Journal of Advances in Science and Engineering 4 (2021) 98 – 107

Journal of Advances in Science and Engineering
(JASE)

Journal homepage: www.sciengtexopen.org/index.php/jase

Statistical prediction of the drying behavior of blanched ginger rhizomes

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ARTICLE INFO

Article history:
Received 2 January 2021
Received in revised form
10 April 2021
Accepted 11 April 2021
Available online
16 April 2021

Keywords:
Drying models
Ginger rhizomes
Moisture ratio
Thin layer

ABSTRACT

ARS-680 environmental chamber was employed in this study to determine the drying behavior of sliced ginger rhizomes. Blanched and unblanched treated ginger rhizomes were considered at drying temperature of 40 °C for a period of 2 – 24 h. Linear and non-linear regression analyses were employed to establish the correlation that exits between the drying time and the moisture ratio. Correlation analysis, root mean square error (RMSE) and standard error of estimate (SEE) analysis were chosen in selecting the best thin layer drying models. Higher values of determination coefficient (R^2) show goodness of fit and lower values of SEE implies better correlation; and RMSE values were also utilized in determining the goodness of fit. The drying data of the variously treated ginger samples were fitted into the twelve thin layer drying models and the data obtained were fitted by multiple non-linear regression technique. Blanched treated sample exhibited a better drying behavior losing about 82.87 % moisture content compared with unbleached sample that lost about 62.03 % of moisture content. Two-term exponential drying model proved to be the most suitable model for predicting the drying behavior of ginger rhizome. The model exhibited high R^2 values of 0.9349-0.9792 (which are close to unity) for both blanched and unbleached samples. Also, it recorded relatively low values of RMSE and SEE (3.6865 - 2.0896 and 3.6564-2.7486 respectively) for both treatments.

1. Introduction

Convective drying could be employed in getting rid of volatile liquid from permeable materials such as food stuffs (ginger), ceramics, and wood [1]. Convection drying is an aeration process wherein the material receives heat from the flow of air [2]. Convective drying has been reported as one of the most frequently used methods for drying of fruits, vegetables and medicinal root preservations [3]. Permeable materials have miniature openings, which allow concurrent transfer of moisture and mass when subjected to cooling or heating [4]. The drying of a moist permeable material consists of concurrent transfer of mass and heat [1]. Moisture is eradicated by means of evaporation into an unsaturated gas phase.

Drying is essential for the preservation of agricultural produces for future usage [5]. Convective drying can meaningfully reduce

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https://doi.org/10.37121/jase.v4i2.147

the mold and bacteria growth in crops and roots [3]. Crops are conserved by eliminating sufficient moisture from them to avoid decay [4]. For example, the drying process of ginger rhizomes entails reducing the moisture content of the ginger to a lesser value to discourage the actions of the micro-organisms that can spoil the ginger. Nevertheless, the heat of the drying process might slew some important enzymes in ginger rhizomes. However, the basic advantage of convective drying is the possibility of controlling temperature of the drying chamber [2], [6], which invariably aids in maintaining the quality of the drying samples.

Thin layer drying can be seen as just drying a slice of a sample [7]. A thin-layer is assumed to be fully exposed to stream of the drying air. The thickness of the layer should be the same all through and is not expected to be more than three layers of the sample [8]. Therefore, thin layer drying requires drying one layer to three layers of sample slices [7]. The temperatures of thin layers are assumed to be uniformly distributed and very ideal for lumped parameter models [9]. Research [10] showed that thin layer drying relationships were having varied applications owing to their simplicity in usage and fewer information requirements in contrast to more data required in the distributed models.

Thin layer drying relations could be expressed in the different models (theoretical, semi-theoretical and experimental). Theoretical models take into consideration only the internal resistance to moisture transfer [11] but other models have to do with external resistance to moisture exchange occurring between the product and its environment [12]. Theoretical concerns as well as empirical analyzes of drying methods are centered on the drying kinetics, which comprise changes in moisture content and variations in average temperature with respect to drying time. Drying models are employed in the examination of the drying kinetics [13]. Different researchers had proposed various drying models for different agricultural products as shown in Table 1. These models can help in the design and operations of dryers since they can estimate the drying time [14]. The notional models elucidated the drying features of the samples succinctly and could find their applications in many process situations. Fick's second law of diffusion was employed in the derivation of some theoretical models. Semi-theoretical models are derived from Fick's second law of diffusion as well, and alterations of its basic forms. They are easy to use and involve fewer assumptions owing to the use of some empirical data and are valid within the limits of the process circumstances obtainable [15].

2. Material and Methods

The Ginger rhizomes used in this study were gotten from Kachia in Southern Kaduna, Nigeria and stored at room temperature before being used for the experimentations. The ginger rhizomes utilized were treated blanched sample and non-treated sample (unblanched). The drying experiments were carried out at the Electronic Manufacturing Engineering Laboratory (ERMERG) Hawke's building, University of Greenwich. The gingers were cut into slices of 30 mm diameter and 18 mm thickness by scoopers designed for this purpose. Thin layer drying was conducted at different conditions. The relative humidity of the heating chamber and the heat transfer coefficients were measured simultaneously during the experiments. The results obtained for the dried gingers were compared in terms of their response to heat by convection and their thermal conductivity.

Table 1 Drying models for agricultural products.

Name	Model	References
Newton	$MR = \exp(-kt)$	[16]
Page	$MR = \exp(-kt^n)$	[17]
Modified Page	$MR = \exp\ -(kt)^n$	[18]-[20]
Henderson and Pabis	$MR = a.\exp(-kt)$	[21]
Logarithmic	$MR = a.\exp(-kt) + c$	[22] [23]
Two-term	$MR = a.\exp(-k_o t) + b.\exp(-k_1 t)$	[24] [25]
Two-term exponential	$MR = a.\exp(-kt) + (1-a)\exp(-kat)$	[26]
Wang and Singh	$MR = 1 + \mathrm{at} + \mathrm{bt}^2$	[27]
Diffusion approach	$MR = a.\exp(-kt) + (1-a)\exp(-kbt)$	[28]-[32]
Modified Henderson and Pabis	$MR = a.\exp(-kt) + b.\exp(-gt) + c.\exp(-ht)$	[33]
Verma et al.	$MR = a.\exp(-kt) + (1-a)\exp(-gt)$	[34]
Midilli et al.	$MR = a.\exp(-kt^n) + bt$	[35]

MR is the moisture ratio; *a*, *b*, *c* and *n* (dimensionless) are the model constants; k, k_0, k_1, g and h (s^{-1}) are the drying constants; t (s) is the drying time

The temperature and humidity chamber installed at the Hawke building was employed for the drying of the ginger rhizomes at temperatures of 10 °C – 60 °C for drying times of 2, 4, 8, 10, 14, 18 and 24 hours. Linear heat conduction experiment was utilized to measure the thermal conductivity of the sample. ESPEC’s ARS-0680 environmental humidity and temperature chamber was used for heating specimen at low or high temperature in controlled humidity. ESPEC's environmental chambers can tolerate heat loads generated by the specimen, enhance temperature change rates, and supply extended spans for humidity and temperature. The ginger drying experiment was conducted according to ASAE Standard S352.2.

2.1. Determination of the Most Appropriate Drying Model

A decent knowledge of statistical analyses is essential for thin layer drying. In this study, the linear and non-linear regression analyses were utilized in establishing the relationship between moisture ratio and time in drying slice layer of ginger for certain models. The endorsed models were verified using different statistical tools comprising determination coefficient (R^2), standard error of estimate (SEE) and root mean square error (RMSE) as expressed in equations (1) – (3).

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

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

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{1/2} \tag{3}$$

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

In this paper, the experimental moisture ratio data of the diversely treated ginger were fitted to twelve established drying models [16] – [35] shown 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 was carried out by means of the *R* Project for Statistical Computing (R version 3.5.2). The R^2-value is the main index for selecting the best relationship, which defines the drying models. The highest R^2-value and lowest SEE and RMSE values are used to determine the goodness of fit [7], [9], [34].

3. Results and Discussion

3.1. Drying Behavior of Blanched and Unblanched Ginger

This paper investigated the drying behavior of blanched treated and untreated thin layer of ginger rhizomes. Drying curves were studied for time period of 2 – 24 h for moisture ratio varying from 79.2 % to 17 % final moisture ratio at 40 °C. Fig. 1 presents the change of moisture content of blanched and unblanched ginger samples with drying time of 24 h at temperature of 40 °C. The convective drying process downgraded the moisture content of the unblanched sample by 62.03 % (from a preliminary value of 79.32 % to a final value of 30.12 %) in 24 hours drying period while the blanched sample lost about 82.87 % of moisture (from 70.11 % to 12.01 %) in the same time frame.

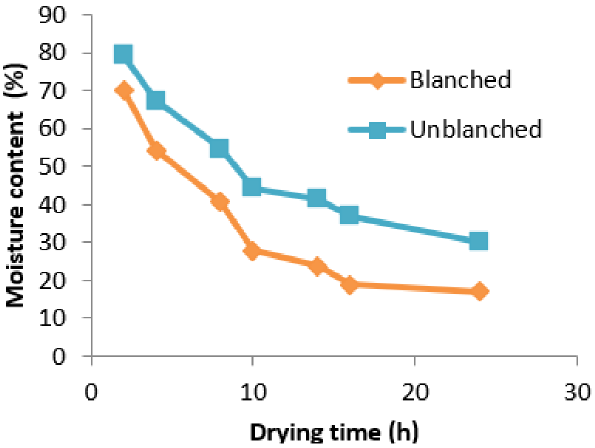

Fig. 1 Drying curve of variation of moisture content with drying time.

The result indicates that blanch treatment encourages better drying behavior and leads to lower moisture content in the ginger rhizome. The blanched treated sample attained moisture content of 12.01 % while the untreated sample attained moisture content of 30.12 % during the drying period of 24 h in the convective environment. The moisture content of properly dried food has been reported to vary from 5 % to 25 %, depending on the food [36]. The moisture content achieved for the blanched sample is suitably within this range but the final moisture content of the unblanched sample did not get to 25 %, which is the upper limit and should be subjected to further drying. Nevertheless, the moisture content for well dried ginger has been recommended to be within the range of 7 % to 12 % [37]. The final moisture content of the blanched sample is approximately 12 %, which is within the acceptable limit. The dried blanched sample would not likely be subjected to decay or other damages due to excess moisture content.

It can be inferred from Fig. 1 that blanched ginger sample lost highest quantity of moisture within the drying period, especially between 10 to 20 h drying period. Generally, the moisture content reduces with time for the ginger samples. The higher drying rate found in blanched treated sample could be traced to diffusion for the sliced ginger sample as a result of its two surfaces with small diffusion length traveling towards the cut surfaces. Previous research [38] showed that blanching increased the drying rate of porous material. These differences could be due to the fact that during blanching, the samples are moderately exposed to warm water and some cells might be loosened or disrupted; the result of which causes the moisture diffusion to be higher and as a consequence the drying rate is higher.

3.2. Validation of the Drying Model

Tables 2-3 show the results of the curve fitting for the twelve models with statistical analysis. The model with the highest of R^2 values is the most suitable model for describing the thin layer drying characteristics of the ginger samples. The values of SEE and RMSE should be low for good fit. It can be seen (Table 2) that Page model can be employed to calculate the drying characteristics of unblanched ginger treatment at temperature above 40 ^{0}C. But below 40 ^{0}C, this model might not be appropriate to model the drying characteristics of unblanched ginger. Table 2 showed that four models (Henderson and Pabis, Logarithmic, Two-term and Two-term exponential) could be utilized in predicting the drying properties of unblanched ginger rhizome treatment; but, Two-term exponential as well as Henderson and Pabis are most appropriate for the prediction of the drying properties.

Henderson and Pabis model generated fairly high values of R^2 for all the drying temperatures considered with drying temperatures of 30 °C and 50 °C giving the least and highest values of 0.9139 and 0.9867 respectively. Also, the values of RMSE and SEE are relatively low with the least values of 2.0894 and 2.7490 respectively recorded at 50 °C. The result implies that the drying behavior of unblanched ginger sample at 50 °C drying temperature could be fairly predicted using Henderson and Pabis model. Logarithmic model produced a very high value of 0.9990 for R^2 at drying temperature of 50 °C and this value is approximately equal to unity. Likewise, the least values of RMSE and SEE of 0.5567 and 2.4776 respectively were recorded at temperature of 50°C.

Table 2 Coefficient of models and goodness of fit for unblanched ginger

Model	Temp. (°C)	Parameters	R-Square	RMSE (%)	SEE (%)
Newton	10	$k = -0.1738$	0.4557	64.3219	0.0437
	20	$k = -0.1723$	0.4562	59.8300	0.0422
	30	$k = -0.1663$	0.4405	60.7943	0.0494
	40	$k = -0.1564$	0.4307	48.3551	0.0496
	50	$k = -0.1399$	0.4035	40.8199	0.0616
	60	$k = -0.1171$	0.3624	39.1357	0.1006
Page	10	$k = -4.7054, n = -0.0491$	0.7746	6.6736	0.1182
	20	$k = -4.6631, n = -0.0525$	0.8475	5.1806	0.0975
	30	$k = -4.7522, n = -0.0649$	0.7382	8.8685	0.1657
	40	$k = -4.6913, n = -0.0889$	0.9559	3.3324	0.0763
	50	$k = -4.7001, n = -0.1220$	0.9412	4.1183	0.1139
	60	$k = -4.8946, n = -0.1692$	0.8743	7.4558	0.2314
Modified Page	10	$k = -2110000, n = 0.0832$	0.2677	30.7637	39900000
	20	$k = -2141000, n = 0.0822$	0.2628	28.5385	40790000
	30	$k = -4409000, n = 0.0784$	0.2132	31.6093	104800000
	40	$k = -3496000, n = 0.0763$	0.1725	26.3335	90820000
	50	$k = -6722000, n = 0.0993$	0.1199	24.6464	243400000
	60	$k = -0.00008, n = -0.1693$	0.8743	7.4558	0.0313

Table 2 Coefficient of models and goodness of fit for unblanched ginger (cont'd)

Model	Temp. (°C)	Parameters	R-Square	RMSE (%)	SEE (%)
Henderson and Pabis	10	$k = 0.0299$, $a = 95.8216$	0.9345	3.7042	3.8099
	20	$k = 0.0303$, $a = 89.9556$	0.9310	3.6031	3.7144
	30	$k = 0.0409$, $a = 97.2675$	0.9139	5.2717	5.7999
	40	$k = 0.0506$, $a = 83.5059$	0.9588	3.4020	3.9632
	50	$k = 0.0722$, $a = 79.7556$	0.9867	2.0894	2.7490
	60	$k = 0.1077$, $a = 89.5462$	0.9792	3.1820	5.0421
Logarithmic	10	$k=0.0297$, $a=96.2870$, $c=- 0.4886$	0.9345	3.7041	171.5739
	20	$k = 0.0566$, $a = 63.6015$, $c = 29.1920$	0.9380	3.3824	44.7031
	30	$k = 0.0374$, $a = 102.5839$, $c = -5.7667$	0.9144	5.2667	155.2513
	40	$k = 0.1155$, $a = 66.0792$, $c= 26.4788$	0.9911	1.5304	6.6286
	50	$k = 0.1121$, $a = 72.1372$, $c = 13.3545$	0.9990	0.5569	2.4776
	60	$k= 0.0997$, $a = 90.9417$, $c = -2.6588$	0.9800	3.1412	15.9152
Two-term	10	$k_1 = 0.0328, k_2 = 0.4860, a = 100.12, b = -14.18$	0.9408	3.5478	67.3540
	20	$k_1 = -0.1975, k_2 = 0.0359, a. = 0.0652, b = 92.50$	0.9494	3.0662	8.6839
	30	$k_1 = 0.0484, k_2 = 0.4031, a = 108.48, b = -27.04$	0.9281	4.8917	84.5508
	40	$k_1 = 0.0172, k_2 = 0.1602, a = 44.07, b = 50.50$	0.9916	1.4888	68.4724
	50	$k_1 = 0.0386, k_2 = 0.1812, a = 43.44, b = 44.82$	0.9994	0.4129	25.9763
	60	$k_1 = 0.0101, k_2 = 4.353, a = 83.38, b = 36130$	0.9824	2.9025	394605484
Two-term Exponential	10	$k = 0.0300, a = 95.93$	0.9349	3.6865	3.6564
	20	$k = 0.0306, a = 90.2740$	0.9307	3.6283	3.5850
	30	$k = 0.0409, a = 97.2743$	0.9138	5.2696	5.7670
	40	$k = 0.0505, a = 83.53$	0.9588	3.4048	3.9541
	50	$k = 0.07221, a = 79.75$	0.9867	2.0896	2.7486
	60	$k = 0.1077, a = 89.5462$	0.9792	3.1820	5.0421
Wang and Singh	10	$a = 12.4486, b = -0.4665$	0.3867	32.7700	3.85
	20	$a = 11.4252, b = -0.4242$	0.3676	31.5500	3.71
	30	$a = 11.6757, b = -0.4523$	0.3623	33.4244	3.9258
	40	$a = 8.8782, b = -0.3432$	0.3113	29.5096	3.4660
	50	$a = 7.3172, b = -0.2974$	0.2963	27.0252	3.1742
	60	$a = 6.6709, b = -0.2924$	0.2939	28.3493	3.3297
Diffusion Approach	10	$k = 0.1600, a = 195300, b = 1.001$	0.6767	16.2880	11510000000
	20	$k = 0.1612, a = 191300, b = 1.001$	0.6397	16.6644	4285000000
	30	$k = 0.1806, a = 72100, b = 1.004$	0.7638	14.0258	2017000000
	40	$k = 0.200, a = 6468, b = 1.032$	0.7066	14.6413	12530070
	50	$k = 0.2402, a = 221300, b = 1.001$	0.8086	10.8549	10980000000
	60	$k = 0.2869, a = 471100, b = 1.00$	0.8913	8.4190	4267000000
Modified Henderson and Pabis	10	$k = -0.5331, a = 0.00003, b = 298.4,$ $g = 0.0775, c = -213.5, h = 0.1197$	0.9728	2.3789	64638.62
	20	$k = -0.0319, a = 285.0, b = 164.1,$ $g = -0.0835, c = -361.9, h = -0.0665$	0.9717	2.2788	15457702
	30	$k = 0.4411, a = -21.57, b = 301.1,$ $g = 0.0603, c = -196.92, h = 0.0695$	0.92665	4.9615	19006351
	40	$k = 0.1252, a = 100.1, b = 250.9,$ $g = 0.0415, c = -256.6, h = 0.0557$	0.9916	1.4863	22319738
	50	$k = 0.1252, a = 100.1, b = 250.9,$ $g = 0.0415, c = -256.6, h = 0.0557$	0.7720	10.4271	22319738
	60	$k = 0.1252, a = 100.1, b = 250.9,$ $g = 0.0415, c = -256.6, h = 0.0557$	0.6302	17.5589	22319738
Verma et al.	10	$k = 0.0315, a = 97.9646, g = 1.6684$	0.9387	3.5989	7.1512
	20	$k = 0.0315, a = 97.9646, g = 1.6685$	0.8576	6.0239	7.1512
	30	$k = 0.0441, a = 101.52, g = 1.4019$	0.9209	5.0911	11.1057
	40	$k = 0.0441, a = 101.52, g = 1.4019$	0.6988	14.4358	11.1057
	50	$k = 0.0441, a = 101.52, g = 1.4019$	0.5952	24.2886	11.1057
	60	$k = 0.0441, a = 101.52, g = 1.4019$	0.5574	30.6585	11.1057
Midilli et al.	10	$k = -4.4492, a = -0.2297, b = 1.2110$	0.6801	11.7124	1.1793
	20	$k = -4.4356, a = -0.2418, b = 1.1722$	0.7837	8.5460	0.87393
	30	$k = -4.3899, a = -0.2158, b = 0.5625$	0.8661	7.8576	0.7985
	40	$k = -4.5787, a = -0.3113, b = 0.7594$	0.8040	8.6490	0.9213
	50	$k = -4.5178, a = -0.3290, b = 0.2430$	0.89709	6.2558	0.7030
	60	$k = -4.5607, a = -0.3298, b = -0.3387$	0.9613	4.5454	0.5032

Table 3 Coefficient of models and goodness of fit for blanched ginger.

Model	Temp. (°C)	Parameters	R-Square	RMSE (%)	SEE (%)
Newton	10	$k = -0.1675$	0.4487	56.9359	0.0449
	20	$k = -0.1611$	0.4320	56.9113	0.05228
	30	$k = -0.1422$	0.3983	55.2101	0.0790
	40	$k = -0.1352$	0.3850	37.7302	0.0636
	50	$k = -0.1216$	0.3659	36.9169	0.0854
	60	$k = -0.1171$	0.3624	39.1357	0.1006
Page	10	$k = -4.6889, n = -0.0633$	0.9176	4.1165	0.0808
	20	$k = -4.7754, n = -0.0777$	0.8124	7.8502	0.1553
	30	$k = -4.9152, n = -0.1088$	0.71565	12.8780	0.2713
	40	$k = -4.7471, n = -0.1448$	0.9388	4.4175	0.1342
	50	$k = -4.7528, n = -0.1572$	0.8127	8.3007	0.2700
	60	$k = -4.8946, n = -0.1692$	0.8743	7.4558	0.2313
Modified Page	10	$k = -4226000, n = 0.0782$	0.2309	28.0725	92440000
	20	$k = -3125000, n = 0.0789$	0.1842	31.2239	78310000
	30	$k = -588800, n = 0.0738$	0.1241	35.3529	220500000
	40	$k = -18740000, n = 0.0643$	0.0996	24.0806	874700000
	50	$k = -9024000, n = 0.0651$	0.0874	25.3152	483500000
	60	$k = -0.00008, n = -0.1693$	0.87432	7.4558	0.0313
Henderson and Pabis	10	$k = 0.0364, a = 89.3923$	0.9745	2.3897	2.5594
	20	$k = 95.8828, a = 89.9556$	0.9503	4.2258	4.8620
	30	$k = 0.0738, a = 105.85$	0.9270	6.7505	8.9577
	40	$k = 0.0881, a = 80.21$	0.9633	3.7128	5.3178
	50	$k = 0.0995, a = 81.56$	0.9528	4.3866	6.6680
	60	$k = 0.1077, a = 89.5462$	0.9792	3.1820	5.0421
Logarithmic	10	$k = 0.0746, a = 64.2547, c = 29.8133$	0.9890	1.5410	12.2574
	20	$k = 0.0571, a = 88.52, c = 8.5958$	0.9507	4.1861	54.2203
	30	$k = 0.0462, a = 131.86, c = -30.57$	0.9401	6.2679	122.0081
	40	$k = 0.1498, a = 75.83, c = 13.78$	0.9874	2.0737	7.9296
	50	$k = 0.0941, a = 82.68, c = -1.8811$	0.9536	4.3728	23.9501
	60	$k = 0.0997, a = 90.94, c = -2.6588$	0.9800	3.1412	15.9152
Two-term	10	$k_1 = -0.1352, k_2 = 0.0441,$ $a = 0.3545, b = 92.0785$	0.9902	1.4544	6.3997
	20	$k_1 = 0.0516, k_2 = 0.4456,$ $a = 100.32, b = -11.46$	0.9526	4.1547	79.6655
	30	$k_1 = 0.1260, k_2 = 0.2279,$ $a = 255.99, b = -179.65$	0.9623	5.0445	2635.26
	40	$k_1 = -0.0904, k_2 = 0.1121,$ $a = 1.2774, b = 84.96$	0.9891	1.9295	10.3514
	50	$k_1 = -0.0904, k_2 = 0.1121,$ $a = 1.2774, b = 84.96$	0.9105	5.8401	10.3514
	60	$k_1 = 0.1007, k_2 = 4.353,$ $a = 83.38, b = 36130$	0.9824	2.9025	394605484
Two-term exponential	10	$k = 0.0365, a = 89.51$	0.9743	2.4011	2.5274
	20	$k = 0.0484, a = 95.88$	0.9503	4.2256	4.8540
	30	$k = 0.0738, a = 105.85$	0.9270	6.7505	8.9576
	40	$k = 0.0881, a = 80.21$	0.9633	3.7128	5.3177
	50	$k = 0.0995, a = 81.56$	0.9528	4.3866	6.6679
	60	$k = 0.1077, a = 89.5462$	0.9792	3.1820	5.0421
Wang and Singh	10	$a = 10.7915, b = -0.4071$	0.3520	31.3122	3.6776
	20	$a = 10.74, b = -0.4217$	0.3406	33.1157	3.8895
	30	$a = 10.29, b = -0.4353$	0.3428	35.0269	4.1139
	40	$a = 6.3126, b = -0.2574$	0.2548	27.2138	3.1963
	50	$a = 6.2735, b = -0.2702$	0.2823	26.7532	3.1422
	60	$a = 6.6709, b = -0.2924$	0.2939	28.3493	3.3297
Diffusion Approach	10	$k = 0.2738, a = 286200, b = 1.001$	0.6627	16.2673	9949000000
	20	$k = 0.1949, a = 75260, b = 1.003$	0.7796	3.5730	9504000000
	30	$k = 0.0231, a = 101600, b = 1.002$	0.9083	9.1213	3442000000
	40	$k = 0.2720, a = 276900, b = 1.001$	0.8364	10.1288	4205000000
	50	$k = 0.2402, a = 221300, b = 1.001$	0.9038	7.2400	4776000000
	60	$k = 0.2869, a = 471100, b = 1.00$	0.8913	8.4190	4267000000

Table 3 Coefficient of models and goodness of fit for blanched ginger (cont'd).

Model	Temp. (°C)	Parameters	R-Square	RMSE (%)	SEE (%)
Modified Henderson and Pabis	10	$k = -0.1252, a = 100.1, b = 250.9,$ $g = 0.0415, c = -256.6, h = 0.0557$	0.7502	11.2536	22319738
	20	$k = -0.5382, a = 0.00003, b = 297.7,$ $g = 0.1028, c = -214.6, h = 0.1537$	0.9818	2.5323	48486.55
	30	$k = -0.5382, a = 0.00003, b = 297.7,$ $g = 0.1028, c = -214.6, h = 0.1537$	0.7861	10.3395	48486.55
	40	$k = -0.5382, a = 0.00003, b = 297.7,$ $g = 0.1028, c = -214.6, h = 0.1537$	0.6085	23.7125	48486.55
	50	$k = -0.4659, a = 0.00007, b = 171.4,$ $g = 0.1499, c = -105.1, h = 0.2611$	0.9671	3.6323	13977.55
	60	$k = 0.1367, a = 127.6, b = 4432,$ $g = 1.670, c = -1221, h = 0.9579$	0.9971	1.1897	2665399
Verma et al.	10	$k = 0.0440, a = 101.52, g = 1.4019$	0.9293	4.8420	11.1057
	20	$k = 0.0495, a = 97.19, g = 1.98$	0.9510	4.2036	10.6059
	30	$k = 0.0885, a = 126.07, g = 0.8917$	0.9468	5.8809	24.0566
	40	$k = 0.0885, a = 126.07, g = 0.8917$	0.7114	18.8661	24.0567
	50	$k = 0.1004, a = 82.35, g = 2.3186$	0.9530	4.3842	19.6168
	60	$k = -0.0491, a = 1.00, g = -1.00$	0.5001	45221.66	2299.48
Midilli et al.	10	$k = -4.5065, a = -0.2643, b = 1.0657$	0.7582	9.5627	0.9778
	20	$k = -4.4475, a = -0.2372, b = 0.4568$	0.8890	7.2390	0.7340
	30	$k = -4.4283, a = -0.2211, b = -0.4783$	0.9475	6.2365	0.6280
	40	$k = -4.6171, a - 0.3675, b = 0.1731$	0.9011	6.2294	0.7263
	50	$k = -4.36909, a = -0.3080, b = -0.3485$	0.9502	4.6823	0.5370
	60	$k = -4.5607, a = -0.3298, b = -0.3387$	0.9613	4.5454	0.5032

Similarly, logarithmic model could be employed in simulating the drying characteristics of unblanched ginger sample at drying temperature of 50°C. Two-term model generated high R^2 value of 0.9994 at 50°C; it recorded the least value of RMSE (0.4129) at the same temperature. Two-term exponential model generated relatively high values of R^2 for all the drying temperature considered; it also gave fairly low RMSE and SEE values for all the drying temperature considered. Therefore, it the most accurate model for defining the thin layer drying characteristics of the unblanched ginger samples and it could be employed in determining the goodness of fit. Henderson and Pabis model, Logarithmic model, and Two-term model could be employed to simulate the drying features of unblanched ginger at drying temperature of 50°C, but Two-term exponential model could be utilized to calculate the drying characteristics of unblanched ginger at various drying temperatures (10 °C – 60 °C).

As observed from Table 3, five models (Page, Henderson and Pabis, Logarithmic, Two-term and Two-term exponential) can be applied to model the drying characteristics of blanched ginger treatment. Nevertheless, Page and Logarithmic models have reasonably high SEE. Also, Two-term model has a very high SEE at temperature of 60 ^{0}C. Although, Page model generated R^2 value of 0.9388 at drying temperature of 40 °C, it could be best employed to predict the drying behavior of blanched ginger at drying temperature of 10 °C. Page model generated R^2, RMSE and SEE values of 0.9176, 4.1165 and 0.0808 respectively at 10 °C. Similarly, logarithmic model generated R^2 and RMSE values of 0.9890 and 1.5410, respectively at drying temperature of 10 °C; implying it could be fairly predicting the drying behavior of blanched ginger at 10 °C. At drying temperature of 10 °C, Henderson and Pabis model generated R^2, RMSE and SEE values of 0.9745, 2.3897 and 2.5594 respectively. Besides, it generated values of R^2 that are close to unity and fairly low RMSE and SEE values for all drying temperatures considered; hence, Henderson and Pabis could be employed in simulating the drying characteristics of blanched ginger. Moreover, Two-term exponential model generated relatively high values of R^2 for all the drying temperature considered. It also gave fairly low RMSE and SEE values for all the drying temperatures considered. From Table 3, it could be noticed that Two-term exponential and Henderson and Pabis models are suitable models for modeling the drying characteristics of blanched ginger treatment [1], [39].

The moisture ratio of the ginger was also model with dimensional analysis [5]. The results are presented in equations (4) and (5) for blanched treated ginger and unblanched ginger respectively.

$$M_{bl} = 2837.62(W/kTt)^{0.39} \quad (4)$$

$$M_{unbl} = 4912.06(W/kTt)^{0.47} \quad (5)$$

Where, M_{bl} (%) and M_{unbl} (%) are the moisture content of the blanched and unblanched ginger, respectively, W (N) is the weight of the ginger sample, T (K) is the drying temperature, t (s) is the drying time, and k (W/m-K) is the thermal conductivity.

Fig. 2 presents the comparison among two-term exponential model, prediction (dimensionless) model and the experimental data for blanched ginger treatment. As observed, the two-term exponential model and experimental data agree reasonably while the dimensionless model deviates somewhat from the two trends. The prediction model predicted higher moisture ratio value [4].

Fig. 3 presents the comparison among two-term exponential model, dimensionless model and the experimental data for unblanched ginger treatment. Also, it is observed that the two-term exponential model and experimental data agree satisfactorily while the dimensionless model deviates fairly from both trends. At temperature below 33 °C, the prediction model falls below the other trends and beyond 33 °C, it has higher values than the other trends [40].

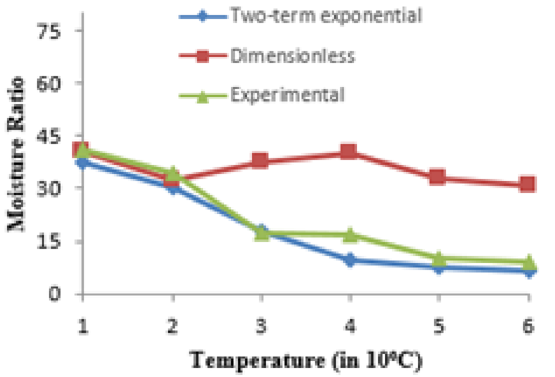

Fig. 2 Comparison of drying models for blanched ginger.

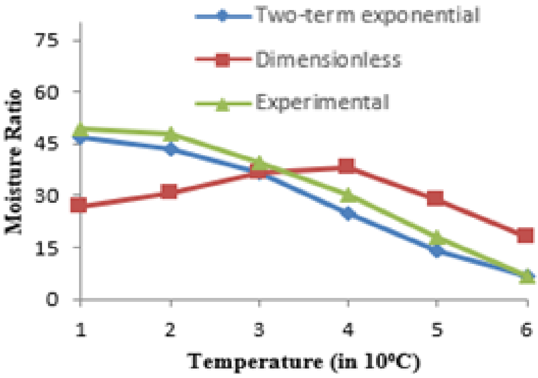

Fig. 3 Comparison of drying models for unblanched ginger.

Fig. 4 presents the variation of moisture content of unblanched and blanched treated ginger samples with drying time at 50 °C. Unblanched treated ginger sample lost about 62.03 % of moisture content at drying time of 24 h while blanched treated sample lost about 82.87 % of moisture at the same drying time.

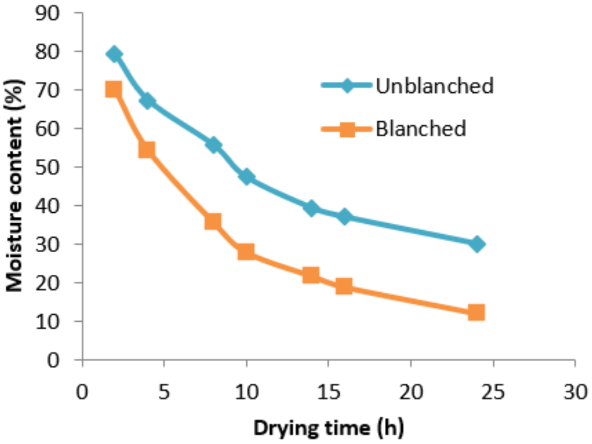

Fig. 4 Variation of moisture content with drying time at 55 °C.

As stated earlier, the two-term exponential model is the best model for simulating the drying characteristics of sliced ginger rhizome. Figs. 2 and 3 show that two-term exponential model agrees satisfactorily with the experimental results. The dimensionless model derived by dimensionless analysis predicted the moisture ratio fairly well but not as accurate as the two- term exponential model.

4. Conclusion

Blanched treatment positively affected the drying of ginger rhizome. Blanched treated sample lost about 82.87 % of moisture ratio during drying period of 24 h. This paper has shown the significance of drying ginger rhizomes for a long time at even lower temperature about 40 °C. At elevated temperatures, ginger shrinkage and surface discoloration could occur. As shown in this paper, good results are attainable at 40 °C to sustain the quality of the products. The thermal conductivity of dried ginger (i.e., ginger dried for 24 h at 40 °C) is 0.056 W/mk. This paper showed that five drying models (Page, Henderson and Pabis, Logarithmic, Two-term and Two-term exponential) can be used to predict the drying characteristics of the blanched ginger treatment. Nevertheless, the Two-term exponential proved to be the best model for simulating the drying characteristics of ginger rhizome.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

To Prof. Greg Chukwudi Nwakoby, for the immense support; and the Tertiary Education Trust Fund (TETFUND) for the financial support, encouragement of staff to be attending conferences and presenting papers. This helps in boosting the image of Chukwuemeka Odumegwu Ojukwu University through its output in researches; thus, making our academic activities robust and excellent in diverse fields.

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