ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XX [2022] | Fascicule 1 [February]

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MATHEMATICAL MODELING OF THIN LAYER CONVECTIVE DRYING OF SULPHITED STEAM-COOKED WHITE YAM (*DIOSCOREA ROTUNDATA*)

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Abstract: Yam is the next most significant root crop in West Africa after cassava, and adds greatly to the food security of Nigeria. The thin layer drying behaviour of steam-cooked yam slices was investigated in a convective hot air dryer at 60 to 100 °C for 1 to 6 hours, at constant air velocity of 0.98 m/s. The effective moisture diffusivity for dried yam chips increased from 2.814×10^{-10} to 4.169×10^{-10} m^2s^{-1} at increasing drying temperature while the activation energy for yam chips was found to be 10.75 kJ/mol. Considering eleven thin layer drying models curve fitted to the drying data, Logarithmic model was most appropriate in predicting the drying behaviour of parboiled yam slices because of its high coefficient of determination (R^2), lowest chi-square (χ^2), low Sum of Square Error (SSE) and Root Mean Square Error (RMSE).
Keywords: steam-cooked yam; mathematical modelling; activation energy; χ^2; drying rate

1. INTRODUCTION

Yam (*Dioscorea* spp.) is planted for its starchy tubers for food in Asia, Africa, Oceania and South America (Anuonye, 2011). It adds immensely to food security in Nigeria (Ikeh *et al*., 2012) and is a principal staple food being the next most important root crop in West Africa after cassava (Ayodeji *et al*., 2012). In the eastern part of Nigeria, many important cultural values are attached to yam in diverse social events, other traditional occasions and rituals (Obidiegwu and Akpabio, 2017). Yam is often eaten as roasted, boiled, fried, amala or pounded yam while accompanying it with various sauces or soups as preferred by native consumers. Yam has greater amounts of calories and protein in comparison with its root and tuber counterparts (Nweke, 2017).

High moisture content of 50 – 80% (Abano and Amoah, 2015) and poor post-harvest management is accountable for yearly waste of harvested yam. In addition, yam is extremely overpriced during the growing period compared to other basic food, which makes it unaffordable for most consumers. For value addition yam slices can be dried and further processed into instant yam flour with the aid of hot air dryers, which are readily available unlike other types of dryers, for rapid drying and better sanitation compared to sun drying in open air. The essence of removing water in food to a minimum level of microbial decay, without the need for cooling, is to extend stability and storage time (Bonazzi and Dumoulin, 2011). Mathematical modelling of a process which is centered on arrays of equations to define the system and the experimental setup are pertinent features of drying (Darvishi *et al*., 2012).

There has been significant number of researches in literature on the drying behavior of agricultural produce, such as cocoyam slices (Afolabi *et al*., 2015), plantain chips (Ashaolu and Akinbiyi, 2015), apple slices (Beigi, 2016) and banana slices (Doymaz, 2010). However, research on drying characteristics of steam-cooked yam slices is scarce. Abano and Amoah (2015) investigated the effect of microwave and blanch pretreatments on the drying kinetics and quality of white yam cubes and showed that micro wave drying enhances the quality of dried yam products. Sobukola *et al.* (2008) researched the convective drying of blanched and a day steeped white yam slices satisfactorily fitted by diffusion model. Onimisi and Sule (2016) studied the effect of drying temperature at 40 to 60 °C on thicknesses of fresh yam slices of 2 to 6 mm on yam quality and concluded that the rate of drying depends on the sample thickness and drying temperature. There is however, little or no information about the drying behavior of steam-cooked yam slices in literature. The aim of the study was (1) to investigate the thin layer drying characteristics of steam-cooked yam slices under convective drying; (2) to determine the effective diffusivities and activation energy for steam-cooked white yam, and (3) to fit the experimental data to eleven thin layer drying models within the drying conditions in this study.

2. MATERIAL AND METHODS

— Raw Samples

Fresh white yam tubers used in this study were purchased from a local market in Lagos State, Nigeria, and were stored in an adequately ventilated area at ambient temperature at 80 to 90 % relative humidity prior to the experiments. The yam tubers were peeled using a stainless steel knife, washed in potable water, sliced with a fabricated mechanical slicer to obtain thickness of 4.5 ±1.2 mm. Yam slices were immediately soaked in a solution of 0.1 g of sodium metabisulphite per litre of water for thirty minutes and thereafter steamed for 20 minutes before placing in the dryer.

— Experimental Method

The drying experiments were carried out in a cabinet dryer at five inlet temperatures of 60 to 100 °C at 10 °C interval, and drying duration of 1 to 6 hours at 1 hour interval. The hot air dryer (Mitchell dryer, Carlisle, UK) was equipped with an electrical fan, electrical heater, and trays and digital temperature controller. The air velocity in dryer was measured using a digital anemometer (Kestrel 1000, UK) with a precision of ± 0.1 m/s. The air temperature in the dryer was regulated to ±1°C with the aid of the temperature controller at a constant velocity of 0.98 m/s. The dryer was run for at least 1 hour to obtain steady conditions prior to commencing the drying process, after which a single layer of 1.128±0.023 kg of yam slices were placed on the drying trays and inserted in the dryer. The weight loss of the samples was recorded using Camry digital balance (Model CE550) with an accuracy of ±1 g at 60 minutes intervals. The moisture content of steam-cooked yam slices was 70.93 ± 1.03 % wet basis (w.b.). At the end of each drying duration the trays were pulled out of the dryer and weighed, and dried samples were removed, cooled in a desiccant and sealed in polyethylene bags. The moisture content of dried yam slices was determined using three replications at 103 °C for 24 h. (Precoppe *et al.,* 2015), and the average moisture ratio values were used to plot the drying curves (Doymaz, 2010).

— Determination of Moisture Ratio and Drying Rate

The moisture ratio of yam slices during drying experiments, according to Abano and Amoah (2015), was expressed as:

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

Since the values of equilibrium moisture content (M_e) are relatively small compared to M or M_o (Darvishi *et al.*, 2012). The MR was simplified to:

$$MR = \frac{M}{Mo} \quad (2)$$

By measuring the change in moisture content with time (Afolabi et al., 2015) the drying rate was expressed as:

$$R = \left(\frac{dM}{dt}\right) = \frac{M_{t+dt} - M_t}{t} \quad (3)$$

Where: MR, M, M_0 and M_e are the moisture ratio, moisture content at any time, initial moisture content and equilibrium moisture content respectively, and R is the drying rate ($kghr^{-1}$), dM is the change in moisture content (kg), dt is the change in drying time (hr), M_{t+dt} and M_t are moisture content at the time of t+dt (kg) and moisture content at the time, t and t is the drying time interval (hr).

— Determination of Effective Moisture Diffusivity

Effective moisture diffusivity is determined with the aid of the drying curves (Garba et al., 2015) which signifies all the conductive mechanisms of moisture transfer (Tulek, 2011). Assuming that the only process available for movement of water to the surface of agricultural material is diffusivity, the equation of mass-diffusion during the falling rate denoted by the second law of diffusion of Fick was represented as:

$$\frac{\partial M}{\partial t} = D_{eff} \frac{\partial^2 M}{\partial x^2} \quad (4)$$

where: D_{eff} is effective moisture diffusivity (m^2s^{-1}); δM/δt is moisture content (d.b.) per unit time (s) and x is thickness (m).

The yam slices were deemed as possessing a slab geometry as a result of their flat surface (Rayaguru and Routray, 2012). With assumptions of unvarying initial moisture distribution, insignificant effects of shrinkage, temperature gradients and external resistance (Crank, 1975), the moisture ratio can be related to the effective moisture diffusivity for slab geometry and expressed as:

$$MR = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \left(\frac{1}{2n+1}\right) \left[\exp\left(-\frac{(2n+1)\pi^2}{4l^2} D_{eff} t\right)\right] \quad (5)$$

Equation (5) can be simplified to Equation (6) as:

$$MR = \frac{8}{\pi^2} \exp\left[-\frac{D_{eff}}{4l^2} \pi^2 t\right] \quad (6)$$

where: D_{eff} is effective moisture diffusivity (m^2s^{-1}); t is drying time (s) and *l* is half thickness (m).

With the aid of linear regression analysis, the experimental data was tuned to Equation (7) to obtain D_{eff} of steam-cooked yam chips from the slope (K_1) of the graph of Ln MR versus the drying time, and this gives a negatively sloped straight line graph (Doymaz, 2012). The slope is related to D_{eff} (Abano and Amoah, 2015) as follows:

$$\text{Slope } K_1 = \frac{D_{eff}}{4l^2}\pi^2 \quad (7)$$

— Determination of Activation Energy

The activation energy (E_a) of steam-cooked yam slices was obtained by plotting Ln (D_{eff}) versus $1/T_{abs}$ and determining the value of E_a from the slope ($-E_a/R$) and intercept (Ln *Do*) (Rosa *et al.*, 2015). The relationship between D_{eff} and temperature is described using an Arrhenius equation (Onwude *et al.*, 2016) expressed as:

$$D_{eff} = D_o \exp\left(-\frac{E_a}{R(T+273.15)}\right) \quad (8)$$

where: D_o is the pre-exponential factor of Arrhenius equation, m^2s^{-1}; E_a is the activation energy, $kJmol^{-1}$; R is the universal gas constant (8.314), $kJmol^{-1}K^{-1}$, and T is the drying air temperature, °C.

— Mathematical Modeling of Drying Curves

Eleven thin layer drying moisture ratio models were fitted to the drying curves obtained from the experimental data using non-linear least squares regression analysis. The algorithm used to estimate the drying rate constants and coefficients of all of the models by means of Curve Expert 2010 software was Levenberg-Marquardt. The Eleven thin layer drying models were mathematically represented in Table 1.

Table 1. Thin layer drying models fitted for steam-cooked yam slices

No.	Model name	Model equation
1	Newton	$MR = \exp(-kt)$
2	Henderson and Pabis	$MR = a\exp(-kt)$
3	Logarithmic	$MR = a\exp(-kt) + c$
4	Wang and Sing	$MR = 1 + at + bt^2$
5	Modified Midilli et al. (II)	$MR = \exp(-kt) + bt$
6	Diffusion approach	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$
7	Demir et al., model	$MR = a\exp(-kt)^n + b$
8	Vega- Galvez et al. (II)	$MR = \exp(n+kt)$
9	Vega- Galvez et al. (III)	$MR = (a+bt^2)$
10	Henderson and Henderson (I)	$MR = c[\exp(-kt) + (1/9)\exp(-9kt)]$
11	Henderson and Henderson (II)	$MR = c\exp(-kt) + (1/9)\exp(-9kt)$

Source: Bassene *et al.* (2013); Ertekin and Firat (2017)

Drying models were evaluated for thin layer drying, based on the highest coefficient of determination (R^2) as the primary factor in assessing an equation of the drying curve, the other factors are lowest values of the sum of squared errors, chi-square value and root mean square error. These statistical parameters were calculated as:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(MR_{predict} - MR_{exp})^2}{\sum_{i=1}^{N}(MR_{exp} - \overline{MR_{exp}})^2} \quad (9)$$

$$SSE = 1/N\sum_{i=1}^{N}(MR_{exp} - MR_{predict})^2 \quad (10)$$

$$\chi^2 = \left[\frac{\sum_{i=1}^{N}(MR_{exp} - MR_{predict})^2}{N-z}\right]^{1/2} \quad (11)$$

$$RMSE = \left[1/N\sum_{i=1}^{N}(MR_{predict} - MR_{exp})^2\right]^{1/2} \quad (12)$$

Where: R^2 is coefficient of determination; MR_{exp} is the experimental moisture ratio; $MR_{predict}$ is the predicted moisture ratio; SSE is Sum of Square Error; χ^2 is reduced chi square, N is the number of observations; z is the number of constants; RMSE is Root Mean Square Error.

3. RESULTS AND DISCUSSION

— Analysis of Moisture Ratio

Table 2 and Figure 1 show the effect of drying temperature and drying time on drying behavior of yam slices. There was a reduction of moisture content (wet basis) from 70.93% to less than 10% at the end of drying duration (Table 2). The moisture ratio decreased non-linearly as drying temperature and drying time increased (Figure 1), this may be due to water evaporation from agricultural material with continuous drying as was similarly reported by Afolabi *et al.* (2015) for drying of untreated and pretreated cocoyam slices.

— Analysis of Drying Rate

Figure 2 shows the maximum and minimum drying rates were 0.643 kg/hr at 100°C, 1 hour and 0.540 kg/hr at 60°C, 1 hour respectively. At the sixth hour, drying rate ranged from 0.003 to 0.010 kg/hr with highest and lowest values at 60 °C and 100 °C respectively. Drying rates increased as drying temperatures increased and gradually reduced with time. Drying rates were highest at the initial hours of drying and reduced with time. Drying rates peaked when the moisture content was very high, this could be due to the removal of free moisture near the surface of the yam slices and minimal moisture resistance within the slices during the early stages of drying as reported by Ashaolu and Akinbiyi (2015) for drying of plantain chips. Similar observations in drying rates were reported by Beigi (2016) for convective drying of apple slices, Stegou–Sagia and Fragkou (2015) for drying of mushrooms, Aviara *et al.* (2014) for tray drying of native cassava starch, Senapati *et al.* (2014) for convective - microwave drying of Ashwagandha (*Withania Somnifera*) roots and Minae *et al.* (2014) for drying of St. John's Wort (*Hypericum Perfoatum)* leaves. Higher drying rates giving rise to shorter drying times were obtained at higher drying temperatures; similar occurrence was reported by Motevali *et al.* (2011).

Table 2. Effect of process conditions on moisture content of yam slices during drying

Drying Time (hr)	60 °C	70 °C	80 °C	90 °C	100 °C
Moisture content (wet basis)					
0	70.93(±1.03)	70.93(±1.03)	70.93(±1.03)	70.93(±1.03)	70.93(±1.03)
1	44.26(±2.79)	39.60(±4.06)	35.65(±2.44)	33.23(±1.80)	32.40(±2.44)
2	39.37(±3.29)	26.82(±1.39)	14.23(±0.54)	12.73(±1.17)	7.94(±1.35)
3	36.89(±2.60)	21.34(±1.01)	12.66(±2.16)	9.09(±2.00)	6.10(±1.19)
4	28.31(±2.20)	11.06(±1.57)	9.13(±1.84)	5.29(±1.47)	4.51(±1.52)
5	11.55(±2.13)	9.88(±2.66)	7.79(±0.81)	3.78(±2.06)	2.87(±1.23)
6	9.03(±2.70)	7.36(±1.02)	4.54(±1.43)	2.87(±0.15)	2.14(±0.30)

Mean values of triplicate determination with standard deviation in parenthesis.

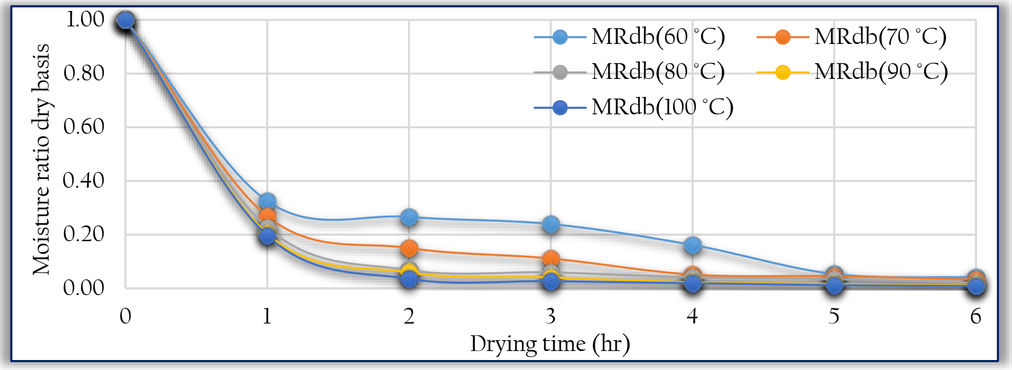

Figure 1. Graph of moisture ratio (dry basis) versus drying time for steam-cooked yam slices.

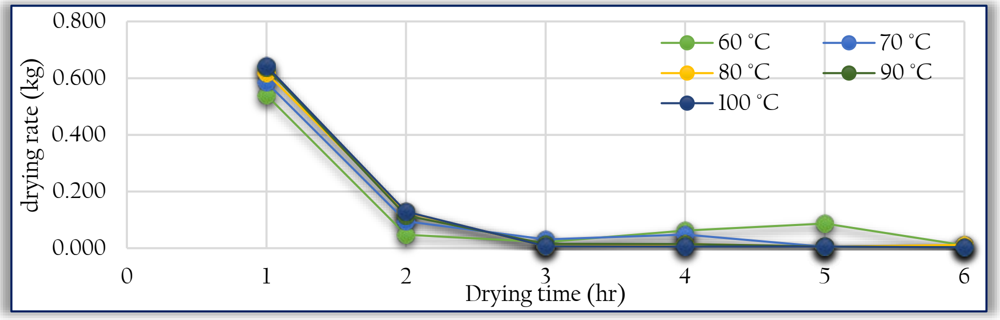

Figure 2. Drying rate versus drying time of steam-cooked yam slices

— Effective Moisture Diffusivity

The maximum value of moisture diffusivity coefficient (D_{eff}) was 4.169×10^{-10} m^2s^{-1} at air temperature of 100°C and the minimum value of moisture diffusivity was 2.814×10^{-10} m^2s^{-1} at air temperature of 60 °C. Results showed that the increase in drying temperature led to an increase in effective moisture diffusivity; this agrees with the reports of Rasouli *et al.* (2011) for drying of garlic. Similar observations were seen in drying other agricultural crops like *Dioscorea schimperiana* (Leng *et al.*, 2011), *Dioscorea alata* (Torres *et al.*, 2012), Tomato (Taheri-Garavand *et al.*, 2011), and Squash (Chayjan *et al.*, 2013). The value of D_{eff} in this study is within the general range of 10^{-11} - 10^{-9} m^2/s for food material as reported by Aghbashlo *et al.* (2008). The effective moisture diffusivity for dried steam-cooked yam chips and the effect of drying temperature on effective diffusivity are shown respectively in Table 5.

Table 5. Effective moisture diffusivity for parboiled yam chips at various drying temperatures.

Temp (°C)	Absolute Temperature (1/K)	Deff (m^2s^{-1})
60	0.003001651	2.813946E-10
70	0.002914177	3.063919E-10
80	0.002831658	3.298743E-10
90	0.002753683	3.956030E-10
100	0.002679887	4.169346E-10

— Activation Energy

Figure 3 shows the slope of a straight line obtained from a plot of the logarithm of effective diffusivity (D_{eff}) as a function of the reciprocal of absolute temperature (T) in the range of temperatures investigated, indicating Arrhenius relationship. From the slope of the straight line the value of activation energy for drying parboiled yam chips was found to be 10.75 $kJmol^{-1}$ with a high correlation of 0.967. Aghbashlo *et al,* (2008) reported that the activation energy for food materials was in the range of 12.7 - 110 $kJmol^{-1}$. However, the value of activation energy in this study exceeded 8.831 $kJmol^{-1}$ for yam slices (Sobukola *et al.,* 2008), 0.200 $kJmol^{-1}$ for plantain chips (Ashaolu and Akinbiyi, 2015), 10.67 $kJmol^{-1}$ for Chia seeds (Oliviera *et al*., 2016). Activation energy in this study was within the range of 10.39 - 15.56 $kJmol^{-1}$ for corn kernels of different hybrids (Voća *et al.,* 2007), 3.05 to 45.13 $kJmol^{-1}$ for infra-red drying of garlic slices (Younis *et al.,* 2018), 6.77 $kJmol^{-1}$ and 15.37 $kJmol^{-1}$ for boiled aerial yam slabs of 1 cm and 0.5 cm thicknesses (Sanful *et al.,* 2015) and was less than 41.149 and 33.499 $kJmol^{-1}$ for raw and blanched yam slices (Fang *et al.,* 2015), 22.28 $kJmol^{-1}$ for tomatoe slices (Abano *et al.,* 2011), 32.65 $kJmol^{-1}$ for drying of banana slices (Doymaz, 2010) and 26.4 $kJmol^{-1}$ for drying of onion slices (Mota *et al.,* 2010).

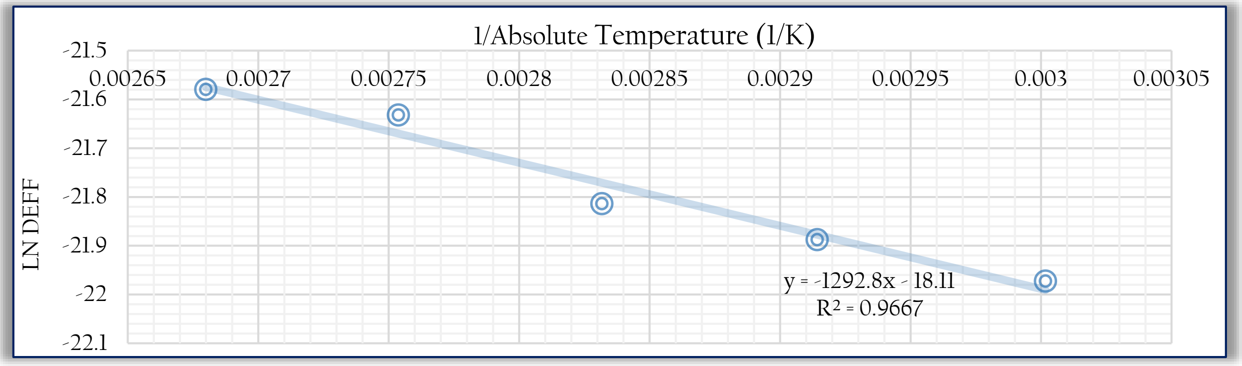

Figure 3. The Arrhenius relationship between inverse of absolute temperature and Ln D_{eff}.

— Statistical Evaluation of Thin Layer Drying Models

The moisture ratio as a function of drying time were curve fitted to eleven thin-layer drying models namely Lewis or Newton, modified Midili *et al* (II), Henderson and Pabis, Logarithmic, Vega-Galvez *et al.* (II), Vega-Galvez *et al.* (III), Demir *et al*., Wang and Singh, Diffusion, Henderson and Henderson (II) and Henderson and Henderson (III) models. The model with the least values of SSE, χ^2 and RMSE and the highest values of R^2 for all drying conditions, when compared with other models, was the Logarithmic model, and so it was considered as the model of best fit for the drying conditions under study. Apart from Vega-Galvez *et al* (III) and Wang and Singh model, the R^2 values for the mathematical models were greater than 0.90 depicting a good fit (Kaushal and Sharma, 2013). Results also showed that an increase in drying temperature resulted in an increase in drying rate constant (k).

The values of the constants of the Logarithmic model were regressed against drying temperature using multiple regression technique in order to consider the effect of drying temperature, T (K), on the constants. The equations, which gave the highest R^2 value, from the different graphs are as follows:

$$a = 0.0017 + 0.2168\ln(T) \qquad R^2 = 0.8996 \tag{12}$$

$$k = -3.3886 + 1.12\ln(T) \qquad R^2 = 0.9181 \tag{13}$$

$$c = 4E + 06T^{-4.221} \qquad R^2 = 0.9993 \tag{14}$$

Logarithmic model has been used to describe the drying behaviour of banana slices (Doymaz, 2010) and grated coconut (Abidin *et al.,* 2014). The statistical analysis of mathematical models and the equation constants and coefficient are shown in Tables 3 and 4.

Table 3: Selected drying models and their equation constants.

Models	Temperature (°C)	k	n	a	c	b
Lewis or Newton	60	0.70381				
	70	1.11028				
	80	1.41727				
	90	1.53646				
	100	1.62067				
Modified Midili *et al* (II)	60	0.85890				0.01641
	70	1.21363				0.01019
	80	1.48542				0.00679
	90	1.57739				0.00398
	100	1.64794				0.00268

Henderson and Pabis	60	0.65491		0.94129		
	70	1.09772		0.98765		
	80	1.41512		0.99764		
	90	1.53525		0.99859		
	100	1.62045		0.99976		
Logarithmic	60	1.13645		0.87276	0.11461	
	70	1.39441		0.93825	0.05872	
	80	1.61396		0.96492	0.03500	
	90	1.66286		0.97854	0.02116	
	100	1.69962		0.98728	0.01296	
Vega-Galvez *et al.* (II)	60	-0.65491	-0.06050			
	70	-1.09771	-0.01243			
	80	-1.41512	-0.00236			
	90	-1.53525	-0.00141			
	100	-1.62021	-0.00024			
Vega-Galvez *et al.* (III)	60			0.93055		-0.18966
	70			0.91275		-0.21262
	80			0.89342		-0.21333
	90			0.88602		-0.21174
	100			0.88120		-0.21176
Demir *et al*	60	0.92294	1.23132	0.87276		0.11461
	70	1.01185	1.37815	0.93825		0.05872
	80	1.03417	1.56064	0.96492		0.03500
	90	1.10524	1.50454	0.97854		0.02116
	100	1.20186	1.41415	0.98728		0.01296
Wang and Singh	60			-0.42750		0.04680
	70			-0.50763		0.06059
	80			-0.54333		0.06676
	90			-0.55492		0.06845
	100			-0.56484		0.07016
Diffusion	60	0.70381		1.00000		1.00000
	70	1.11028		1.00000		1.00000
	80	1.41727		1.00000		1.00000
	90	1.53646		1.00000		1.00000
	100	1.62067		1.00000		1.00000
Henderson and Henderson (I)	60	0.58505			0.85249	
	70	0.99423			0.88866	
	80	1.31259			0.89786	
	90	1.43327			0.89877	
	100	1.52169			0.89988	
Henderson and Henderson (II)	60	0.56860			0.83090	
	70	0.97923			0.87467	
	80	1.30005			0.88621	
	90	1.42105			0.88736	
	100	1.51019			0.88876	

Table 4. Statistical analysis of the mathematical models.

Models	Temperature (°C)	SSE	R^2	χ^2	RMSE
Lewis or Newton	60	0.00783	0.91472	0.00913	0.08847
	70	0.00219	0.97872	0.00255	0.04677
	80	0.00078	0.99286	0.00091	0.02786
	90	0.00030	0.99734	0.00035	0.01727
	100	0.00013	0.99886	0.00015	0.01140
Modified Midili *et al* (II)	60	0.00557	0.93928	0.01301	0.07466
	70	0.00102	0.99013	0.00237	0.03186
	80	0.00021	0.99809	0.00048	0.01442
	90	0.00010	0.99908	0.00024	0.01014
	100	0.00004	0.99964	0.00010	0.00643
Henderson and Pabis	60	0.00735	0.91994	0.01029	0.08572
	70	0.00217	0.97893	0.00303	0.04655
	80	0.00078	0.99287	0.00109	0.02784
	90	0.00030	0.99734	0.00042	0.01727
	100	0.00013	0.99886	0.00018	0.01140
Logarithmic	60	0.00416	0.95464	0.00729	0.06453
	70	0.00059	0.99422	0.00104	0.02438
	80	0.00008	0.99929	0.00014	0.00879
	90	0.00004	0.99961	0.00008	0.00658
	100	0.00003	0.99972	0.00006	0.00567
Vega-Galvez *et al.* (II)	60	0.00735	0.91994	0.01286	0.08572
	70	0.00217	0.97893	0.00379	0.04655

	80	0.00078	0.99287	0.00136	0.02784
	90	0.00030	0.99734	0.00052	0.01727
	100	0.00013	0.99886	0.00023	0.01140
Vega-Galvez *et al.* (III)	60	0.01450	0.84198	0.02538	0.12043
	70	0.01405	0.86333	0.02459	0.11855
	80	0.01935	0.82203	0.03387	0.13911
	90	0.02176	0.80597	0.03809	0.14753
	100	0.02369	0.79276	0.04146	0.15391
Demir *et al*	60	0.00416	0.95464	0.00972	0.06453
	70	0.00059	0.99422	0.00139	0.02438
	80	0.00008	0.99929	0.00018	0.00879
	90	0.00004	0.99961	0.00010	0.00658
	100	0.00003	0.99972	0.00008	0.00567
Wang and Singh	60	0.01753	0.80897	0.02455	0.13242
	70	0.01749	0.82995	0.02448	0.13224
	80	0.02152	0.80214	0.03012	0.14668
	90	0.02254	0.79905	0.03156	0.15013
	100	0.02347	0.79466	0.03286	0.15321
Diffusion	60	0.00783	0.91472	0.01370	0.08847
	70	0.00008	0.97872	0.00383	0.04677
	80	0.00078	0.99286	0.00136	0.02786
	90	0.00030	0.99734	0.00052	0.01727
	100	0.00012	0.99886	0.00023	0.01140
Henderson and Henderson (I)	60	0.00578	0.93708	0.00116	0.07599
	70	0.00179	0.98255	0.00251	0.04236
	80	0.00069	0.99362	0.00097	0.02634
	90	0.00026	0.99772	0.00036	0.01600
	100	0.00184	0.98392	0.00257	0.04287
Henderson and Henderson (II)	60	0.00550	0.94006	0.00110	0.07417
	70	0.00174	0.98303	0.00244	0.04177
	80	0.00068	0.99371	0.00096	0.02615
	90	0.00025	0.99776	0.00035	0.01585
	100	0.00012	0.99892	0.00017	0.01112

4. CONCLUSIONS

The thin layer drying behaviour of steam-cooked yam slices was investigated in a convective dryer at a constant air velocity and at the drying temperature of 60 - 100 °C at 1 - 6 hours. Moisture ratio and drying rate reduced as drying temperature and drying time increased. Effective moisture diffusivity of parboiled yam slices increased from 2.814×10^{-10} to 4.169×10^{-10} m^2/s as drying temperature increased resulting in an activation energy of 10.75 $kJmol^{-1}$. Eleven thin-layer mathematical models were fitted based on lowest SSE, highest R^2 value, lowest χ^2 and lowest RMSE, and Logarithmic model was found to be best suited for predicting the drying behaviour of steam-cooked yam slices. This study is limited to solids and is of importance in the study of dryers and drying behaviour of solids from root and tuber crops, and similar approach may be applied to particulate materials such as grated root and tubers using a suitable dryer. Results obtained in this study were in accordance with that of other agricultural crops in a range reported by numerous researchers.

Acknowledgement

The authors acknowledge research support from the Africa Centre of Excellence in Agricultural Development and Sustainable Environment (CEADESE) based at Federal University of Agriculture, Abeokuta, Nigeria) with World Bank grant no: ACE 023.

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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665