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Research Article

Mathematical Modelling of Drying Characteristics of Coconut Slices

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ABSTRACT

Mathematical modelling is one of the most important Engineering considerations for the effective representation of drying processes. Therefore, the drying behaviour of the coconut slices was modelled using non-linear regression (fitting existing mathematical models). The three thickness of the coconut samples (4 mm, 8 mm and 12 mm) were dried using laboratory oven under five different temperature (40°C, 50°C, 60°C, 70°C and 80°C) and constant air velocity (1 m s^{-1}). Drying properties such as moisture content, moisture ratio, drying rate, drying time, effective moisture diffusivity coefficient (Deff) and activation energy of the process was used to define the behaviour of the coconut slices, the experimentally observed moisture ratios were fitted into fifteen (15) existing thin-layer mathematical model to forecast the behaviour of the coconut slices during process. The result of the modelling showed that the modified Henderson and pabis, Page and Peleg model had the most acceptable level of accuracy in predicting the drying behaviour of the coconut slices at 4mm, 8mm and 12mm, respectively. The obtained values for the effective moisture diffusivity ranges between 6.06×10^{-11} m^2 s^{-1} and 3.16×10^{-10} m^2 s^{-1} for 4mm thickness; 5.46×10^{-10} m^2 s^{-1} and 1.44×10^{-9} m^2 s^{-1} for 8mm thickness; 5.97×10^{-10} m^2 s^{-1} and 2.83×10^{-9} m^2 s^{-1} for 12mm thickness, whilst the activation energy ranges between 27.44892 and 27.563 kJ mol^{-1} for 4mm thickness; 27.45371 and 27.53017 kJ mol^{-1} for 8mm thickness; 35.64817 and 35.84369 kJ mol^{-1} for 12 mm. Therefore, the Modified Henderson and Pabis, Page and Peleg thin-layer mathematical models were chosen for the best prediction of the dehydration behaviour of coconut slices of 4 mm, 8 mm and 12 mm thickness respectively.

RESEARCH ARTICLE

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- Coconut,
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INTRODUCTION

Coconut (*Cocos nucifera*) is a tree and a member of the Arecaceae family that is grown for a variety of reason, the most important of which are its nutritional and therapeutic properties. In the traditional coconut arming locations, all the components are used in some form in the everyday lives of the inhabitants, it is a good source of natural materials for the creation of medications for a variety of ailments as well as industrial goods. The tender coconut kernel and water, for example contain anti-bacteria, antifungal, antiviral, antiparasitic, anti-dermatophytes, and antioxidant hypoglycemic, characteristics, also, it contains micro-minerals and nutrients that were important for health, thus, it is widely consumed by people all over the world, mostly in the tropical areas. Coconut is one of the most highly significant crop in the tropics, its highly cultivated in over 80 countries worldwide, with total annual production of 61 mt (FAO, 2010). Between 2004 and 2008, Nigeria produced 1.088.500 million tons of coconut palm (Uwubanwen, 2011). Coconut milk, juice, flour and oil are just a few examples of coconut-derived goods (Madhiyanon *et al.*, 2009). Desiccated coconut, which has a moisture level of around 3% dry weight, may be used to decorate ice cream, cakes, and doughnuts, as well as to flavor chocolate bars, candies, and biscuits (Madhiyanon e*t al.*, 2009; FAO, 2010).

Drying method is one of the oldest methods for improving the shelf life ethnic foods. It's becoming more well-known as one of the rising technologies that necessitates new study methods. There are two basic principles that govern drying. To begin, hot air must be delivered to the material, followed moist air (vapour) migration from the material to its immediate environment (Sigge *et al.*, 1998). Because moisture removal in an energy intensive process, it's effectiveness might be enhanced by increasing the rate of drying, which affects the time taken. Long drying times might result in worse final goods (Sigge *et al.*, 1998; Horner, 1993). Higher drying rates are desired in order to produce acceptable end products that are both economically and nutritionally viable (Sigge *et al.*, 1998). The modelling of the drying method is one of the vital parts of drying technology and developments. Modelling represents the development of a set of equations that accurately represent the real time systems and processes. Scientific models for prediction of drying process are mostly used in the design of new drying structures, enhance the performance of the existing systems, and even control the process of drying. Several models and methods for forecasting of the drying behaviour was proposed in literatures, with thin layer drying models being the most widely used. Several studies were recently carried out to highlight the drying behaviour of fruit (Yaldiz *et al.*, 2001; Akpinar, 2006), vegetables (Karaaslan and Tuncer, 2008), spices (Murthy and Manohar, 2012), oilseeds (Gowen *et al.*, 2008), nuts (Moreira *et al.*, 2005), red pepper (Doymaz and Pala, 2002), and other foods. To this end, the study models the characteristics of coconut slice during drying using existing thin-layer mathematical models and the specific objectives of the study are to determine the influence of the temperature and slice thickness on drying behaviour of coconut slices in a laboratory oven, model the drying behaviour of the coconut slices using fifteen (15) existing models and choose the best model for predicting the behaviour of the coconut slices during the drying.

MATERIALS and METHODS

Sample preparation

Experimental drying of the coconut slices was done in the Crop Processing Laboratory of the Department of Agricultural and Environmental Engineering, using some available materials which include laboratory oven, weighing scale, desiccators: weighing balance, and thermometer. The coconuts in this research were acquired from a local municipal market in Akure (Oja-Oba market), Nigeria's south-western area. The coconut meat was manually taken from the coconuts and cleaned with water before being cut into a standard rectangular form (30 x 10 mm) with thicknesses of 4 mm, 8 mm, and 12 mm, respectively. The coconut slices were carefully cleaned, and those that had black stains were removed. The oven-drying approach was utilized for the measurement of the initial moisture content of the coconut slices, which was done 105°C for 24 hours in the laboratory oven and moisture content was measured in replicate using three samples in total.

Drying experimentation

Before each drying cycle, The laboratory oven (Searchtech Instruments, DHG-9053 Model) was turned on for roughly 30 minutes to create steady-state conditions. The coconut slices were then put in a stainless tray and placed inside the laboratory oven; the hot air flows perpendicular to the samples in the drying trays. Prior to the experiment, the tray's and sample's original weights were recorded. Thereafter, the trays were taken out every 30 minutes and weighed using a smart weighing balance. After cooling of the sample in the desiccator at room temperature, the dry product was packed in low-density polyethene bags and kept in a desiccator, the moisture removal experiment were done at different temperature (40, 50, 60, 70 and 80°C), the drying tests were conducted three times (Kaveh *et al.*, 2018).

Determination of moisture content and moisture ratio

The subsequent equations are related to the modeling of the behaviour of coconut slices during drying. Though some of the equation is computed by the computer in the validation of the statistical data. However, the moisture content equation given by the Equation (1 and 2) is used in the computation of the coconut moisture content with the weight of coconut at time T=0 and T= t.

$$M_t = \frac{W_t - W_o}{W_o} \times 100 \quad (1)$$

$$M_t = \frac{W_t - W_e}{W_e} \times 100 \quad (2)$$

The experimental data for the coconut slices during the drying experiments were used to represent the dimensionless form of moisture ratio (MR) as reported by Midilli and Kucuk (2003) and Ng *et al.* (2015) presented in Equation 3.

$$MR = \frac{(M_t - M_e)}{(M_0 - M_e)} \quad (3)$$

Where *MR* is the moisture ratio, M_t is the moisture content of the coconut slices at each time (%), M_o is the initial moisture content of coconut slices (%) and M_e is the moisture coconut of the coconut slice (%) at saturation point.

Determination drying rate

The rate of drying for the coconut slices were estimated using the Equation (4), which was utilized in the drying studies by Guine and Fernandes (2006).

$$\frac{dm}{dt} = \frac{m_0 - m_t}{t - t_0} \tag{4}$$

Where $\frac{dm}{dt}$ is the drying rate, $m_0 - m_t$ is the change in coconut moisture content and $t - t_0$ is the change in the time of drying.

Determination of effectiveness moisture diffusivity and activation energy

Garcia *et al.* (2007) reported a model equation using Fick's second law of diffusion that state the relation between the effective moisture diffusivity, dimensionless moisture ratio, diffusivity constant and minimal shrinkage, which is given in the Equation (5).

$$MR = \left(\frac{8}{\pi^2}\right) \exp\left[\frac{-D_{eff}}{4L^2} \pi^2 \text{ t}\right] \tag{5}$$

Where D_{eff} is moisture diffusivity constant (m^2 s^{-1}), t is time of drying (s) and L is sample thickness.

For estimation of the activation energy, the moisture diffusivity was defined as a function of temperature using Arrhenius equation (Dissa *et al.*, 2011) as shown Equation (6):

$$D_{eff} = D_o \exp\left(-\frac{E_a}{R(T + 273.15)}\right) \tag{6}$$

Where D_{eff} is moisture diffusivity constant (m^2 s^{-1}), D_O is pre-exponential constant (m^2 s^{-1}), E_a is the activation energy (kj mol^{-1}), *T* is hot air temperature (°C) and *R* is the universal gas constant (kJ mol^{-1} K) as stated by Celen *et al.* (2010); Caliskan and Dirim, (2017) and Demiray et al. (2017). The Equation (6) above can further be simplified as shown in Equation (7).

$$\ln D_{eff} = \ln D_o - \frac{E_a}{R(T+273.15)} \tag{7}$$

Model Fitting

The experimental moisture ratio data was fitted into 15 mathematical models (Table 1) using solver addin on Microsoft Excel software version 2016, the most suitable model was chosen based on some parameters such as determination coefficient *(R^2)*, chi square *(χ^2)* and root mean squared error *(RMSE)*.

Table 1. Selected models for prediction of the drying characteristics.

S/N	Model	Equation	Reference
1	Newton	$MR = \mathrm{Exp}\ (-kt)$	Ayensu (1997); Toğrul and Pehlivan (2004)
2	Henderson and pabis	$MR = a\mathrm{Exp}\ (-kt)$	Kashaninejad *et al.* (2007)
3	Page	$MR = Exp(-kt^n)$	Kaleemullah and Kailappan (2006)
4	Logarithmic	$MR = a\mathrm{Exp}\ (-kt)\ + c$	Onwude *et al.* (2018)
5	Two term	$MR = a\mathrm{Exp}\ (-kt)\ + bExp(-gt)$	Wang *et al.* (2007)
6	Verma et al.	$MR = a\mathrm{Exp}\ (-kt)\ + (1 + a)Exp(-gt)$	Yaldiz and Ertekin (2001)
7	Diffusion approach	$MR = a\mathrm{Exp}\ (-kt) + (1 - a)Exp(-gt)$	Wang *et al.* (2007)
8	Midilli *et al.*	$MR = aExp(-kt^n) + bt$	Midilli and Kucuk (2003)
9	Wang and Singh	$MR = 1 + at + at^2$	Wang and Singh (1978)
10	Hii et al.	$MR = a\mathrm{e}^{-kt^n} + cExp(-gt^n)$	Hii *et al.* (2009)
11	Modified henderson pabis	$MR = a\mathrm{Exp}\ (-kt) + bExp(-gt) + cExp(-ht)$	Doymaz (2005); Karathanos (1999);
12	Modified Page	$MR = aExp(-(kt)^n)$	Lahsasni *et al.* (2004); Wang *et al.* (2007)
14	Two term exponential	$MR = aExp(-kt) + (1 + a)Exp(-kat)$	Midilli and Kucuk (2003); Sacilik *et al.* (2006); Tarigan *et al.* (2007)
15	Peleg	$\mathrm{MR} = 1 - \frac{t}{(a+bt)}$	Da Silva *et al.* (2014)

RESULTS and DISCUSSION

Drying Curves

The curves of the time against time against moisture content, time against moisture ratio, time against drying rate and moisture content against drying rate for coconut samples of 4 mm, 8 mm and 12 mm thickness are presented in Figures 1-3 respectively at different hot-air temperature (40, 50, 60, 70 and 80°C). It was observed from the Figures that the drying rate, moisture ratio and moisture content decrease continuously with increase in the time (Doymaz, 2005). The total period taken to dry the coconut sample increases and the moisture content reduces, the rate of drying significantly reduce as well. The rate at which moisture migrates in the laboratory oven started slow and then gradually increased before decreasing as the sample approached equilibrium similar observation was reported by Arslan and Ozcan (2010), Sharma *et al.* (2009) and Bozkir *et al.* (2018) for onion, garlic cloves and garlic respectively. More specifically, due to low diffusion process, about 2/3 of the total time taken might be spent in drying of the final 1/3 of moisture in the sample. Also, higher amount of moisture removal was recorded at high temperature and the required total time taken to dry the sample was reduced significantly with the rise in the hot-air temperature. Decrease in the amount of moisture removed from the sample at higher time might be due to the fact the moisture content in the sample is low and it requires more energy to vaporize the moisture which therefore shows that the drying of the coconut slices is guided by diffusion and this finding agrees with the study of Kingsley *et al.* (2007) and Piga *et al.* (2004). The drying time and final moisture content of the product was reduces with increase in the thickness of the sample similar findings was reported by Ikrang and Umani (2019) during optimization of process condition for the drying of catfish using response surface methodology.

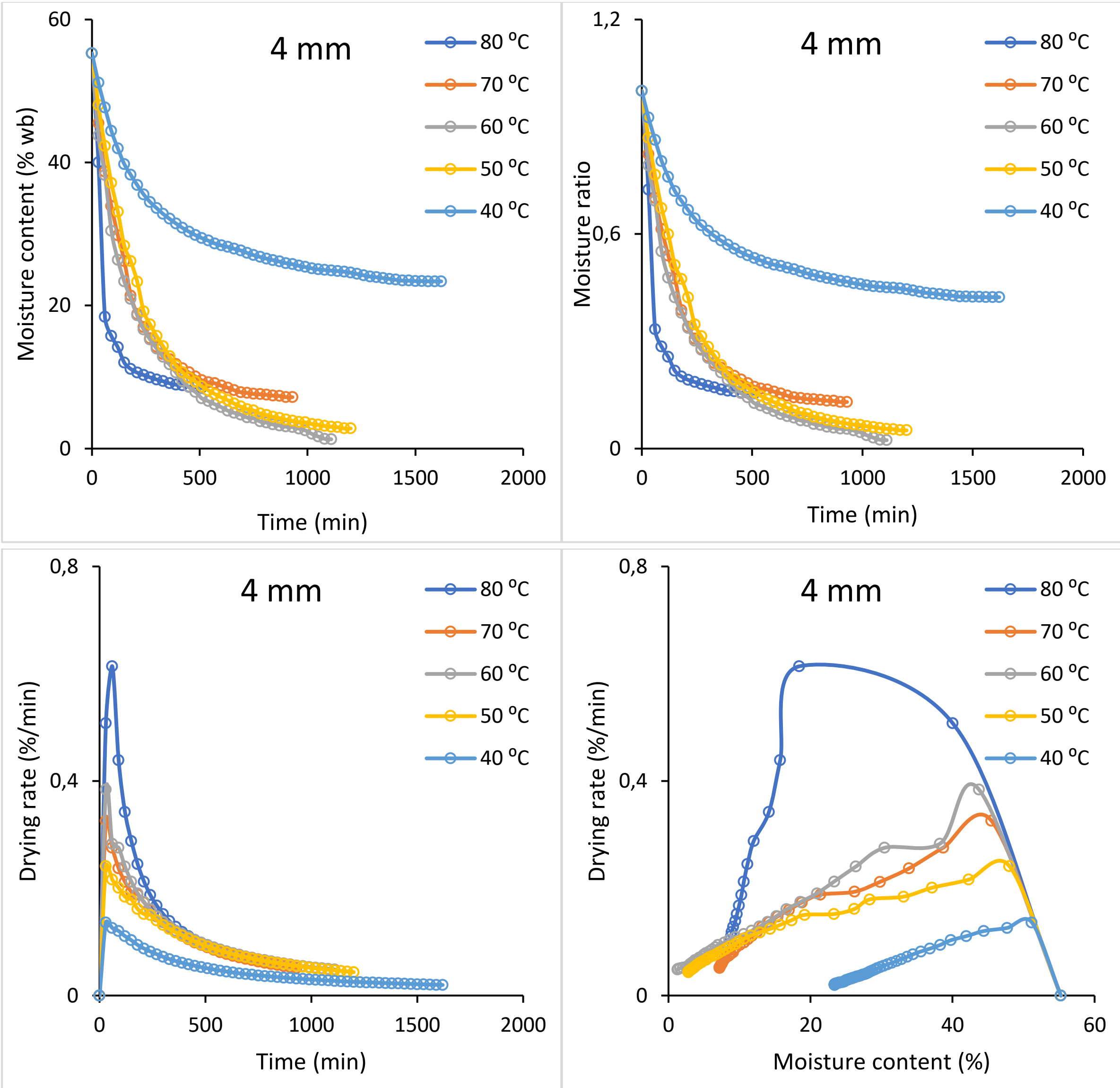

Figure 1. Drying curves of coconut slices of 4 mm diameter at different temperature for laboratory oven.

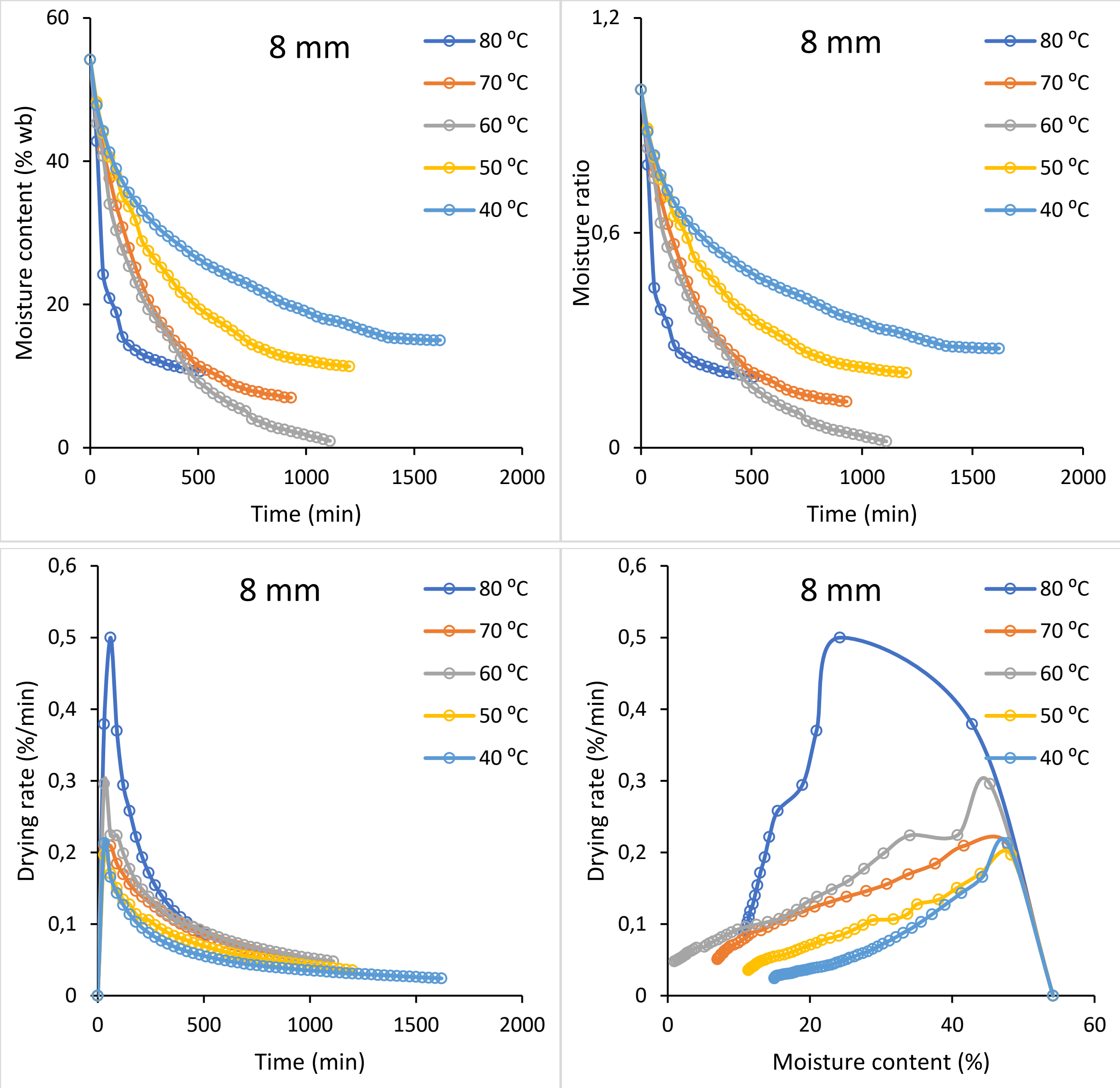

Figure 2. Drying curves of coconut slices of 8 mm diameter at different temperature for laboratory oven.

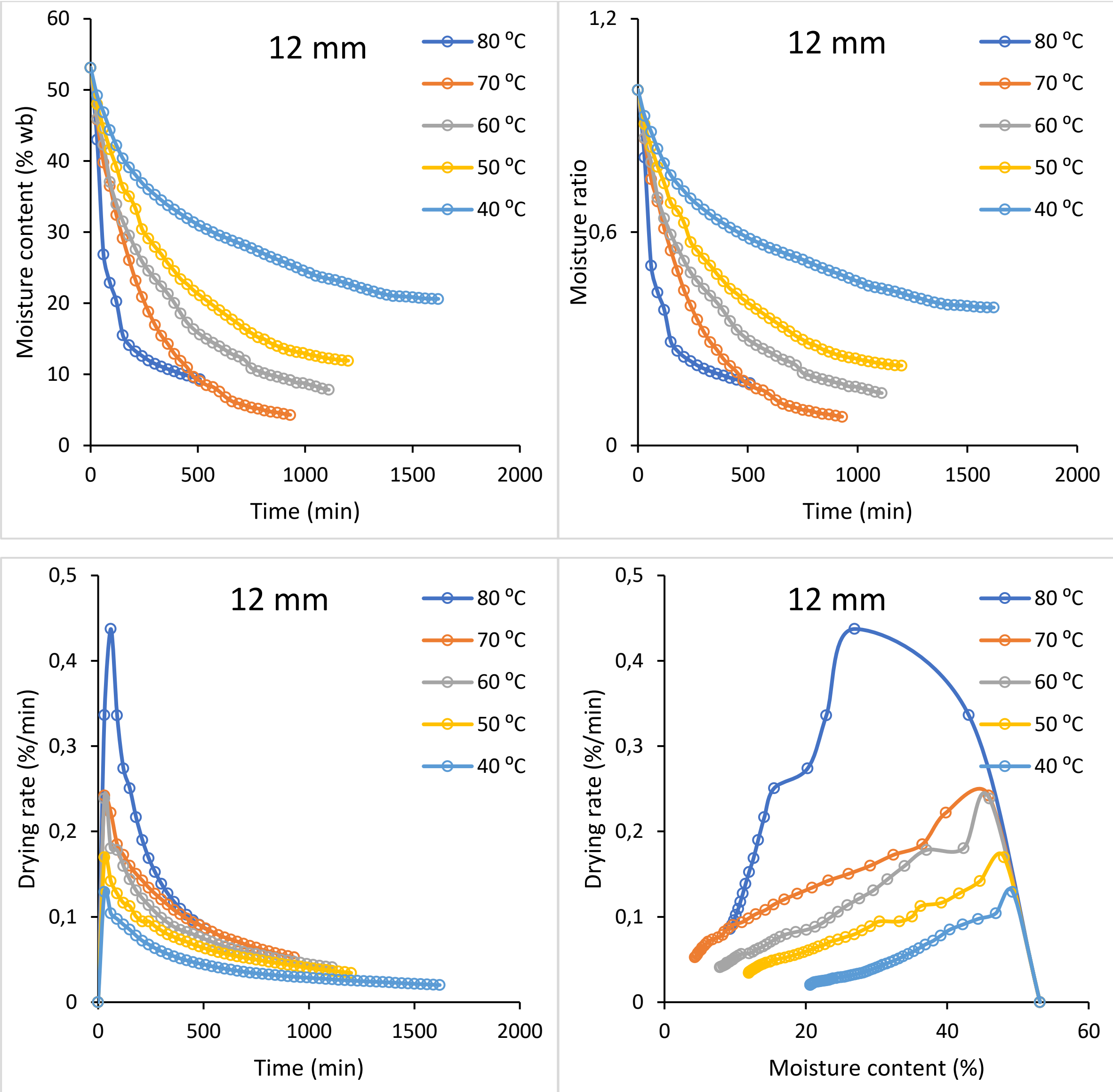

Figure 3. Drying curves of coconut slices of 12 mm diameter at different temperature for laboratory oven.

Evaluation of drying models

Experimental moisture ratio was fitted into 15 mathematical models (Table 1), the most suitable mode was chosen based on some statistical parameters which include the highest value of determination coefficient *(R^2)*, low value of reduced-chi-square *(χ^2)* and root-mean-square-error *(RMSE)*. The goodness of fit statistics and model coefficient of each of the model under different slice thicknesses (4 mm, 8 mm and 12 mm) and air temperature (40, 50, 60, 70 and 80°C) are shown in Table 2.

For the thickness of 4 mm, Modified henderson and pabis model, Modified Henderson and pabis model, Peleg model, Modified Henderson and pabis model and Peleg model recorded the best performance with high R^2 (0.9720, 0.9971, 0.9991, 0.9989, and 0.9995 respectively), low χ^2 (0.0021, 0.0002, 0.0001, 0.0001, and 0.0001 respectively) and RMSE (0.0.037, 40.0117, 0.0080,0.0069, and 0.0030 respectively) for the drying air temperature of 80°C, 70°C, 60°C, 50°C, and 40°C, respectively.

For the thickness of 8 mm, the diffusion approach model, Peleg model, Modified page II model Peleg model and page model recorded has the most suitable performance with high

R^2 (0.9747, 0.9815, 0.9843, 0.9897 and 0.9972 respectively), low χ^2 (0.0049, 0.0040, 0.0027, 0.0296, and 0.0056 respectively) and low RMSE (0.0678, 0.0610, 0.0490, 0.1678 and 0.0732 respectively) for the drying air temperature of 80°C, 70°C, 60°C, 50°C, and 40°C, respectively.

For the thickness of 12 mm, the best fitting performance was observed in the Verma et al. model, Verma et al. model, Page model, Logarithmic and Modified page II model, with high R^2 (0.9894, 0.9992. 0.9984, 0.9990, and 0.9967 respectively), low χ^2 (0.0007, 0.0001, 0.0001, 0.0001, and 0.0001 respectively) and low RMSE (0.0233, 0.0078, 0.0089, 0.0064, and 0.0085 respectively) for the drying air temperature of 80°C, 70°C, 60°C, 50°C, and 40°C, respectively. The range of accuracy of the model agrees with the report of Younis *et al.* (2018) for garlic slice with the Page, Logarithmic, Midilli and Hii *et al.* models as the best model for prediction the drying characteristics, also, Onwude *et al.* (2018) reported the Page, Logarithmic, and Midilli model as the best model for predicting the drying behavior of sweet potato.

Table 2. Drying model constants and goodness of fit parameters for coconut samples of 4 mm thickness.

Temp.	Model	Model constant	R^2	RMSE	X^2
80 ºC	Newton	K = 0.5771	0.8788	0.1176	0.0146
	Henderson and Pabis	K = 0.4248, a = 0.8255	0.8042	0.1099	0.0136
	Page	K = 0.8608, n = 0.4524	0.9236	0.0608	0.0042
	Logarithmic	K = 0.0505, a = 1.4893, c = -0.9414	0.5127	0.1531	0.0281
	Two term	K = 0.3747, g = 0.3734, a = 13.7957, c = -12.9931	0.7868	0.1103	0.0156
	Verma et al.	K = 0.7329, g = 0.0059, a = 0.8756	0.9278	0.0662	0.0053
	Diffusion	K = 0.5094, g = 0.9994, a = 122.4643	0.8655	0.1184	0.0168
	Midili et al.	K = 0.0133, b = -0.0567, a = 0.5225, n = 0.3652	0.4773	0.1585	0.0323
	Wang and smith	a = -0.3457, b = 0.0313	0.7702	0.1409	0.0223
	Hii et al.	K = 0.041, g = -0.0009, a = 15.5101, c = -14.4773, n = 0.1829	0.8909	0.0725	0.0073
	Modified Henderson and pabis	**K = -10.827, a = 0.5601, g = 4.4332, b = 0.3778, h = 7.4428, c = 0.7429**	**0.972**	**0.0374**	**0.0021**
	Modified Page I	K = 0.718, n = 0.4524	0.9236	0.0608	0.0042
	Modified Page II	K = 1.0037, a = 0.0358, n = 0.4846, L = 0.0015	0.9231	0.0612	0.0048
	Two term exponentials	K = -0.0902, a = -0.2636	0.4224	0.1669	0.0313
	Peleg	a = 0.6386, b = 1.0769	0.959	0.0447	0.0022
70 ºC	Newton	K = 0.2438	0.9636	0.0726	0.0054
	Henderson and Pabis	K = 0.201, a = 0.8574	0.9353	0.0617	0.0041
	Page	K = 0.4277, n = 0.6444	0.979	0.032	0.0011
	Logarithmic	K = 0.3534, a = 0.8397, c = 0.1246	0.9969	0.0123	0.0002
	Two term	K = 0.1685, g = 0.1663, a = 9.0072, c = -8.1707	0.9257	0.0631	0.0046
	Verma et al.	K = 0.6881, g = 0.1135, a = 0.5282	0.989	0.0241	0.0006
	Diffusion	K = 0.2376, g = 0.9992, a = 25.5376	0.9629	0.0727	0.0058
	Midili et al.	K = 0.3634, b = 0.0065, a = 0.9905, n = 0.8409	0.9963	0.0135	0.0002
	Wang and smith	a = -0.1767, b = 0.0083	0.9225	0.0888	0.0084
	Hii et al.	K = 0.4111, g = -0.3791, a = 1.0194, c = 0.0054, n = 0.7564	0.9955	0.0146	0.0003

Table 2 (continues). Drying model constants and goodness of fit parameters for coconut samples of 4 mm thickness.

70 ºC	**Modified Henderson and pabis**	**K = -1.487, a = 0.0969, g = 0.3982, b = 0.0321, h = 1.0607, c = 0.3147**	**0.9971**	**0.0117**	**0.0002**
	Modified Page I	K = 0.2677, n = 0.6444	0.979	0.032	0.0011
	Modified Page II	K = 1.0417, a = 0.0056, n = 0.616, L = 0.0008	0.9802	0.0313	0.0011
	Two term exponentials	K = -0.0615, a = -0.2375	0.6034	0.138	0.0203
	Peleg	a = 2.057, b = 0.9846	0.9923	0.0195	0.0004
60 ºC	Newton	K = 0.2846	0.9882	0.0475	0.0023
	Henderson and Pabis	K = 0.2477, a = 0.8868	0.9791	0.0371	0.0015
	Page	K = 0.427, n = 0.7265	0.9981	0.0102	0.0001
	Logarithmic	K = 0.3446, a = 0.8914, c = 0.0656	0.9892	0.0235	0.0006
	Two term	K = 0.1673, g = 0.1472, a = 2.5277, c = -1.6963	0.9648	0.0436	0.0021
	Verma et al.	K = 0.2856, g = 0.2848, a = -1.3819	0.9886	0.045	0.0022
	Diffusion	K = 0.234, g = 0.9923, a = 20.6985	0.9862	0.0478	0.0025
	Midili et al.	K = 0.3036, b = 0.002, a = 0.9234, n = 0.9212	0.9916	0.0207	0.0005
	Wang and smith	a = -0.1605, b = 0.0063	0.9067	0.1103	0.0128
	Hii et al.	K = 0.3665, g = 0.7653, a = 0.9606, c = 0, n = 0.7916	0.9958	0.0148	0.0003
	Modified Henderson and pabis	K = -7.2489, a = 0.0807, g = 1.7682, b = 0.0375, h = 6.33, c = 0.1105	0.97	0.039	0.0018
	Modified Page I	K = 0.3099, n = 0.7257	0.9982	0.0097	0.0001
	Modified Page II	K = 1.9946, a = 0.0008, n = 0.7492, L = 0.0002	0.9979	0.0106	0.0001
	Two term exponentials	K = -0.0508, a = -0.265	0.6404	0.1355	0.0194
	Peleg	**a = 2.0627, b = 0.9157**	**0.9991**	**0.0069**	**0.0001**
50 ºC	Newton	K = 0.2323	0.9933	0.0336	0.0012
	Henderson and Pabis	K = 0.2177, a = 0.9434	0.989	0.0302	0.001
	Page	K = 0.3107, n = 0.8237	0.9946	0.0184	0.0004
	Logarithmic	K = 0.2887, a = 0.935, c = 0.0665	0.9988	0.0085	0.0001
	Two term	K = 0.2718, g = 0.3036, a = 2.7455, c = -1.7971	0.9895	0.0349	0.0014
	Verma et al.	K = 0.235, g = -0.4294, a = 1	0.9923	0.0279	0.0008
	Diffusion	K = 0.2586, g = 1.006, a = 18.0861	0.9938	0.0352	0.0013
	Midili et al.	K = 0.3508, b = 0.0027, a = 1.0567, n = 0.8338	0.9965	0.0142	0.0002
	Wang and smith	a = -1.1448, b = 0.0052	0.9347	0.0874	0.008
	Hii et al.	K = 0.3497, g = -0.4188, a = 1.0427, c = 0, n = 0.7765	0.9949	0.0177	0.0004
	Modified Henderson and pabis	**k = -16.4817, a = 0.2603, g = 1.034, b = 0.1467, h = 16.4595, c = 0.2694**	**0.9989**	**0.008**	**0.0001**
	Modified Page I	K = 0.2417, n = 0.8163	0.9943	0.0189	0.0004
	Modified Page II	K = 1.0387, a = 0.0008, n = 0.7801, L = 0.0004	0.9947	0.018	0.0004
	Two term exponentials	K = -0.0505, a = -0.2494	0.6332	0.1453	0.0222
	Peleg	a = 2.7545, b = 0.8894	0.9937	0.0196	0.0004
40 ºC	Newton	K = 0.0588	0.8644	0.0942	0.0091
	Henderson and Pabis	K = 0.0388, a = 0.8116	0.8315	0.056	0.0033
	Page	K = 0.2186, n = 0.4641	0.9732	0.0225	0.0005
	Logarithmic	K = 0.048, a = 0.7172, c = 0.1031	0.8471	0.0534	0.0031
	Two term	K = 0.0414, g = 0.0426, a = 2.2248, c = -1.4108	0.832	0.0561	0.0035
	Verma et al.	K = 0.0741, g = -0.2838, a = 0.9989	0.9159	0.0628	0.0043
	Diffusion	K = 0.0665, g = 1.0052, a = 22.6842	0.8642	0.0948	0.0097
	Midili et al.	K = 0.236, b = 0.0012, a = 1.0138, n = 0.4474	0.9735	0.0214	0.0005

Table 2 (continues). Drying model constants and goodness of fit parameters for coconut samples of 4 mm thickness.

40 ºC	Wang and smith	a = -0.065, b = 0.0017	0.9055	0.0652	0.0044
	Hii et al.	K = 0.2136, g = -0.1505, a = 0.9868, c = 0, n = 0.4497	0.9625	0.0255	0.0007
	Modified Henderson and pabis	k = -9.6475, a = 0.0945, g = 3.2654, b = 0.0498, h = 7.3452, c = 0.1176	0.9943	0.01	0.0001
	Modified Page I	K = 0.0321, n = 0.4181	0.9665	0.0244	0.0006
	Modified Page II	K = 1.0396, a = 0.0014, n = 0.397, L = 0.00	0.9687	0.0234	0.0006
	Two term exponentials	K = -0.0338, a = -0.1564	0.6574	0.0774	0.0062
	Peleg	**a = 5.2046, b = 1.534**	**0.9995**	**0.003**	**0.0001**

Effective Moisture Diffusivity and Activation Energy

The moisture diffusivity that was obtained for the coconut slices were presented in Table 3, the values ranges between $6.06 \times 10^{-11}\, m^2\, s^{-1}$and $3.16 \times 100^{-10}\, m^2\, s^{-1}$ for 4 mm thickness, $5.46 \times 10^{-10}\, mm^2\, s^{-1}$and $1.44 \times 10^{-9}\, m^2 s^{-1}$ for 8 mm thickness, $5.97 \times 10^{-10}\, m^2\, s^{-1}$and $2.83 \times 10^{-9}\, m^2\, s^{-1}$ for 12 mm thickness. In addition, the rise in the temperature of the laboratory oven increases the moisture diffusivity coefficient of the coconut slices sample. The D_{eff} values recorded for the coconut slices was within the 10^{-12}-10^{-08} m^2 s^{-1} posited for moisture removal from agricultural material by Doymaz (2005).

The activation energy was measured based on the slope of $\ln(D_{eff})$ against temperature inverse $\left(\frac{1}{T+273.15}\right)$. The activation energy of the coconut slices ranges between 27.44892 and 27.563 $kJ\, mol^{-1}$ for 4 mm thickness, 27.45371 and 27.53017 $kJ\, mol^{-1}$ for 8 mm thickness, 35.64817 and 35.84369 $kJ\, mol^{-1}$ for 12 mm, respectively.

Table 3. Activation energy, E_a and Effective moisture diffusivity, D_{eff}.

Thickness		80 ºC	70 ºC	60 ºC	50 ºC	40 ºC
4 mm	$D_{eff} \times 10^{-10}$	2.91	2.14	3.16	2.64	6.06×10^{-1}
	E_a	27.449	27.496	27.515	27.527	27.563
	$d_o \times 10^{-10}$	0.244	0.179	0.264	0.221	0.051
8 mm	$D_{eff} \times 10^{-9}$	1.09	9.44×10^{-1}	1.44	5.46×10^{-1}	3.57×10^{-1}
	E_a	27.454	27.500	27.511	27.530	27.46955
	$d_o \times 10^{-9}$	0.192	0.142	0.209	0.174	0.040
12 mm	$D_{eff} \times 10^{-9}$	2.83	2.64	1.57	1.19	5.97×10^{-1}
	E_a	35.648	35.737	35.719	35.741	35.844
	$d_o \times 10^{-9}$	0.465	0.435054	0.259	0.196	0.098

CONCLUSION

In conclusions of the mathematical modelling of the drying characteristics of coconut slices:

1. The drying process happened in a continuous falling rate and no constant drying rate was recorded.
2. The moisture diffusivity value ranges between $6.06 \times 10^{-11}\, m^2\, s^{-1}$ and $3.16 \times 10^{-10}\, m^2\, s^{-1}$ or 4 mm thickness, $5.46 \times 10^{-10}\, m^2 s^{-1}$ and $1.44 \times 10^{-9}\, m^2\, s^{-1}$ for 8 mm thickness, $5.97 \times 10^{-10}\, m^2\, s^{-1}$ and $2.83 \times 10^{-9}\, m^2\, s^{-1}$ for 12 mm thickness.

3. The activation energy of the sample ranges between 27.44892 and 27.563 $kJ\ mol^{-1}$ for the 4mm thickness, 27.45371 and 27.53017 $kJ\ mol^{-1}$ for 8mm thickness, 35.64817 and 35.84369 $kJ\ mol^{-1}$ for 12mm, respectively.
4. Among the fifteen thin-layer mathematical model considered in this study, the Modified Henderson Pabis, Page and Peleg model were chosen as the most appropriate model for effective prediction of the experimental data for 4 mm, 8 mm and 12 mm thickness respectively. Therefore, they are recommended for effective prediction of the drying characteristics of the coconut slices.

DECLARATION OF COMPETING INTEREST

The authours declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

John Isa: Conceptualization, methodology, investigation, review and writing original.
Kabiru Ayobami Jimoh: Formal analysis, data curation, validation, visualisation and editing.

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