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THIN LAYER MODELING OF FHIA-21 (TETRAPLOID PLANTAIN)

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ABSTRACT

Thin-layer modeling of FHIA-21 (Tetraploid Plantain) slices was studied in a conventional hot-air dryer. The samples were dried at 50, 60, 70 and 80°C air temperature with control and blanching as pretreatments. Increase in drying air temperature from 50 to 80°C decreased the drying time from 16 and 17.5 hours to 3 and 7 hours for untreated and blanched samples, respectively. Drying of the plantain occurred in falling rate period. Five thin layer drying models were evaluated by fitting to the experimental moisture ratio data. Among the mathematical models investigated, the Page model satisfactorily described the drying behaviour of the slices with high r^2 values and low χ^2 and RMSE. The effective moisture diffusivity of the plantain slices increased as the drying air temperature was increased. Also the moisture diffusivity and activation energy were lower for blanched samples.

Keywords: tetraploid plantain, thin layer, moisture diffusivity, activation energy, drying.

INTRODUCTION

Plantain (Musa AAB) is a major source of carbohydrate in diets of people from Latin America, through most of Africa and from countries of South-east Asia (Marriott and Lancaster, 1983). It is estimated that 60 million people in West Africa derive more than 25% of their carbohydrate intake from plantain (Ortiz and Vuylsteke, 1996). They are consumed both as energy-yielding food and as dessert, providing more than 200 calories (food energy) a day (Stover and Simmonds, 1987). Plantains are known to be a great source of calcium, vitamins A, B_1, B_2, B_3, B_6, C and minerals such as potassium and phosphorous.

In Ghana, plantains contribute about 13.1% of the Agricultural Gross Domestic Product (AGDP) and its per capita annual consumption of 96.4 kg per head (Lescot, 2000) is higher than other starchy staples except cassava. It is of great socio-economic and nutritional significance and generates considerable employment. Annual production in the country is about 1.8 metric tonnes for AAB subgroup of which only 0.5 tonnes is exported (Lescot, 1999).

Despite the high value of plantain, growing pest and disease pressures have affected production, the most notable being the fungal disease Black Sigatoka (*Mycosphaerella fijiensis*) (Stover and Simmonds, 1987; Swennen, 1990). Yield losses due to the disease are highly significant ranging from 20 to 50%. Under very severe conditions yield losses may be as high as 80% (Hemeng and Banful, 1994). Unfortunately all the landraces in Ghana are susceptible to the Black Sigatoka disease. In view of this, new hybrids were introduced in 1994 to supplement the landraces. The tetraploid (AAAB) hybrids are high yielding and disease tolerant.

Plantain is a seasonal and highly perishable crop. Ogazi (1982) reported that over 80% of the crop is harvested during the period of September to February, and that there is much wastage during this period as some of the products do not store for a long period. This results in seasonal unavailability and limitations on the use by urban population. Therefore, there is a need to develop preservation methods for this crop.

Air-drying is considered to be one of the simplest and most economical ways of commercially processing fruit and vegetables (Brennan *et al*., 1990). Air-drying could be considered as appropriate to developing countries as the product, suitably packaged, can be stored for several months without the risk of spoilage and can be milled into flour and rehydrated for a variety of uses (Marriott and Lancaster, 1983).

Consequently, knowledge of moisture content in FHIA-21 is important for process design and conditions. Moreover, mathematical models would also be desirable for describing the drying mechanism. Thin-layer drying models have found application among mathematical models and these kinds of models have three categories. While theoretical thin layer models take into account resistance to moisture transfer, semi-theoretical and empirical models consider external resistance to moisture transfer between product and heated air. Some parameters are related to the properties of the sample such as thickness, shape, particle size and drying air temperature. Therefore, description of a model and the repeatability of the drying curves are important. In this study attention is focused on drying and modeling of FHIA-21 using mathematical models. In addition, the effective moisture diffusivities and activation energy were calculated.

MATERIALS AND METHODS

Material

FHIA-21 produced by Crop Research Institute of the CSRI, Fumesua was used in the study. FHIA-21 had an initial moisture content of 69.5% ± 2.04 (wet basis) determined by drying in an oven (Genlaboven model D35, MIDO/3/SSF, England) to a constant weight.

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Sample preparation

Finger samples were collected from the second hand from the proximal end of the bunch following the recommendation of Baiyeri and Ortiz (2000) the same day the bunch was harvested. Samples were immersed in a plastic bowl with potable water and then peeled with the aid of stainless kitchen knife. The pulp was then sliced into cylindrical pieces with same thickness of 10mm. sliced samples were thoroughly mixed and divided into two. One portion was not pretreated and it served as the control. The second portion was steam blanched (BLA) for 10 minutes.

Drying equipment and process

An experimental Gas dryer was used in the study. The dryer consists of a wooden chamber on wooden stand, a compartment at the base for housing the gas burner, and a single door serving as the main opening. The drying compartment had ten moveable trays with wire mesh base. The walls of the chamber were double layered and had an air gap of 0.02m thick. The fifth tray was used in the study.

Sliced samples all of equal thickness of 10mm and diameter 30mm were loaded in the gas dryer on trays with a wire mesh base (0.2m x 0.2m; an average of 30 discs) in a single layer. Drying experiments were conducted at 50, 60, 70 and 80°C (±1°C). The dryer was allowed to run for 30 minutes to reach the set drying air temperature conditions. The rate of drying and the drying profile of the various plantain cultivars were determined by evaluating the moisture content of the samples taken at a constant interval of 30 minutes by a digital balance of (Triton 201, USA) 0.01 g accuracy. Drying curves of moisture ratio over drying period were constructed to depict drying profile graphically.

Modeling of drying data

In order to determine the moisture ratio as a function of drying time, five different thin layer drying models obtained from literature were used. These models were also used by other investigators; Diamante and Munro (1991); Ertekin and Yaldiz (2004); Karathanos and Belessiotis (1999); Midilli, Kucuk, and Yapar (2002). The selected mathematical models namely: Lewis, Page, Modified Page, Logarithmic and Henderson and Pabis are identified in Table-1.

Table-1. Thin layer drying curve models considered.

Model name	Model	References
Lewis	MR = exp (-kt)	Bruce (1985)
Page	MR = exp(-kt^y)	Page (1949)
Modified page	MR = exp(-kt)^y	Overhults *et al*., (1973)
Henderson and pabis	MR = a exp(-kt)	Henderson and pabis (1961)
Logarithmic	MR = a exp(-kt) + c	Togrul and pehlivan (2002)

In these models MR is the dimensionless moisture ratio = (M - Mc)/ (Mo - Mc), where M is the moisture content of the product at each moment, Mo is the initial moisture content of the product and Mc is the equilibrium moisture content. The values of Mc are relatively small compared to M and Mo. Thus MR= (M - Mc)/ (Mo - Mc) was reduced to MR= M/Mo (Doymaz, 2004; Doymaz and Pala, 2002; Lomauro *et al*., 1985).

Non linear regression using STATGRAPHICS CENTURION XV was used to obtain each constant of the selected mathematical models. Moreover the criteria such as coefficient of determination (r^2), reduced chi-square (χ^2) and root mean square error (RMSE) were calculated to evaluate the fitting of the model to experimental data. The highest values for r^2 and lowest values of χ^2 and RMSE were chosen for goodness of fit.

These parameters were calculated as follows:

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

$$\chi^2 = \left[\frac{\sum_{i=1}^{n}\left(\mathbf{MR_{pre,i}} - \mathbf{MR_{exp,i}}\right)^2}{N-Z}\right] \quad (2)$$

Where $MR_{exp,i}$ is the ith experimental moisture ratio, $MR_{pre,i}$ is the ith predicted model moisture ratio N is the number of sampling times and z is the number of constants in the drying model.

Effective moisture diffusivity

The effective moisture diffusivity was calculated by the following equation (Crank, 1975):

$$MR = \frac{M_t - M_C}{M_o - M_C} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left[\frac{-(2n+1)^2\pi^2 D_{eff}\, t}{4L^2}\right] \quad (3)$$

Where D_{eff} is the effective moisture diffusivity (m^2s^{-1}), L is the half thickness which in this case is 5mm and t is the drying time.

Several researchers have demonstrated that equation (3) could further be simplified to a straight line equation (8) (Dadali *et al*., 2007).

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$$ln\ MR = ln\left[\frac{8}{\pi^2}\right] - \left[\frac{\pi^2 D_{eff}\ t}{4L^2}\right] \quad (4)$$

The effective moisture diffusivities were calculated by plotting experimental drying data in terms of ln(MR) versus time equation (5) and the plot gives a straight line with a slope of:

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4L^2} \quad (5)$$

Activation energy

The temperature dependence of the effective diffusivity was represented by an Arrhenius relationship (Madamba *et al*., 1996, Sanjuan, Lozano *et al*., 2003).

$$D_{eff} = D_o \exp\left[{}^{E_a}/_{RT}\right] \quad (6)$$

Where, D_{eff} is effective moisture diffusivity (m^2/s), D_o is the pre-exponential factor of the Arrhenius equation (m^2/s), E_a is the activation energy (KJ/mol), R is the universal gas constant (KJ/mol K), T is the absolute temperature (K). The natural logarithm of Deff as a function of the reciprocal of absolute temperature (K) was plotted and the slope was evaluated to find the activation energy. Slope = Ea/R.

RESULTS AND DISCUSSIONS

Analysis of drying curves

Moisture ratio versus drying time for FHIA-21 slices at the various temperatures and treatments are given in Figures 1-2.

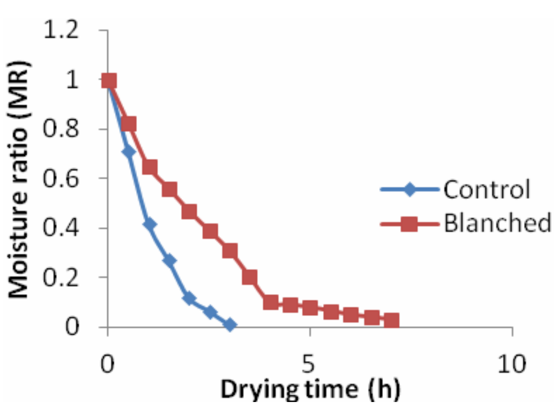

Figure-1. Moisture ratio of FHIA-21 slices dried at 80°C.

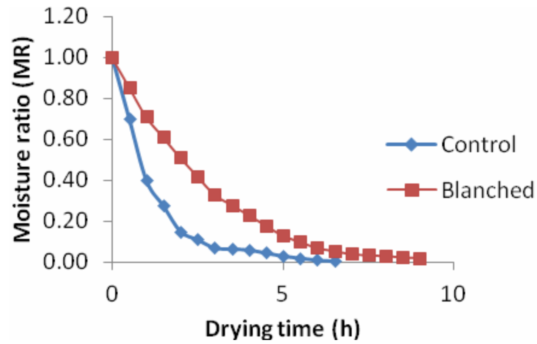

Figure-2. Moisture ratio of FHIA-21 slices dried at 70°C.

It can be seen that moisture ratio decreases continuously with drying time and no constant drying rate exists. This observation is in agreement with previous literature studies on the convective drying of banana (Demirel and Turhan, 2003; Maskan, 2000). The rate of moisture loss was initially high (Figures 3 and 4).

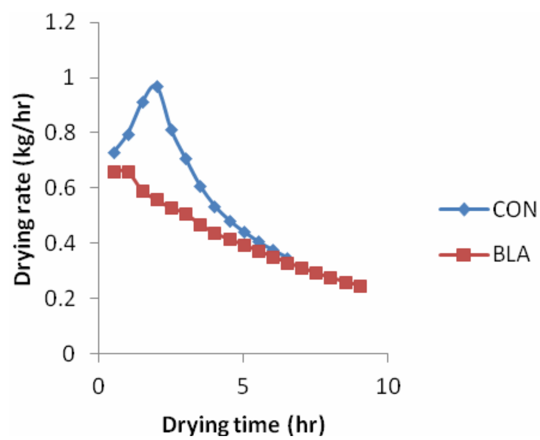

Figure-3. Drying rate curve of FHIA-21 slices dried at 80°C.

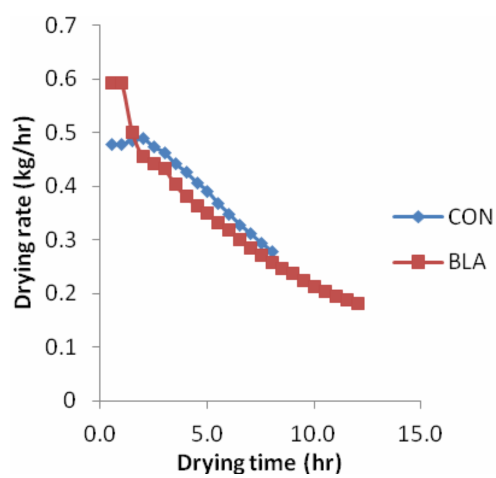

Figure-4. Drying rate curve of FHIA-21 slices dried at 70°C.

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However two-thirds of the time was spent removing the last third of the moisture content due to the slow diffusion process. Moreover, the rate of moisture loss was greater at higher temperature. As expected the increase in drying temperature resulted in a substantial increase in drying rate for both the Control and the Blanched due to the quick removal of moisture from the samples thereby affecting the total drying time. Meanwhile the Control had a higher drying rate in all temperature variations compared to the Blanched samples. This may be attributed to the steam which partially cooked the sliced surfaces during blanching thereby ceiling the surface pores preventing ease of removal of moisture from the interior to the surface during dehydration. In separate studies blanching did not result in reduced drying time in banana due to the effect of starch gelatinization (Dandamrongrak *et al*., 2003). Also blanching of potato did not increase the rate of drying because of starch gelatinization (Alzamora and Chirife, 1980) that resulted in reduced porosity (Mate *et al.*, 1998).

Modeling of drying curves

The results of the statistical computation are summarized in Table-2.

Table-2. Statistical results obtained from the different thin layer drying models.

Model	Treatment	T (^oC)	r^2	χ^2	RMSE
Lewis	Control	50 ^oC	0.978	0.00201	0.04419
		60	0.976	0.00245	0.04801
		70	0.994	0.00046	0.02059
		80	0.985	0.00208	0.04219
	Blanched	50	0.975	0.00223	0.04656
		60	0.997	0.00201	0.01391
		70	0.993	0.00063	0.02444
		80	0.985	0.00146	0.03692
Page	Control	50	0.999	0.00014	0.01149
		60	0.999	0.00009	0.00918
		70	0.995	0.00047	0.02017
		80	0.998	0.00028	0.01421
	Blanched	50	0.994	0.00058	0.02350
		60	0.998	0.00014	0.01142
		70	0.999	0.00012	0.01067
		80	0.991	0.00090	0.02801
Modified page	Control	50	0.978	0.00306	0.04419
		60	0.977	0.00261	0.04801
		70	0.994	0.00049	0.02059
		80	0.985	0.00249	0.04219
	Blanched	50	0.976	0.00229	0.00229
		60	0.997	0.00021	0.01391
		70	0.994	0.00067	0.02444
		80	0.985	0.00157	0.03692
Henderson and Pabis	Control	50	0.986	0.00133	0.03538
		60	0.983	0.00184	0.06282
		70	0.995	0.00047	0.02022
		80	0.987	0.00219	0.03962
	Blanched	50	0.987	0.00114	0.03286
		60	0.998	0.00019	0.01337
		70	0.995	0.00053	0.02170
		80	0.986	0.00145	0.03550
Logarithmic	Control	50	0.995	0.00047	0.02107
		60	0.996	0.00042	0.01938
		70	0.996	0.00040	0.01864
		80	0.997	0.00048	0.01860
	Blanched	50	0.989	0.00103	0.03130
		60	0.998	0.00015	0.01041
		70	0.998	0.00017	0.01264
		80	0.992	0.00090	0.02785

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In all cases r^2 values were greater than 0.97 indicating a good fit. Figures 4 and 5 show the comparison of predicted and experimental moisture ratio for the Page model at 70°C. Similar results were obtained at other temperatures. It was seen that the drying curves of all models tend to under or overestimate the experimental data at different stages of the drying process. It was seen that the Lewis model provided a good fit at 70°C for the Control and 60°C and 70°C for the Blanched samples. The Modified Page was generally tending to a good fit at higher temperatures for both Control and Blanched samples. The Henderson and Pabis model which is a semi theoretical model was tending to a good fit at temperatures of 60°C and 70°C for both Control and Blanched samples. Although the Logarithmic model showed good results, the Page model was the best descriptive model for both Control and Blanched samples at all temperatures as indicated by high r^2 values and lower X^2 and RMSE values compared to the other models (Table-2). Generally r^2, X^2 and RMSE values ranged from 0.995 to 0.999, 0.00009 to 0.00047 and 0.00918 to 0.02017 for the Control and 0.991 to 0.999, 0.00092 to 0.00058 and 0.01067 to 0.02801 respectively for the Blanched samples.

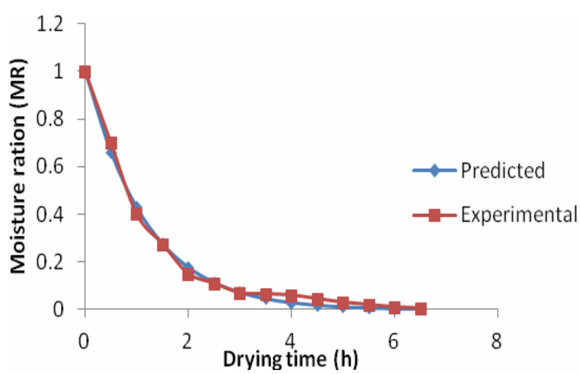

Figure-5. Moisture ratio for predicted and experimental (Control) at 70°C using page model.

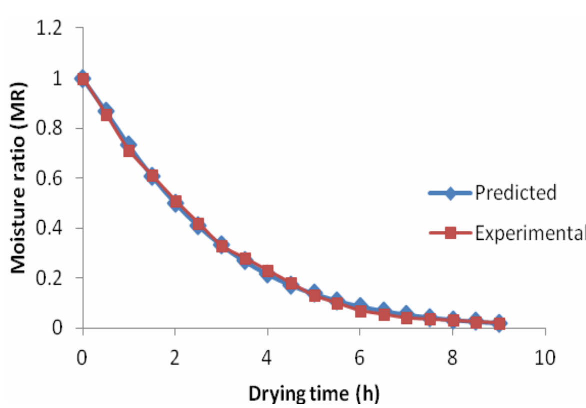

Figure-6. Moisture ratio for predicted and experimental (Blanched) at 70°C using page model.

Moisture diffusivity and activation energy

Values of D_{eff} are given in Table-3. Effective moisture diffusivity of FHIA-21 ranged from 5.40 x 10^{-10} to 3.98 x 10^{-9} m^2/s. These values are comparable to 1-3x10^{-11} mentioned for the drying of apricot in the temperature range of 50 -80°C (Abdelhaq and Labuaza, 1987) and 2.32 x 10^{-10} to 2.76 x10^{-9} m^2/s for mulberries dried at 60-80°C (Doymaz, 2004). The moisture diffusivity increased as drying air temperature was increased. Due to the influence of blanching on internal mass transfer of FHIA-21 during drying, blanched samples had lower moisture diffusivity values. This is contrary to results of the influence of pretreatments on the moisture diffusivity during air drying of apricot (Pala *et al*., 1996).

Table-3. Values of effective diffusion coefficient for FHIA-21 dried at different temperatures and pretreated differently.

T (°C)	**Deff** (m^2/s)	
	Control	Blanched
80	3.98x10^{-9}	1.48x10^{-9}
70	2.05x10^{-9}	1.29x10^{-9}
60	1.38x10^{-9}	5.93x10^{-10}
50	5.96x10^{-10}	5.40x10^{-10}

Activation energy of FHIA-21 slices was found to be 56.61 kJ/ mol and 35.23 for untreated and blanched samples, respectively. This might be due to the high moisture content of the variety and that pretreatment proved to be more effective. Ea values reported correspond to reported activation energies for food materials (Saravacos and Maroulis, 2001; Rizvi, 1986).

Table-4. Drying times for treated and untreated FHIA-21 at different temperatures.

T (°C)	**Drying time** (h)	
	Control	**Blanched**
80	3	7
70	6.5	9
60	8	12
50	16	17.5

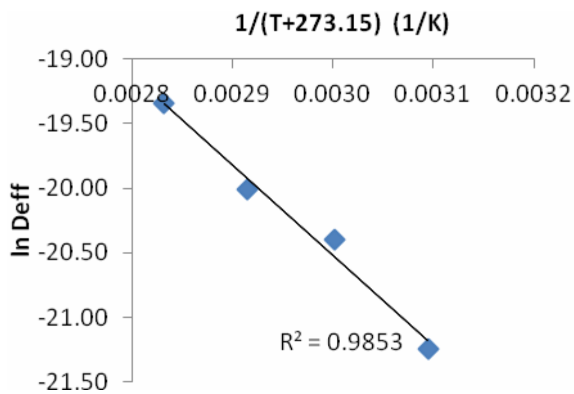

Figure-7. Influence of air temperature on deff for CON.

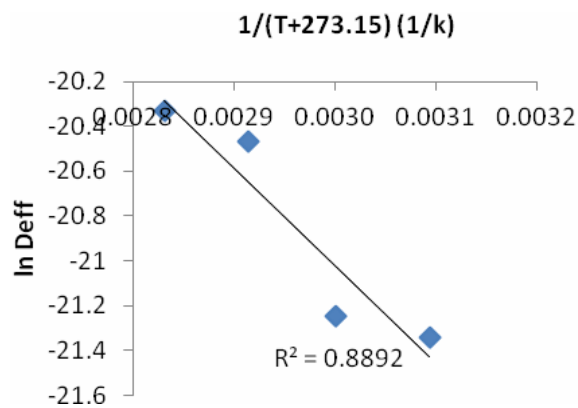

Figure-8. Influence of air temperature on deff for BLA.

CONCLUSIONS

The effect of temperature and blanching on thin layer drying of FHIA-21 slices in a hot-air dryer was investigated. Increase in drying air temperature from 50 to 80°C decreased the drying time from 16 and 17.5 hours to 3 and 7 hours for untreated and blanched samples respectively. The entire drying process occurred in the falling rate period. The Page thin layer drying model showed better fit than the other four models evaluated, with high r^2 and low X^2 and RMSE values. The moisture diffusivity of FHIA-21 slices ranged from 5.40×10^{-10} to 3.98×10^{-9} m^2/s and activation energy of blanched and untreated samples 35.23 and 56.61 kJ/ mol, respectively.

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