American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-8, Issue-8, pp-160-166
www.ajer.org
Research Paper Open Access

Fittingmodel for the thin layer drying of plantain (Musa acuminata)

Fawohunre, A.J.[1], Adewumi, B.A.[2], Dairo, O. U.[2], and Sobukola, O. P.[2]
[1]Department of Agricultural and Bio-Environmental Engineering Technology,Rufus Giwa Polytechnic, Owo, Nigeria
[2]Department of Agricultural and Bio-Resources Engineering,University of Agriculture, Abeokuta, Nigeria
Corresponding Author: Fawohunre, A.J.

ABSTRACT *-The study was conducted to assess the effects of temperature and moisture content on the thin layer drying kinetics of Musa acuminata at 50, 60 and 70^{O}C. Data obtained from the drying experiments were fitted to nine established thin layer drying (TLD) models namely Diffusion, Henderson and Pabis, Logarithmic, Midilli et al., Wang and Singh, Page, Two Term, Verma et al. and Newton. The performances of the nine models were evaluated by comparing the Coefficient of Determination (R^2), Root Mean Square Error (RMSE) and Standard Error of Moisture Content (SEMC) between observed and predicted moisture ratio. It was found that Midilli et al., model gave the best fit of drying curves with R^2 of 0.998 to 0.999, RMSE of 0.002 to 0.004 and SEMC of 0.011 to 0.015. Effective diffusivity (D_e) increased with increasing temperature; it ranged between 6.75 x 10^{-9} and 9.57 x 10^{-9} m^2/s while the activation energy (E_a) was found to be 32.18 kJ/mol.*

Keywords: *musa acuminata, thin layer models, mathematical modeling, diffusivity, activation energy.*

Date of Submission: 17-08-2019 Date of acceptance: 31-08-2019

I. INTRODUCTION

Plantain is a green to yellow boat shaped fruit of a large shrub called Musa paradisiacal and belongs to the family of plants referred to as Musaceae. Musa acuminata is one of the most common species found in Nigeria. Plantain is found in other parts of the tropics, from Florida to Brazil, Egypt, Ghana, Japan to the Caribbean. Plantaincanbeeatenboiled, roasted, grilled, or fried. In central and western Nigeria, plantains are sliced (or chipped), dried and milled into flour, the flour may be reconstituted in boiling water to produce plantain fufu, a dough that is much like the dough from dried yam and cassava (Satimehin et al., 2010).

Drying process plays an important role in the preservation of agricultural products (Waewsak et al., 2006). When a wet solid is subjected to thermal drying, two processes occur simultaneously:transfer of energy (most as heat) from the surrounding environment to evaporate the surface moisture and transfer of internal moisture to the surface of the solid and its subsequent evaporation due to the first process (Sahin and Dincer, 2005). The understanding of drying operations is of great practical and economic importance. An understanding of the fundamental mechanism and knowledge of the moisture and temperature distributions within the product is crucial for process design, quality control, product handling and energy savings (McMinn, 2006).

Thin layer drying normally forms the basis of understanding the drying characteristics of food materials since every material is unique (Sobukola and Dairo, 2007). Thin layer drying have been used to estimate drying times of several products and to generalize drying curves. The mathematical modeling and computer simulation of food drying makes it possible to gain insight into the comparative performance of various drying systems and to allow the engineers to choose the most appropriate method of drying for a given product, as well as to choose suitable operating conditions. Although, in the past, many number of theoretical, semi- theoretical and empirical drying models are reported in literature for various foods and agro-based products (Jayas et al., 1991; Sobukola and Dairo, 2007; Satimehin et al., 2010; Midilli et al., 2002; Kajuna et al., 2001; Doymaz and Pala, 2003). Some studies have been done on plantain with a view to generating scientific data for its storage and industrial processing. Satimehin et al., 2010 obtained data on the drying characteristics of plantain during convective air drying at various temperatures. Igbeka (1980) dried slices of plantain using a solar dryer equipped with a parabolic cylindrical concentrator. Karim and Hawlader (2005) presented a mathematical model for food drying and applied the model to drying of banana. Alakali et al. (2008) carried out some studies on the osmotic dehydration kinetics of plantain chips using various sucrose concentrations at different temperatures. There appears to be little information in the literature on the thin-layer drying of Musa acuminata variety of plantain. To properly model the drying process of this crop, there is need to study the dying kinetics with a view to providing useful information which will enhance the drying process. Therefore, the objectives of this study were to determine the effect of air temperatures on the moisture reduction of Musa acuminata during drying process, select the suitable mathematical model for the drying curves by fit in the experimental data into nine mathematical models and calculate the effective diffusivity and activation energy of the crop.

II. MATERIALS AND METHODS

Mature samples of the cultivars of plantain (M. acuminata) were obtained from International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and used for the experiment. This cultivar was selected on the basis of the consistence agronomic performance, availability, economic importance, high yield and production level in Nigeria. The plantains were peeled and sliced to thickness of 3mm based on the literature (Akpinar et al., 2003; Satimehin et al., 2010). One layer of the slices was spread on a sample holder and initial mass of the sample were measured by means of a digital weighing balance EK – H6000i. The drying experiments were carried out in the laboratory of the Federal Institute of Industrial Research, Oshodi (FIIRO), Nigeria. The dryer consists of an axial flow fan, heating control system, drying chamber, and operated by letting air stream at a rate of 1m/s over the heating element flow through the sample. The drying chamber constructed from sheet iron and the entire dryer casing is lagged, thus enclosing the functional units. The drying system was run for about one hour to obtain a suitable condition at the selected dry bulb temperature; 50, 60 and 70^{O}C before placing samples in the chamber. The prepared sample was placed in the drying compartment and the drying process initiated. Moisture losses in the sample were monitored by determining the weight change at 30 minutes intervals during drying. The drying process was continued until the samples reached the desired moisture content level (9.6-13.3 % db) and the test was terminated. The moisture content of the samples was determined by the oven drying method (AOAC, 1990). The procedure was replicated three times for each drying temperature.

III. ANALYSIS OF THE DRYING DATA

The moisture ratio (MR) of the M. acuminata slices during the thin layer drying experiments was calculated using the
equation of Silayo (1995) and Kajuna et al., (2001) given as:

$$MR = \frac{M_{t-M_e}}{M_{o-M_e}} \qquad (1)$$

where M_t, M_o and M_e are the moisture content at any time, the initial moisture content and the equilibrium moisture content in % db respectively.

The drying rate (DR) of the drying data was calculated using equation (2) (Sobukola and Dairo, 2007).

$$DR = \frac{M_{t+dt} + \ M_t}{dt} \qquad (2)$$

Where $M_{t\,+\,dt}$ and M_t are moisture content at t + dt (kg water/kg dry matter) and moisture content at time t respectively and t is drying time (min).

The nine mathematical models used for fitting the drying characteristics were presented in **Table 1**. A non – linear regression package, Data Fit software Version 9.0.59 (Datafit Oakland, 2008) was used to fit the models to experimental data obtained. The initial parameters estimates were obtained by linearization of the models through logarithmic transformation and application of
linear regression analysis. Model parameters were estimated by taking the moisture ratio (MR) to be the dependent variables. The Coefficient of determination (R^2) was the primary criterion for
selecting the best model to describe the drying curves. In addition to R^2, the Standard Error of Moisture Content (SEMC) and Root Mean Square Error (RMSE) were used to determine the goodness of fit. They were calculated as:

$$RMSE = \left\{ \sqrt{\frac{1}{N} X \Sigma_{i=1}^{n} (MR_{pre,i} - MR_{exp,i})^2} \right\} (3)$$

$$R^2 = \frac{\Sigma_{i=1}^{n}(MR_i - MR_{pre,i}) x \Sigma_{i=1}^{n}(MR_i - MR_{exp,i})}{\sqrt{\Sigma_{i=1}^{n}(MR_i - MR_{pre,i})^2 x \Sigma_{i=1}^{n}(MR_i - MR_{exp,i})^2}} \qquad (4)$$

$$SEMC = \frac{\Sigma_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{N} (5)$$

Where, $MR_{exp,i}$ is the ith experimentally observed moisture ratio, $MR_{pre,i}$ is the ith predicted moisture ratio, N is the number of observation and n is the number of constant (Yaldiz and Ertekin, 2001; Togrul and Pehlivan, 2004).

The experimental drying data for the determination of effective diffusivity coefficient (D_e) were interpreted using Fick's second law for spherical bodies according to Doymaz, 2004. This is because the shape of the crop is closer to being spherical than the commonly used flat object (slab assumption). The effective diffusivity (D_{eff}) was calculated at different temperatures as follows:

$$MR = \frac{6}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff}}{r^2}\right) (6)$$

Where, r is the effective radius of the sample being dried, n is a positive integer and D_{eff} is the effective diffusivity in m^2/s. From Eq. (6), a plot of ln(MR) versus drying time gave a straight line with the slope of:

$$\text{slope} = \frac{\pi^2 D_{eff}}{r^2} (7)$$

The effect of air temperature on the effective diffusivity is expressed using the Arrhenius-type relationship:

$$D_{eff} = D_o \exp\left(\frac{-Ea}{R(T + 273.15)}\right) (8)$$

Where Do is the maximum diffusion coefficient (at infinite temperature), Ea is the activation energy for diffusion (J/mol), T is the temperature (^oC) and R is the gas constant. The activation energy is typically calculated by plotting $\ln D_{eff}$ against $\frac{1}{T}$. The slope produced a straight line and multiplied by 8.314 J/mol to obtain the activation energy.

IV. RESULTS AND DISCUSSION

Drying curves: **Figure 1** shows the variation of moisture ratio with drying time for M. acuminata at 50, 60 and 70^OC.In general the curves show a decreasing trend as drying progressed. It demonstrates the influence of air temperature on the change in the moisture ratio of the dried sample and shows that air temperature had a significant effect. The changes in the drying rates with drying time are shown in **Fig. 2.** It is apparent that drying rate decreases continuously with drying time and the whole drying process was observed to have taken place in the falling rate period. This observation has been made earlier by many researchers (Satimehin et al., 2010; Sobukola and Dairo, 2007; Jayas et al., 1991) and shows that temperature had a significant effect. The curve fitting computations with the drying time were done by using the nine drying models in **Table 1**. The results of statistical analyses undertaken on these models are given in **Table 2**. The average value of R^2, SEMC and RMSE of the nine models at 50, 60 and 70 ^OC gave consistently high Coefficient of determination R^2 values with the range of 0.9741 – 0.9989 while RMSE and SEMC vary between 0.0022 – 0.0599 and 0.0117 – 0.0540.. Among the thin layer drying model used, the Midilli model had the highest R^2 values and the lowest RMSE and SEMC at all the temperatures and thus was selected to be the best fit to represent the TLD of Musa acuminata. This criteria for selection of the best model as earlier stated by many researchers (Ajibola, 1989; Sobukola et al., 2007; Satimehin et al., 2010 and Doymaz, 2004). The accuracy of the established model (Midilli) was also evaluated by comparing the experimental with predicted values at different levels of temperature as shown in **Figs. 3 - 5.** The results showed the closeness of the plotted data to the straight line and this implies that equality exist between the experimental and predicted values of Midilli and illustrate the suitability of Midilli model for describing the drying behavior of M. acuminata variety of plantain. The analysis of variance on R^2, RMSE and SEMC by using Two way ANOVA and mean comparison using the paired t – test at 5 % significant level for the range of temperature used and for the nine models showed that there was significant difference ($p < 0.05$) between the nine models. The effective diffusivity values deduced were 6.75×10^{-9}, 7.32×10^{-9} and 9.57×10^{-9} m^2/s for the respective temperatures of 50, 60 and 70 ^OC. The effective diffusivity of the samples was influenced by the air drying temperature. These values increased with increase in the air temperature due rapid movement of water at high temperatures and the values lie within the general range of 10^{-12} – 10^{-8} m^2/s reported for food material (Ojediran and Raji, 2010; Sobukola et al., 2007;Yaldiz and Ertekin, 2001). The value of activation energy was found to be 32.18 kJ/mol. The value falls within the range for diffusion – controlled processes (0 – 63 kJ/mol) as reported by Doymaz (2007).

V. CONCLUSION

In this study, the drying behavior of Musa acuminata variety of plantain was investigated in a convective hot air dryer with forced convection mode. The drying process at each temperature of study occurred in the falling rate period, no constant rate period of drying was observed. The drying behavior was explained using nine thin layer drying models and the results showed that the Midilli model observed to be most suitable for describing the drying curve of Musa acuminate with R^2 of 0.9981 – 0.9989 ; SEMC of 0.0117 – 0.0155 and

RMSE of 0.0022 – 0.0046 for the temperature used. The effective diffusivity values deduced were 6.75 x 10^{-9}, 7.32 x 10^{-9} and 9.57 x 10^{-9} m^2/s and increases as temperature increases while the value of activation energy was found to be 32.18 kJ/mol.

Table 1: Thin layer mathematical models used for drying characteristics

S/N	Model name	Model equation
1.	Newton	MR = exp (-kt)
2.	Page	MR = exp ($-kt^n$)
3.	Henderson And Pabis	MR = a exp (-kt)
4.	Logarithmic	MR = a exp (-kt) + c
5.	Two Term Model	MR = a exp (-kt) + c exp (-gt)
6.	Midilli	MR = a exp ($-kt^n$) + bt
7.	Diffusion Approach	MR = a exp (-kt) + (1-a) exp (-kbt)
8.	Wang And Singh	MR = 1 + at + bt^2
9.	Verma et al.	MR = a exp (-kt) + (1-a) exp (-gt)

Source: Ajibola O.O., 1989; Akpinar, 2006; Sobukola and Dairo, 2007 and Satimehin et al., 2010.

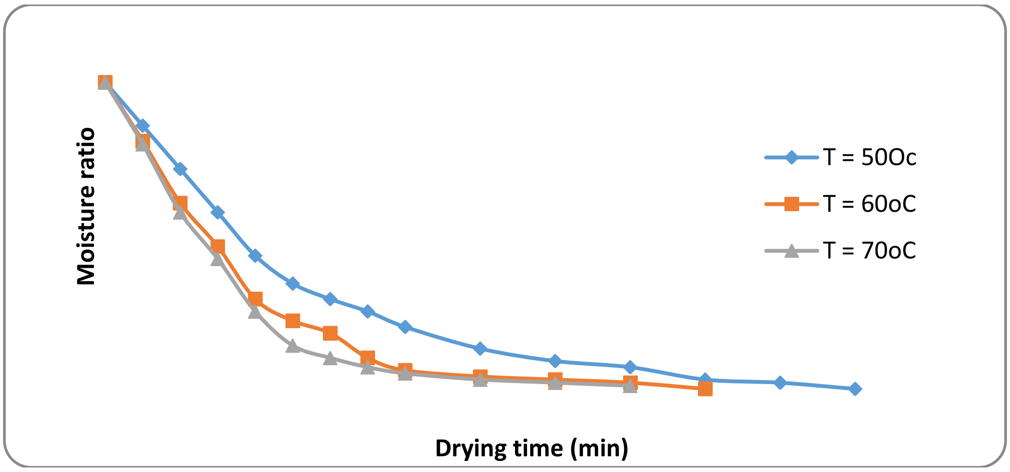

Fig. 1: Effect of drying time on moisture ratio at various drying temperatures

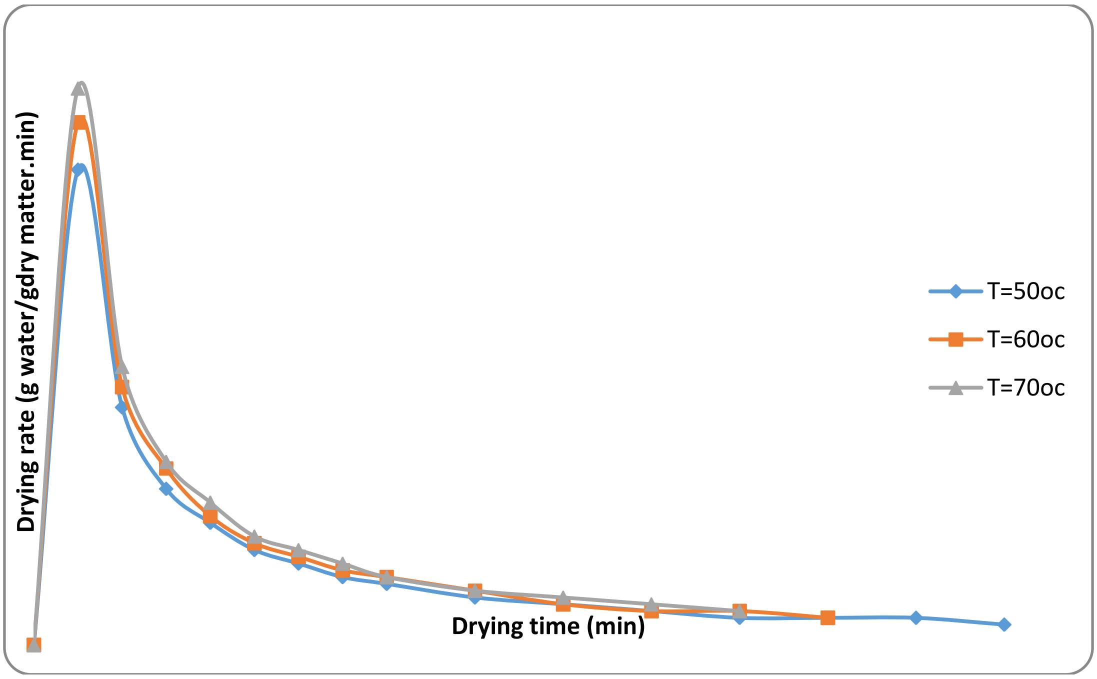

Fig.2: Drying rate curve at different drying temperature

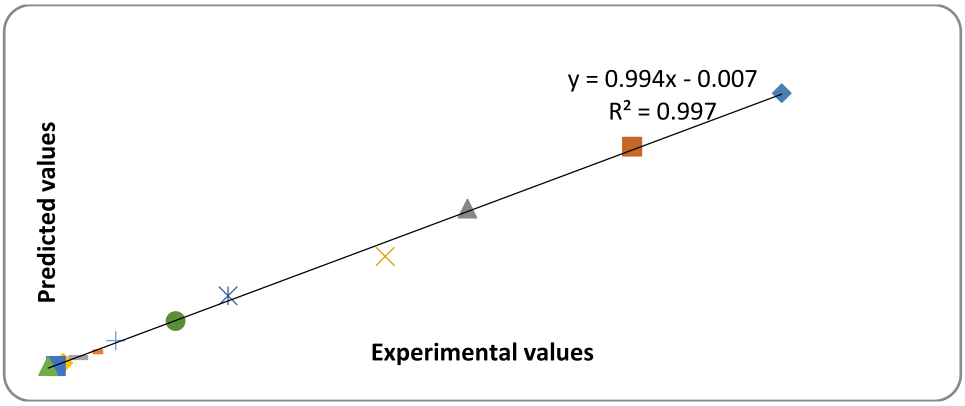

Fig. 3: Comparison of experimental and predicted moisture ratios byMidill model for M. acuminata at70^{O}C

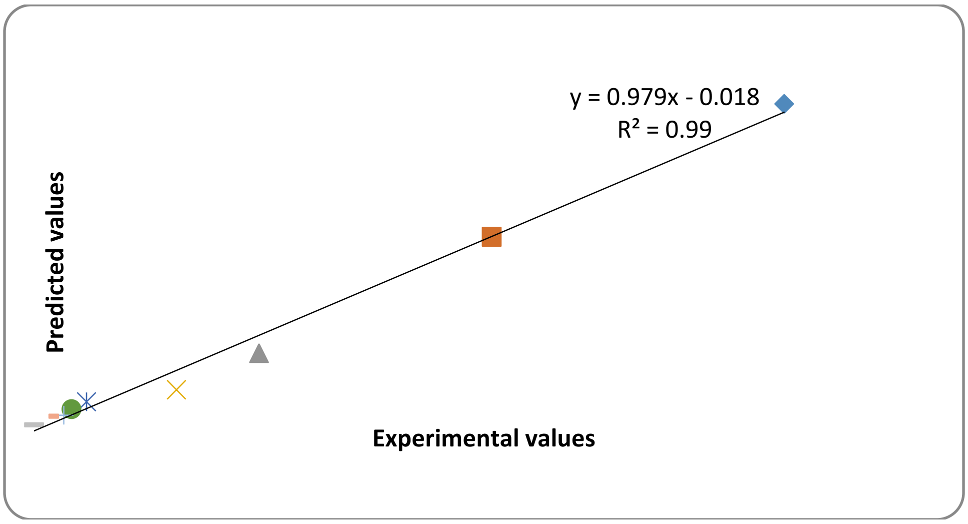

Fig. 4: Comparison of experimental and predicted moisture ratios by Midill model for M. acuminata at 60^{O}C

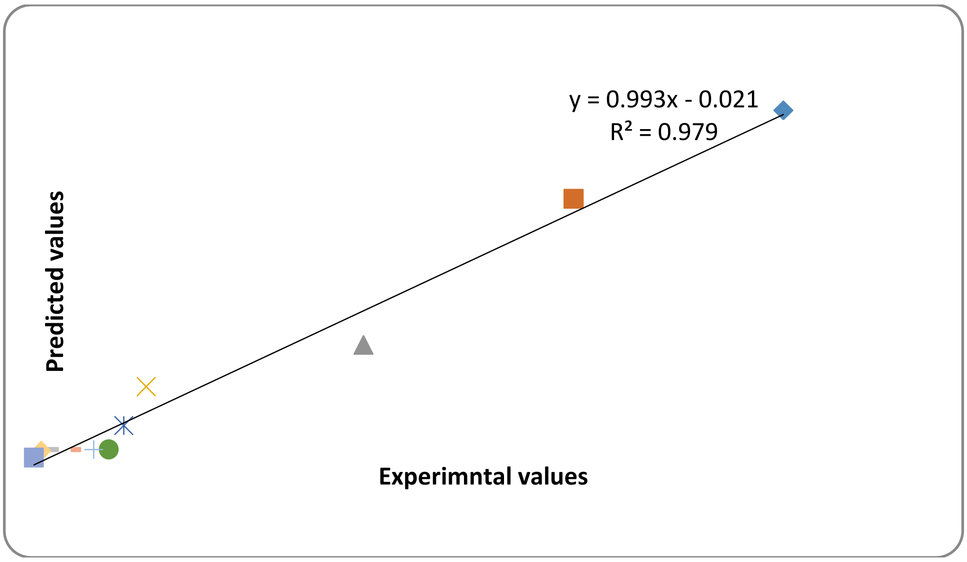

Fig. 5: Comparison of experimental and predicted moisture ratios by Midill model for M. acuminata at50^{O}C

TABLE 2: Statistical results obtained from various thin - layer drying model

Model no	Temperature (^{o}C)	R^2	RMSE	SEMC
1	50	0.9953	0.0110	0.0223

	60	0.9912	0.0188	0.0307
	70	0.9863	0.0280	0.0384
2	50	0.9976	0.0057	0.0165
	60	0.9982	0.0038	0.0142
	70	0.9982	0.0037	0.0143
3	50	0.9969	0.0072	0.0185
	60	0.9944	0.0120	0.0252
	70	0.9911	0.0183	0.0319
4	50	0.9970	0.0071	0.0189
	60	0.9949	0.0108	0.0246
	70	0.9920	0.0162	0.0310
5	50	0.9984	0.0048	0.0160
	60	0.9944	0.0120	0.0266
	70	0.9911	0.0183	0.0310
6	50	0.9981	0.0046	0.0155
	60	0.9986	0.0030	0.0133
	70	0.9989	0.0022	0.0117
7	50	0.9983	0.0048	0.0143
	60	0.9939	0.0130	0.0277
	70	0.9905	0.0194	0.0348
8	50	0.9744	0.0599	0.0534
	60	0.9741	0.0554	0.0540
	70	0.9769	0.0472	0.0512
9	50	0.9959	0.0096	0.0219
	60	0.9986	0.0035	0.0140
	70	0.9917	0.0184	0.0328

REFERENCE

[1]. Ajibola, O.O (1985). Desorption isotherm for plantain at several temperatures. Journal of Food Science 51 (1): 169- 171.
[2]. Ajibola, O.O (1989). Thin layer drying of melon seed.Journal of Food Engineering 9; 305-320.
[3]. Akanbi C.T., Adeyemi, R.S. and Ojo, A. (2006).Drying characteristics and sorption isotherm of tomato slices.Journal of Food Engineering 73:157-163.
[4]. Akpinar, E. K., Bieer, Y. and Midilli, A. (2003). Modelling and experimental study on drying of apple
[5]. Akpinar, E.K. (2006). Determination of suitable thin layer drying curve model for some vegetables and fruits.Journal of Food Engineering, 73: 75-84.
[6]. Alakali, J. S., Irtwange, S. V. and Yusuf, P. A. (2008). Mass Transfer Considerations in Osmotic Dehydration of Plantain (Musaparadisiacal) Chips. AgriculturalEngineering International: the CIGRE-journal. Manuscript FP 07 026. Vol. X.December, 2008.
[7]. AOAC (1990). Official method of analysis. N0.934.06. Association of Official Analytical Chemist, Arlington, USA.
[8]. Datafit Oakdale (2008): Data fit version 9.0.59 Oakdale Engineering, Oakdale, PA 15070, USA.
[9]. Doymaz, I. (2004). Convective air drying characteristics of thin layer carrots.Journal of Food Engineering 61:359-364.
[10]. Doymaz I. (2007). Thin layer behavior of mint leaves. Journal of Food Engineering 74:370-375.
[11]. Doymaz and Pala, (2003): The thin layer drying characteristics of Corn. Journal of Food Engineering 60(2): 125 - 130.
[12]. Igbeka, J. C. (1980). Solar Energy Utilization for Drying Agricultural Products. Paper presented at the International Symposium on Solar Energy Utilization, University of Western Ontario, London,Ontario,Canada, August 10 – 24, 1980.
[13]. Jayas D.S., Cenkowski S. and Pubis S. (1991): Review of thin layer drying and wetting equations. Drying Technology, 3: 551-588.
[14]. Kajuna, S.T.A.R., Silayo V.C.K. Mkenda, A., Makungu, P.J.J. (2001). Thin layer drying of diced cassava roots.
[15]. Africa Journal of Science and Technology: Science and Engineering Series 2(2): 94-100.
[16]. Karim, M. A. and Hawlader, M. N. A. (2005). Drying characteristics of banana:theoretical modelling and experimental validation. Journal of Food Engineering, 70:35-45
[17]. McMinn, W.A.M. (2006). Thin layer modeling of the convective and microwave – vacuum drying of lactose powder. Journal of Food Engneering 72, 113 – 123
[18]. Midilli A., Kucuh A., Yapar Z. (2002). A new model for single layer drying. Drying Technology, 20 (7), 1503-1513.
[19]. Ojediran J.O., and Raji A.O., (2010): Thin layer drying of millet and effect of temperature on drying characteristics. International Food Journal 17: 1095-1106.

[20]. Sahin, A.Z. and Dincer, I. (2005). Prediction of drying times for irregular shaped for ulti-dimensional moist solids. JournalofFoodEngineering 71, 119-126.

[21]. Satimehin A.A., Alkal, J.S. and Alabi, O.T. (2010). Thin layer drying characteristics of plantain. Journal of Tropical Agriculture, Food, Environmental and Extension 9(1): 31-37.

[22]. Sobukola, O.P., and Dairo, O.U. (2007).Modeling drying kinectics of fever leaves (ocimenviride) in a convective hot air drier.Nigerian Food Journal. 25(1): 145 - 153pp

[23]. Togrul I.T., and Pehlivan D., (2004).Modeling of thin layer drying kinetics of some fruits under open air sun drying process.J. Food Eng, 65, 413-425.

[24]. Waewsak J., Chindaruka S. and Punlek C. (2006): A mathematical modeling study of hot air drying for some agricultural products. Thammasat International Journal of Science and Technology 11(1): 14-20.

[25]. Yaldiz, O. and Ertekin, C. (2001).Thin layer solar drying of some vegetables.Drying Technology 19: 583-596.

Fawohunre, A.J." Fittingmodel for the thin layer drying of plantain "American Journal of Engineering Research (AJER), vol. 8, no. 8, 2019, pp. 160-166