Modelling of Hot-Air Drying of Pretreated Cassava Chips

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ABSTRACT

Effects of pretreatment (soaking and boiling) on cassava chips dried in a hot air drier at temperature of 60^{o} C and constant air velocity of 1.5 m/s were investigated. Mass transfer during air-drying of pretreated cassava chips was described using Fick's diffusion model. Drying took place entirely in the falling rate period. The form of pretreatment was observed to have an effect on drying rate of the samples. In order to select a suitable drying model for prediction of the drying kinetics of dried cassava chips, four thin-layer drying models were fitted to the experimental data. The Page model best described the drying behaviour of pretreated cassava chips with high correlation coefficient values. The effective moisture diffusivities of the pretreated samples varied from 7.31 x 10^{-7} m^2/s – 8.06 x 10^{-7} m^2/s.
Keywords: Modeling, cassava chips, pretreatment, batch drying

NOTATION
a – drying constant
b – drying constant
k – drying constant, 1/min
L – the half–thickness of the samples
M – moisture content, kg water/kg dry matter
M_e – equilibrium moisture content, kg water/kg dry matter
M_i – initial moisture content, kg water/kg dry matter
N – number of observations
n – drying constant, positive integer
R^2 – coefficient of determination
t – drying time, min
z – number of constants in models
χ^2 – reduced chi–square (reduced mean square of the deviation)

1. INTRODUCTION

Cassava (*Manihot esculenta Crantz*) is the 4th most important staple in the world after rice, wheat and maize (IFAD/FAO, 2000). Cassava is one of the most popular tropical root crops grown in West Africa especially Nigeria. It is a starchy root crop, which can be used as a food security and famine reserve (Cock, 1982). In Africa about 90% of the cassava produced is used for human consumption while 50% of cassava produced is consumed in Asia and 40% consumed in Latin America and the Caribbean respectively (IFAD/FAO, 2000). Cassava root and its products are excellent sources of dietary energy but they are poor sources of protein minerals and vitamins

(Ayankunbi et al., 1991). Cassava roots contain about 32% starch, 65% moisture and 0.8–1% protein on a wet weight basis (Cock, 1985). Its starchy roots are a major source of calories for more than 200 million people worldwide, and it is also one of the most efficient calories producers of all food crops, supplying up to 250 kilo calories/ha (Cock, 1985).

Most of the tuber and root crops do not store well in the fresh form and storage potentials of tubers and root crops also vary. Thus the processing into staple non-perishable and easily transportable products such as flour, chips etc, reduce its perishability. Cassava can be processed into cassava flour, garri and peels can be used as a source of feed to some class of animals. It is also used to produce *ethanol* and *glucose.* Cassava meal from dried root chips has been exported for animal feed purpose (IITA, 1996). Cassava chips help to reduce the volume –to-weight ratio which helps to lower shipping or transportation costs.

The cultivation of cassava requires minimal input, but the processing of cassava roots is laborious and time consuming (Lancester et al., 1982). Production of cassava chips include the following processing steps peeling, washing, soaking or boiling, chipping, drying and packaging. The quality of the dried chips produced is determined mainly in the drying stage. Undesirable biochemical changes and subsequent contamination and spoilage of the chips can only be prevented if the drying process is fast enough and the final product is dry enough (Maskan, 2000). Heat application to food during drying helps to achieve this. Though sun drying is the common method of drying of cassava in the tropics, it has a main disadvantage of slowness of the drying process due to ambient temperature that is used for dying. There is the need for alternative drying methods that will dry the product faster. Hot-air drying which has an extra advantage of providing uniformity of drying (Minguez-Mosquera et al., 1994; Ayensu 1997; Tiris et al, 1994) has been investigated. Product pretreatment has also been considered as a way to accelerate drying (Del Valle et al., 1998; Kudra, 2004).

Drying kinetics of food crops are generally affected by factors which include drying temperature, pretreatment method, relative humidity, and product sizes (Kudra, 2004; Ade-Omowaye et al., 2002) and are crop specific. Thus, research has been carried out on the drying characteristics and kinetics of various food crops (Sacilik et al., 2006; Doymaz, 2007; Vengaiah and Pandey, 2007; Goyal et al., 2008; Therdthai and Zhou, 2009). Physical and thermal properties of agriculture products such as heat and mass transfer, moisture diffusion, energy of activation, and energy consumption are required for ideal dryer design. Several researchers are known to calculate the moisture diffusion, and the energy of activation of agriculture products, and the evaluation of the effect of the drying conditions in the thin-layer drying (Akpinar et al., 2003; Babalis and Belessiotis, 2004; Goyal et al., 2007). This study is carried out to determine and model the drying kinetics of cassava chips dried in a hot-air batch dryer.

2. MATERIALS AND METHODS

2.1 Material Preparation

Cassava tubers were obtained from the University farm of the Ladoke Akintola University of Technology. The cassava were washed, peeled manually, washed and cut into rectangular size of

3x3cm using very sharp stainless steel knives. The initial average moisture content which was about 13% wet basis was obtained by using oven method according to AOAC method (1984).

Cassava slices were dried with pretreatments namely

(i) soaking in water at ambient temperature for 3 days (Sample SK),

(ii) soaking in water for 2 days and then blanching at 100^{o} C for 5 min (Sample SKB),

(iii) blanching at 100^{o} C for 5 min and then soaking in water for 2 days (Sample BSK),.

After each pretreatment, the pretreated slices were dried at hot air temperatures of 60^{o} C.

2.2 Drying procedure

A laboratory scale hot-air dryer of the static-tray type, developed at the Department of Food Science and Engineering, Ladoke Akintola University of Technology (Nigeria), was used for this study. The dryer was installed in an environment with the relative air humidity of about 40–50% and the ambient air temperature about 34^{o}C. The air velocity through the drier was controlled by the speed of the blower. Before beginning the experiments, the dryer system was started in order to achieve a desirable steady state condition of temperature of 60^{o} C and at constant air velocity of 1.5 m s^{-1}. Pretreated samples of 200 g were loaded into the drier and removed at regular intervals until three consecutive weights were constant, indicating equilibrium condition. Firstly weighing was made at short intervals (approximately every 30 min), gradually weighing intervals increased to the maximum of 1 h during the experiment, by using a precision balance with an accuracy of 0.01 g. Moisture contents at equilibrium were determined according to the method of AOAC (1984). Drying experiments were conducted in triplicate and average values were recorded.

2.3 Analysis

A number of theoretical, semi theoretical and empirical drying models have been reported in the literature. The most frequently used model for thin layer drying is the lumped parameter type such as the Newton equation (Liu and Bakker-Arkema, 1997; Kingsly et al., 2007). The moisture ratio during drying is determined by the following equation:

$$\mathrm{MR} = \frac{\mathrm{M - M_e}}{\mathrm{M_i - M_e}} = \exp(-kt) \qquad (1)$$

For the mathematical analysis, it is assumed that the moisture gradient driving force during drying is a liquid concentration gradient. The effect of heat transfer is neglected as a simplifying assumption. For all experimental conditions, the value of $(M\text{-}M_e)/(M_i\text{-}M_e)$ expressing dimensionless moisture content are obtained.

Since during drying, the samples were not exposed to uniform relative humidity and temperature continuously. Therefore, the moisture ratio was simplified according to Pala et al. (1996), Doymaz (2004) and Goyal et al. (2007), and expressed as:

$$MR = \frac{M}{M_i} \qquad (2)$$

2.4 Mathematical Modelling

To select a suitable model for describing the drying process of cassava chips, drying curves were fitted with four thin-layer drying equations. The moisture ratio models are presented in Table 1.

Table 1: Mathematical models given by various authors

Equation	Name	References
MR = exp (-kt)	Newton	Liu and Bakker-Arkema (1997) Kingsly et al., (2007) O'callaghan et al., (1971)
MR = exp (-ktn)	Page	Zhang and Litchfield (1991)
MR = a exp (-kt)	Henderson and Pabis	Henderson and Pabis (1961) Chhinnman (1984)
MR = a exp (-kt)+c	Logarithmic	Yaldiz et al., (2001)

Non-linear regression analysis was performed using SPSS (Statistical Package for Social Scientists) 11.5.1 software package. The coefficient of determination R^2 was one of the main criteria for selecting the best equation. In addition to the coefficient of determination, the goodness of fit was determined by various statistical parameters such as reduced mean square of the deviation χ^2, mean bias error MBE and root mean square error RMSE. For quality fit, R^2 value should be higher and χ^2 , MBE and RMSE values should be lower (Sarasvadia et al., 1999; Togrul and Pehlivan, 2002; Erenturk et al., 2004; Demir et al., 2004; Goyal et al., 2006). The above parameters can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{(\exp,i)} - MR_{(pred,i)}\right)^2}{N - z} \qquad (3)$$

where $MR_{exp,i}$ and $MR_{pre,i}$ are experimental and predicted dimensionless moisture ratios, respectively; N is number of observations; z is number of constants

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{pred,i} - MR_{\exp,i}) \qquad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pred,i} - MR_{\exp,i})^2\right]^{\frac{1}{2}} \qquad (5)$$

2.5 Effective Moisture Diffusivity

Fick's diffusion equation for objects with slab geometry is used for calculation of effective moisture diffusivity. As the cassava slices were dried, the samples were considered to approximate slab geometry. The equation is expressed as (Maskan et al. 2002):

$$MR = \frac{8}{\pi^2} \exp \frac{-\pi^2 D_{eff} t}{4L^2} \tag{6}$$

where MR is the dimensionless moisture ratio, D_{eff} is the effective moisture diffusivity in $m^2\ s^{-1}$, t is the time of drying in seconds and L is half of the slab thickness in metres.

The diffusion coefficient was typically calculated by plotting experimental drying data in terms of ln (MR) versus drying time. The effective diffusivity, D_{eff} can be calculated using method of slopes (Maskan et al. 2002; Doymaz, 2004).

The effective diffusivity of the pretreated cassava slices was calculated thus,

$$Slope(k) = \frac{D_{eff} \pi^2}{4L^2} \tag{7}$$

3. RESULTS AND DISCUSSIONS

3.1 Drying Behavior of Batch Dried Cassava Chips

The drying curves (Fig 1) show the changes in the experimental data-moisture ratio of the different pretreated cassava chips with drying time. The drying of the pretreated cassava chips exhibited the characteristic moisture desorption behaviour, An initial high rate of moisture removal was followed by slower moisture removal in the latter stages. This characteristic behaviour is due to the various forms in which water is present in food products. As the drying process progressed the moisture ratio was observed to decrease non linearly with increase in drying time for all the samples. This is a general trend reported for other food products e.g. mulberry, eggplant, tomatoes, sweet pepper and peach slices. (Doymaz, 2004; Ertekin and Yaldiz, 2004; Doymaz, 2007: Vengaiah and Pandey, 2007; Kingsly et al., 2007). From Table 2, the type of pre-treatment is important during cassava drying because it affect the drying time. Pretreatment thus reduces the resistance to moisture transport thereby increasing the drying rate.
The curve of drying rate of pretreated cassava chips versus drying time is shown in Fig 2. The mean drying rate for SK pretreated cassava chips of 0.0434 kg water per kg dry matter per hour was the highest, followed by SKB having 0.0272 kg water per kg dry matter per hour while that for the BSK pretreated cassava chips which was 0.0165 kg water per kg dry matter per hour was the lowest which indicates that the type of pretreatment carried out has an effect on drying rate.

From the curves shown in Figs 1 and 2, there was no constant rate-drying period in the entire drying process, all drying processes occurred in falling rate-drying period and during the falling drying rate period, the drying process of pretreated cassava chips was mainly controlled by diffusion mechanisms. This is in the agreement with earlier research workers. (Lopez et al., 2000; Piga et al., 2004; Kingsly et al., 2007; Doymaz, 2004, 2005; Akanbi et al., 2006; Ertekin and Yaldiz, 2004; Sacilik et al., 2006).

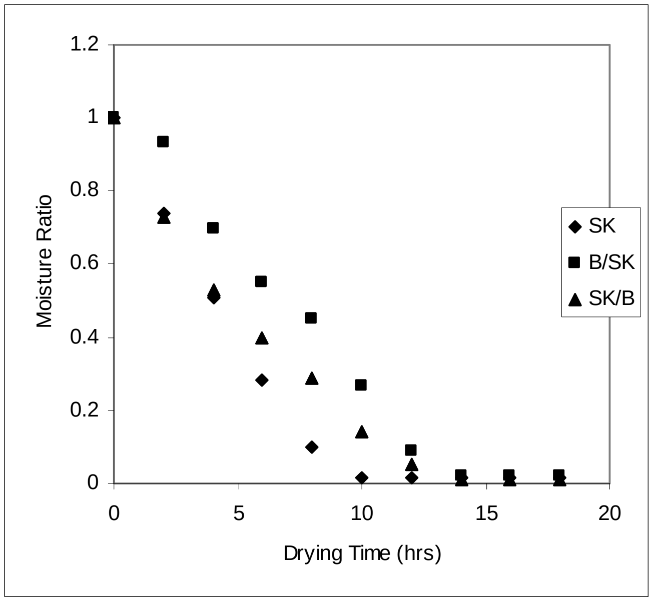

Fig 1 Batch drying curves for pretreated cassava chips

Table 2: Effective moisture diffusivity for drying of pretreated cassava chips

Drying Method	Pretreatment	Drying time (hrs)	Effective Moisture Diffusivity (m^2/s) (D_{EFF} x 10^{-7})
Batch drying	SK	8b*	8.06a
	BSK	13a	7.31b
	SBK	12a	7.75ab

* Values with same superscript in the same column are not significantly different (P < 0.05)

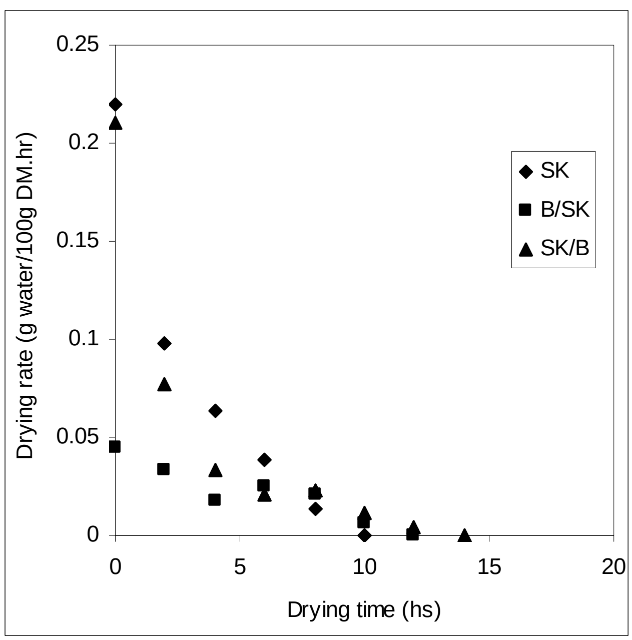

Fig 2. Drying rate of batch dried cassava chips versus drying time

3.2 Mathematical Modelling of Drying Curves

The drying data obtained (moisture ratio against drying time) for the different pretreatments samples were fitted by Handerson and Pabis, Newton, Logarithmic and Page models. The models were evaluated based on coefficient of determination (R^2), the reduced chi-square (χ^2) and root mean square error (RMSE). The selection of the best model to describe the drying behavior of pretreated cassava chips will be based on the highest R^2 and lowest χ^2 and RMSE values. The drying constants (k) and (b) and coefficients (a) and (n) values for the thin-layer drying models are shown in Table 3 while the results of statistical analysis for four models are shown in Table 4 for different experimental conditions. Values of R^2 greater than 0.92 were obtained for all the models except the Newton model.

Table 3: Values of model constants for batch dried pretreated cassava chips

Model	Drying method	Treatment	n	a	k	b	R^2
Henderson and Pabis	Batch	SK		1.0596	0.2372		0.9676
		BSK		1.1223	0.1490		0.9290
		SKB		1.033	0.1866		0.9786
Newton	Batch	SK			0.2266		0.9638
		BSK			0.1345		0.9119
		SKB			0.1814		0.9773
Logarithmic	Batch	SK		0.9439		-0.3626	0.9230
		BSK		1.3206		-0.4710	0.9657
		SKB		1.005		-0.3652	0.9769
Page	Batch	SK	1.5750		0.08457		0.9899
		BSK	1.8481		0.2184		0.98115
		SKB	1.2581		0.1096		0.9783

Table 4: Values of statistical parameters for batch dried pretreated cassava chips

Model	Drying method	Treatment	R^2	χ^2 x 10^{-3}	RMSE
Henderson and Pabis	Batch	SK	0.9676	4.819	0.06239
		BSK	0.9290	4.069	0.05706
		SKB	0.9786	1.869	0.03813
Newton	Batch	SK	0.9638	4.866	0.06586
		BSK	0.9119	12.076	0.09829
		SKB	0.9773	2.766	0.04840
Logarithmic	Batch	SK	0.9230	5.681	0.06741
		BSK	0.9657	13.331	0.10953
		SKB	0.9769	2.929	0.04989
Page	Batch	SK	0.9899	0.894	0.02636
		BSK	0.9812	2.733	0.04610
		SKB	0.9783	1.637	0.03618

The R^2 varied from 0.9786 to 0.929, from 0.9773 to 0.9119, from 0.9769 to 0.9230 and varied from 0.9899 to 0.9783 for Henderson and Pabis model, Newton model, Logarithmic model and Page's model. The R^2 values for Page's model are higher than that from the other three models. This indicates that Page's model gave a better correlation between the moisture ratio and drying time. The χ^2 values varied from 1.869 x 10^{-3} to 4.819 x 10^{-3}, 2.766 x 10^{-3} to 12.076 x 10^{-3}, 2.929 x 10^{-3} to 13.331 x 10^{-3} and 0.894 x 10^{-3} to 2.733 x 10^{-3} for Henderson and Pabis, Newton, Logarithm, and Page models respectively. While RMSE changed between 0.03813 and 0.10953 for all examined models, this value changed between 0.02636 and 0.04610 for Page model according to the different experimental conditions. According to the results of RMSE and chi-square values of all the thin layer drying models for all drying conditions, the Page model gave the lowest values and thus it was chosen to represent the thin layer hot-air drying of pretreated cassava chips.

It can be seen that, this model was in good agreement with the experimental results since the highest values of R^2 and the lowest values of χ^2 and RMSE was obtainable with the Page drying model. Thus, it can be concluded that Page model gave the best results compared with other models to describe the drying characteristics of pretreated cassava chips. Similar results were reported in the literature for various food products (Karathanos and Belessiotis, 1999; Ahmed and Shivhare, 2001; Akpinar and Bicer, 2004, 2005; Doymaz and Pala, 2002; Kashaninejad and Tabil, 2004; Doymaz, 2007; Dissa et al., 2008). The experimental and predicted moisture ratio values with drying time were compared in Fig 3. Validation of the established model was made by comparing the experimental moisture ratio values with the predicted ones. There was good agreement between the experimental and predicted variables which indicates that the Page model could be used satisfactorily to predict the thin layer hot-air drying of pretreated cassava chips.

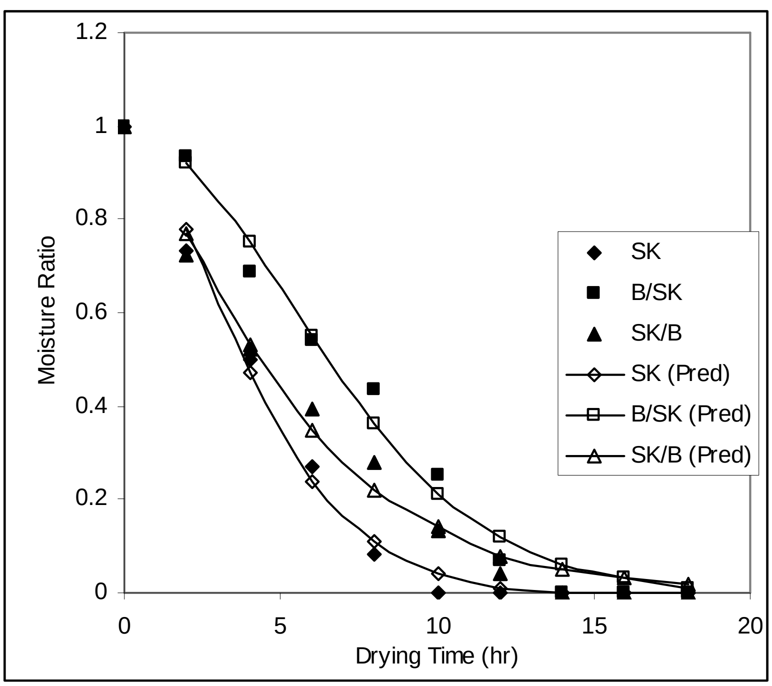

Fig 3. Experimental and predicted moisture ratio for batch dried pretreated cassava chips

3.3 Effective Moisture Diffusivity

The slope method was used to determine the effective moisture diffusivity, Deff. The calculated values of Deff for different temperatures are presented in Table 2. The highest effective diffusivity value of 8.06×10^{-7} m^2/s was obtained for SK pretreated samples while the lowest 7.31×10^{-7} m^2/s was obtained for BSK pretreated cassava chips. The moisture diffusivity in pretreated cassava chips was affected by the pre-treatments and hence the pretreatment affected the internal mass transfer during drying. A similar result of the influence of pretreatments on the moisture diffusivity during air drying has been found in apricots, mulberry, peach slices, tomatoes (Pala et al., 1996; Doymaz, 2004; Kingsly et al., 2007; Doymaz, 2007).

Though values obtained are within the suitable range for food products (10^{-11} to 10^{-6} m^2/s) reported in the literature (Marinos-Kouris and Maroulis, 1995; Zogzas et al., 1996; Maskan et al., 2002), it can be observed that the values of Deff for pretreated cassava chips was higher than that for most fruits and vegetables. The Deff values obtained for other vegetables include 3.91 - 7.53 X 10^{-10} m^2/s for tomatoes dried at 55^o C to 70^o C (Doymaz, 2007); 3.72–12.27 X 10^{-9} m^2/s for tomatoes dried at 45^o C to 75^o C (Akanbi et al., 2006); 2–4.2 X 10^{-10} m^2/s for garlic slices (Madamba et al., 1996); 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 $\mu m^2/s$ for peach slices (Kingsly et al., 2007); 0.87–2.17 X 10^{-9} m^2/s for potato (Ahrne et al., 2003). This higher moisture diffusivity of cassava is expected because of the lower moisture content, texture and composition of cassava which reduces the transfer of moisture compared with fruits and vegetables. The effective moisture diffusivity is however similar to that for yam obtained by Falade et al (2008) which varied from 9.92×10^{-8} to 1.02×10^{-7} and 0.829×10^{-6} to 1.298×10^{-5} m^2/s for *D. alata* and *D. rotundata*. Samples pretreated with soaking only had higher Deff values than samples pretreated with blanching. This is because in samples pretreated with blanching there is the occurrence of resistance to moisture migration as a result of gelatinization of starch granules. This is similar to the results of Dandamrongrak et al. (2003), Njitang and Mbbofung (2003) and Falade et al. (2008) for banana, taro and yam.

4. CONCLUSION

The following conclusions can be made from the results obtained from the study of the effect of pretreatments on drying of pretreated cassava chips.

- Pretreated cassava chips using SK had shorter drying times and higher drying rates than other samples.
- Drying curves of oven dried pretreated cassava chips showed a falling rate-drying period only under the experimental conditions employed.
- The highest R^2 value (0.9899) and lowest value of χ^2 (0.894×10^{-3}) and of RMSE (0.02636) for the thin layer oven drying process for pretreated cassava chips was obtained from the Page model.
- According to the results, the Page model could adequately describe drying characteristics of pretreated cassava chips than the other models since it has shown a better fit to the experimental data as compared to the other models (Henderson and Pabis, Newton and Logarithmic).

– Effective moisture diffusivity values of oven drying which ranged from 7.31 x 10^{-7} m^2/s to 8.06 x 10^{-7} m^2/s are in the suitable range for similar products.

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