Modeling and Prediction of Thin Layer Drying Characteristics of Ginger Rhizome Slices in Convective Environment

Gbasouzor Austin Ikechukwu, *Member IAENG*; Sam Nna Omenyi

***Abstract*: This paper is an extension of the previous work done with ARS-680 environmental chamber. The prediction of thin layer drying characteristics of ginger rhizome slices in convective environment was conducted at six drying temperatures of 10°C-60°C and the data was fitted to drying models. Non-linear regression analysis was used to determine models parameters. Twelve common thin layer drying model were fitted to the experimental data and several statistical tools (R^2, RMSE and SEE) were used to adjudge the most appropriate model. This study revealed that five drying model can be used to predict the drying characteristics of the various ginger treatment. There are Page, Henderson and Pabis, Logarithmic, Two Term and Two Term Exponential models. Two term exponential proved to be the model most suitable for predicting the drying characteristics of ginger rhizome.**

Keywords: Drying Time, Ginger rhizome, moisture content, moisture ratio, Drying Models.

I. INTRODUCTION

Thin layer drying studies provide the basis for understanding the unique drying characteristics of any particular food material. The results of such studies have been widely used to simulate dryers under deep-bed drying conditions and for quantifying parameters for the design of specialized drying equipment.

Fig. 1 Fresh Ginger Rhyzome/Dried Split Ginger

Several studies show that thin layer drying equations were found to have wide applications due to their ease of use and less data requirements unlike complex data distributed models (Özdemir and Onur Devres, 1999).

In thin layer drying, the moisture content of a bio-material exposed to a stream of drying air of known relative humidity, velocity and temperature is monitored over a period of time. A number of mathematical models have been developed to simulate moisture movement and mass transfer during the drying of many agricultural products

The thin layer drying simply means to dry as one layer of sample, particles or slices (Akpinar, 2006). The temperature of thin layers are assumed to be of uniformly distributed and very ideal for lumped parameter models (Erbay and Icier, 2010).

Thin layer drying equations may be expressed in the following models: theoretical, semi-theoretical, and empirical. The theoretical takes into account only the internal resistance to moisture transfer (Parti, 1993) while others are concerned with external resistance to moisture transfer between the product and air (Fortes & Okos, n.d.). The theoretical models explain drying behaviors of the product succinctly and can be employed in all process situations. They also include many assumptions causing significant errors. Fick's second law of diffusion are used for the derivation of many of the theoretical models.

II. THEORETICAL ASPECTS

Semi-theoretical models are also derived from Fick's second law of diffusion and modifications of its simplified forms. They are easier and require fewer assumptions due to use of some experimental data and are valid within the limits of the process conditions applied (Fortes, Okos and Member Asae, no date).

Convective drying can be employed to remove volatile liquid from porous materials such as food stuffs, ceramic products, clay products, wood and so on. Porous materials have microscopic capillaries and pores which cause a mixture of transfer mechanisms to occur simultaneously when subjected to heating or cooling. The drying of moist porous solids involves simultaneous heat and mass transfer. Moisture is removed by evaporation into an unsaturated gas phase. Drying is essentially important for preservation of agricultural crops for future use. Crops are preserved by removing enough moisture from them to avoid decay and spoilage. For example, the principle of the drying process of ginger rhizomes involves decreasing the water content of the product to a lower level so that micro-organisms cannot decompose and multiply in the product. The drying process unfortunately can cause the enzymes present in ginger rhizomes to be killed.

Semi-theoretical models

The semi-theoretical models can be classified according to their derivation as:

Newton's law of cooling: includes all models derived from the Newton's law of cooling and are sub-classified into:

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Lewis (Newton) model

This model corresponds to the Newton's law of cooling. Many researchers have named it Newton's model. Lewis (1921) proposed that during the drying of porous hygroscopic materials, the change in moisture content of material in the falling rate period is proportional to the instantaneous difference between the moisture content and the expected moisture content when it comes into equilibrium with drying air.

In this proposition, it is assumed that the material is very thin, the air velocity is high and the drying air conditions such as temperature and relative humidity are kept constant.

III. MATHEMATICAL MODELING OF DRYING CURVES

It is expressed mathematically as (Marinos-Kouris and Maroulis, 2006):

$$\frac{dM}{dt} = -K(M - M_e) \quad (1)$$

Where, K is the drying constant(s^{-1}). In the thin layer drying concept, the drying constant is the combination of drying transport properties such as moisture diffusivity, thermal conductivity, interface heat, and mass coefficients.
If K is independent from M, then Eq.1can be re-expressed as:

$$MR = \frac{M_t - M_e}{M_i - M_e} = exp(-kt) \quad (2)$$

Where, k is the drying constant (s^{-1}) obtained from the experimental data in Eq. 2also known as the Lewis (Newton) model.

a. *Page model and modified forms*

Page (1949) further modified Lewis model to obtain an accurate model by introducing a dimensionless empirical constant (n). This modified model in the drying of shelled corns:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} exp(-kt^n) \quad (3)$$

The following are modified Page models:

i. *Modified Page-I Model:* This form was used to model the drying of soybeans (Overhults et al, 1973). Mathematically expressed in Eq. 3 as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp(-kt)^n \quad (4)$$

ii. *Modified Page-II Model*: This model was introduced by (White et al., 1976) and is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp - (kt)^n \quad (5)$$

iii. *Modified Page equation-II Model:*This model was employed in a study to describe the drying process of sweet potato slices (Diamante and Munro, 1993). It is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp - (k/l^2)^n \quad (6)$$

Where l is an empirical dimensionless constant?

Fick's second law of diffusion: the models in this group are derived from Fick's second law of diffusion and are sub-classified into:

Henderson and Pabis (Single term exponential) model and modified forms:
This is a drying model obtained from Fick's second law of diffusion and applied on drying corns (Henderson and Pabis, 1961). was employed in the derivation of this model. In this model, for long drying times, only the first term (i=1) of the general series solution of can be utilized with negligible error. In Henderson and Pabis (1961) assumption, can be re-expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = A_1 exp\left(-\frac{\pi^2 D_{eff}}{A_2} t\right) \quad (7)$$

Where D_{eff} is the effective diffusivity (m^2/s).
If D_{eff} is constant during drying, then Eq. 6 can be re-arranged by using the drying constant k as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\ exp(-kt) \quad (8)$$

Where a is defined as the indication of shape and generally named as model constant from experimental data. Equation 7 is generally known as the Henderson and Pabis model.
Other forms of Henderson and Pabis models includes:

a. Logarithmic (Asymptotic) model
A new logarithmic model of the Henderson and Pabis was proposed by (Chandra and Singh, 1995) and was applied in the drying of laurel leaves (Yagcioglu et al., 1999). This is expressed mathematically as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\ exp(-kt) + c \quad (9)$$

Where c is an empirical dimensionless constant

b. Two-Term Model
Henderson (1974) proposed to use the first two term of the general series solution of Ficks second law of diffusion Eq. (8) for correcting the shortcomings of the Henderson and Pabis model. This model was applied in the drying of grain (Glenn, 1978). The model is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a \exp(-k_1 t) + b\ exp(-k_2 t) \quad (10)$$

Where a, b are defined as the indication of shape and generally named as model constants and k_1, k_2 are the drying constants(s^{-1}). These constants are obtained from experimental data and equation (10) is referred as Two-Term Model.

c. Two-Term Exponential Model
Sharaf-Eldeen et al. (1980) re-expressed the Two-Term Model by cutting down the constant number and organizing the second exponential term's indication of shape constant (b). They stressed that the (b) in the Two-Term Model in Eq. 10) should be $(1 - a)$ at $t = 0$ to get $MR = 1$ and proposed a modification as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a \exp(-kt) + (1 - a)\ exp(-kat) \quad (11)$$

Eq. (11) is called the Two-Term Exponential model

d. Wang and Singh Model
Wang and Singh (1978) created a model for intermittent drying of rough rice.

$$MR = 1 + at + bt^2 \quad (12)$$

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where, b (s^{-1}) and a (s^{-2}) were constants obtained from experimental data.

Diffusion Approach Model
Kaseem (1998) rearranged the Verma model (15) by separating the drying constant term k from g and proposed the renewed form as:

$$MR = aexp(-kt) + (1-a)\exp(-kbt) \quad (13)$$

This modified form is known as the Diffusion Approach model. These two modified models were applied for some products' drying at the same time, and gave the same results as expected (Toğrul and Pehlivan, 2003; Akpinar et al., 2003; Gunhan et al., 2005; Akpinar, 2006; Demir et al., 2007).

The Three Term Exponential Models (Modified Henderson and Pabis)
Henderson and Pabis model and the Two-Term Exponential model were improved by adding the third term of the general series solution of Fick's second law of diffusion Eq. (10) with the view of amending any defect in the models. Karathanos (1999) stressed that the first term, second term and third term highlighted in details the last, the middle and the initial parts of the drying curve ($MR - t$) as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\exp(-kt) + b\,exp(-gt) + cexp(-ht) \quad (14)$$

Where, $a, b, and\ c$ indicates the dimensionless shape constants and $k, g\ and\ h$ are the drying constants (s^{-1}). Equation (14) is referred to as the Modified Henderson and Pabis model.

Modified Two-Term Exponential Models (Verma et al model)
Verma et al. (1985) in their study modified the second exponential term of the Two-term Exponential model by adding an empirical constant and used it in the drying of rice. The model modified is referred to as the Verma model and expressed mathematically as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\exp(-kt) + (1-a)\,exp(-gt) \quad (15)$$

Midilli et al Model
Midilli et al (2002) modified the Henderson and Pabis by adding extra empirical term that includes t. The model combined the exponential term with a linear term. It was applied to the drying of yellow dent maize and it is expressed as:

$$MR = a.\exp(-kt^n) + bt \quad (16)$$

Developed models from existing models
From Equation (3), the following equations were obtained for exponent, n and drying constant, k respectively

$$n = \frac{(M_e - M_t)}{(M_e - M_i)kt} \quad (17)$$

$$k = \frac{(M_e - M_t)}{(M_e - M_i)n} \quad (18)$$

IV DETERMINATION OF THE MOST SUITABLE MODEL FOR DRYING

Thin layer drying always require a good understanding of the regression and correlation analysis. Linear and non-linear regression analysis are used to ascertain the relationship between variables MR and t in thin layer drying for selected drying models. The recommended models chosen for applications were further validated using correlation analysis, standard error of estimate (SEE) and root mean square error (RMSE) analysis respectively. The major indicator for selecting the best models is the determination coefficient (R^2). The highest determination coefficient and lowest standard error of estimate and RMSE values are used to determine the goodness of fit (Akpinar, 2006; Erbay & Icier, 2010; Verma et al., 1985). The determination coefficient (R^2); standard error of estimate (SEE) and root mean square error (RMSE) calculations can be performed using the following equations:

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{pre,i})\sum_{i=1}^{N}(MR_i - MR_{exp,i})}{\sqrt{\left[\sum_{i=1}^{N}(MR_i - MR_{pre,,i})^2\right] - \left[\sum_{i=1}^{N}(MR_i - MR_{exp,i})^2\right]}} \quad (19)$$

$$SEE = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{d_f} \quad (20)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{1/2} \quad (21)$$

Where N is the number of observations, $MR_{pre,i}$ ith predicted moisture ratio values, $MR_{exp,i}$ ith experimental moisture ratio values, and d_f is the number of degree of freedom of regression model.

Statistical Validation of the Drying Model
Both theoretical considerations and experimental investigations of drying processes are focused on the drying kinetics. The drying kinetics includes changes in moisture content and changes in mean temperature with respect to drying time. Drying studies provide the basis for understanding the unique drying characteristics of any particular food material. In the study of drying process, the moisture content of bio material exposed to a stream of drying air is monitored over a period of time.

Drying models are used for the investigation of the drying kinetics (Ceylan et al., 2007). A number of mathematical models have been developed to simulate moisture movement and mass transfer during the drying of many agricultural products. In this work, the experimental moisture ratio data of the various ginger treatments were fitted to twelve drying models. (Equations 2, 3, 5, 8-16) and the summary is given in Table 1.

The drying data of the ginger samples were fitted to the twelve thin layer drying models and the data subsets were fitted by multiple nonlinear regression technique. Regression analysis were performed using the R Project for Statistical Computing (R version 3.5.2).The determination

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coefficient (R^2), is the primary basis for selecting the best equation to describe the drying curve. The models with the highest values of R^2 are the most suitable models for describing the thin layer drying characteristics of the ginger samples. Besides R^2, the standard error of estimate (SEE) and root mean square error (RMSE) were used to determine the goodness of fit. The values of SEE and RMSE should be low for good fit. Tables 2-3 presented the results of the curve fitting computations with the drying time for the twelve models with statistical analysis.

Table1: Drying Models for Agricultural Products

S/N	Model Name	Drying Model
1	Newton	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Modified Page	$MR = \exp -(kt)^n$
4	Henderson and Pabis	$MR = a.\exp(-kt)$
5	Logarithmic	$MR = a.\exp(-kt) + c$
6	Two term	$MR = a.\exp(-k_o t) + b.\exp(-k_1 t)$
7	Two term exponential	$MR = a.\exp(-kt) + (1-a)\exp(-kat)$
8	Wang and Singh	$MR = 1 + \mathrm{at} + \mathrm{bt}^2$
9	Diffusion approach	$MR = a.\exp(-kt) + (1-a)\exp(-kbt)$
10	Modified Henderson and Pabis	$MR = a.\exp(-kt) + b.\exp(-gt) + c.\exp(-ht)$
11	Verma et al.	$MR = a.\exp(-kt) + (1-a)\exp(-gt)$
12	Midilli et al.	$MR = a.\exp(-kt^n) + bt$

Table 2: Coefficient of models and goodness of fit for peeled ginger

S/N	Model	Temp	Parameter	R-Square	RMSE	SEE
1	Newton	10	k= -0.1776	0.4653	62.1822	0.0386
		20	k= -0.1652	0.4423	59.2895	0.0494
		30	k= -0.1565	0.4256	59.4701	0.0608
		40	k= -0.1478	0.4138	44.4870	0.0559
		50	k= -0.1281	0.3740	37.1697	0.0739
		60	k= -0.1153	0.3418	34.2501	0.0916
2	Page	10	k= -4.6685, n= -0.0462	0.8983	3.8610	0.0695
		20	k= -4.7402, n= -0.0662	0.8325	6.6486	0.1266
		30	k= -4.8213, n= -0.0801	0.7351	10.4099	0.2003
		40	k= -4.7045, n= -0.1067	0.9098	5.1406	0.1294
		50	k= -4.7316, n= -0.1493	0.8551	7.0034	0.2214
		60	k= -4.9415, n= -0.2037	0.9565	4.1659	0.1535
3	Modified Page	10	k= -2706000, n= 0.0821	0.2864	28.3455	47990000
		20	k= -4392000, n=0.0782	0.2172	30.3384	102600000
		30	k= -3333000, n= 0.0787	0.1725	33.7539	89940000
		40	k= -5086000, n=0.0727	0.1386	25.9576	161300000
		50	k= - -2536000, n= 0.0704	0.1029	25.1014	113900000
		60	k= -0.0003, n= -0.2037	0.9565	4.1659	0.0227
4	Henderson and Pabis	10	k= 0.0253, a= 90.74	0.8869	4.2218	4.2175
		20	k= 0.0402, a= 94.65	0.9694	2.9409	3.2225
		30	k= 0.0523, a= 101.5	0.9468	4.8076	5.6582
		40	k= 0.0629, a= 82.49	0.9614	3.5608	4.4518
		50	k= 0.0961, a=81.64	0.3801	2.9839	4.4559
		60	k= 0.1314, a= 87.42	0.9809	2.9870	5.3356
5	Logarithmic	10	k= 0.1029, a= 49.12, c= 49.95	0.9447	2.8856	14.0887
		20	k= 0.0399, a= 95.00, c= -0.3819	0.9694	2.9409	76.1108
		30	k= 0.0258, a= 157.49, c= -59.85	0.9580	4.3489	266.6928
		40	k= 0.0995, a= 72.18, c= 15.47	0.9722	2.9522	15.0035
		50	k= 0.1177, a= 78.70, c= 6.0698	0.9808	2.6938	11.4802
		60	k= 0.1803, a= 88.28, c= 7.4852	0.9917	1.8916	7.3957
6	Two Term	10	k1= -0.2257, k2= 0.0347, a= 0.0638, b= 95.48	0.9603	2.4432	6.0690
		20	k1= 0.04268, k2= 0.2811, a= 98.37, b= -6.6067	0.9705	2.8971	65.5043
		30	k1= 0.0729, k2= 0.2668, a= 139.52, b= -58.19	0.9736	3.4759	186.4536
		40	k1= -0.3571, k2= 0.0696, a= 0.0014, b= 85.20	0.9791	2.5559	7.4420
		50	k1= -0.4324, k2= 0.1014, a= 0.0001, b= 83.45	0.9874	2.1677	8.3306
		60	k1= 0.1036, k2= 0.9256, a= 66.82, b= 104.58	0.9953	1.4380	170.3199
7	Two Term Exponential	10	k= 0.0260, a= 91.49	0.8864	4.2939	3.9553
		20	k= 0.0402, a= 94.68	0.9694	2.9421	3.2016
		30	k= 0.0523, a= 101.5	0.9468	4.8074	5.6552
		40	k= 0.0629, a= 82.50	0.9614	3.5611	797
		50	k= 0.0961, a= 81.64	0.9774	2.9839	4.4559

		60	k= 0.1314, a= 87.42	0.9809	2.9870	5.3357
8	Wang and Singh	10	a= 11.64, b= -0.4186	0.3573	33.0116	3.8773
		20	a= 11.4299, b= -0.4242	0.3691	32.1510	3.7762
		30	a= 11.5435, b=-0.4670	0.3755	33.5090	3.9357
		40	a= 8.0601, b= 0.3215	0.3003	28.6259	3.3622
		50	a= 6.2309, b= -0.2617	0.2653	27.0580	3.1780
		60	a= 5.2180, b= -0.2252	0.2339	27.0332	
9	Diffusion Approach	10	k= 0.1540, a= 196900, b= 1.001	0.5672	19.3964	16890000000
		20	k= 0. 1780, a= 80140, b= 1.003	0.7295	14.7209	6117000000
		30	k= 0. 1905, a= 3371, b= 1.078	0.8462	11.3862	767920
		40	k= 0.2222, a= 206600, b= 1.001	0.7790	12.0862	6389000000
		50	k= 0.2798, a= 295400, b= 1.001	0.9171	6.9287	2891000000
		60	k= 0.3393, a= 453400, b= 1.00	0.8876	8.4264	10250000000
10	Modified Henderson and Pabis	10	k= -0.0819, a= 4.693, b= 211.1, g= 0.0845, c= -1.240, h= 0.1319	0.9628	2.3659	157971.5
		20	k= 1.204, a= 17.06, b= 295.9, g= 0.0583, c= -204.4, h= 0.0701	0.9705	2.9043	1812176
		30	k= 0.2993, a= -31.57, b= 303.0, g= 0.0896, c= -188.5, h= 0.1165	0.9728	3.5402	2462192
		40	k= -0.2428, a= 0.0523, b= 290.8, g= 0.0251, c= -208.7 , h= 0.0557	0.9803	2.4858	4416167
		50	k= 1.028, a= 591.8, b= 0.00005, g= -1.00, c= -526.5, h= 0.489	0.4999	531789.3	1931900290
		60	k= 0.1146, a= 74.34, b= 0.0001, g= -0.4172, c= 1092, h= 2.284	0.9992	0.5609	70478.76
11	Verma et al.	10	k= -0.2756, a= 1.0003, g= 1.6684	0.4319	55.4450	10.7223
		20	k= -0.4515, a= 1, g= -0.9696	0.4991	6098.755	393.06
		30	k= -0.4442, a= 1.0001, g= -0.9619	0.5005	10439.87	311.3278
		40	k= -0.0911, a= 1.00, g=- 1.00	0.5000	50541.75	718.58
		50	k= -0.0480, a= 1.00, g=- 1.00	0.5000	53762.02	2705.80
		60	k= -0.0241, a= 1.00, g=-1.00	0.5000	51625.9	3292.332
12	Midilli et al.	10	k= - -4.5451, a= -0.2620, b= 1.6243	0.6759	10.5410	1.0607
		20	k= -4.4589, a= -0.2390, b= 0.7725	0.8044	9.3216	0.9431
		30	k= -438, a= -0.2195, b= 0.1672	0.8455	9.6972	0.9770
		40	k= -4.4730, a= -0.2977, b= 0.3120	0.9317	5.0630	0.5488
		50	k= - 761, a= -0.3287, b= -0.1340	0.9023	6.4256	0.7419
		60	k= -4.7967, a= -0.4207, b= -0.1312	0.9731	3.5040	0.4295

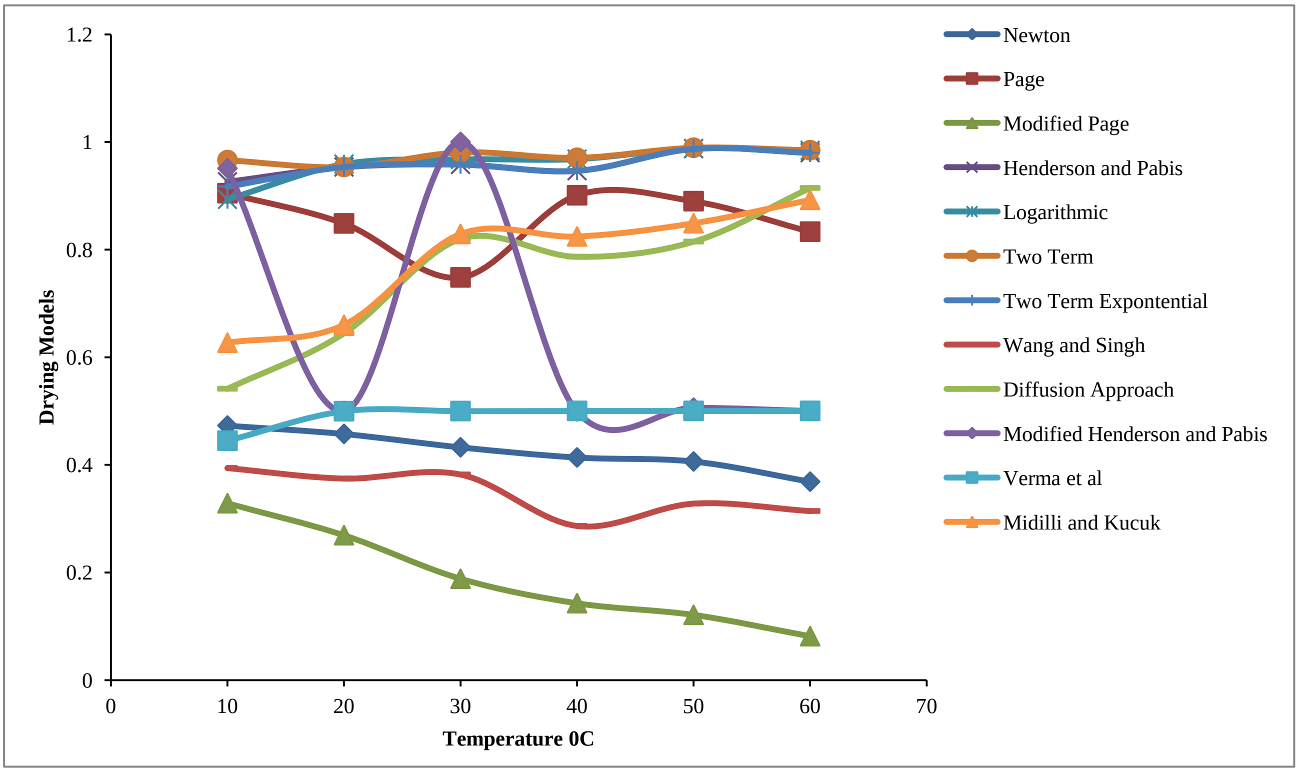

Figure 2: Drying models versus temperature for determination coefficient (Peeled Treatment)

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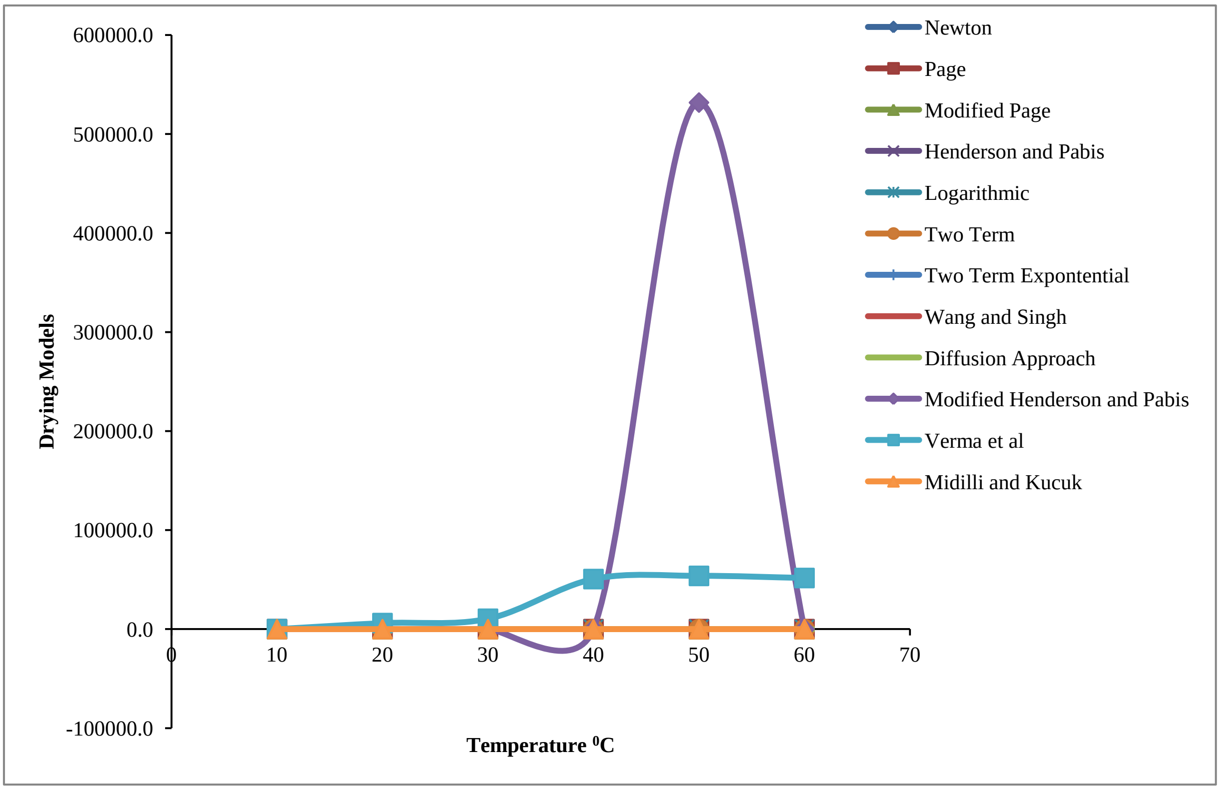

Figure 3: Drying models versus temperature for RMSE (Peeled Treatment)

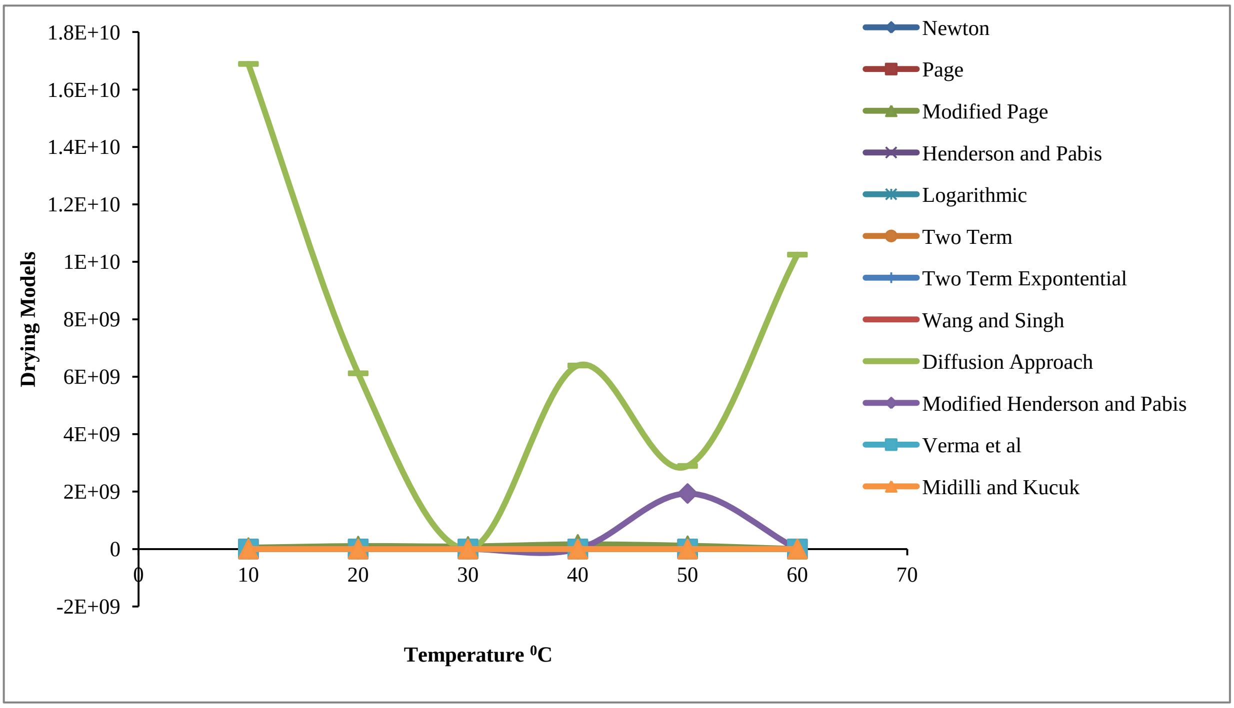

Figure 4: Drying models versus temperature for SEE (Peeled Treatment)

Figures 2 to 4 were plotted using table 2. Also, it can be seen that Page, Henderson and Pabis, Logarithmic, two term and two term exponential models can be used to predict the drying characteristics of peeled ginger treatment. Figure 4 showed that two term and logarithmic models had relatively high standard error for estimate. Figure 4 showed that Page model has best standard error for estimate out of the five models; nevertheless, Figure 2 showed that the coefficient of determination for Page model is 0.74 at temperature of 30°C. Also, Henderson and Pabis' model has coefficient of determination of 0.38 at temperature of 50°C. From figures 2 to 4, it can be seen that two terms exponential is the best suitable model for predicting the drying characteristics of peeled ginger treatment.

Table 3: Coefficient of models and goodness of fit for unpeeled ginger

S/N	Model	Temp	Parameter	R-Square	RMSE	SEE
1	Newton	10	k= -0.1819	0.4729	66.3958	0.0372
		20	k= -0.1732	0.4574	61.3710	0.0423
		30	k= -0.1602	0.4325	60.4977	0.0568
		40	k= -0.1515	0.4136	48.5415	0.0558
		50	k= -0.1373	0.4061	40.2028	0.0646
		60	k= -0.1182	0.3686	41.2707	0.1035
2	Page	10	k= -4.6460, n= -0.0348	0.9046	3.0463	0.0521
		20	k= -4.6713, n= -0.0502	0.8485	5.0895	0.0937
		30	k= -4.7943, n= -0.0729	0.7482	9.4711	0.1788
		40	k= -4.7957, n= -0.1056	0.9008	5.9562	0.1370
		50	k= -4.6344, n= -0.1159	0.8898	5.3958	0.1527
		60	k= -4.8811, n= -0.1573	0.8332	8.7907	0.2566
3	Modified Page	10	k= -2235000, n= 0.0842	0.3285	28.3148	34790000
		20	k= -2132000, n= 0.0826	0.2691	29.0093	39870000
		30	k= -3156000, n= -0.0796	0.1883	33.0412	78360000
		40	k= k= -3496000, n=0.0763	0.1428	28.8198	134000000
		50	k=-6932000, n= 696.5	0.1212	23.8724	247400000
		60	k= -18690000, n= 0.0642	0.0815	28.5251	1043000000
4	Henderson and Pabis	10	k= 0.0190, a= 92.15	0.9259	2.7535	2.6411
		20	k= 0.0294, a= 91.56	0.9533	2.9244	2.9981
		30	k= 0.0 471, a= 100.1	0.9581	3.9791	.5429
		40	k= 0.0223, a= 163.55	0.9464	4.6920	5.9165
		50	k= 0.0683, a= 76.56	0.9873	1.9206	2.4748
		60	k= 0.1021, a= 91.81	0.9799	3.1848	4.9043
5	Logarithmic	10	k= 0.0010, a= -1326, c= 1416	0.8932	3.2536	130450
		20	k= 0.0521, a= 65.88, c= 28.11	0.9587	2.7249	2.1523
		30	k= 0.0223, a= 163.55, c= -66.825	0.9676	3.5566	291.06
		40	k= 0.1185, a= 78.57, c= 20.70	0.9681	3.4930	14.8009
		50	k= 0.0768, a= 89.5462, c= 4.1163	0.9879	1.8705	14.1307
		60	k= 0.0824, a= 97.25, c= -8.5818	0.9843	2.8703	19.2747
6	Two Term	10	k1= -0.1702, k2= 0.0254, a= 0.1746, b= 95.07	0.9662	1.8321	5.7762
		20	k1= 0.0205, k2= 93.901, a= 0.0652, b= 92.50	0.9534	2.9232	2.4529
		30	k1= 0.0617, k2= 0.2966, a= 124.99, b= -42.92	0.9806	2.7704	84.1033
		40	k1= -0.1034, k2= 0.0824, a= 1.1100, b= 95.31	0.9705	3.3548	18.1470
		50	k1= 0.0634, k2= 0.5221, a= 71.81, b= 13.36	0.9892	1.7637	2.3807
		60	k1= 0.1543, k2= 0.1727, a= 533.0, b=-449.6	0.9845	2.8378	221004.2
7	Two Term Exponential	10	k= 0.0205, a= 93.90	0.9170	3.0476	2.4529
		20	k= 0.0296, a= 91.80	0.9534	2.9233	2.8602
		30	k= 0.0471, a= 100.1	0.9581	3.9781	4.5349
		40	k= 0.0645, a= 90.63	0.9464	4.6920	5.9155
		50	k= 0.0683, a= 76.56	0.9873	1.9208	2.4737
		60	k= 0.1021, a= 91.81	0.9799	3.1848	4.9043
8	Wang and Singh	10	a= 12.6298, b= 0.4488	0.3941	32.5889	3.8276
		20	a= 11.7577, b -0.4363	0.3746	31.8720	3.7434
		30	a= 11.8001, b= -0.4708	0.3821	33.0778	3.8851
		40	a= 8.6262, b= -0.3417	0.2864	31.8283	3.7383
		50	a= 7.4729, b= -0.3074	0.3280	25.4157	2.9852
		60	a= 7.2436, b= -0.3183	0.3141	29.0227	3.4088
9	Diffusion Approach	10	k= 0.1387, a= 63350, b= 1.001	0.5413	19.7390	5516000000
		20	k= 0.1600, a= 198000, b= 1.001	0.6444	16.7848	6701000000
		30	k= 0.1890, a= 89570, b= 1.003	0.8199	12.2230	7052000000
		40	k= 0.2311, a= 195500, b= 1.001	0.7867	13.3911	8539000000
		50	k= 0.2402, a= 221300, b= 1.001	0.8148	9.9827	165201.2
		60	k= 0.2780, a= 296000, b= 1.001	0.9144	7.6163	5180000000
10	Modified Henderson and Pabis	10	k= 0.0616, a= -5.523, b= 0.0000002, g= -0.6402, c= 99.04, h= 2.590	0.9508	2.2749	62837.38
		20	k= - 0.3036, a= -71.76, b= 0.00, g= -1.00, c= 153.1, h= 0.2477	0.5000	59898.73	2419747970
		30	k= 0.3613, a= 32.16, b= 0.000001, g=-0.9950, c= 23.88, h= -0.1593	0.9999	9969.08	201187.2
		40	k= 0.0857, a= -13.87, b= 0.000001, g= -0.9774, c= 95.01, h= 0.1903	0.4993	7007.75	11602604
		50	k= 1.287, a= -977.0, b= -0.000002, g= -0.8501, c= 1064, h= 0.6661	0.5061	810.10	24903272

		60	k= 0.1005, a= 97.59, b= -0.000003, g= -1.00, c= -13.32, h= 0. 1150	0.5001	40037.12	20466604565
11	Verma et al.	10	k= -0.3170, a= 1.2163, g= -0.3879	0.4448	57.7136	62.264
		20	k= -0.4472, a= 1, g= -0.9167	0.4996	10714.09	979.63
		30	k= -0.4885, a= 1.00, g= -0.9167	0.4998	30930.09	1406.83
		40	k= -0.1035, a= 1.00, g= -1.00	0.5001	40996.2	1319.494
		50	k= -0.0713, a= 1.00, g= -1.00	0.5001	43038.15	1798.76
		60	k= -0.06755, a= 1.00, g= -1.00	0.5001	76978.86	3077.04
12	Midilli et al.	10	k= -4.5123, a= -0.2479, b= 1.9045	0.6269	11.0497	1.1074
		20	k= -4.4743, a= -0.2479, b= 1.3156	0.6602	11.4929	1.1669
		30	k= -485, a= -0.2189, b= 0.3547	0.8289	9.7878	0.9874
		40	k= -4.6278, a= -0.3100, b= 0.4769	0.8243	9.2670	0.9678
		50	k=-347, a= -0.3123, b= 0.1740	0.8489	7.4782	0.8520
		60	k= -4.5442, a -0.3158, b= -0.3465	0.8923	8.0241	0.8722

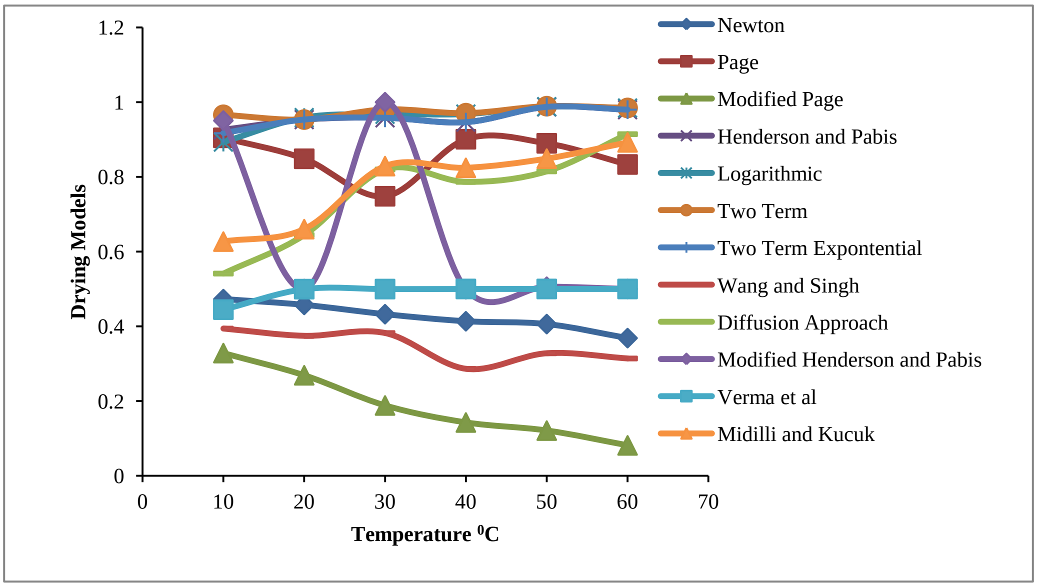

Figure 5: Drying models versus temperature for determination coefficient (UnpeeledTreatment)

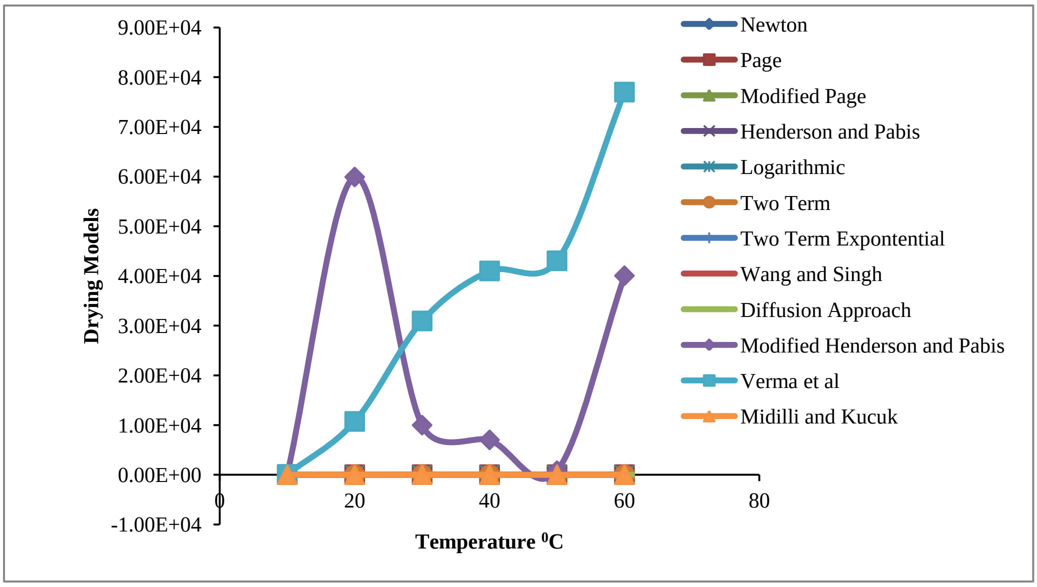

Figure 6: Drying models versus temperature for RMSE (Unpeeled Treatment)

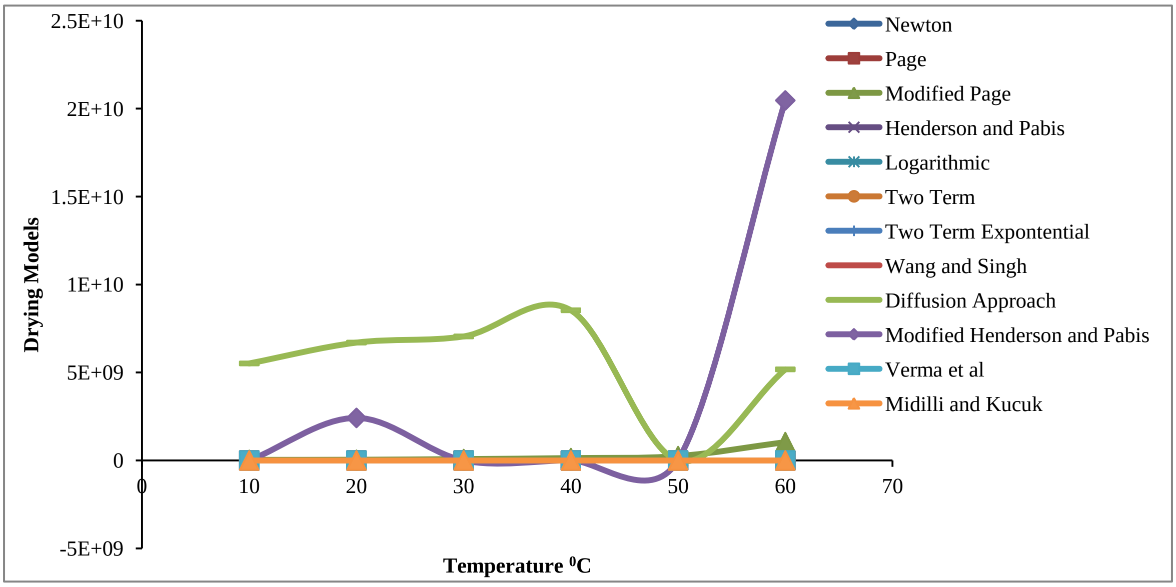

Figure 7: Drying models versus temperature for SEE (Unpeeled Treatment)

Figures 4 to 7 were plotted using table 3. The plots showed that Page, Henderson and Pabis, Logarithmic, two term and two term exponential models can be used to predict the drying characteristics of unpeeled ginger treatment. Also, figure 7 showed that two term and logarithmic models had relatively high standard error for estimate. Figure 4 showed that Page model has best standard error for estimate when compared with the other four models; but, figure 4 showed that the determination coefficient is 0.75 at the temperature of 30⁰C. From figures 4 to 7, it can be seen that two terms exponential and Henderson and Pabis models are suitable models for predicting the drying characteristics of unpeeled ginger treatment.

This study revealed that five drying models can be used to predict the drying characteristics of the various ginger treatments. There are Page, Henderson and Pabis, Logarithmic, two term and two term exponential models. Nevertheless, two terms exponential proved to be the model most suitable for predicting the drying characteristics of ginger rhizome.

V. CONCLUSION

Thin layer drying characteristics of ginger rhizome slices was conducted in ARS-680 environmental chamber. The data obtained was fitted into twelve models. From the experimental results the following conclusion were drawn. This study revealed that five drying model can be used to predict the drying characteristic of the various ginger treatment. There are page, Henderson and Pabis, logarithmic, two term and two term exponential models. Two term exponential proved to be the model most suitable for predicting the drying characteristics of ginger rhizome.

The drying data of the ginger samples were fitted to the twelve thin layer drying models and the data subsets were fitted by multiple nonlinear regression technique. Regression analysis were performed using the R Project for Statistical Computing (R version 3.5.2).The determination coefficient (R^2), is the primary basis for selecting the best equation to describe the drying curve.

The values of SEE and RMSE should be low for good fit. Tables 2-3 presented the results of the curve fitting computations with the drying time for the twelve models with statistical analysis.

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