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Statistical Examination of Uncaria gambir Roxb Drying Modeling

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Abstract*: This study investigates the drying modeling of Uncaria gambir Roxb using convective desiccant examined by statistical parameters. Three types of drying modeling are investigated, i.e. the Newton, Page and Henderson-Pabis models. The drying conditions of Uncaria gambir Roxb were set at 35°C, 45°C and 55°C and air velocity of 1.2 m/s. The results show that the Page modeling is the best fit model for this investigation based on values of R^2 (coefficient of determinant), RMSE (root mean square error) and χ^2 (chi-square) goodness of fit test derived from (MR) moisture ratio equation. The Page modeling shows R^2 value nearest to unity and lowest values of RMSE and χ^2 are obtained for all given temperatures (35°C, 45°C and 55°C) at air velocity of 1.2 m/s. The drying modeling is useful for optimization in design process encountered with product quality and cost of production.

***Keywords*: Henderson-Pabis model, Newton model, Page model, statistics parameter**

I. INTRODUCTION

A lot of investigations on drying kinetic modeling applying statistical and mathematical approach for various food has been investigated [1-11]. Mathematical modeling has become increasingly popular for drying kinetics of agricultural and food products during last decades in relation to reducing loss product quality and increasing cost of production by optimization of process controlling and operating conditions. A mathematical modeling is necessary for optimization and design process and therefore, the drying kinetic modeling of agricultural, herbals, fruits and vegetables products is very substantial.

Several drying kinetic modeling of agricultural and food products applying some mathematical equations have reported. Naderinezhad et al. [1] found that the Midilli-Kucuk equation is the best fit model for explaining single layer drying of potato slices based on multiple regression analysis using air velocity and temperature variables. Onwude et al. [2] proposed a thin layer drying modeling for fruits and vegetables in a comprehensive review including thorough discussion of some model equations often used in food drying technology. On other occasion, Fernando and Amarasinghe [3] reported a mathematical modeling of hot air drying of coconut husk and found that Wang and Singh model, as well as linear model are adequate for accurate prediction of hot air drying behavior on the basis of coefficient of determinant, root mean square error and chi-square. At earlier time, Coradi et al. [4] found the Two Terms exponential model is adequate for the drying behavior of lemon grass plant at varied temperatures (40°C – 70°C) and velocities (0.8 m/s and 1.3 m/s), and the results showed that the applied manual control system not affected the essential oil content rather than the automatic control system at given drying conditions. Omolola et al. [5] gave an understanding of drying kinetics banana encountered with mathematical modeling of drying behavior and transport mechanism that is important for design of equipment, optimization of drying conditions and heat transfer mechanism. While at the same year, Darici and Sen [6] observed a good agreement between experimental and predicted data from Midilli equation model for convective drying kinetics of kiwi based on coefficient of determinant (0.9949 – 0.9996) under varied temperatures (50°C – 80°C), air velocities (0.5 m/s – 2.0 m/s) and relative humidity values (5% - 20%). Furthermore, Tzempelikos et al. [7] reported Weinbull equation model as the best fit thin layer drying model to experimental data in non linear regression analysis on convective drying of quince slices at varied air temperatures (40°C – 60°C), and Afolabi et al. [8] found that logarithmic and parabolic models are the best fit model for experimental data based on coefficient of determinant, root mean square error and chi-square test for hot air drying of cocoyam slices at varied temperatures (50°C – 70°C).

This study plans to apply a mathematical modeling on convective desiccant drying of *Uncaria gambir* Roxb leaves at varied temperatures (35°C, 45°C and 55°C) and air velocity of 1.2 m/s. The experimental data of this investigation was previously reported [9]. This investigation will attempt to use three types of drying modeling (Newton, Page and Henderson-Pabis) to examine the best fit model adequate with experimental data obtained from convective desiccant drying of *Uncaria gambir* Roxb leaves. The goodness of fit test will use three parameters, i.e. coefficient of determinant (R^2), root mean square error (RMSE) and chi-square (χ^2).

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II. EXPERIMENTAL

A. Convective desiccant drying of *Uncaria gambir Roxb*

The mathematical modeling applied three drying models (Newton, Page and Henderson-Pabis) is designed based on experimental data of convective desiccant drying of *Uncaria gambir* Roxb using silica gel desiccant at varied temperatures (35°C, 45°C and 55°C) and air velocity of 1.2 m/s. The experimental data was reported previously [9].

The moisture ratio (MR) used for drying kinetics and characteristics in previous report [9] is defined as

$$MR = \frac{X - X_e}{X_o - X_e} = \exp(-kt) \qquad (1)$$

Where MR is the moisture ratio. X, Xo and Xe are moisture ratio at any time, initial and equilibrium, respectively, and t is the time of drying. The MR in eq. (1) will be applied in three drying models to examine the experimental data fitting with the predicted models selected.

B. Thin Layer Drying Model

The convective desiccant drying of *Uncaria gamb*ir Roxb leaves is considered as moisture transfer between air and product and therefore, the drying behavior of *Uncaria gambir* Roxb can be characterized as thin layer drying model. Thin layer drying can be illustrated as removal process of moisture from porous media by evaporation where excess drying air is passed through a thin layer of material until equilibrium moisture content is achieved [10]. According to Inyang et al. [10], there are three types of thin layer drying models, i.e. the theoretical, empirical and semi-empirical models. The theoretical model has some limitations, while the empirical model gives inadequate information particularly in relation to heat and mass transfer during drying process [11]. On the other hand, the semi-empirical model is developed to achieve a good correlation between theory and practice use [10]. A semi-empirical model is derived from Newton's law of cooling applied to mass transfer. Among semi-empirical models are the model of Two Terms, Henderson-Pabis, Lewis, Page and modified Page.

On account of that reason, this study selects the Newton, Page and Henderson-Pabis models adjusted with adequate facilitation. The mathematical equations presented in exponential and linear forms of the three types drying model are shown in Table-I based on the report of Rayaguru et al. [12].

Table-I: Exponential and linear equations of drying models defined by Newton, Page and Henderson-Pabis [12]

Drying model	*Exponential equation*	*Linear equation*
Newton	MR = exp (-kt)	ln MR = -kt
Page	MR = exp (-kt^n)	ln (-ln MR) = ln k + (n) ln (t)
Henderson-Pabis	MR = a exp (-kt)	ln MR = ln a – kt

C. Drying Constant

According to the understanding of thin layer drying, the drying constant involves with drying transport properties such as moisture diffusivity, thermal conductivity, density, specific heat, interface heat and mass coefficient [10]. With regard to linear modeling (Table-I), the Newton and Henderson-Pabis models are graphically plot as ln MR vs. t, while the Page model plot as ln (-ln MR) vs. ln t. Applying a computer software the drying constants of each model given will be obtained as shown in Table-II.

According to Inyang et al. [10] the air temperature and material thickness (size) are the most influential factors in thin layer drying kinetics rather than air velocity and relative humidity. However, air temperature yielded more effects on drying constant rather than material thickness. Moreover, the interaction between air temperature and material thickness did not significantly affect the value of drying constant.

D. Goodness of Fit Statistic Test

Thin layer drying models can be assayed by statistical parameters. The quality of the approved drying models can be verified through several statistical parameter options such as correlation coefficient, coefficient of determinant, chi-square, mean bias error, root mean square error, sum square error, mean relative error root square, modeling efficiency, mean percent error, mean square error [10]. This study applied three options of selected statistical parameters, i.e. the coefficient of determinant (R^2) expressed in Eq. (2), root mean square error (RMSE) in Eq. (3) and chi-square (χ^2) in Eq.(4). The most fitted drying model will be defined based on the highest value of R^2 and the lowest value of RMSE and χ^2, respectively. The results are shown in Table-III with respect to three given temperatures (35°C, 45°C and 55°C) at air velocity of 1.2 m/s.

$$R^2 = \frac{[\Sigma_{i=1}^{N}(MR_{\exp,i} - MR_{\exp})(MR_{pre,i} - MR_{pre})]^2}{\Sigma_{i=1}^{N}(MR_{\exp,i} - MR_{\exp})^2 \, \Sigma_{i=1}^{N}(MR_{pre,i} - MR_{pre})^2} \qquad (2)$$

$$RMSE = \sqrt{\frac{1}{N}\Sigma_{i=1}^{N}(MR_{\exp,i} - MR_{pre,i})^2} \qquad (3)$$

$$\chi^2 = \frac{\Sigma_{i=1}^{N}(MR_{\exp,i} - MR_{pre,i})^2}{N - z} \qquad (4)$$

III. RESULTS AND DISCUSSION

As already mentioned the temperature is more dominant rather than air velocity on the drying kinetics [10]. Therefore, the thin layer drying models of *Uncaria gambir* Roxb leaves are investigated with respect to given temperatures at a given value of air velocity. By applying the computer software, the drying constants of each model (Newton, Page and Henderson-Pabis) are found with respect to given temperatures (35°C, 45°C and 55°C) at air velocity of 1.2 m/s. Table-II shows this finding.

Table-II: Drying constant of each exponential model (Newton, Page and Henderson- Pabis) for three given temperatures (35°C, 45°C and 55°C) at air velocity of 1.2 m/s. Convective desiccant drying of *Uncaria gambir* Roxb leaves.

Temp. (°C)	Newton	Page		Henderson-Pabis	
	k	k	n	k	a
35	0,5965	0.6243	0.9272	0.6017	1.0173
45	0.7889	0.8207	0.9893	0.7678	0.9325
55	1.2842	1.4951	0.8828	0.8033	1.2180

In order to examine the most fitted drying model among the three drying models proposed, statistics parameters are selected with respect to coefficient of determinant (R^2), root mean square (RMSE) and chi-square (χ^2). Table-III presented the results of given statistics parameter. As shown in Table-III, the coefficient of determinant belong to the Page model (bold print) shows the highest value compared to that belong to the other two drying models (Newton and Hemderson-Pabis) for all given temperatures (35°C, 45°C and 55°C). At the meantime, both the RMSE and chi-square of the Page model (bold print) show the lowest value among that values belong to the other two drying models for all given temperatures.

Table-III: Statistical parameters used to examine the most fitted drying model for three given temperatures (35°C, 45°C and 55°C) at air velocity of 1.2 m/s. *Uncaria gambir* Roxb convective desiccant drying.

Temp. (°C)	Model	R^2	RMSE	χ^2
35	Newton	0.9887	0.006176	0.000625
	Page	**0.9889**	**0.006100**	**0.000608**
	Henderson – Pabis	0.9888	0.007042	0.000810
45	Newton	0.9845	0.009541	0.001372
	Page	**0.9901**	**0.008302**	**0.001126**
	Henderson – Pabis	0.9857	0.010024	0.001641
55	Newton	0.9870	0.011935	0.002148
	Page	**0.9970**	**0.003718**	**0.000226**
	Henderson – Pabis	0.9919	0.006393	0.000667

The application of the three drying models of interest (Newton, Page, and Henderson-Pabis) was implemented for experimental drying rate data obtained from previous work [9] as shown by Fig.1. The thorough discussion of drying rate of *Uncaria gambir* Roxb was already reported in the drying kinetics and characteristics of convective desiccant drying of *Uncaria gambir* Roxb leaves [9].

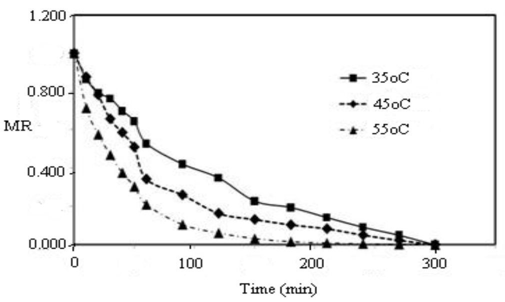

Fig. 1 Drying rate data of *Uncaria gambir* Roxb leaves at 1.2 m/s. Convective desiccant drying [9].

The exponential Page equations for three given temperatures (35°C, 45°C and 55°C) at air velocity of 1.2 m/s are presented in Table-IV. The values of drying constant of the Page drying model in Table-II are used in the exponential equation form in Table-IV with respect to each given temperature.

The thin layer drying modeling is useful for design process and predicted effective drying condition that is necessary for cost of production and product quality. Selection of goodness fit drying model and drying conditions (air temperature, air velocity, relative humidity and material size/thickness) are important factors involved in simplified thin layer drying modeling for practice purpose.

Table-IV: Exponential Page model for given temperatures (35°C, 45°C and 55°C) of convective desiccant drying of *Uncaria gambir* Roxb at air velocity of 1.2 m/s.

Air velocity	Temp.(°C)	Page exponential equation
1.2 m/s	35	MR= exp (-0,6243 $t^{0,9272)}$
	45	MR= exp (-0,8207 $t^{0,9893)}$
	55	MR= exp (-1,4951 $t^{0,8828)}$

IV. CONCLUSION

This study shows that Page drying model is the most fitted drying model for experimental data obtained from convective desiccant drying of Uncaria gambir Roxb leaves for each given temperature (35°C, 45°C and 55°C) as verified from selected statistics parameters.

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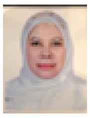

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