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RESEARCH ARTICLE

Thin Layer Drying Characteristics of Cocoyam Corm Slices

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ABSTRACT

A study of thin layer drying characteristics of cocoyam (*X. Sagittifolium)* slices was carried out using hot air convective dryer. The drying experiments were performed at five different drying temperatures of 65, 70, 75, 80 and 85ºC at air velocity of 2 m/s with relative humidity of 50, 40, 39.5, 33.8 and 22.2% respectively. Non linear regression analysis was used to model the drying of the cocoyam slices. Drying pattern was observed to be in the falling rate period. Out of the four thin-layers drying models investigated (Newton, Page, Henderson and Pabis and Logarithmic), Logarithmic model best described the drying parameters of cocoyam slices with high values of coefficient of determination of 0.973, 0.988, 0.991, 0.999 and 0.99. The moisture diffusivities at the drying temperatures varied from 2.53 x 10^{-5} m^2/s to 1.09 x 10^{-5} m^2/s. The results compared well with works on similar materials.

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INTRODUCTION

Cocoyam belongs to the Araceae family which serves as staple food for many people in Africa, Asia and the Pacific (Aguegui *et al*., 1992). It has subterranean stems (corm) which are rich in carbohydrates and have nutritional value comparable to potato. Nigeria is the world's largest producer of cocoyam, accounting for about 37% of total world output (FAO, 2006). In the Eastern part of Nigeria, it serves as staple food and is used as a thickener in food preparations especially the varieties *Colocasiaesculenta* and *Xanthosoma cultivar*. The starch grain of cocoyam is small and has improved digestibility and this is an important factor when selecting a starchy food that will not be cumbersome on the digestive system (Ihekoronye and Ngoddy, 1985). Apart from this starch, Cocoyam is rich in good quality protein, vitamin C, thiamine, riboflavin, niacin and high scores of protein and essential amino acids (Amandikwa and Chinyere, 2012; Onayemi and Nwigwe, 1987; Lewu *et al.,* 2009). It forms a good base for infants' foods formulation because of the high digestibility of its starch, reasonable content of calcium and phosphorus (for bone building), B-complex vitamins and pro-vitamin A (Nwabanne, 2009; Onwueme, 1987; Eleje, 1987). Infants in some developing countries are traditionally weaned solely on starch prepared from precooked, wet-milled and wet-sieved corn (Nwabanne, 2009; Akobundu and Hoskins, 1987). Cocoyam, like other root crops, deteriorates few weeks after harvest due to post harvest problems which make the crop scarce and expensive outside the harvesting period. There is therefore need to know the engineering properties of this important root crop necessary for quality assessment, process design and control systems. Understanding of the drying kinetics is needed for design, operation and optimization of crop dryers. The objective of this paper is therefore to model the thin-layer drying characteristics of cocoyam slices in a convective cabinet dryer.

MATERIALS AND METHODS

Material preparation

Cocoyam (*X. Sagittifolium*) samples for the experiments were purchased from Awka, in Anambra State, Nigeria. The fresh corms were thoroughly washed with tap water, peeled using a stainless steel knife and then cut into 0.3 cm thick slices.

Experimental procedure

The moisture content of the cocoyam slices was determined by oven method where bya known mass of the slices was placed in an oven at 103ºC for 72 hours until no variation in weight after two or more subsequent weighing was noted. The moisture content was calculated as the ratio of weight of water removed to weight of the dry matter in the cocoyam slices expressed in percentage (dry basis).

A cabinet dryer fitted with digital thermometers, sling hygrometers air anemometer, fan and electric heater was used in this study. Five temperature settings namely, 65, 70, 75, 80 and 85ºC at air velocity of 2 m/s with relative humidity of 50, 40, 35, 30 and 22% respectively. Air velocity was monitored by an air anemometer (Type 5 anemometer, Air flow Developments Ltd, High Wycombe, UK). Dry-bulb and wet-bulb temperatures of ambient air, drying chamber air and exhaust air were measured by digital thermometers and sling psychrometer respectively.

Experimental samples were loaded into the drier and weighed at intervals of 30mins. This process continued until three consecutive weights for the three drying trays remained constant, indicating equilibrium condition. Figs1.A, 1.B and 1.C, show a sample of cocoyam corms, slices after drying to equilibrium moisture content and that dried in oven respectively. The weighing system consists of a Metler precision balance with an accuracy of 0.01 gram.

Analysis

The lumped parameter and diffusion models were investigated using the data obtained from the experiments. In these models, moisture content of the drying material was expressed in a dimensionless parameter popularly called moisture ratio (MR) as follows:

$$MR = \frac{M_t - M_i}{M_o - M_i} \quad (1)$$

Empirical drying models

Drying in thin layers has attracted sufficient attention and different models have been developed for analyzing and characterizing drying process. Some of the prominent thin layer models are presented in table 2.

Diffusion coefficient

Using Fick's liquid diffusion model the drying rate constant and moisture diffusion coefficients were obtained by solving analytically the following partial differential equation:

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

Equation (2) is subjected to the following initial and boundary conditions:

$M = M_i$, everywhere in the slab at $t = 0$
$M = 0$, at $x = a$ (top, evaporating surface),

$\frac{\partial M}{\partial x} = 0$ at $x = 0$

The model assumes one-dimensional liquid diffusion with constant effective diffusivity, D_{eff}, and no heat (Soret) effects.

The solution of Fick's diffusion law is sum of an infinite series. For long drying times the first term in the series solution of the partial differential equation gives a satisfactory result.

A: cocoyam corms

B: cocoyam slices dried in the dryer

C: A sample of oven-dried cocoyam slices

Fig. 1: Fresh cocoyam corms and slices dried in the convective dryer and oven respectively

The diffusion is usually presented in the form of Eq. (3).

$$MR = \frac{M_t \quad M_i}{M_o - M_i} = B_o e^{-k_o t} \quad (3)$$

For a slab, $B_o = \frac{8}{\pi^2}$ and $k_o = \frac{\pi^2 D_L}{4X_1^2}$
Taking the logarithm of Eq. (3) we have,

$$\text{In MR} = InB_o - K_o t \quad (6)$$

When ln (MR) is plotted against time (t), the values of the intercept (In B_o), the gradient (K_o) were obtained.From these k is evaluated and subsequently D_L.

RESULTS AND DISCUSSION

Moisture content (%db), moisture ratio (MR), drying rate (g/g-min) were plotted against drying time (min). The selected drying temperature were 65ºC, 70ºC, 75ºC, 80ºC and 85ºC at air velocities of 2 m/s and relative humidity of 50, 40, 35, 30 and 22% respectively. The summary of the results of the data analysis was presented in table 2.

Drying characteristics of the cocoyam slices

The drying curves for the slices are shown in Figures 2 below. The curve exhibited falling rate period which is often the characteristics of most agricultural products as reported by Karel and Lund, (2003); Ramaswamy and Marcotte, (2006) and Velic *et al.,* (2007). Samples dried at 65ºC, 70ºC, 75ºC, 80ºC and 85ºC exhibited a single falling rate. The effect of drying time on the moisture ratio of the chips is shown in figures 3.2. For instance, It took 180 minutes to reduce moisture ratio from 1.00-0.0014 at 75ºC of drying temperature, 120 minutes to reduce moisture ratio from 0.91-0.002 at 65ºC of drying temperature and 100 minutes to reduce moisture ratio from 1.00 to 0.09 at 85ºC of drying temperature respectively.

Drying curve constants

The drying data were statistically fitted to Newton, Page, Handerson and Pabis, and Logarithmic models. The models were compared based on their values of coefficient of determination (R^2). Thus the best fit was selected to describe the drying behavior of cocoyam chips. The drying rate constants (k) and other constants of the thin-layer drying models are shown in Table 1.

The R^2 values range from 0.911 to 0.998, from 0.891 to 0.995, from 0.803 to 0.983 and varied from 0.973 to 0.999 for Newton model, Page's model , Henderson and Pabis model, Logarithmic model respectively. The R^2 values for Logarithmic model are higher than that from the other three models. This indicates that Logarithmic model gave a better correlation between the moisture ratio and drying time. It can be seen that, this model was in good agreement with the experimental results. Thus, it can be concluded that Logarithmic model gave the best results compared with other models to describe the drying characteristics of cocoyam slices. Logarithmic model was considered the best model in the present study to represent hot air drying characteristics of cocoyam slices and hence it was used further to determine the values for effective diffusivities of moisture transfer during its drying. Logarithmic model is therefore most suitable to describe the drying process of the slices using tray-batch dryer in the range of the experimental conditions.

Moisture diffusivity (D_L)

The values of D_L for different temperatures are presented in Table 2. The highest moisture diffusivity value of 2.53 x 10^{-5} m^2/s was obtained for the five values of drying temperature of cocoyam slices while the lowest was 1.09 x 10^{-5} m^2/s. The moisture diffusivity in cocoyam chips was affected by the drying temperature and hence the drying temperature affected the internal mass transfer during drying. A similar result of the influence of drying temperature on the moisture diffusivity during air drying has been found in apricots, mulberry, peach slices, tomatoes (Kingsley *et al*., 2007 and (Doymaz, 2007). Though values of D_L for cocoyam have not been reported in the literature, it can be observed that the values were higher than that for most fruits and vegetables. The D_L values for other vegetables include 3.91 - 7.53 x 10^{-10} m^2/s for tomatoes dried at 55ºC to 70 ºC (Doymaz, 2007); 3.72–12.27 x 10^{-9} m^2/s for tomatoes dried at 45 ºC to 75 ºC (Kingsley *et al*., 2007); 4.69 X 10^{-10} m^2/s and 4.26 X 10^{-11} m^2/s for sun drying of mulberry (Doymaz, 2004); 3.04 to 4.41 µm^2/s for peach slices(Kingsly *et al*., 2007); This higher moisture diffusivity of cocoyam is expected because of the lower moisture content, texture and composition of cocoyam which reduces the transfer of moisture compared with fruits and vegetables. The moisture diffusivity of cocoyam is similar to that of yam obtained by Falade *et al.* (2008) which varied from 9.92 x 10^{-7} to 1.02 x $10^{-6}$and 0.829 x 10^{-6} to 1.298 x 10^{-5} m^2/s for *D. alata* and *D. rotundata and* for potato 0.87–2.17 x 10^{-9} m^2/s (Ahrne *et al*., 2003).

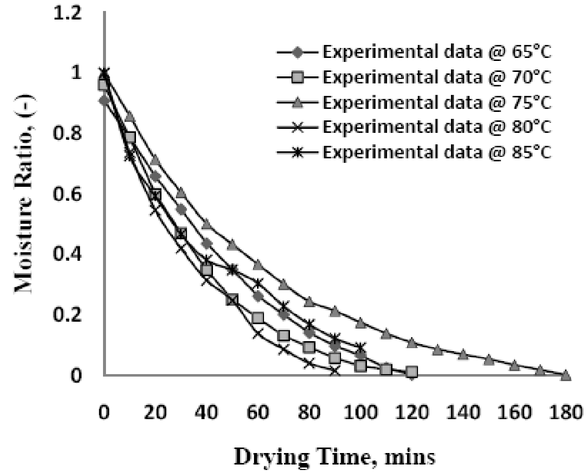

Fig. 2: Plot of moisture Ratio (-) against drying time (min)

Table 1: Model constants with their corresponding R-Square

Model name	Drying temp ºC	Parameter	R^2
	65	k=0.1782	0.927
Newton	70	K=0.1916	0.998
	75	K=0.1879	0.911
	80	K=0.1616	0.991
	85	K=0.1143	0.988
	65	k = 1.1756, n = 0.1807	0.97
Page	70	k= 1.2237, n = 0.1946	0.995
	75	k= 1.2141, n = 0.1897	0.956
	80	k= 1.1031 , n= 0.1657	0.967
	85	k= 0.8746, n= 0.1164	0.891
	65	k=0.3318, a= 0.4406	0.803
Henderson & Pabis	70	k=0.3524, a=0.4122	0.975
	75	k=0.3579, a=0.3726	0.835
	80	k=0.2814 , a=0.5378	0.942
	85	k= 0.2078, a=0.4959	0.983
	65	k=0.7380,a= -0.1899 ,c= 4.0618	0.973
Logarithmic	70	k=0.7343, a=-0.1825,c= -3.8182	0.988
	75	k=0.6994,a=-0.1881, c= -3.4151	0.991
	80	k= 0.7837,a=-0.2060,c= -.0233	0.999
	85	k= 0.6635, a= -0.2286, c=4.5568	0.996

Table 2: Moisture diffusivity of cassava at various temperatures

Drying temp. (ºC)	Moisture Diffusivity (D_L) and drying constants (K)at different temperatures				
	65ºC	70ºC	75ºC	80ºC	85ºC
K	-0.0246	-0.0307	-0.0180	-0.0417	-0.0209
D_L ($m^2 s^{-1}$)	1.495E-05	1.870E-05	1.090E-05	2.530E-05	1.270E-05

Conclusion

In conclusion, the Thin-layer drying of cocoyam slices took place in the falling rate period. Higher temperatures increased the drying rate and shortened the drying time. Logarithmic model fitted the drying data best with highest coefficient of determination (R^2) value of0.999 for thin layer drying of cocoyam corm slices. Therefore, the logarithmic model can adequately be used to describe drying characteristics of cocoyam cormslices. Effective moisture diffusivity of cocoyam corm slices ranged from 2.53 x 10^{-5} m^2/s to 1.09 x 10^{-5} m^2/s in the temperature range of 65ºC to 80ºC. The values fall within the range of those reported for yam and potato chips. The models can be used to simulate the drying characteristics of cocoyam slices and chips which are required to adequately analyze and design drying and storage systems.

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