Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com
RJEES

Original Research Article

Modelling of Thin Layer Drying of Cocoyam Slices of Varying Thickness at Different Temperatures

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ARTICLE INFORMATION

Article history:
Received 02 May, 2021
Revised 20 May, 2021
Accepted 24 May, 2021
Available online 30 Jun, 2021

Keywords:
Cocoyam
Moisture ratio
Drying rate
Thickness
Temperature
Drying

ABSTRACT

Drying of agricultural and food products reduces their moisture content and this help to avoid microbiological action which could lead to deterioration. In this study, the convective hot air oven was used to dry sliced cocoyam pieces to enable uniform drying. Proximate and functional analyses were carried out before and after drying. Eight selected semi-empirical drying models were fitted to the drying data using non-linear regression analysis. The most appropriate models were selected using the coefficient of determination (R^2) and sum square error (SSE). The result obtained showed that there were reductions of the values of the cocoyam nutrients after drying. The cocoyam drying regime was characteristically in the constant and falling rate period. The optimum drying temperature for cocoyam was found to be 60 ^oC. The logarithmic model showed a better fit for the drying kinetic data of cocoyam in comparison with other tested models. Empirical models developed gave the relationship between moisture ratio to sizes and drying time for the various slice thicknesses and at the different temperatures studied. Activation energy obtained was between 14.802 kJ/mol and 19.138 kJ/mol while the effective moisture diffusivity was between 7.02×10^{-7} and 2.00×10^{-7} m·/s for the different thicknesses at the various temperatures studied.

1. INTRODUCTION

Drying operations have been applied for the reduction of moisture content in food materials for the prevention of microbial growth and deterioration, for shelf life elongation, to minimize packaging and improving storage for easy transportation (Kabiru *et al.*, 2013). Although there are many ways in which drying can be achieved, the choice of a method depends on the material and the sanitary measures (Inyang, *et al.,* 2018).

Cocoyams are monocotyledonous herbs that belong to the family Araceae and are grown primarily for their roots which are edible (Bolarin *et al.*, 2017). There are two major species of cocoyam grown in Nigeria and many other parts of the world, namely *Colocasia exculanta* (taro) and *Xanthosoma sagittiffolum* (tannia) (Ndukwu and Nwabuisi 2011).

Cocoyam can be used as food for man and feed for animals, and mucilage which can be utilized in the paper industry or possibly in medicinal tablet manufacture. Cocoyam is consumed when cooked and if not properly cooked, the presence of raphids which are minute bundle of crystal of calcium oxalate causes irritation to the skin. Long storage of the product in fresh form is not successful and thus discouraged. Since cocoyam cannot not be stored for long in fresh form; it is dried and processed into flour which can be prepared in many form for consumption. This method of preservation makes it readily available all the year round. Therefore, it is necessary to predict the removal of moisture from the sample (product) for preservation to avoid deterioration or spoilage (Ndukwu and Nwabuisi, 2011).

Amer *et al.* (2003) and Amer *et al.* (1999) applied multiple linear regression analysis to establish mathematical equations for the drying kinetics which relates the drying process with the affecting factors. The non – linear regression technique could be used to develop a model that takes care of many variables (Khazaei and Daneshmandi, 2007; Maisnam *et al.,* 2017).

Many authors had developed semi-empirical models based on the diffusion theory to predict the drying kinetics of moist substances in a thin layer as could be seen in different thin layer models (Ademiluyi and Abowei, 2013). Onwude *et al.* (2016) and Naderinezhad *et al.* (2017) maintained that some of the thin layer models depend on one or more parameters such as thickness, temperature and moisture content for drying agricultural products.

Empirical models fail to take into account the fundamentals of drying process and can explain only the drying curve for drying condition but not the processes that occur during drying (Irudayaraj *et al.*, 1992). Empirical models help to understand the trend of experimental / process variables both dependent and independent. The main challenges faced by the empirical models are that they depend largely on experimental data and provide limited information about the heat and mass transfer during the drying process (Erbay and Icier, 2010).

The aim of this study is to develop a mathematical model for predicting the removal of moisture in the thin layer drying of cocoyam slices of different thicknesses and at different drying temperatures.

2. MATERIALS AND METHODS

2.1. Sample Preparation

The cocoyam samples used for this study were obtained from Itam market in Uyo, Akwa Ibom State, Nigeria. The cocoyam was prepared for drying by peeling it and cutting it into cylindrical pieces of diameter 30 mm before slicing into different dimensions of 2 mm, 4 mm, 6 mm and 8 mm as required by measuring with Vernier caliper (Famurewa and Adejumo, 2015; Oforkansi and Oduola, 2016). This was repeated until the required quantity of 200 g mass was obtained using the electronic weighing balance (Famurewa and Adejumo, 2015).

2.2. Proximate Analysis

The following proximate parameters namely moisture, ash content, crude fat, crude fibre, and caloric value were determined using the method of AOAC, (1990). While some proximate parameters were determined as follows:

2.2.1. Protein determination

Determination of crude protein was carried by the method used by Senanayake *et al.* (2013) in their work where the titre values of the duplicate samples were recorded and the percentage calculated. Equation 1 was used for the determination of protein content.

$$\%\ \text{Protein} = \%\ \text{Nitrogen} \times 6.25 \qquad (1)$$

2.2.2. Determination of carbohydrate

Carbohydrate content was determined as the result obtained after subtracting protein, fat, ash and fibre from the total of 100%. Equation 2 was used for the determination of carbohydrate content.

$$\text{Carbohydrate} = 100 - (\text{Protein} + \text{Fat} + \text{Ash} + \text{Fibre}) \qquad (2)$$

2.3. Functional Properties

2.3.1. Water – binding capacity

The water-binding capacity of the cocoyam flour was evaluated by placing 2 g samples in a centrifuge tube. Forty (40) ml of distilled water was added and the resultant slurry was shaken for one hour before centrifugation at 2,200 rpm for 15 minutes with a centrifuge. The supernatant was decanted and the amount of water in grams absorbed by a 100 g sample was determined by calculation (Medcalf and Gilles, 1998). Equation 3 was used for the determination of water binding capacity.

$$\text{Water binding capacity} = \frac{(\text{Wet sample weight} - \text{Dry sample weight}) - \text{Weight of water retained by disc}}{\text{Sample weight}} \times 100 \qquad (3)$$

2.3.2. Bulk density

The bulk density of the cocoyam flour was determined by placing 10 g of sample in a 50 ml graduated cylinder with gentle uniform tapping during filling. The cylinder was filled to the mark and the weight of the flour was measured. The bulk density was calculated as mass by volume in grams per milliliter (g/ml). The average of the two is reported (Medcalf and Gilles, 1998). Equation 4 was used for the determination of bulk density.

$$\text{Bulk density} = \frac{\text{Mass of sample}}{\text{Volume of the whole sample}} \qquad (4)$$

2.3.3. Swelling power and percentage solubility

About 1.0 g of powder was placed into a pre-weighed centrifuge tube. Forty (40.0) ml of distilled water was then added and stirred. The mixture was placed on water was maintained at 85 °C with continuous stirring for 30 minutes. It was cooled to room temperature and then centrifuged at 2,200 rpm for 15 minutes. The supernatant was poured into a pre-weighed crucible and then placed in an oven to evaporate at 100 °C. The solid residue in the crucible was weighed again and the difference in weight calculated as percentage solubility. The paste in the tube then weighed and the swelling power determined using Equation 5 (Senanayake *et al.,* 2013). The supernatant was separated; 5 ml was obtained and dried in the oven.

$$\%\ \text{Swelling Power} = \frac{\text{Weight of sedimented paste}}{\text{Weight of original sample X}(100 - \text{Percentage solids})} \text{X} 100\% \qquad (5)$$

$$\%\ \text{Solubility} = \frac{\text{Weight of soluble starch}}{\text{Weight of original sample}} \text{X} 100\% \qquad (6)$$

2.3.4. pH

The pH of the cocoyam flour was determined by the method of Oduro *et al.* (2006). Ten grams of the flour was weighed, mixed with 20 ml of distilled water to form slurry and allowed to stand for 10 minutes. The pH of the slurry was measured with the Corning pH meter (Model 240).

2.3.5. Rehydration ratio

Ten grams (10 g) of cocoyam flour was loaded into aluminum sample dishes. Five hundred milliliters (500 ml) of distilled water was transferred into a glass jar and a tripod was also placed in the jar. The dishes were placed on the tripod in the jar which was then tightly closed and kept at room temperature until equilibration. The dishes were periodically weighed until equilibrium was reached. The rehydration percentage was used to express the rehydration of the flour (Oduro *et al.*, 2006). Equation 7 was used for the determination of rehydration ratio.

$$\text{Rehydration ratio} = \frac{\text{Weight of rehydrated material}}{\text{Weight of dehydrated material}} \tag{7}$$

2.4. Mineral Analysis

The following minerals namely Phosphorus, Calcium, iron, Sodium and Potassium were analysed using the method of AOAC, (1990).

2.5. Kinetic Modelling

Mathematical drying models describe the drying phenomenon regardless of the controlling mechanisms (Kingsley et al., 2007; Agarry and Aworanti, 2012). In thin layer drying, the moisture ratio can be calculated according to Equation (8).

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{8}$$

Where *MR* is the dimensionless moisture ratio, *M*, the average moisture content at time *t*, M_0, the initial moisture content, and *Me*, the equilibrium moisture content respectively, on a dry weight basis.

Eight known semi-empirical mathematical drying models that expresses relationship between moisture ratio (*MR*) and the drying time, *t* as presented in Table 1 were fitted to the drying curves obtained for the cocoyam sample at drying temperatures of 40 °C, 50 °C, 60 °C and 70 °C for varied thicknesses.

Table 1: Semi-empirical mathematical drying models (Inyang *et al.*, 2018)

S/N	Model	Equation
1.	Lewis	$MR = \exp(-kt)$
2.	Page	$MR = \exp(-kt^n)$
3.	Modified Page	$MR = \exp\left[(-kt)^n\right]$
4.	Henderson and Pabis	$MR = a\exp(-kt)$
5.	Logarithmic	$MR = a\exp(-kt) + c$
6.	Aghbashalo	$MR = \exp-\left(\frac{k_1 t}{1 + k_0 t}\right)$
7.	Demir	$MR = a\exp(-kt)^n + b$
8.	Two term	$MR = a\exp(-k_0 t) + b\exp(-k_1 t)$

where a, c, n are empirical constants, k is a drying constant and t is drying time. Non-linear regression analysis was carried out using the Solver add-in tool in Microsoft Excel. The coefficient of determination (R^2) and sum square error (SSE) were major criteria for selection of the best model equation to describe the drying curve. For quality fit, R^2 value should be high and SSE should be low (Naderinezhad *et al.*, 2017).

2.6. Model Development

In developing the empirical model for the drying of cocoyam, the following assumptions were made as follows:

- the moisture movement is based on the diffusion theory and this will be unidirectional
- the drying process is isothermal, shrinkage is neglected, materials to be dried is spherical but thin in size
- the coefficient factor (α_0), is independent of moisture concentration
- the temperature to be applied ranges from 40 ^{O}C to 70 ^{O}C
- thickness used were 2 mm, 4 mm, 6 mm and 8 mm.

For the development of the correlation in this paper, the moisture ratio (MR) was assumed to depend directly on thickness and inversely on time (Inyang *et al.*, 2019). Based on this assertion, the relationships of MR with the drying parameters are presented in Equations 9 and 10:

$$\mathrm{MR} \; \alpha \frac{1}{\mathrm{t}} \tag{9}$$

$$\mathrm{MR} \; \alpha \, \mathrm{X} \tag{10}$$

Thus, the proposed correlation will consider the proportionality of the MR to the different drying factors (thickness and time) as presented in Equations 9 and 10. Thickness (sizes) and time were considered for the development of proposed moisture ratio for drying of cocoyam. The moisture ratio was expressed as a function of the mentioned parameters in Equation 11.

$$\mathrm{MR} = \mathrm{f(t, X)} \tag{11}$$

Equations 9 and 10 can be expanded in the basic form of nonlinear multivariable algebraic expression as $\mathrm{MR} = \mathrm{f(t, X)}$ given in Equation 12.

$$\mathrm{MR} = \alpha_0 (\mathrm{X}^{\alpha_1}, \mathrm{t}^{-\alpha_2}) \tag{12}$$

Alternatively, the Equation 12 can be represented as;

$$\mathrm{MR} = \alpha_0 \left[\frac{\mathrm{X}^{\alpha_1}}{\mathrm{t}^{\alpha_2}} \right] \tag{13}$$

Applying logarithmic transformation to linearize Equation 13 resulted in:

$$\mathrm{Log(MR)} = \mathrm{Log}(\alpha_0) + (\alpha_1 \mathrm{Log(X)} - \alpha_2 \mathrm{Log(t)}) \tag{14}$$

α_o is a coefficient while α_1 and α_2 are exponential constants of the drying parameters.

These variables in Equation 13 were determined iteratively using a multivariable numerical optimization method. The unknown coefficient (α_o) and the exponential constants (α_1 and α_2) were solved iteratively using general reduced gradient (GRG) protocol in the Microsoft Excel Solver.

2.7. Drying Experiments

A mass of 200 g with different thickness of dimension (2 mm, 4 mm, 6 mm and 8 mm) and diameter (30 mm) of sliced samples were used for drying directly at different temperatures without blanching. The convective hot air oven was turned on and allowed for 30 minutes to reach the steady-state set drying air temperature. The samples were placed on wire mesh and loaded into the laboratory drying oven. The wire mesh was chosen because of the ease and fastness in drying. Drying was maintained at the set temperatures of 40 °C, 50 °C, 60 °C and 70 °C (Famurewa and Adejumo, 2015). Every thirty (30) minutes, the sample was removed from the oven and weighed using a digital weighing balance until equilibrium moisture content (weight) was attained (Ndukwu and Nwabuisi, 2011). The initial and final moisture contents at 105 °C were determined (Kabiru *et al.*, 2013). Also, the dynamic equilibrium moisture content for cocoyam was calculated (Maisnam *et al.,* 2017). The dried product obtained was ground to 0.02 µm before it was used for analysis.

3. RESULTS AND DISCUSSION

3.1. Proximate Analysis

Table 2 presents the proximate analysis for Cocoyam before and after drying. In Table 2, from the results obtained it was observed that there were reductions in the nutritional content of the cocoyam these may be due to the method of processing because heat was applied and it could also be due to the genetic composition where the organic dry matter constitutes protein (Senanayake *et al.,* 2013; Tumuhimbise *et al.*, 2013). The processing of the product alters the nutrient composition slightly. This collaborate the work of Ndukwu *et al.* (2017). Table 3 shows the mineral analysis for the cocoyam samples before and after drying. In Table 3 it showed that there was a reduction in all the minerals analyzed and this may be because of the heat used in processing (drying) the product (Rivero *et al.,* 2003; Ukom *et al.,* 2009).

Table 2: Proximate analysis for Cocoyam before and after drying

Parameter	Before drying	After drying
Moisture content (%)	71.20 ± 0.46	13.12 ± 0.56
Ash content (%)	1.99 ± 0.13	3.34 ± 0.15
Crude fibre (%)	4.84 ± 0.42	3.89 ± 0.31
Crude lipid (%)	4.35 ± 0.15	2.08 ± 0.21
Crude protein (%)	4.68 ± 0.32	2.01 ± 0.32
Carbohydrate (%)	88.68 ± 0.43	84.14 ± 0.31
Caloric value (kcal)	394.43 ± 0.13	381.48 0.18

Table 3: Mineral analysis of cocoyam samples before and after drying

Mineral (mg/100g)	Before drying	After drying
Calcium (Ca)	49.34 ± 1.60	40.18 ± 1.91
Iron (Fe)	9.42 ± 0.12	3.57 ± 0.12
Potassium (K)	36.94 ± 1.06	25.83 ± 1.06
Sodium (Na)	89.36 ± 2.21	48.69 ± 2.21
Phosphorus (P)	2.12 ± 0.13	1.90 ± 0.15
Zinc (Zn)	0.86 ± 0.01	0.31 ± 0.01
Magnesium (Mg)	24.16 ± 1.01	22.28 ± 1.12

In Table 4, the bulk density, water binding capacity, pH, rehydration ratio, swelling power and percentage solubility are shown. Thus, temperature and relative humidity plays a significant role in measuring pH, hence low temperature affects the pH of the products (Dadzie, 1998; Ayim, 2011). The obtained results for the products in this study are in the acidic region which is more shelf-stable than their non-acidic counterparts (Ihekoronye and Ngoddy, 1985). The reason why the rehydration ratio was low maybe because of the fine particle size and this can easily absorb moisture from the environment (Noomhorm, 2007). The size of particles, types of variety and the processing technique or conditions such as temperature, time, stirring and centrifugation of the samples studied probably could affect the swelling power (Noomhorm, 2007; Dako *et* *al.,* 2016). Like the swelling power, the solubility, is temperature-dependent. Granular size also affects the solubility of starches. From this study, cocoyam dissolves faster in water because of the small granule size and this resulted in the higher solubility value (Moorthy, 2002). Higher water-binding capacity suggests a weak association of amylose- amylopectin which allows permeability of water into the granule structure (Otegbayo *et al.*, 2010). The bulk density for all the products was relatively low and this may be because of the fine particle size (Moorthy, 2002; Noomhorm, 2007). The lower the bulk density, the higher the amount of sample particles that can bind together leading to higher energy values (Onimawo and Egbekun, 1998). Also, the reason for low bulk density may be due to variation in environmental conditions such as soil type, climate, application of fertilizer, etc. (Naz *et al.*, 2011; Tumuhimbise *et al.*, 2013).

Table 4: Results of functional analysis for samples

Physical property	Value
pH	6.60 ± 0.03
Rehydration ratio	1.07± 0.00
Swelling power (g/g)	3.65 ± 0.08
% solubility	9.98 ± 0.27
Water-binding capacity (%)	145.67 ± 1.53
Bulk density (g/ml)	1.24 ± 0.01

3.2. Effective Moisture Diffusivity

In this study, the effective moisture diffusivity increased as the temperature was increased while the effective moisture diffusivity decreased as the thickness increased as can be seen in Table 5. This is as a result of the increase in temperature which causes a decrease in water viscosity and increases the activity of water molecules (Limpaiboon, 2011). These phenomena facilitate diffusion of water molecules in object capillaries, consequently increasing the moisture diffusivity. Thus, higher temperatures and flow rates of drying air facilitate the heat transfer rate between thermal source and the material leading to faster moisture evaporation and lower drying time (Beigi, 2016; Olajire *et al.*, 2018).

Table 5: Effective moisture diffusivity at different temperatures for cocoyam

Temperature (°C)	Thickness (mm)	$D_{eff}\,(m^2/s)$
40	2	2.94E-07
	4	2.78E-07
	6	2.53E-07
	8	2E-07
50	2	4.45E-07
	4	3.63E-07
	6	2.71E-07
	8	2.5E-07
60	2	4.94E-07
	4	4.56E-07
	6	3.2E-07
	8	3.05E-07
70	2	7.02E-07
	4	6.39E-07
	6	3.82E-07
	8	3.73E-07

3.3. Activation Energy

Table 6 presents the activation energy results obtained for the cocoyam. It was observed that the activation energy values increased with increasing slice thickness. This may be as a result of the quantity of moisture removed, since higher thickness will accumulate much moisture, thus showing the sensitivity of D_{eff} values to the slice thickness. The greater the activation energy, the more sensible, is to temperature (Limpaiboon, 2011; Olajire *et al.*, 2018). Table 6 shows values for activation energy studied obtained for cocoyam as observed that the obtained result falls within the range as in literature (Limpaiboon, 2011; Olajire *et al.*, 2018; Srivastava et *al.,* 2015). From Table 6, it was seen that at a thickness of 2 mm and 4 mm, the activation energy was low due to the high drying rate.

Table 6: Activation energies for cocoyam

Thickness (mm)	Ea (KJ/mol)
2	14.802
4	15.321
6	17.160
8	19.138

3.4. Kinetic Modelling

Eight different kinetic models were selected and fitted to the experimental data. The best models were the ones with the highest coefficient of determination (R^2) values and the lowest sum of squares error (SSE) values as shown in Table 7. It was observed that the statistical measurements of some selected models for drying products gave a good fit when the experimental data were used. The Logarithmic model gave high values of coefficient of determination (R^2) for the various thickness and different drying temperatures studied and was also found to have corresponding low values for the sum of squares calculated as they tended towards zero. This observation was found to agree with the findings of other researchers (Onwude *et al.*, 2016). The kinetic model constants for the eight models studied were obtained. It was observed that the rate constants were small which indicated that the evaporation rates were small so the moisture content decreased very slowly (Haghi, 2001). Also, the drying coefficient indicated the time required to dry out moisture from the material under study (Scheffler and Plagge, 2005). These models are appropriate for the prediction of moisture removal from cocoyam during drying and better control of the process and achieving high quality of the dried product.

The coefficients obtained after non-linear regression are the values given in Table 8 and can be written in the place of their expressed symbols in Equation 13. It could be seen that α_1 has the highest value in all the products while others were closed to zero. From this work, the constants (α_o, α_1, and α_2) may be affected by density, temperature moisture diffusivity, specific heat, interface heat and mass coefficient (Marinos - Kouris and Maroulis, 1995). The quality of the developed models was evaluated using different statistical criteria. The values of R^2 and other statistical measures obtained were good as seen in previous works (Ndukwu and Nwabuisi, 2011; Ayim *et al.,* 2012). The model could be used in predicting of moisture ratio of the various sizes of cocoyam studied, so as to reduce moisture content in the product for better storage and to prevent it from deterioration.

It can be seen from Table 9 that prediction from the developed model gave the best performance of drying cocoyam to be at 60 °C for the thickness of 4 mm slice. This is because the values of 0.000096, 0.001913 and 0.99991 were obtained for SSE, RSME and R^2 respectively.

Table 7: Selected kinetic models and their parameters

		40 °C			50 °C			60 °C			70 °C		
	Thickness	Model constant	SSE	R^2	Model constant	SSE	R^2	Model constant	SSE	R^2	Model constant	SSE	R^2
Lewis	2	K =0.003075	0.1221	0.8458	K = 0.004883	0.1112	0.7318	K =0.006167	0.1065	0.6799	K = 0.007627	0.1661	-0.4634
	4	K =0.002137	0.0218	0.9758	K = 0.003146	0.0954	0.8012	K = 0.004257	0.1177	0.6893	K = 0.007058	0.0696	0.7459
	6	K =0.001844	0.0177	0.9691	K = 0.00278	0.0320	0.9707	K = 0.003257	0.0873	0.8775	K = 0.004086	0.0746	0.8440
	8	K =0.001369	0.0054	0.9981	K = 0.002424	0.0688	0.9200	K = 0.002648	0.0614	0.9224	K = 0.003886	0.1128	0.7331
Page	2	K=0.016845 n=0.704487	0.0527	0.9335	K = 0.032744 n = 0.640995	0.0429	0.8967	K = 0.042625 n = 0.621345	0.0409	0.9752	K = 0.145792 n = 0.39475	0.0285	0.7488
	4	K =0.003293 n =0.926995	0.0188	0.9791	K = 0.020851 n = 0.662791	0.0312	0.9349	K = 0.033109 n = 0.617816	0.0419	0.8896	K = 0.039297 n = 0.653847	0.0262	0.9044
	6	K =0.003275 n =0.905513	0.0120	0.9886	K = 0.005125 n = 0.895262	0.0245	0.9776	K = 0.015573 n = 0.724809	0.0347	0.9513	K = 0.023967 n = 0.676667	0.0159	0.9668
	8	K =0.001683 n =0.966758	0.0047	0.9984	K = 0.010483 n = 0.752787	0.0219	0.9746	K = 0.010798 n = 0.759242	0.0208	0.9738	K = 0.031845 n = 0.616641	0.0259	0.9387
Modified Page	2	K = 0.05882 n =0.052284	0.1221	0.8458	K = 0.063789 n = 0.076546	0.1112	0.7318	K = 0.089044 n = 0.069257	0.1065	0.6799	K = 0.094331 n = 0.080855	0.1661	-0.4634
	4	K =0.053381 n =0.040035	0.0218	0.9758	K = 0.06636 n = 0.047406	0.0954	0.8012	K = 0.075335 n = 0.056501	0.1177	0.6893	K = 0.099406 n = 0.071004	0.0696	0.7459
	6	K =0.048685 n =0.037866	0.0177	0.9831	K = 0.056361 n = 0.049316	0.0320	0.9837	K = 0.061639 n = 0.052833	0.0873	0.8775	K = 0.069045 n = 0.059181	0.0746	0.8440
	8	K = 0.02616 n =0.052321	0.0054	0.9947	K = 0.052631 n = 0.046052	0.0688	0.9200	K = 0.054581 n = 0.048516	0.0614	0.9224	K = 0.073755 n = 0.052682	0.1128	0.7331
Logarithmic	2	a =0.846338 K =0.007035 C =0.248697	0.0062	0.9921	a = 0.885088 K = 0.013277 C = 0.268674	0.0034	0.9917	a = 0.917884 K = 0.016546 C = 0.252932	0.0052	0.9974	a = 1.189367 K = 0.039788 C = 0.318965	0.0001	0.9987
	4	a =0.850378 K =0.003592 C =0.211974	0.0076	0.9916	a = 0.750848 K = 0.008166 C = 0.312804	0.0047	0.9902	a = 0.839835 K = 0.013084 C = 0.310009	0.0037	0.9903	a = 0.928807 K = 0.018289 C = 0.25091	0.0016	0.9940
	6	a =0.842179 K = 0.00293 C =0.198823	0.0032	0.9970	a = 0.908286 K = 0.004583 C = 0.173102	0.0046	0.9958	a = 0.828937 K = 0.006943 C = 0.242568	0.0045	0.9938	a = 0.77035 K = 0.008136 C = 0.239127	0.0013	0.9974
	8	a =0.854306 K =0.001976 C =0.178154	0.0012	0.9988	a = 0.79346 K = 0.004802 C = 0.247027	0.0013	0.9985	a = 0.800283 K = 0.00523 C = 0.244676	0.0014	0.9983	a = 0.76635 K = 0.009925 C = 0.286726	0.0008	0.9981
Henderson and Pabis	2	a = 0.87 K =0.002554	0.0906	0.8857	a = 0.81127 K = 0.003666	0.0735	0.8230	a = 0.779239 K = 0.004408	0.0675	0.7970	a = 0.587151 K = 0.003196	0.0483	0.5740
	4	a =0.990489 K =0.002107	0.0216	0.9761	a = 0.85035 K = 0.002466	0.0573	0.8800	a = 0.808266 K = 0.003115	0.0730	0.8070	a = 0.799934 K = 0.005248	0.0436	0.8410
	6	a =0.978131 K =0.001785	0.0163	0.9845	a = 0.979175 K = 0.002707	0.0312	0.9710	a = 0.878572 K = 0.00274	0.0617	0.9140	a = 0.831477 K = 0.003185	0.0357	0.9250
	8	a =0.999576 K =0.001367	0.0054	0.9950	a = 0.900848 K = 0.002099	0.0452	0.9470	a = 0.903546 K = 0.002303	0.0413	0.9480	a = 0.800325 K =0.002824	0.0558	0.8680
Demir	2	a = 0.84634 K =0.108283 n = 0.06497 b =0.248698	0.0062	0.9921	a = 0.885085 K = 0.124456 n = 0.106677 b = 0.268672	0.0034	0.9917	a = 0.917878 K = 0.111398 n = 0.148531 b = 0.252933	0.0052	0.9840	a = 1.189355 K = 0.141046 n = 0.282092 b = 0.318965	0.0001	0.9990
	4	a = 0.84634 K =0.108283 n = 0.06497 b =0.248698	0.3215	0.7236	a = 0.750847 K = 0.098991 n = 0.082493 b = 0.312807	0.0047	0.9902	a = 0.839847 K = 0.099062 n = 0.132083 b = 0.31001	0.0037	0.9900	a = 0.928814 K = 0.110422 n = 0.165633 b = 0.25091	0.0016	0.9940
	6	a =0.842186 K =0.066297 n =0.044198 b =0.198818	0.0032	0.9970	a = 0.908287 K = 0.080104 n = 0.057217 b = 0.173099	0.0046	0.9960	a = 0.828943 K = 0.127282 n = 0.054549 b = 0.242573	0.0045	0.9940	a = 0.770358 K = 0.028524 n = 0.28524 b = 0.239127	0.0013	0.9970
	8	a =0.854338 K =0.051326 n =0.038494 b =0.178099	0.0012	0.9988	a = 0.79347 K = 0.080021 n = 0.060016 b = 0.247029	0.0013	0.9990	a = 0.800289 K = 0.079222 n = 0.066018 b = 0.244679	0.0014	0.9980	a = 0.766352 K = 0.057517 n = 0.172551 b = 0.286726	0.0008	0.9980
Two term	2	a =0.870102 K_0=0.002554 b =0.400219 K_1=0.500152	0.0906	0.8857	a = 0.701508 K_0 =0.576663 b = 0.81131 K_1 = 0.003666	0.0735	0.8230	a = 0.50035 K_0 =0.396635 b = 0.779316 K_1 = 0.004408	0.0675	0.7970	a = 0.403213 K_0 =0.001089 b = 18.28288 K_1 = 0.138165	0.0050	0.9560
	4	a =0.274509 K_0=0.499915 b = 1.14 K_1=0.005671	0.0150	0.9834	a = 0.300019 K_0 =0.399696 b = 0.850476 K_1 = 0.002467	0.0573	0.8805	a = 0.900431 K_0 =0.796933 b = 0.808185 K_1 = 0.003115	0.0730	0.8070	a = 0.799963 K_0 =0.005249 b = 0.500012 K_1 = 0.708908	0.0436	0.8410
Aghbashalo	2	K_1=0.005192 K_2=0.001967	0.0260	0.9670	K_1 = 0.009257 K_2 = 0.004049	0.0211	0.9490	K_1 = 0.011905 K_2 = 0.005091	0.0214	0.9350	K_1 = 0.024738 K_2 = 0.016014	0.0137	0.8790
	4	K_1=0.002484 K_2=0.000398	0.0147	0.9840	K_1 = 0.005754 K_2 = 0.002805	0.0145	0.9700	K_1 = 0.008575 K_2 = 0.004346	0.0204	0.9460	K_1 = 0.012703 K_2 = 0.005072	0.0131	0.8090
	6	K_1 = 0.00218 K_2 = 0.00038	0.0077	0.9926	K_1 = 0.003388 K_2 = 0.00057	0.0165	0.9850	K_1 = 0.00822 K_2 = 0.004319	0.0015	0.9880	K_1 = 0.007076 K_2 = 0.002799	0.0052	0.9890
	8	K_1=0.001475 K_2=0.000143	0.0036	0.9960	K_1 = 0.003697 K_2 = 0.001281	0.0081	0.9910	K_1 = 0.003992 K_2 = 0.001349	0.0082	0.9900	K_1 = 0.007773 K_2 = 0.003798	0.0085	0.9800

Table 8: Coefficients for the developed models for different slice thickness at different temperatures

Temperature (^oC)	Thickness (mm)	Constant	SSE	R^2
40	2	$\propto_0=0.006965$ $\propto_1=0.952474$ $\propto_2=0.022908$	0.000155	0.999805
	4	$\propto_0=0.006042$ $\propto_1=0.972514$ $\propto_2=0.011377$	9.74E-05	0.999892
	6	$\propto_0=0.005977$ $\propto_1=0.973709$ $\propto_2=0.010062$	9.38E-05	0.99991
	8	$\propto_0=0.00585$ $\propto_1=0.975355$ $\propto_2=0.007072$	0.000105	0.999896
50	2	$\propto_0=0.008485$ $\propto_1=0.922906$ $\propto_2=0.037976$	9.87E-05	0.999762
	4	$\propto_0=0.010731$ $\propto_1=0.891244$ $\propto_2=0.051066$	9.86E-05	0.999006
	6	$\propto_0=0.006077$ $\propto_1=0.973146$ $\propto_2=0.013773$	9.61E-05	0.999912
	8	$\propto_0=0.006517$ $\propto_1=0.960281$ $\propto_2=0.015588$	0.000102	0.999881
60	2	$\propto_0=0.008472$ $\propto_1=0.922484$ $\propto_2=0.039398$	9.99E-05	0.999699
	4	$\propto_0=0.008389$ $\propto_1=0.921413$ $\propto_2=0.032566$	9.99E-05	0.999736
	6	$\propto_0=0.006812$ $\propto_1=0.954731$ $\propto_2=0.02039$	9.69E-05	0.999864
	8	$\propto_0=0.917596$ $\propto_1=0.150396$ $\propto_2=0.277211$	0.000157	0.998362
70	2	$\propto_0=0.008082$ $\propto_1=0.922527$ $\propto_2=0.03095$	9.93E-05	0.999125
	4	$\propto_0=0.011119$ $\propto_1=0.883178$ $\propto_2=0.06153$	9.96E-05	0.999636
	6	$\propto_0=0.007931$ $\propto_1=0.931256$ $\propto_2=0.030855$	0.000102	0.999845
	8	$\propto_0=0.009231$ $\propto_1=0.907137$ $\propto_2=0.038873$	9.85E-05	0.999767

Table 9: Predicted performance for the drying of cocoyam

Temperature (°C)	Thickness (mm)	SSE	RSME	R^2
40	2	0.000121	0.002398	0.99985
	4	0.000097	0.002145	0.99989
	6	0.000100	0.002669	0.99974
	8	0.000103	0.001913	0.99990
50	2	0.000099	0.002656	0.99976
	4	0.000756	0.006667	0.99842
	6	0.000096	0.002044	0.99991
	8	0.000102	0.002062	0.99988
60	2	0.000100	0.002882	0.99970
	4	0.000096	0.001913	0.99991
	6	0.000097	0.002197	0.99986
	8	0.178360	0.090040	0.79382
70	2	0.000099	0.003322	0.99913
	4	0.000100	0.003156	0.99964
	6	0.000103	0.002536	0.99978
	8	0.000098	0.002480	0.99977
	Best	0.000096	0.001913	0.99991

4. CONCLUSION

Drying is inevitable in preserving agricultural products for future use which prevents spoilage of materials when harvested and also, dried product can be used as a further product mix for secondary production. The proximate and functional analyses were carried out on cocoyam before and after drying. As a result of the processing treatment in the convective hot air dryer, the nutritional content of the cocoyam samples was slightly reduced after they were dried, but it was not significant. The kinetic models studied could be used as tools for optimization of the drying process and description of heat penetration mechanism during the drying process. The empirical models developed could be used for predicting the drying time. In this study the empirical models developed gave the relationship between moisture ratio to thickness (sizes) and drying time and can be used to predict the moisture ratio of the sliced cocoyam between 2 – 8 mm (thin layer) and temperatures of 40, 50, 60 and 70 °C. Activation energy obtained was between 14.802 kJ/mol to 19.138 kJ/mol while the effective moisture diffusivity was between 7.02×10^{-7} to 2.00×10^{-7} m./s for all drying conditions studied. The optimum drying temperature for cocoyam may be suggested to be 60 °C. The use of the semi empirical logarithmic model allowed for sufficient description of the drying curves of cocoyam slices under hot air drying and this could present a useful tool for engineering purposes.

5. ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance and contributions of the laboratory staff of Department of Chemical and Petroleum Engineering and Department of Chemistry, University of Uyo, Uyo toward the success of this work.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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