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Prediction of the Drying Rates of Cassava Slices During Oven Drying

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Abstract: Fresh cassava (*Manihot* sp.) NR 8082 tubers were peeled and diced into cubes of size thicknesses 5 and 10 mm, respectively. The cubes were dried in thin layers in an oven drier. Thicknesses (x = 5 and 10 mm) drying temperatures of the air (70 and 80°C) and drying times (from 0 min until the sample attained equilibrium, at intervals of 10 min). The response variable was the moisture content of the cassava slices. Results showed that high temperatures and smaller thickness of slices resulted in faster approaches to equilibrium moisture content of the samples. Two drying models namely page and exponential models were used to compare with the obtained experimental data. The drying data of the cassava slices fitted well with Page model with high accuracy for artificial drying (R^2>0.9). The predicted and experimental results were very much in agreement.

Key words: Prediction, drying rates, cassava slices, oven drying, thickness, respones variable

INTRODUCTION

Cassava (*Manihot esculenta*) is the third most important staple food in the tropics. It provides 37% of the calorie requirement in Africa. Cassava possesses high energy when compared to other foods. Low inputs and efforts are required for its production (Odogola, 1988). Over two thirds of the total production of cassava is consumed in various forms by humans. Its usage as a source of ethanol for fuel, energy in animal feed and starch for industry is increasing.

Problems limiting utilization and consumption of cassava include rapid spoilage of the roots after harvesting (Nghiem, 1991). Drying of cassava chips reduces the risks of contamination and mold growth (Jeon and Halos, 1994). To compare the drying rate of cassava chips with existing models becomes an important study. Drying rate can be expressed as:

$$R = \frac{Wos}{A} \frac{dX}{dt} \tag{1}$$

Where:
A = Drying surface area
Wos = Weight of dry sample

Assuming the drying rate represented by Eq. 1 are established in terms of the moisture gradient between the sample and the surrounding drying air (Olivas-Vargas *et al*., 2003) then:

$$\frac{dX}{dt} r = k_y (X_r - X_e) \tag{2}$$

Where:
dX_r/dt = Drying rate
X_r = Moisture content of sample (dry basis)
Xe = Moisture content of air
Ky = Mass transfer co-efficient – (dry constant)

The moisture content is normalized using the dimensionless relation:

$$\theta = \frac{Xr - Xe}{Xo - X_e} \tag{3}$$

Where, Xo is moisture content at initial time i.e., t = 0. Molina-Corral (1998) had a normalized form of Eq .2 to be;

$$\frac{d}{dr}\left[\frac{Xr - X_e}{Xo - X_e}\right] = Ky\left[\frac{X_r - X_e}{Xo - X_e}\right] \tag{4}$$

Equation 4 can be made explicit and transposed as:

$$\frac{d\theta}{\theta} = k_y dt \tag{5}$$

Integrating Eq. 5, we have:

$$\text{In}\theta = k_y t + C \tag{6}$$

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Taking natural logarithm on both sides of Eq. 6, transforms into:

$$\theta = \text{Exp}(K_y\, t + C) \quad (7)$$

Given:

$$A = \text{Exp}\, C \quad (8)$$

Then Eq. 7 becomes:

$$MR = \theta = A\text{Exp}(k_y\, t) \quad (9)$$

Where:

MR = Moisture Ratio

Therefore:

$$MR = Ae^{kyt} \quad (10)$$

Equation 10 can be linearized into:

$$\text{In}\, MR = \text{In}\, A + K_y t \quad (11)$$

This is the exponential equation for drying rates. The page equation is empirical (Sun and Woods, 1994; Hernandez *et al*., 2000) it is given as:

$$MR = \frac{Xr - Xe}{Xo - Xe}, \quad = \text{Exp}(-Kt^N) \quad (12)$$

Where:

MR = Moisture Ratio
X_r = Moisture content of product at time t
X_o = Initial moisture content of the product
X_e = Equilibrium moisture content
K = Drying constant
t = Drying time
N = Regression constant

The drying rate of the Page model becomes:

$$\frac{dX}{dt} = (-KNt^{N-1})(X - Xe) \quad (13)$$

or

$$\text{In}(-\text{In}\, MR) = \text{In}\, K_y + N\, \text{In}\, t \quad (14)$$

MATERIALS AND METHODS

Freshly harvested cassava tubers (NR 8082) were obtained from the National Root Crops Research Institute (NRCRI) Umudike farms. The roots were sliced into 2 categories of 5 and 10 mm thick rectangular slices of 40 mm length and 40 mm breadth. The samples were subjected to oven drying in trays at two selected temperatures of 70 and 80°C, respectively. The drying response variable measured was weight loss at time intervals of 200 sec. This involved rapid removal of the sample from the oven dryer and quickly weighing on an electronic balance to determine the moisture content and quickly putting them back to continue drying. This process was allowed to continue until no more weight losses were recorded between successive readings. The percentage of moisture content wet basis calculated as follows:

Percentage of moisture content (wet basis):

$$\frac{W_2 - W_3}{W_2 - W_1} \times \frac{100}{1} \quad (15)$$

Where:

W_1 = Initial weight of empty tray (g)
W_2 = Weight of tray + weight of fresh sample (g)
W_3 = Weight of tray + weight of dry sample (g)

The Moisture Ratio MR was also obtained and is defined as:

$$MR = \frac{Xo - Xe}{Xt - Xe} \quad (16)$$

Where:

Xo = Initial moisture content of sample
Xt = Sample moisture content at time t
Xe = Equilibrium moisture content

The experimental data obtained were fitted into both the Page and Exponential models and analysed statistically (Table 1-3).

Table 1: Anova table of the experimental data on completely randomized design

Sources of variance	Degrees of freedom	SS	MSS	F_{cal}	F_{tab}
Treatment	3	1116.124	388.708	10.624	2.68
Error	135	4399.391	31.880	-	-
Total	138	5505.515	-	-	-

SS: Sum of Squares; MSS: Mean Sum of Squares

Table 2: Constants and regression coefficients for the exponential model

	Temperature of the air (°C)			
	5 mm	10 mm	5 mm	10 mm
Parameters	70°C		80°C	
A	1.2800**	1.4160**	0.8680***	1.6770*
K_y	-0.0107*	-0.0091*	-0.0099*	-0.0126*
R^2	0.6620	0.8630	0.6240	0.8950

*, ** and *** indicate that the values are significant at 1, 5 and 10% levels of probability, respectively

Table 3: Constants and regression for the Page model

	Temperature of the air (°C)			
	5 mm	10 mm	5 mm	10 mm
Parameters	70°C		80°C	
N	1.1560**	1.0120**	1.0040*	1.1410*
K_y	0.0040*	0.0066*	0.0117*	0.0042*
R^2	0.9620	0.9620	0.9960	0.9600

R^2 = Coefficient of multiple determination

RESULTS AND DISCUSSION

The graphs of the moisture content versus time and moisture ratio versus time of the experiments are shown, respectively in Fig. 1 and 2. At the temperature of 70%, the equilibrium moisture content of 5 mm slices was reached after 18000 sec (300 min) and 430 min for 10 mm thick slices (Fig. 1). At 80°C the equilibrium moisture content of 5 mm slices was reached after 240 min while for 10 mm slice it was reached after 350 min.

These trends showed that increased temperature of drying caused a faster attainment of equilibrium moisture content and hence also increased the drying rate. Also, the thicker the slices the slower the approach to equilibrium moisture content and the slower the drying rate. For the exponential model for a thickness of 5 mm the deviation of the constant A from unity is about 28% for 70°C and 13.2% for 80°C.

For 10 mm thickness deviations were 41.6 and 67.7% at 70 and 80°C, respectively. For the Page model, the deviation of N from the ideal values were 15.6 and 0.4% for 5 mm slices at 70 and 80°C, respectively and 1.2 and 14.1% for 10 mm thickness slices at 70 and 80°C, respectively. From the experimental data, the best correlation between the drying air T, drying time t and thickness of slices x are best fitted on a model with the following linear function:

$$K_y = Bo + B_1T + B_2t + B_3x + B_4Tt + B_5tx + B_6T_x \quad (17)$$

Where ky is drying constant. Bo, B_1.... B6 are regression coefficients with the following values: B_o = 0.006336, B_1 = 0.000597, B_2 = 0.001019, B_3 = 0.000939, B_4 = 0.000134, B_5 = 0.000127, B_6 = -0.002287. Therefore, the model for predicting the drying rates of cassava slices is given by:

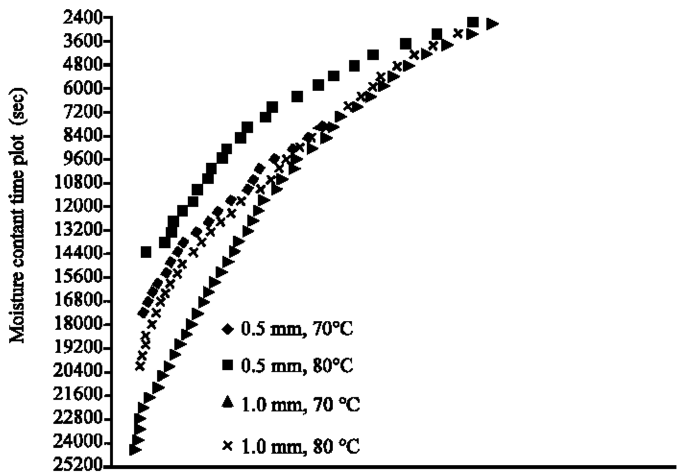

Fig. 1: The equilibrium moisture content versus time

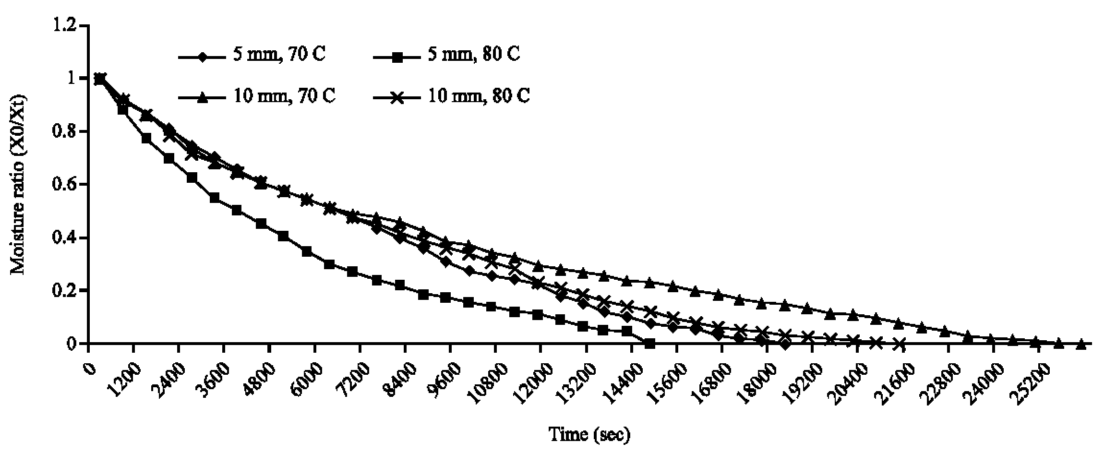

Fig. 2: Moisture ratio versus time of the experiment

$$DR = -(Bo + B_1T + B_2t + B_3x + B_4Tt + B_5tx + B_6Tx)\,Nt^{N-1}\,[X_t - X_e] \quad (18)$$

Where:

DR = Drying Rate

N = Regression constant

CONCLUSION

The study indicates a high correlation between the experimental results and the two models compared. However, the 5 mm thick slices exhibited the best correlation to the Page model at 80°C with high R^2.

The Page model, therefore is a better model for predicting the drying rates for cassava slices. Also, higher temperatures and smaller thickness resulted to faster drying.

RECOMMENDATIONS

It is recommended that other root and tuber crops be studied the same way to see how their drying rates compare with the models. Other temperatures of drying may also be investigated.

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