Determination of drying characteristics and kinetics of bitter kola (garcinia kola) using page's model

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Abstract: Single-layer drying characteristics and kinetics of garcinia kola was studied with slice thicknesses of 1mm, 3mm, 5mm and 7mm at temperatures 45oC, 55oC, 65oC and 75oC using natural convention laboratory oven. The results obtained revealed that garcinia kola slices dried in the falling rate period. Moisture ratio, characteristics drying rate constant, drying time, effective diffusivity and activation energy were significantly ($p<0.05$) affected by drying air temperature and slice thickness. The effect of moisture diffusivity of garcinia kola increased with increase in drying air temperature and slice thickness from 0.82x10-8 to 5.24x10-8 m2/s. Activation energy (Ea) also increased from 3.53kJ/mol to 35.56kJ/mol as slice thickness increased from 1mm to 7mm. Moisture transfer from garcinia kola slices were described by applying page's model. Non-linear regression analysis was used to predict the effect of temperature on page's model indicators. Slice thickness of 5mm had the best goodness of fit of the indicators with lowest reduced chi-square (x2 = 0.00015), root mean square error (RMSE = 0.00236), mean bias error (MBE = -0.0557) and high coefficient of determination (R2 = 0.997). The mathematical model showing the relationship between pages model constant, characteristics drying constant and drying air temperature were also shown.

Keywords: Garcinia kola, kinetics, diffusion, activation energy, page's model.

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1 Introduction

Biter kola is a rain forest tree crop, well cultivated and distributed throughout West Indies, West and central Africa especially in Nigeria. It belongs to botanical family of *Guttifarae*. The trees are always green and are about 15-17m tall with fairly narrow crown. *Garcinia kola* is a seasonal tree crop that is usually harvested annually from July to October. The fruits are edible and reddish yellow when ripened. Each fruits contained about 6-8 smooth elliptically shaped, milk-colour seeds with brown coating. Bitter kola seeds contain 39.52 g/kg crude protein, 43.25 g/kg lipids extract, 11.42 g/kg ash and 114.02 g/kg crude fibre and 215.10 mg/kg sodium mineral) (Afolabi *et al.*, 2006). It contains caffeine and is used for brewery purposes and ethanol production (Dosunmu and Johnson, 1995; Ogu and Agu, 1995; Eleyinmi and Oloyo, 2001; Eleyinmi *et al*., 2004 and Bukola *et al.*, 2006).

Garcinia kola is used in Africa especially Nigeria for cultural and social ceremonies and in both natural and orthodox medicine to treat illnesses like AIDS and the Ebola virus. The extracts; biflavonoids, xanthones and benzophenones have anti-inflammatory, antimicrobial and antiviral properties (Iwu, 1993; Okoro, 1993; Ofor *et al.,* 2010). It is also used to treat cough, nasal congestions, sore throat, cancer, measles and mumps, diarhoea, tuberculosis and, as a detoxifier (Faromi, 2003).

At harvest, the fruits and seeds are of moisture content 50% and 11.58% wet basis respectively.

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Garcinia kola seeds do not require any preservatives and can survive under any atmospheric condition. They remain fresh if kept in the refrigerator while they dry when exposed to open sun. In the local setting, the peasant farmers always preferred to sun-dry the seeds to some extent before storage, either in jute or polyethylene bags. Ofor *et al.*, (2010) discovered in their study that the most popular and acceptable material for enhancing the shelf life of *Garcinia kola* before marketing them is the polyethylene bag.

For decades, drying has been the major means of reducing crop losses improve dried product quality and enhance the shelf life of agricultural products. Simulation models are used for the design and operation of dryers. Drying theory consists of a constant and falling rate periods. In between the two periods lies the critical moisture content, where a sharp discontinuity in drying rate is felt. Most agricultural material do not exhibit constant rate period because it is very short and insignificant for research studies (Geankopolis, 2003). Drying of agricultural materials is mostly in the falling rate period. This is controlled by moisture migration from the interior to outer surface of the material due to water vapour diffusion in the material is governed by moisture gradient (Ertekin and Yaldiz, 2004). In recent times, many researchers have developed a lot of simulation models for natural and forced convection drying systems. Satimehin et al., (2010): studied the drying kinetics of plantain chips; Akpinar, (2003), red pepper; Mohammadi *et al.*, (2008), kiwifruit; Abano, (2010), pineapple slices. The aim of this work is to study the thin-layer drying kinetics of Garcinia kola.

2 Materials and methods

Fresh *Garcinia kola* seeds used for this experiment were purchased from the main market of Umuahia town, the capital city of Abia State, Ngeria. Umuahia, is located on latitude 05^o 29'N and longitude 07^o 33'E of the state. Fresh *Garcinia kola* seeds were sliced to thicknesses of 1, 3, 5, 7 mm and each thickness dried at the temperature levels of 45^o C, 55^o C, 65^o C and 75^o C. Each slice thickness was replicated three times in each of the temperatures levels. The drying oven used was preset at various temperatures and was allowed for thirty minutes to reach a steady state before introducing the drying samples. In the course of drying, the weights of the samples were measured using electronic weighing balance of 0.01kg accuracy. The drying process continued until there was no weight difference recorded. The moisture content dry basis of the samples was calculated as Equation 1:

$$M_{db} = \frac{W_{in} - W_{dm}}{W_{dm}} \tag{1}$$

where: M_{db} = moisture content dry bases. W_{in} = initial weight of the wet solid and W_{dm} = weight of the bone dried sample.

Mathematical equations have been formulated on theories of moisture migration and diffusion through capillaries of agricultural products (Sahay and Singh, 2005). Moisture diffusivity of bitter kola (*Garcinia kola)* was studied by employing Page's equation as shown Equation 2:

$$MR = \exp\left(-kt^n\right) \tag{2}$$

where: MR = moisture ratio; k = constant;
t = drying time

For distribution of moisture within the material, Ficks second law was used to describe the moisture diffusion during drying of spherically shaped objects as specified by Equation 3 (Sahay and Singh, 2005):

$$\frac{M - M_e}{M_o - M_e} = MR = \frac{6}{\pi^2}\left[\sum_{n=1}^{\infty}\frac{1}{\pi^2}\exp\left(\frac{n^2\pi^2 D_{eff}\, t}{6R^2}\right)\right] \tag{3}$$

where; M = moisture content at time t; M_e = equilibrium moisture content; M_o = initial moisture content; D_{eff} = effective diffusivity; R = product thickness

Moisture ratio (MR) can further be simplified as Equation 4 (Doymaz, 2004):

$$MR = \frac{M}{M_o} \tag{4}$$

Taking n = 1 (Geankopolis, 2003), Equation 3 becomes Equation 5:

$$MR = \frac{6}{\pi^2}\left[\sum_{n=1}^{\infty}\frac{1}{\pi^2}\exp\left(\frac{n^2\pi^2 D_{eff} t}{6R^2}\right)\right] \quad (5)$$

Simplifying Equation 5 further Equation 6:

$$\frac{M}{M_o} = Ae^{-kt} \quad (6)$$

Linearizing Equation 6, we have Equation 7:

$$\ln\left(\frac{M}{M_o} = \ln A - kt\right) \quad (7)$$

$$k = \frac{\pi^2 D_{eff} t}{6R^2}$$

Supposing drying is taken place from top and bottom parallel faces of the material, then the thickness of the sphere to be dried from one face is assumed to be half of the total thickness, hence Equation 8;

$$R = \frac{R_{total}}{2} \quad (8)$$

Where: R_{total} = total thickness of the sphere Equation 9

$$k = \frac{2\pi^2 D_{eff}}{3R^2} \quad (9)$$

Page's equation has also been used to study moisture diffusivity of rough rice (Lido cultivar) and kiwifruit (cv. Hayward) (Iguaz *et al*., 2003 and Mohammadi *et al*., 2008 respectively).

2.1 Activation energy (E_a)

Activation energy for diffusion can be estimated using Arrhenius type relationship given Equation 10 and Equation 11 (Rafiee *et al*, 2008).

$$D = D_o \exp\left({}^{E_a}\!/_{TR}\right) \quad (10)$$

$$\ln D_{eff} = \ln D_o - \left({}^{E_a}\!/_{TR}\right) \quad (11)$$

Where: E_a = activation energy (kJ/mol), R = universal gas constant, D_o = effective diffusivity at O° K (m^2/min) and D_{eff} = effective diffusivity at T° K (m^2/min)

The E_a of *Garcinia kola* can be calculated by plotting $\ln D_e$ against $1/T$, which gives a straight line graph with the slope equal to E_a/R.

The goodness of fit of page's model for slice thicknesses studied at various temperatures were evaluated using four statistical parameters; the reduced chi-square (x^2), root mean square error *(RMSE)*, mean bias error (*MBE*) and coefficient of determination (R^2). These statistical parameters were calculated as Equation 12, Equation 13, Equation 14 and Equation 15 (Ertekin and Yaldiz 2004):

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

(12)

$$x^2 = \frac{\sum_{i=1}^{n}\left(MR_{pre,i} - MR_{\exp t,i}\right)^2}{N - l} \quad (13)$$

$$RMSE = \left[\frac{1}{l}\sum_{i=1}^{n}\left(MR_{pre,i} - MR_{\exp t,i}\right)^2\right]^{1/2} \quad (14)$$

$$MBE = \frac{1}{l}\sum_{i=1}^{n}\left(MR_{\exp,i} - MR_{pre,i}\right) \quad (15)$$

where: $MR_{exp,i}$ = i^{th} experimental observed moisture ratio, $MR_{pre,i}$ = i^{th} predicted moisture ratio, N = number of observations and l = number of constants in the model.

3 Results and discussions

3.1 Effect of drying temperature

The results of drying behaviour of *garcinia* kola at 45°C, 55°C, 65°C and 75°C are presented in Figure 1, Figure 2, Figure 3 and Figure 4.

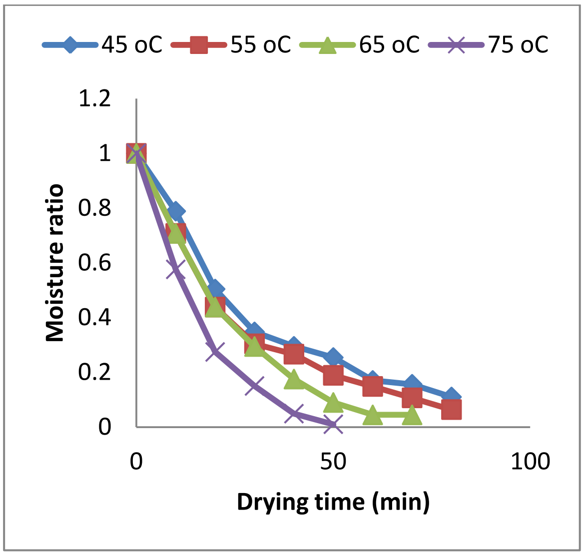

Figure 1 Drying curve of 1mm at various temperatures

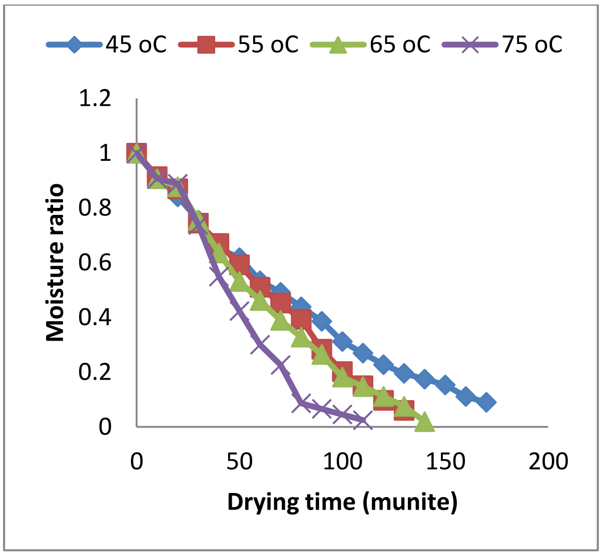

Figure 2 Drying curve of 3mm at various temperatures

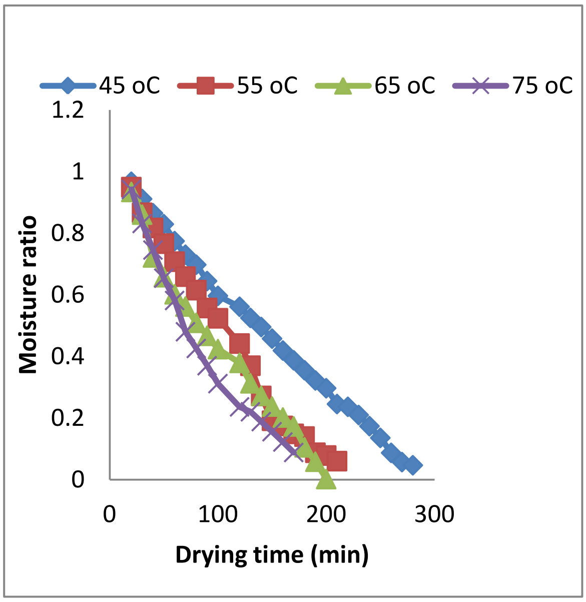

Figure 3 Drying curve of 5mm at various temperatures

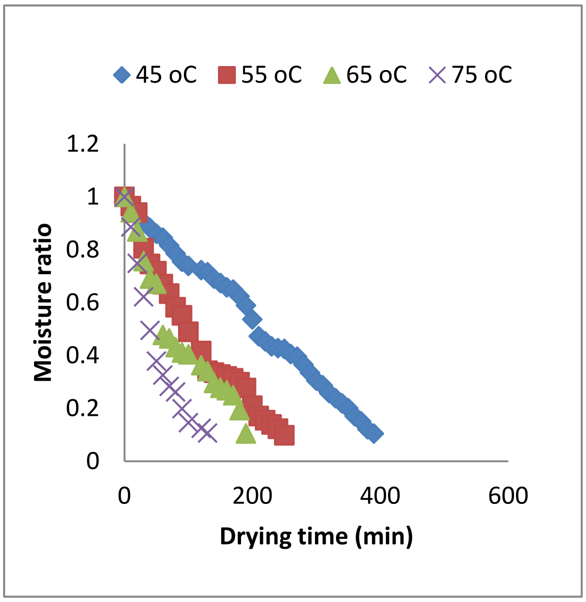

Figure 4 Drying curve of 7mm at various temperatures.

The Figures for all the slice thicknesses (1 mm, 3 mm, 5 mm and 7 mm) studied revealed that moisture content decreases appreciably with increase in temperature. For instance, 75^{o} C for all the slice thicknesses studied dried faster than 45^{o} C. This result agree with the findings of Abano (2010), Aghashlo *et al*., (2010), Singh *et al*., (2008) for dried pineapple slices, apple slices, okro slices and button mushroom respectively. As the material gets dryer, removal of moisture from the particles of *garcinia* kola become very slow thereby requiring more energy to detach water from the solid matrix. This showed that diffusion was the dominant moisture mechanism of moisture movement in the drying of *garcinia* kola and drying process took place in the falling rate period. This is also in line with the recommendation of other researchers that drying of most of agricultural products take place in the falling rate period (Ezikiel and Otten, 1991 and Rahman and Lamb 1991). Drying temperatures also had significant ($p<0.05$) affect on drying of *garcinia* kola.

3.2 Effect of drying time

Effect of drying time on the moisture ratio was significant at 5% level of significance. The time needed to reduce the moisture level of the samples to any given level was a function of drying air temperature. Drying time required to dry 1 mm, 3 mm, 5 mm and 7 mm slice thicknesses of *garcinia* kola was observed to increase from 50-95, 110-180, 190-300 and 197-450 minutes respectively as shown in Figure 1, Figure 2, Figure 3 Figure 4. Thomas and Paulose (2001) studied the drying characteristics of *garcinia combogia* and found that drying time varied from 36 hours for thinner varieties to 48 hours for thicker varieties. The above result is also in agreement with the observations of other researchers; Taiwo *et al*, 2012 and Nguyen and Price, 2007 for field pumpkin (*cucurbiosta pepo L*) slices and banana slices respectively. Thicker slices took longer drying time under the same drying condition because detached water molecules diffuse longer distances to the surface of the sample before evaporation take place.

Table 1 showed statistical indicators used to study drying behaviour of *garcinia* kola at different temperatures and slice thicknesses. From the table, 5 mm had the lowest values of X^2, *RMSE*, *MBE* and high R^2 (0.0573, 0.1976, 0.1399 and 0.996; 0.00236, 0.04723, 0.04204 and 0.991; 0.00454, 0.06475, 0.0575 and 0.993; 0.00015, 0.0695, -0.0557 and 0.997 respectively) for 45°C, 55°C, 65°C and 75°C respectively. This result showed that 5 mm slice thickness had the best goodness of fit among all the slice thicknesses studied.

Table 1 Statistical indicators used to study different drying kinetic conditions of *garcinia kola nut*

S/N	Drying Parameter	75 °C				65 °C				55 °C				45 °C			
		1 mm	*3 mm*	*5 mm*	*7 mm*	*1 mm*	*3 mm*	*5 mm*	*7 mm*	*1 mm*	*3 mm*	*5 mm*	*7 mm*	*1 mm*	*3 mm*	*5 mm*	*7 mm*
1	$\mathbf{X^2}$	0.83142	0.02275	0.057262	0.06238	0.78865	0.33262	0.002361	0.066401	0.04133	0.30989	0.00454	0.052982	0.065823	0.358031	0.00015	0.117264
2	**RMSE**	0.83237	0.14441	0.197592	0.24309	0.58739	0.55575	0.04723	0.246713	0.19166	0.54326	0.06573	0.225528	0.080629	0.583937	0.06953	0.338307
3	**MBE**	0.73675	0.02085	0.139907	0.218767	0.59974	0.24249	0.04204	0.16797	0.09315	0.51464	0.057591	0.145672	0.072488	0.561371	-0.0557	0.233182
4	$\mathbf{R^2}$	0.994	0.945	0.996	0.994	0.997	0.910	0.991	0.994	0.986	0.998	0.993	0.943	0.982	0.998	0.997	0.994

The multiple regression analysis, constants and coefficients expressed in terms of drying temperature by Page's model for various slice thicknesses as shown in Table 2 also revealed that, 5 mm had the best fit (R^2 = 0.999) with equation expressed as $K = -0.154 + 0.005T - 4E\text{-}05T^2$ and $N = -30.44 + 1.240T - 0.012T^2$

Table 2 The relationship between coefficient and constant of the pages model and temperature through the regression method for different thicknesses and temperatures

S/N	R^2	Model of N	R^2	Model of K	Thickness (mm)
1	*0.867*	$126.9 - 4.404T + 0.035T^2$	*0.991*	$0.183 - 0.006T + 7E\text{-}05T^2$	*1*
2	*0.936*	$0.735 - 0.010T + 7E\text{-}05T^2$	*0.973*	$-0.045 + 0.001T + 2E\text{-}05T^2$	*3*
3	*0.999*	$-30.44 + 1.240T - 0.012T^2$	*0.910*	$-0.154 + 0.005T - 4E\text{-}05T^2$	*5*
4	*0.965*	$18.35 - 0.422T + 0.000T^2$	*0.818*	$-0.102 + 0.003T - 3E\text{-}05T^2$	*7*

This result is in line with the report of Rafiee *et al*., (2008) which stated that the drying constant and coefficient of Page's model can be expressed to be linearly dependent on temperature based on multiple regression analysis.

3.3 Effective moisture diffusivity and activation energy

The calculated effective diffusion and activation energy of *garcinia kola* at various temperatures are presented in Table 3. The effective diffusion revealed the rate of internal diffusion of detached moisture within the pore spaces of samples, increased linearly with temperature and slice thicknesses. Effective diffusivity of 1 mm, 3mm 5mm and 7mm increased from 0.082 to 1.5, 0.6 -1.18, 0.99-2.29 and 1.76-5.25 respectively. It was also observed that the activation energy (heat of sensitivity) of *garcinia* kola increased (3.53-35.56) as slice thickness increased from 1-7mm. Besides, R^2 of all the thicknesses are high 0.854 to 993, showing best fit of relationship between the parameters studied. This result followed the same trend with potatoes, greenpea, carriots and pumpkin (Bon *et al*, 1997; Simal *et al*., 1996; Doymaz 2004 and Taiwo et al 2012). The effective diffusivity of *garcinia* kola is within the range of 10^{-11}-10^{-6} $m^{-2}s^{-1}$ reported by Zogras *et al*,. (1996) for food materials.

Table 3 Effective diffusivities and activation energy of diffusion for various slice thickness of *garcinia* kola

Slice thickness (mm)	Temperature °C	D_{eff} x 10^{-8} (m^2s^{-1})	E_a (kJ mol^{-1})	R^2
1	45	0.082	3.53	0.854
	55	0.65		
	65	0.68		
	75	1.54		
3	45	0.6	14.99	0.894
	55	0.88		
	65	0.93		
	75	1.18		
5	45	0.99	26.64	0.990
	55	1.29		
	65	1.88		
	75	2.29		
7	45	1.76	35.56	0.993
	55	1.81		
	65	3.36		
	75	5.24		

4 Conclusion

Thin layer drying characteristics and kinetics of *garcinia* kola studied at four drying air temperatures and slice thicknesses showed that moisture ratio, characteristics drying rate constant, drying time, effective diffusivity and activation energy were significantly *($p<0.05$)* affected by drying air temperature and slice thickness. Slice thickness increased linearly with drying air temperature, effective diffusivity and activation energy. Drying of *garcinia* kola took place in the falling rate period. The drying behaviour of *garcinia* kola fit in page's model showed a good fit for all the conditions studied. The slice thickness of 5mm had the best values of page's model indicators: x^2, *RMSE, MBE and high* R^2 (0.0573, 0.1976, 0.1399 and 0.996; 0.00236, 0.04723, 0.04204 and 0.991; 0.00454, 0.06475, 0.0575 and 0.993; 0.00015, 0.0695, -0.0557 and 0.997 respectively) for 45°C, 55°C, 65°C and 75°C respectively.

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