study the drying kinetics of Malaysian chili (*Capsicum annuum* L.) by using open sun and solar drying. There are two objectives for this study. The first is to find the kinetics curves of drying, and the second is to determine the best model for drying chili. The experimental result was compared with three different drying models, which were Newton's model, Page's model, and Henderson and Pabis model. The highest value of R^2 (coefficient of determination) and the lowest value of MBE (mean bias error) and RMSE (root mean square error) were selected to estimate the best drying model. Based on the analysis, it shows that Page's model is one of the most suitable drying models for the drying of chilies.

Keywords: Drying kinetics, drying models, chili, open sun, solar drying

1. Introduction

In subtropical and tropical countries, the name such as chili is no stranger to the subject, and was compulsory course in the kitchen. There is main ingredient in all cooking, while has high nutritional value. For Malaysian chili, it was found to contain very nutritious, with high vitamin C (175mg/100g), calcium (15mg/100g), fibre (4.8%), protein (2.8%), iron (1.8mg/100g), ash (0.9mg/100g) and lipids (0.7mg/100g) [1]. The use of chili is not just for adding food palatability, because there are a number of studies have shown that is very beneficial for human health. Furthermore, chili is a good source of antioxidants, being rich in vitamins A and C, minerals and other phytochemicals, which an important source of nutrients in the human diet. For contain nutritious of several chili (*Capsicum annuum*) varieties was reported [2,3].

Traditionally, chili was dried in the direct sun. Direct sun drying requires large open space area, long drying times and very much dependent on the availability of sunshine, susceptible to contamination with foreign materials. Otherwise insects and fungi, which thrive in moist conditions, render them unusable. Moreover, in this method, a low quality dried products was obtained. Most agricultural commodities require drying process in an effort to preserve the quality of the final product. The quality of the products depends on many factors including the drying temperature and duration of drying time [4]. As an alternative to open sun drying, solar drying system is one of the most attractive and promising applications of solar energy systems. It is renewable and environmentally friendly technology, also economically viable in most developing countries.

Recently, many have reported on solar drying system of agricultural and marine products. Thin-layer drying models also have been widely used for analysis of drying of various agricultural [5-8] and marine products [9-13]. Various solar drying for agricultural and marine products have been reviewed by Fudholi et al. [14]. They reported that the chili should be dried until its moisture content achieved 5% with initial moisture content of 80%. Therefore, the present study is to propose drying model for drying curves of Malaysian chili dried by open sun and solar drying.

2. Material and Methods

The chili (*Capsicum annuum* L) var. Malaysian also known as "cili bangi" used in this study was obtained from Farm Universiti Kebangsaan Malaysia (UKM), Malaysia. The initial moisture content of chili was determined by using the drying in an air oven at a temperature of 120^{o}C in order to obtain a constant weight. Average moisture content was found to be 80.2% w.b.

A solar drying was installed at the Green Energy Technology Innovation Park, UKM Malaysia in 2010. The drying is classified as a forced convection indirect type. Schematic diagram of solar drier is shown in Fig.1. The solar drying consists of auxiliary heater, blower, drying chamber and double-pass solar collector. The collector width and length were 1.2 m and 4.8 m respectively. The solar collector array consists of 4 solar collectors. The upper channel depth is 3.5 cm, and the lower depth is 7 cm. The bottom and sides of the collector have been insulated with 2.5cm thick fiber glass to minimize heat losses. The collector consists of the glass cover, the insulated and the black painted aluminium absorber. The size of the collector is 1.2 m wide and 4.8 cm long. In this type of collector, the air initially enters through the first channel formed by the glass covering the absorber plate and then through the second channel formed by the back plate and the finned absorber plate. This drier was capacity of drying 75 kg, and the size of the chamber is 2.4 m in length, 1 m width and 0.6 m in height.

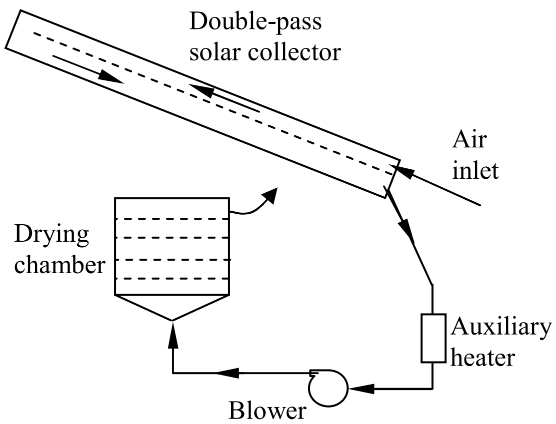

Fig. 1. The schematic of a solar drying

Experiment was done between 8:00 AM to 5:00 PM. The data were measured air temperature in chamber, ambient temperature, radiation intensity and air velocity. The relative humidity sensors were installed in inlet, middle and outlets of drying chamber. Air temperature was measured by T-type thermocouple, and the intensity of solar radiation measured by pyranometer. During the drying process, the temperature and relative humidity in solar drier were recorded at 1 minute intervals during experiments by the ADAM Data Acquisition System connected to a computer. Data was averaged for 30 minutes prior to the period. The moisture loss of chili was determined by means of a digital electronic balance having an accuracy of 0.01 g.

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 chili were fitted to the exponential model thin layer drying models as shown in Table 3 by using non-linear regression analysis.

Table 1. Several one-term thin layer drying exponential models

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

The moisture ratio (MR) can be calculated as

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

where,
Me = Equilibrium moisture content
Mi = 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

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

The moisture content dry basis is

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

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

The drying rate (DR) is expressed as the amount of the evaporated moisture over time, and is defined as [15]

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (4)$$

where,
M_t = moisture content at time t
M_{t+dt} = moisture content at time t + dt

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 chili was chosen as the one with the highest coefficient of determination and the least root mean square error [10-13,16]. This parameter can be calculated as follows:

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

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right]^{\frac{1}{2}} \qquad (6)$$

3. Results and Discussion

During 33 hours drying (without night), the daily mean of drying chamber air temperature, relative humidity of drying chamber and solar radiation range vary from about 28-55°C, 18-74%, 104-820W/m^2, with an average of about 45°C, 30%, 420W/m^2 respectively.

The results of the drying kinetic curves of chili using open sun and solar drying 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 and Fig.3, showed a decrease in moisture content wet basis and dry basis of drying time for open sun drying and solar drying, respectively. It was observed that at low drying time (at open sun drying), the moisture content of chili is increased, slowing down the drying process as the drying time becomes longer. In contrast, by increasing temperature chamber at solar drying, increasing the moisture content caused a reduction in drying time rapidly.

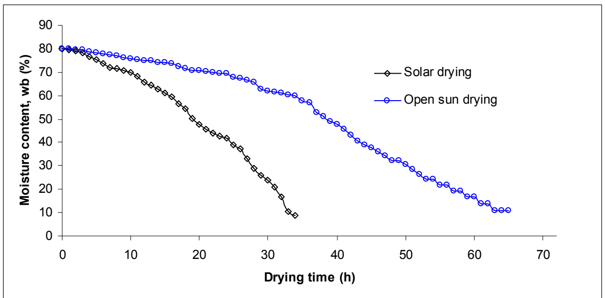

Fig.2. Moisture content variation with drying time

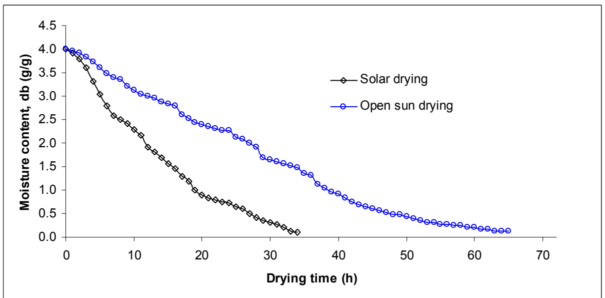

Fig.3. Moisture content variation with drying time

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

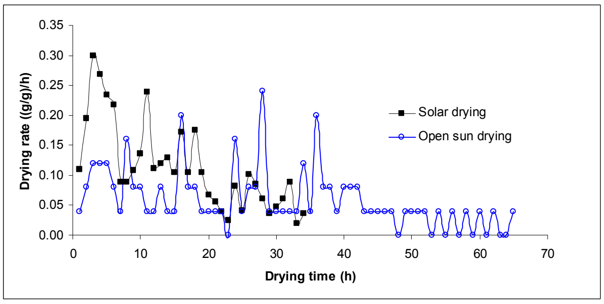

Fig.4. Drying rate curves: dry basis moisture content versus drying time

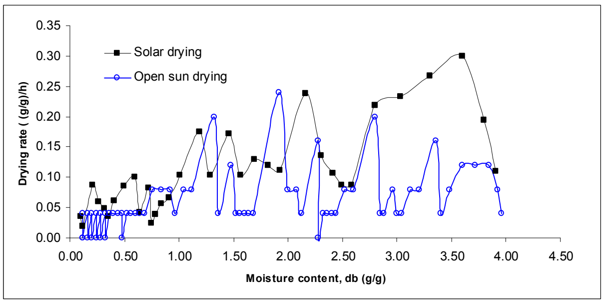

Fig. 5. Drying characteristic curves: dry basis moisture content versus drying time

Fitting of the three drying models has been done with the experimental data of chili drying using open sun and solar drying. Drying models which were fitted with the experimental data of drying were the Newton, Page 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 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 better estimate the drying curve.

Newton's model is the relationship moisture ratio (MR) with drying time, which the curve of this exponential equation as shown in Fig. 6 and Fig.7. These figures clearly showed k constant of 0.0497 and 0.0899 for open sun drying and solar drying, respectively. Page's equation can also be written as the following equation

$$\ln(-\ln MR) = \ln k + n \ln t \qquad (7)$$

Eq. (7) is the relationship ln (-ln MR) versus t and the curve of this logarithmic equation, as shown in Fig.8 and Fig. 9. From these figure, obtained values k constant of 0.0091 and 0.0244 for open sun drying and solar drying, respectively. For the value n constant clearly showed in Figures. Henderson and Pabis equation can also be written as the following equation

$$\ln MR = -kt + \ln a \qquad (8)$$

From Eq. (8), 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.10 and Fig. 11. From these figures obtained the value a constant of 1.8735 and 1.5521 for open sun drying and solar drying, and clearly showed the value k constant of 0.0641 and 0.1090 for open sun drying and solar drying. Results presented in Table 3 showed that the Page drying model has the highest value of R^2 (0.9887), as well as the lowest values of MBE (0.0007) and RMSE (0.0257), compared to Newton and the Henderson and Pabis model. Accordingly, the Page's model was selected as the suitable model to represent the thin layer drying behaviour of chili. This is in accordance with Fudholi et al. [10-12] that Page's model was shown to be a better fit to drying seaweeds among Newton's model and Henderson and Pabis model. Azoubel et al. [17] reported that Page model clearly improve 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's model has been showed better fit than other models at accurately simulate the drying curves of chili pepper [18,19], rapeseed [20], green beans [21], okra [22], kiwi [23] among others.

Fig. 12 and Fig. 13 showed the plotting of the observed moisture ratio against the predicted values for Page's model of open sun drying and solar drying of chili, respectively. This indicates the suitability of the developed model to describe the drying behavior of chili. The developed model is sustainable approach for drying Chilies. Sustainability approaches are highly demanded I Malaysia.

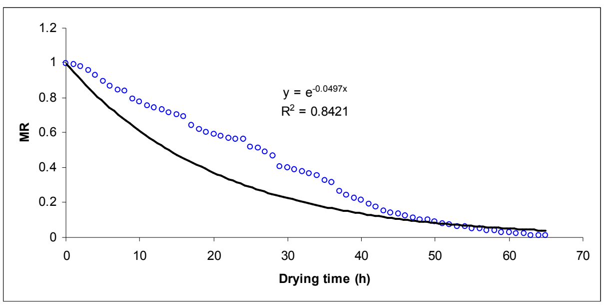

Fig. 6 Plot of MR versus drying time (Newton model) for open sun drying of chili

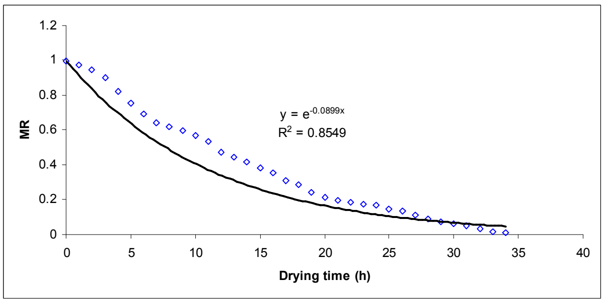

Fig. 7. Plot of MR versus drying time (Newton model) for solar drying of chili

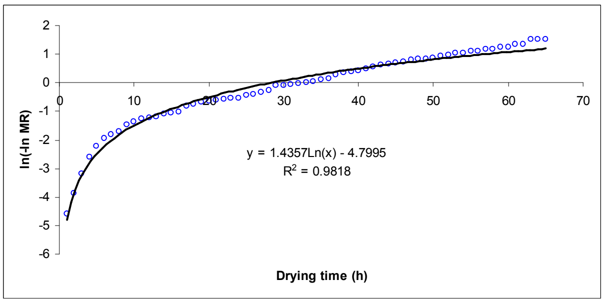

Fig.8. Plot of ln (-ln MR) versus drying time (Page model) for open sun drying of chili

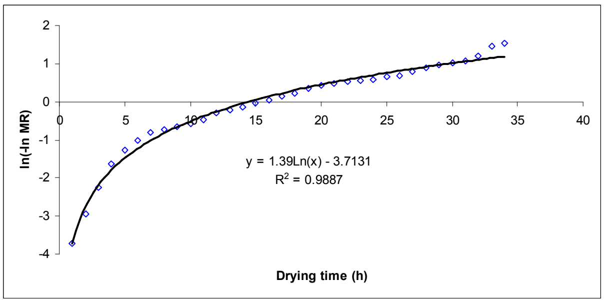

Fig.9. Plot of ln (-ln MR) versus drying time (Page model) for solar drying of chili

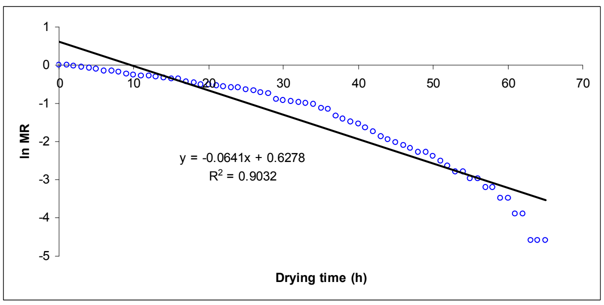

Fig.10. Plot of ln MR versus drying time (Henderson and Pabis model) for open sun drying of chili

ISBN: 978-1-61804-122-7

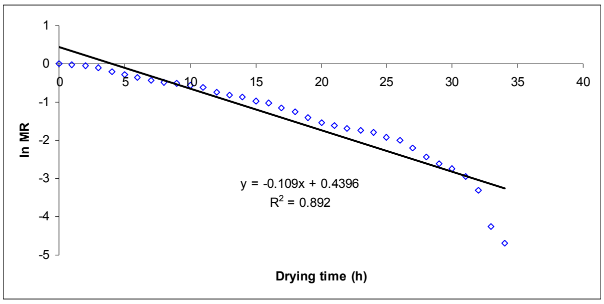

Fig.11. Plot of ln MR versus drying time (Henderson and Pabis model) for solar drying of chili

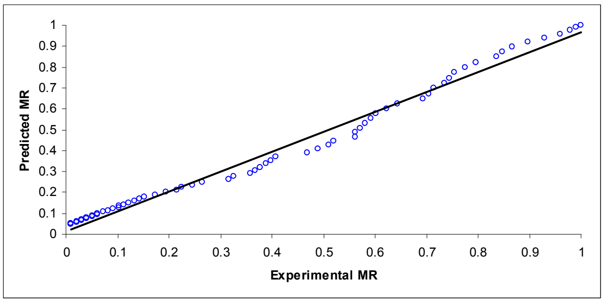

Fig.12. Comparison of experimental MR with predicted MR from Page's model for open sun drying of chili

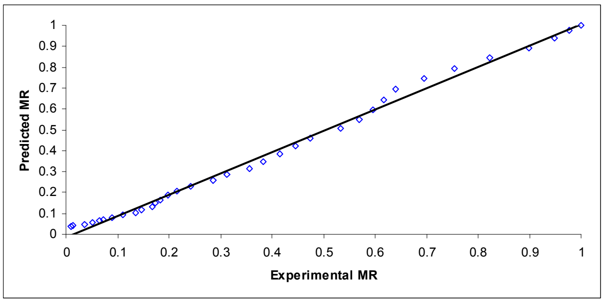

Fig.13. Comparison of experimental MR with predicted MR from Page's model for solar drying of chili

4. Conclusion

A solar drying was tested for drying of Malaysian chili. Kinetic curves of drying of Malaysian chili known to use this system. Several drying models have been used in order to illustrate the best drying model for chili dried by open sun and solar drying. To find the best drying model is through the values of R^2, MBE and RMSE. Based on the drying model curves, it has been found that Page's model is the best model in describing the drying curves of chili. The Page's model clearly showed a better fit to the experimental data between Newton's model and Henderson and Pabis model. The Page's model was resulted in the highest value of R^2 and lowest values of MBE and RMSE.

Acknowledgements

The authors would like to thank the Yayasan Felda for funding this research (RMK9 RS-DL-001-2007) and the Solar Energy Research Institute (SERI), University Kebangsaan Malaysia for providing the laboratory facilities and technical support.

References

[1] Norziah M.H. and Ching C.Y. 2000. Nutritional composition of edible seaweed *Gracilaria changii*. Food Chemistry 68: 69-76.

[2] A.H. Simonne, E.H. Simonne, R.R Eitenmiller, H.A. Milis, N.R. Green. 1997. Ascorbic acid and provitamin A contents in unusually colored bell peppers (*Capsicum annuum* L.). Journal of Food Composition and Analysis 10: 299-311.

[3] J.L. Guil-Guerrero, C. Martinez-Guirado, Ma del Mar Rebolloso-Fuentes, A. Carrique-Peres. 2006. Nutrient composition and antioxidant activity of 10 pepper (Capsicum annuum) varieties. Eur Food Res Techol 224: 1-9.

[4] 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.

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

[6] 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.

[7] 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.

[8] 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.

[9] G.M. Kituu, D. Shitanda, C.L. Kanali, J.T. Mailutha, C.K. Njoroge, J.K. Wainaina, V.K. Silayo. 2010. Thin layer drying model for

simulating the drying of Tilapia fish (Oreochromis niliticus) in a solar tunnel dryer. Journal of Food Engineering 98: 325-331

[10] 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.

[11] 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 in *WSEAS Int. Conf. on Applied Mathematics in Electrical and Computer Engineering,* USA, 2012, pp. 207-211.

[12] 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.

[13] 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.

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

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

[16] 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.

[17] P.M. Azoubel, Maria do A.M.B, Mariana da R.A, Sofia S.B.O 2010. Effect of ultrasound on banana cv Pacovan drying kinetics. Journal of Food Engineering;97: 194-98.

[18] T.Y. Tunde-Akintunde. 2011. Mathematical modeling of sun and solar drying of chilli pepper. Renewable Energy 36: 2139-45.

[19] I. Doymaz, Mehmet P. 2002. Hot-air drying characteristics of red pepper. Journal of Food Engineering 55: 331-335.

[20] L.A. Duc, Jae W.H, Dong H.K. 2011. Thin layer drying characteristics of rapeseed (Brassica napus L.). Journal of Stored Products Research 47: 32-38.

[21] I. Doymaz. 2005. Drying behaviour of green beans. Journal of Food Engineering 69: 161-165.

[22] I. Doymaz. 2005. Drying characteristics and kinetics of okra. Journal of Food Engineering 69: 275-279.

[23] S. Simal, Femenia A, Garau M.C., Rosello C. 2005. Use of exponential, Page's and diffusion models to simulate the drying kinetics of kiwi fruit. Journal of Food Engineering 66: 323-328.

[24] O. Saadatian, C. Haw, S. Mat, K. Sopian, M. Dalman and E. Salleh, "Sustainable development in malaysia-planning and initiatives," the 9th WSEAS International Conference on Environment, Ecosystems and Development (EED '11), WSEAS (Editor), Montreux Switzerland, 2011, pp. 138-143.

Model name	Method drying	Model Coefficients and Constants	R^2	MBE	RMSE
Newton	Open sun drying	k = 0.0497	0.8421	0.0214	0.1462
	Solar drying	k = 0.0899	0.8549	0.0090	0.0950
Page	Open sun drying	k = 0.0091; n = 1.3933	0.9857	0.0018	0.0420
	Solar drying	k = 0.0244; n = 1.3900	**0.9887**	**0.0007**	**0.0257**
Henderson and Pabis	Open sun drying	k = 0.0641; a = 1.8735	0.9032	0.0179	0.1338
	Solar drying	k = 0.1090; a = 1.5521	0.8920	0.0083	0.0912

Table 2. Results fitting of drying model curves

ISBN: 978-1-61804-122-7