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Modelling the Drying of Normal and Blanched Unripe Plaintain using the Oven Dryer

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Abstract: Kinetic modelling of the drying of unripe plantain slices for normal and hot water blanched samples was determined experimentally as a function of drying temperature. The plantain slices were fully exposed to heat at 70°C with the use of laboratory drying oven. Experimental values for moisture ratios, percentage moisture content as well as drying rates with respect to drying time was determined. The drying experimental data obtained were fitted to thin layer drying kinetic models using the nonlinear regression method. Error measurements were carried out using Root Mean Squares Error (RMSE), reduced (χ^2) and coefficient of determination (R^2). The results showed that It the experimental data fitted the diffusion model with coefficient of determination value of 0.999267 followed by RMSE = 0.018159 and χ^2 = 0.00528 for the blanched sample studied, diffusion model was also gave the best fit of R^2 = 0.999724 followed by RMSE = 0.010277 and χ^2 = 0.000211 effective moisture Diffusivity (D_{eff}) was $1.05\times10^{-5}m^2/h$ and $1.39\times10^{-5}m^2/h$ for normal and blanched plantain samples, respectively this indicate that moisture diffusion as well as heat transfer were greater in blanched samples when compared to normal samples. This may be the cause of reduction in the total drying time.

Key words: Drying kinetics, thin layer, plantain, kinetic models, oven, moisture diffusivity, blanch, moisture content

INTRODUCTION

Drying is a complex process involving both heat and mass transfer where water is transferred from the inside of the food to the outside through diffusion. It conditions foods by the elimination of the water until a level that allows its balance with the ambient air in such a way that preserves its physical and chemical characteristics (Ruiz and Montero, 2005). As a result It can cause substantial reduction in weight and volume, minimizing packaging, storage and transportation costs and enables storability of the product under ambient temperature (Ok *et al*., 2007).

Drying time varies widely depending on the drying method selected and the size and amount of moisture in food pieces. Sun drying requires the most time an electric dehydrator requires the least.

In conventional oven heating, the heat is transferred from the surface to the interior of the material. Thus, a pressure is generated between the surface and interior due to evaporation such that the interior moisture is driven out and evaporation continues at the surface. However, conventional oven heating has low energy efficiency with negative quality effects (Huang, 2013).

Blanching is the most commonly used thermal pretreatments before processing of agricultural products as it can destroy enzymes which cause deterioration reactions, off flavor and undesirable changes in color, texture and nutrients. In addition, blanching can also enhance drying rate by expelling intercellular air from the tissues, softening the texture or by dissociating the wax on the products skin (Fang *et al*., 2012).

Musa paradisiaca is a perennial and herbaceous plant belonging to the family Musaceae and the genus Musa. It is a tree like perennial with an underground rhizome (Nweze *et al*., 2015). Plantain pulp is very rich in iron, potassium, vitamin A and ascorbic acid but low in protein (Ketiku, 1973). Unripe plantain is traditionally processed into fufu in Nigeria and other West African Countries (Ukhun and Ukpebor, 1991). It is however, gradually finding application in weaning food formulation and composite flour preparation (Olaoye *et al*., 2006; Ogazi, 1996).

Recently, a number of studies have been reported on modelling and drying of food materials. Experimental studies conducted on thin layer drying process of various food products such as chilli, red pepper, potato, carrot,

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eggplant and tomato have been reported. Modelling is advantageous in the design of new or upgraded drying systems of the existing ones (Olurin *et al*., 2012).

The aim of this study was to evaluate the drying rates of normal and blanched plantain using the oven and to choose suitable model's that best describe drying behaviour of normal and blanched plantain slices using some selected thin layer models.

MATERIALS AND METHODS

Preparation of samples: A bunch of French horn specie of matured unripe plantain produced by the Faculty of Agriculture, University of Uyo, Uyo, Akwa Ibom State was obtained and used for this study.

The unripe plantain bunch was collected and prepared the same day it was harvested. Plantain was immersed in a plastic bowl, washed with potable water to remove dirt and then peeled with the aid of a stainless kitchen knife to have the pulp which was then sliced into cylindrical pieces. The cylindrical ring equipment of 4.2 mm thickness and 30 mm diameter was fused through the slice plantain samples to give an exact shape, size, thickness and diameter while the remaining portions of the plantain slice outside the cylindrical ring was trimmed-off, so that, the dimension of the sliced plantain samples fits to that of the cylindrical ring. This was repeated and 50 pieces were obtained. An electronic weigh balance was used so, the determine that the 50 samples were of equal weight of 3.0 g.

Preparation of blanched pre-treated samples: The 25 pieces of equal weight 3 g, thickness 4.2 mm and diameter 30 mm of sliced portion of plantain samples was blanched by immersion into hot water at boiling point temperature and gently stirred for 5 min. The samples were immediately removed and immersed in fresh water at temperature of 31°C to remove excessive heat. The blanched samples of plantain slices were re-weighed and an approximate increase in weight of 4.2 g (±0.1) each was observed and recorded.

Oven drying process: The oven preheated for 90 min to reach the steady state set drying air temperature conditions of 70°C. The plantain samples were placed in the oven (Model DHG 9101 S.N) with the blanched samples on the top tray and the raw samples on the bottom tray. Drying experiments were carried out at temperature of 70°C (±1+°C). The sliced plantain samples were allowed to dry at intervals of 20 min. At the expiration of the drying time interval the drying samples were removed from the oven and placed on the desiccator and allowed to cool for 5 min before weighing.

Table 1: Thin-layer kinetic models used to describe the drying kinetics of unripe plantain slices

Model names	Model equations	References
Henderson	MR = a exp (-kt)	Radhika
Logarithmic	MR = a exp (-kt)+c	Shen
Two term	MR = a exp (-kt)+b exp (-kt)	Flores
Diffusion	MR = a exp (-kt)+(1-a) exp (-kbt)	Flores
Modified Henderson	MR = a exp (-kt +b exp (-gt)+cexp (-ft)	Lahsani
Two term exponential	MR = a exp (-kt)+(1-a)+exp (-kat)	Doymaz

Where MR = Moisture Ratio (dimensionless); a, b, c, k and n = drying constants; t = Drying time (h)

Kinetic modelling: Since, the time used for the entire drying experiment of sliced plantain samples was 2 h 40 min, hence, Eq. 1 which is suitable for calculation of Moisture Ratio (MR) for long drying time was used (Doymaz, 2004; Doymaz and Pala, 2002):

$$MR = \frac{M_t}{M_o} \tag{1}$$

Thin-layer drying models in Table 1 were used to describe the drying kinetics of unripe plantain using drying oven. These models were chosen because of their wide application in modeling of agricultural produce successfully (Zhang *et al*., 2016; Olawoye *et al*., 2107). Nonlinear regression method using the solver add-in of the Microsoft Excel package was used to obtain the parameters of the selected kinetic models.

Goodness of fit statistics: Goodness of fit criteria was used to evaluate the fitting of model to experimental data. The highest values of coefficient of determination (R^2) and lowest values for reduced (χ^2) as well as Root Mean Square Error (RMSE) were chosen for goodness of fit.

Determination of percentage moisture contents: This was determined from the data obtained during the drying experiment for both raw plantain slice samples as well as blanched samples. Equation 2 was adopted for the calculation of percentage Moisture content (M_t) at different drying time:

$$M_t\,(\%) = \frac{\text{Initial weight-Oven weight}}{\text{Oven dry weight}} \times 100\% \tag{2}$$

Determination of moisture ratio and moisture diffusivity: This shows the relationship between effective moisture diffusivity and moisture ratio for a cylindrical shape according to (Zogzas and Maroulis, 1996):

$$MR = \sum_{i=1}^{\infty} \frac{4}{b_n^2} \exp\left(\frac{-b_n^2 D_{eff} t}{r^2}\right) \tag{3}$$

Where:
MR = Dimensionless Moisture Ratio
D_{eff} = Effective moisture Diffusivity (m^2h^{-1})
r = Radius of cylinder
b = Bessel function (2.4048)

Equation 3 can further be simplified by taking the natural logarithm of both sides to have Eq. 4 as follows:

$$\text{InMR} = \text{In}\frac{4}{b^2} - \frac{b^2 D_{eff} t}{r^2} \quad (4)$$

The effective moisture diffusivities was calculated from the slope Eq. 5 by plotting ln (MR) versus time as can be seen in Eq. 4 (Olurin *et al*., 2012):

$$\text{slope} = \frac{b^2 D_{eff}}{r^2} \quad (5)$$

RESULTS AND DISCUSSION

Table 2 shows that the initial weight of plantain slices for normal and blanched samples were 3 and 4.2 g, respectively. There was a reduction in weight of the plantain slices gradually with a proportionate increase in time from 20-160 min. At 160 min, the equilibrium weight of the normal plantain samples in the oven was observed to be constant at 1.5 g indicating no further decrease in weight irrespective of increase in drying time while that of the blanched plantain samples was observed to be constant at 2.1 g at the time of 120 min.

Modelling of the thin layer drying characteristics: Several research reports suggested that sometimes linearization of non-linear experimental data may distort the error distribution structure of models (Zogzas and Maroulis 1996; Ho, 2004; Kumar, 2007; Kumar, 2006; Ho *et al.*, 2005) which might lead to violation of the theories behind the models (Ho, 2006). The problems due to linearization can be avoided by using nonlinear regression method.

The parameters for the drying kinetics of the various model studied and their error functions as been presented as seen in Table 3 and 4. Experimental data for moisture ratio with drying time were fitted to the 6 drying models studied to express the drying characteristics of normal and blanched plantain slices dried by oven dryer and the statistical evaluation of the models using three error functions are presented in the Table 3 and 4. The quality offit of various models was evaluated using R^2, reduced χ^2 and RMSE values (Kinniburgh, 1986). The results presented in the Table 3 and 4 showed that the two term exponential model had the least coefficient of determination of 0.9979 from the statistical analysis for both the normal and blanched plantain samples.

Table 2: Experimental data for normal sample of French horn plantain

	Weight (g)	
Time (min)	Normal	Blanched
0	3.0	4.2
20	2.8	3.7
40	2.7	3.3
60	2.5	2.8
80	2.3	2.3
100	2.1	1.8
120	1.9	2.1
140	1.7	2.1
160	1.5	2.1
180	1.5	-
200	1.5	-

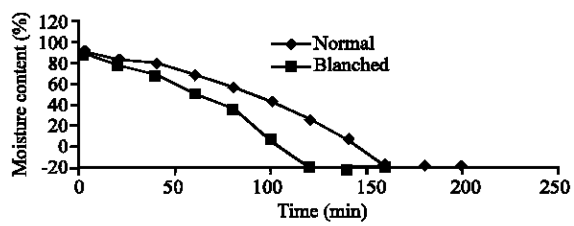

Fig. 1: The relationship between percentage moisture content against time for both normal and blanched plantain samples

Diffusion model was found to describe the drying characteristics better when compared with other five models used in this study. From Table 3 and 4, all the 6 models tested described the drying characteristics of normal and blanched plantain slices reasonably well.

Percentage moisture content: During the early part of drying the blanched plantain samples lose moisture a little faster than the normal plantain samples. As drying continues the rate of loss of moisture content for blanched plantain samples increases until it gets to equilibrium point where the loss of moisture content stops and this occur at 120 and 160 min for normal plantain samples as shown in Fig. 1.

Moisture ratio: Figure 2 show that the moisture ratio for both the normal and blanched sliced plantain samples decreased continuously with the increase of drying time until it gets to the time of 120 and 160 min for blanched and normal plantain samples, respectively. This observation is in agreement with the previous studies (Akpinar, 2006; Akgun and Doymaz, 2005; Falade *et al.*, 2007).

Table 3: Kinetic parameters for normal plantain sample using nonlinear regression method

	Constants						Goodness of fit statistics		
Models	K	A	b	C	f	g	RMSE	χ^2	R^2
Henderson	0.0043	1.0548	-	-	-	-	0.0202	0.0005	0.9987
Logarithmic	0.0043	1.0549	-	-	-	-	0.0202	0.0000	0.9991
Two term	0.0043	0.5294	0.5254	-	-	-	0.0202	0.0007	0.9991
Diffusion	0.0015	2.2937	0.0000	-	-	-	0.0182	0.0005	0.9993
Modified Henderson	0.0043	0.3516	0.3516	0.3516	0.0043	0.0043	0.0202	0.0016	0.9991
Two term exponential	0.5230	0.0071	-	-	-	-	0.0307	0.0013	0.9979

Table 4: Kinetic parameters for blanched plantain sample using nonlinear regression method

	Constants						Goodness of fit statistics		
Models	K	A	B	c	f	g	RMSE	χ^2	R^2
Henderson	0.0058	1.0298	-	-	-	-	0.01491	0.0003	0.9994
Logarithmic	0.0058	1.0299	-	0.0000	-	-	0.01491	0.0004	0.9994
Two term	0.0058	0.5044	0.5255	-	-	-	0.01491	0.0004	0.9994
Diffusion	0.0027	1.7484	0.0000	-	-	-	0.0103	0.0002	0.9997
Modified Henderson	0.0058	0.3433	0.3433	0.3433	0.0058	0.0058	0.0149	0.0000	0.9994
Two term Exponential	0.4645	0.1124	-	-	-	-	0.0038	0.0009	0.99799

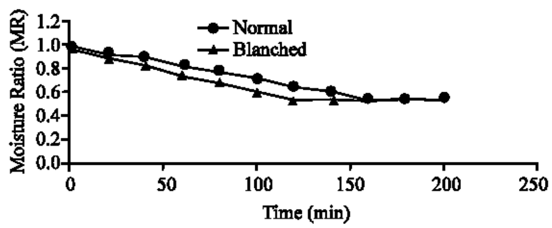

Fig. 2: The relationship between moisture ratio and time for normal and blanched slice samples of plantain

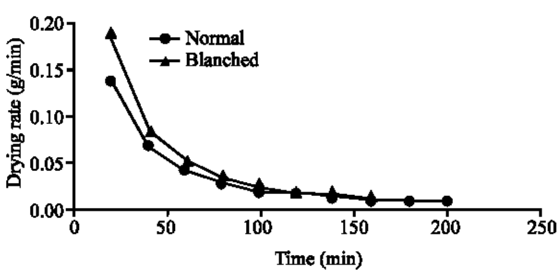

Fig. 3: The relationship between drying rate and time for normal and blanched slice samples of plantain

Drying rate: Figure 3 show the relationship between drying rate and time for both normal and blanched sliced plantain samples. It is seen that the drying rate falls until it gets to 120 and 160 min for the blanched and normal plantain samples, respectively. The drying of most food materials occur in the falling rate period and moisture transfer during drying is controlled by internal diffusion (Akpinar, 2006; Falade *et al.*, 2007; Doymaz and Pala, 2002).

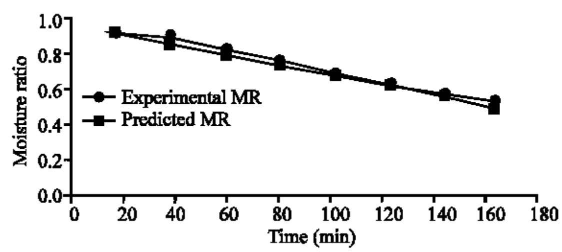

Fig. 4: Graphical comparison of predicted and experimental moisture ratios against drying time (min) for normal plantain sample

Comparison of predicted and experimental moisture ratios at various drying time: Table 3 and 4 show that when experimental data were fitted to the six kinetic models studied, the diffusion model showed best fit for both the normal and blanched plantain samples with the coefficient of determination values of 0.9993 and 0.9997, respectively.

Validation of the selected model: Diffusion model has been shown by comparing the predicted moisture ratio with the experimental moisture ratio at 70°C drying air temperature. A good agreement was observed between experimental moisture ratio and predicted moisture ratio values as they both laid around straight line for diffusion model as shown in Fig. 4 and 5. These suggest that the diffusion model could be used to explain drying behaviour of normal and blanched plantain.

To have a more precise investigation into the various models, a regression analysis of outputs and desired

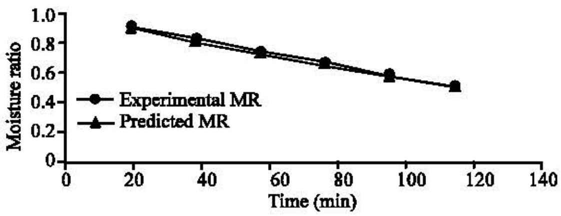

Fig. 5: Predicted and experimental moisture ratios against drying time (min) for blanched plantain sample

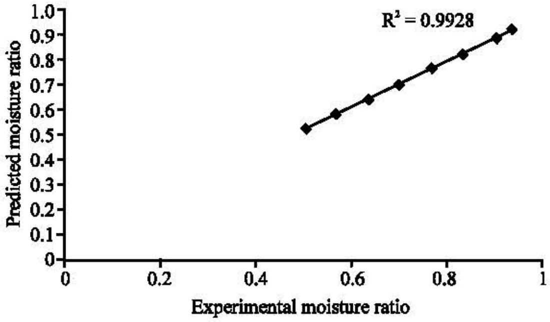

Fig. 6: Predicted and experimental moisture ratios using diffusion model for normal sample

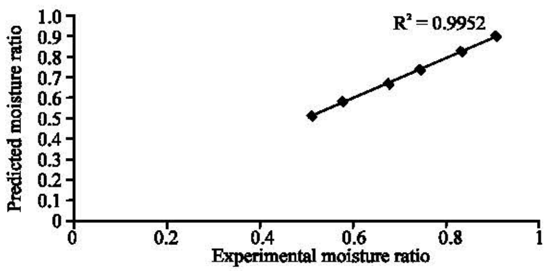

Fig. 7: Predicted and experimental moisture ratios for blanched sample

targets was performed as shown in Fig. 6 and 7. There was a high correlation between the predicted values by the diffusion model and the measured values resulted from experimental data. The correlation coefficient was 0.9928 and 0.9952 for the normal and blanched plantain samples which implied that the diffusion model succeeded in predicting the moisture ratio.

Effective moisture diffusivity for normal and blanched plantain sample: When the effective diffusivities for normal and blanched plantain samples are compared as shown in Fig. 8 and 9, it was observed that the calculated normal plantain sample. This is in agreement with Newton's Law of diffusion. When the interstices or pore D_{eff} for blanched plantain sample was greater than that of

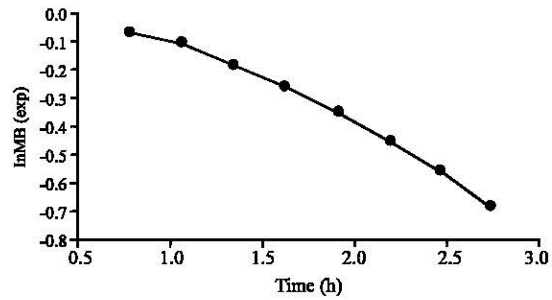

Fig. 8: Graph of lnMR (exp) against time (h) for blanched sample

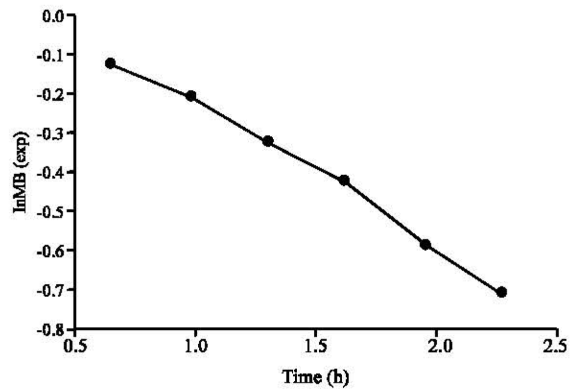

Fig. 9: Graph of lnMR (exp) against time (h) for blanched sample

spaces of any sliced plantain sample is opened-up by blanching, the rate of evaporation of moisture and heat penetration through the pores is always higher than that of normal plantain sliced samples and this enhances short drying time. These values are within the general range for food materials (Zogzas and Maroulis, 1996). An increase in effective moisture diffusivity for blanched plantain sample when compared with the normal plantain sample was also noticed at the same drying air temperature with (Olurin *et al.*, 2012).

CONCLUSION

The influence of blanching on the drying characteristics of plantain slices has been investigated. The results obtained indicated that blanching pre-treatment of plantain slices can drastically reduce total drying time, thereby reducing cost of long drying time.

Kinetic models such as Henderson, logarithmic, two term, diffusion, modified Henderson and two term exponential has experimental data fitted to them to test for goodness of fit. The experimental data were fitted to the models and using nonlinear regression method. The diffusion model showed the best fit for both samples studied with the goodness of fit statistics such as Root Mean Square Error (RMSE), reduced (χ^2) and coefficient of determination (R^2) calculated. The values obtained included RMSE = 0.0182, χ^2 = 0.0053 and R^2 = 0.9993 for normal sample as well as RMSE = 0.0103, χ^2 = 0.0002 and R^2 = 0.9997 for blanched sample. The R^2 values above for normal and blanched samples indicated the closeness of the diffusion model to unity and the values of RMSE and χ^2 indicated that for the diffusion model error measurement tended towards zero. The diffusion model was validated with the experimental data and the R^2 values of 0.9928 and 0.9952 were obtained for the normal and blanched plantain samples, respectively. The effective moisture diffusivities calculated were 1.05×10^{-5}m²/h for normal sample and 1.39×10^{-5}m²/h for blanched sample.

The rate of moisture diffusion and evaporation is greater for blanched samples than in normal plantain sliced samples.

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