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Research Paper

Thin Layer Drying Kinetics and Modeling of Musa Balbisiana Variety of Plantain

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Abstract— Thin layer drying parameters are important in the design of food and agricultural processes such as in drying, heating and cooling systems. For this purpose, it is highly essential to determine the effects of temperature and moisture content on the thin layer drying kinetics of musa balbisiana at 50, 60 and 70 ^{O}C with each drying temperature carried out in three replicas. The experimental curves of the drying data showed that drying process occurred in the falling rate period and no constant rate period was observed. The drying curves obtained were fitted to nine empirical thin layer drying and compared with three statistical parameters. The results of the nine models showed that R^2 values were in the range of 0.9686 to 0.9994; RMSE values were in the range of 0.0014 to 0.0666 while SEMC values were in the range of 0.0133 to 0.0577. Among the nine models considered for this study Midilli model gave the best fit of drying curves with R^2 of 0.9982 to 0.9994, RMSE of 0.0014 to 0.0037 and SEMC of 0.0133 to 0.0144. Further analysis revealed that the value of activation energy was calculated to be 30.76 kJ/mol and effective diffusivity (D_{e}) increased with increasing temperature; it ranged between 6.75 x 10^{-9} and 1.08 x 10^{-8} m^2/s, this implies that temperature clearly has a marked effect on the thin layer drying of musa balbisiana.

Keywords— Drying kinetics, musa balbisiana, moisture ratio, modeling, effective diffusivity, activation energy

1. Introduction

There are various methods of food preservation which include drying that is considered to be one of the major ways of preserving food and it involves transfer of heat and at the same time mass. Drying process is carried out by vaporizing water in the product whereby adequate heat for vaporization is necessary to be provided through decreasing the sensible heat or heat can be engage to the material by conduction, freezing – drying and so on [1]. It is necessary to reduce nutritional losses and control changes in the physical and chemical properties of food product through the control of drying parameters [2]. Both the characteristics of air and food product such as humidity, temperature, velocity, thickness, surface area and moisture diffusion influence drying rate [3]. Primarily, reduction in drying rate leads to increase in humidity but increase in drying rate leads to increase in air temperature.

Thin layer drying can be described as a mean of taking out water from a permeable product through vaporisation whereby surplus drying air is passed through a thin layer product until equilibrium moisture content is accomplished. The utilization of thin layer drying has been applied to evaluate drying period of many crops as well as the establishment of their curves. The thin layer drying kinetics and modeling help to understand the equivalent accomplishment of different drying plans, also engineers can use it to select applicable method for a particular material and suitable operating conditions. The structures of the established drying kinetics and model are complicated for the utilization of control model therefore effective control is highly challenging.

Plantain is one of the most important staple crops in humid forest zone of West and Central Africa. The cultivars of plantain and banana are mostly the products of development in the eumusa sequence of the genus musa. These cultivars had their background in two kinds namely, musa balbisiana and musa acuminata. Plantain produces more starch than banana fruit but the latter is sweeter, the variation between the two fruits is attributes to the musa balbisiana genome. Plantain has a great dietetic importance and rich in calcium, phosphorus, potassium and some vitamins [4]. Therefore, there is a need to know the basic mechanism of thin layer drying kinetics as well as modeling of plantain. It will help to develop a productive and affordable method for the preservation of the product.

1.1 Objectives of this study

The objectives of this research are to carry out kinetics drying on musa balbisiana variety of plantain and consider an appropriate empirical model for the plantain.

2. Related Work

Generally, various dried products possess different qualities that depend on the absolute drying systems, thus, it is necessary to explain the drying kinetics and properties of the individual product.

Modeling of plantain trial was accomplished by [4]. The study considered a proper thin layer model that is appropriate for the drying kinetics of French horn plantain at four different levels of temperature. The data gotten were fixed to three thin level models and Page model presented a best fit for the study. Appropriate model for musa acuminata was performed by [5]. This investigation was aimed to determine the deviations of temperature and moisture content on drying kinetics of musa acuminata. Data found from the test were fixed to nine empirical models and performances of the nine simulations were estimated by analyzing the goodness of fit using three statistical tools and Midilli model gave the superlative fit. In the drying kinetics of musa paradisiaca chips by [6]. The drying rates of the chips were evaluated under convective air dryer and data obtained were fitted to Fick's diffusion equation. The outcome of the test presented that diffusion - skillful procedure described the study and the drying rate increases with temperature. Determination of the thin layer drying characteristics and modelling of ripe plantain slices was performed by [7]. The outcome showed that Henderson model is more appropriate for the test, the cut thickness tends to increase with activation energy at selected temperature. In the drying features of green cardaba banana pieces by [8], twelve empirical models were considered for the study and compared for fitness. Wang model was found to be the best that could be used for the sample, the activation vigor was calculated as 38.46 KJ/mol. Drying kinetics of mabonde banana variety was carried out by [9]. The Wange and Singh model best define the test and the relationship between effective diffusivity and microwave power of the sample showed the same upward trend. The study of the drying kinetics of banana peel was achieved by [10], five mathematical models were studied and Henderson and Pabis proved to be the most suitable model when compared for goodness of fit by using four different statistical tools.

Drying of green musa chips was studied by [11]. In the study fourteen diverse experimental models were used for the statistics obtained and correlated for goodness of fit with the aid of four different statistical parameters, the results presented different suitable models and the appropriate model for each thickness of the slice were different. Drying and quality evaluation of banana slices were explored by [12]. The results of the research showed that both slice thickness and drying time were up surged and the model by Verma best illustrate the drying kinetics. Investigation on the effect of different drying methods of fermented cardaba banana peels by [13]. The study described that drying of banana peels using different methods resulted to different figures of effective diffusivity but same activation vigor, the page model best depicts the drying performance of the sample.

3. Experimental Method

3.1 Sample preparation and drying test

Mature samples of musa balbisiana variety of plantain were obtained from a research institute located in Ibadan, Oyo State, Nigeria. The selection of this variety was based on the elements that favour the economic impact and abundant produce of the crop in Nigeria. After peeling and slicing to thickness of three millimeter according to the literature [5], [6]. A digital weigh balance was used to determine the initial weight of the samples. The dryer was run without load for some minutes to obtain a uniform state at certain temperature of fifty, sixty and seventy degree centigrade before putting the sample in the drying section. After attaining uniform condition, the sample was well arranged in the section and the drying practice commenced. Decrease in moisture content of the musa balbisiana was observed by calculating difference in the mass at every 30 minutes throughout the operation until there was no change in the weight of the sample and the test was concluded with each drying temperature carried out in three replicas. Oven drying method as given by [14] was used to determine the moisture content.

3.2 Moisture content and drying rate

The equation given by [4] was used to evaluate the moisture content of musa balbisiana as:

$$MC = \frac{W_{wt}}{W_{wd}} \times 100 \quad (1)$$

where, MC is moisture content (% d.b)
W_{wt} is weight of water in product (g)
and W_{wd} is mass of dry substance (g).
The instantaneous MC was changed to moisture fraction in dimensionless form by using equation (2) as given by [15], [16]:

$$MR = \frac{M_{at-}M_{eq}}{M_{ic-}M_{eq}} \quad (2)$$

where, M_{at} is MC at any time (% db)
M_{ic} is initial MC (% db)
and M_{eq} is the balanced MC (% db).
Equation (3) was used for the drying rate as given by [17]

$$DR = \frac{M_{t+td} + M_t}{td} \quad (3)$$

where M_{at+td} is MC at t + t_d (kg/kg dry matter)
M_t is MC at any time (%)
and t_d is the differential time (min).

3.3 Mathematical modeling of the drying process

The thin layer drying models in Table 1 were considered in obtaining the best model for illustrating the investigational curves of the plantain and the models were chosen base on the literature. Data Fit package Version 9.0.59 given by [18] was used to fit the models to the data gotten.

In the determination of the model parameter, moisture fraction (MR) was used as a non-fixed variable and goodness of fit was determined by using Root Mean Square Error (RMSE), Standard Error of Moisture Content (SEMC) and Coefficient of determination (R^2). The later was considered as the main standard for choosing the best model to define the drying curves. The following equations were considered:

$$\mathrm{RMSE} = \left\{ \sqrt{\frac{1}{N} X \sum_{i=1}^{n} (MR_{pre,i} - MR_{exp,i})^2} \right\} \quad (4)$$

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

$$R^2 = \frac{\sum_{i=1}^{n} (MR_i - MR_{pre,i}) \, x \, \sum_{i=1}^{n} (MR_i - MR_{exp,i})}{\sqrt{\sum_{i=1}^{n} (MR_i - MR_{pre,i})^2 \, x \, \sum_{i=1}^{n} (MR_i - MR_{exp,i})^2}} \quad (6)$$

where,
$MR_{expl,i}$ is the instantaneous MR for the experimental values,
$MR_{pre,i}$ is the instantaneous MR for the predicted values,
N is the amount of observation and
n is the amount of constant.

Table 1. The mathematical models used for the study

Name of the model	Equation
Page	MR = exp ($-kt^n$)
Newton	MR = exp (-kt)
Henderson and Pabis	MR = b exp (-kt)
Logarithmic	MR = b exp (-kt) + d
Two Term Model	MR = b exp (-kt) + d exp (-gt)
Midilli	MR = b exp ($-kt^n$) + ct
Diffusion Approach	MR = b exp (-kt) + (1-b) exp (-kct)
Wang And Singh	MR = 1 + bt + ct^2
Verma *et al.*	MR = b exp (-kt) + (1-b) exp (-gt)

3.4 Effective diffusivity and activation energy

The nature and data obtained for the plantain were considered for the decision of effective diffusivity coefficient (D_e) by applying Fick's second law for sphere-shaped figures in agreement with [15] as follows:

$$\mathrm{LnMR} = \mathrm{Ln}\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{et}}{r^2}\right) \quad (7)$$

The effective diffusivity was calculated using the curve of LnMR data versus time with a gradient k_1 as given in equation (8) while the relationship between air temperature and effective diffusivity is estimated using the Arrthenius – type correlation as given in equation (9):

$$k_1 = \frac{\pi^2 D_{et}}{r^2} \quad (8)$$

$$D_e = D_o \exp\left(\frac{-Ea}{R(T+273.15)}\right) \quad (9)$$

where D_e is effective diffusivity (m^2/s)
D_0 is diffusivity coefficient (m^2/s)
R is a general gas constant (= 8.314 $Jmol^{-1}k^{-1}$),
T is temperature (^oc),
Ea is activation energy (J/mol)
and r is the radius of the sample being dried (m).

The plot of lnD_e against $\frac{1}{T}$ gave a straight line and the result of the plot multiplied by 8.314 J/mol yielded activation energy.

4. Results and Discussion

The usefulness of the empirical models considered in this study at all the drying temperatures were investigated by showing the effect of experimental moisture ratio (MR) on drying time for the data as shown in Figures 1 to 3, a broad deviation was observed in the plots of Verma *et al.*, and Wang and Singh, implied that the two models were not fitted for the thin layer drying behavior of musa balbisiana variety. Hence, Midilli, Diffusion, Logarithmic, Henderson and Pabis, Two Term, Page and Newton models could be chosen to signify the study. Detail comparisons of coefficient of determination (R^2), standard error of moisture content (SEMC) and root mean square error (RMSE) were also utilize to evaluate goodness of fit. It was found that Midilli gave better prediction with highest figure of R^2 and the lowest figure of SEMC and RMSE at all drying temperatures than other eight models with average values of 0.9987, 0.0140 and 0.0029 respectively. Therefore, these results agree with many researchers [5, 6, 15] that earlier reported that the model which has the maximum figure of R^2 and minimum figure of RMSE and SEMC is the most appropriate one.

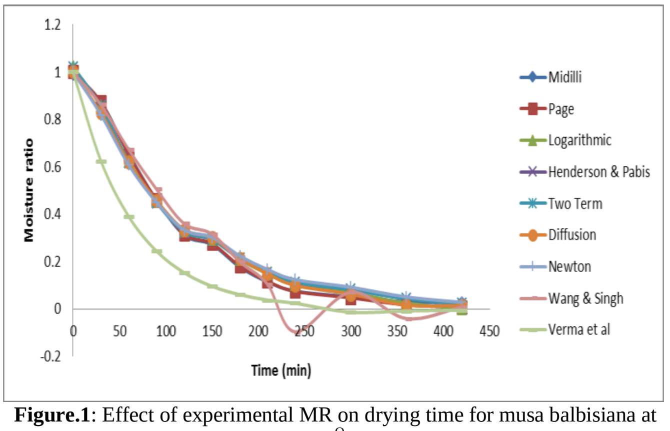

Figure.1: Effect of experimental MR on drying time for musa balbisiana at 70^{O}C

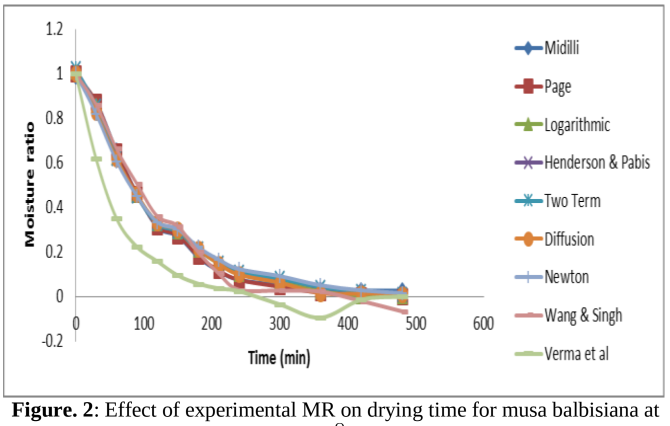

Figure. 2: Effect of experimental MR on drying time for musa balbisiana at 60^{O}C

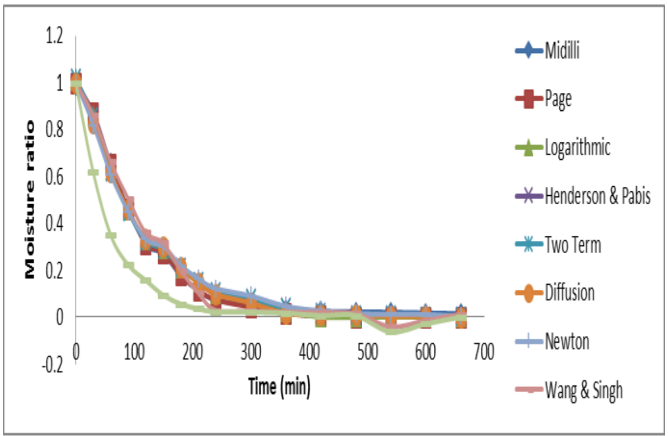

Figure. 3: Effect of experimental MR on drying time for musa balbisiana at 50^{O}C

Midilli model was further evaluated by showing the data on the moisture ratio from the variation of drying time for experimental values and Midilli as shown in Figures 4 to 6, the results showed that there is no wide variation observed in the curves at each drying temperature. After the establishment of the precision of Midilli, it was further assess by showing the variation of experimental and predicted moisture ratio of the model as shown in Figures 7 to 9 and the three figures explained the closeness of the plotted data to the straight line at each drying temperature and this signifies that there is correlation between the experimental and predicted values of Midilli, this shows the fitness of Midilli model for defining the drying behavior of musa balbisiana. The effective diffusivity (De) figures obtained for musa balbisiana were 6.75×10^{-9}, 9.12×10^{-9} and 1.03×10^{-8} m^2/s for temperatures of fifty, sixty and seventy degree centigrade respectively by using method of slope. The values obtained for De increased with increasing temperature and the values agreed with those of many researchers who conducted similar drying test for food products [19], [20], this implies that temperature clearly has a marked effect. The estimate of activation energy was 30.76 kJ/mol by using technique of slope and the value agreed with other researchers for diffusion – controlled processes [20], [21].

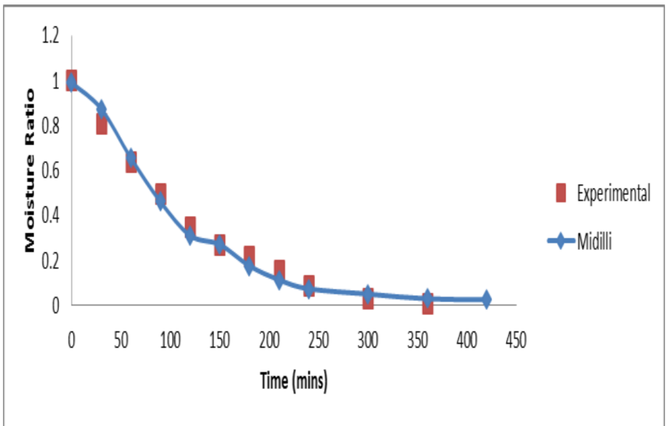

Figure. 4: Moisture ratio versus drying time for experimental values and Midilli at 70^{O}C

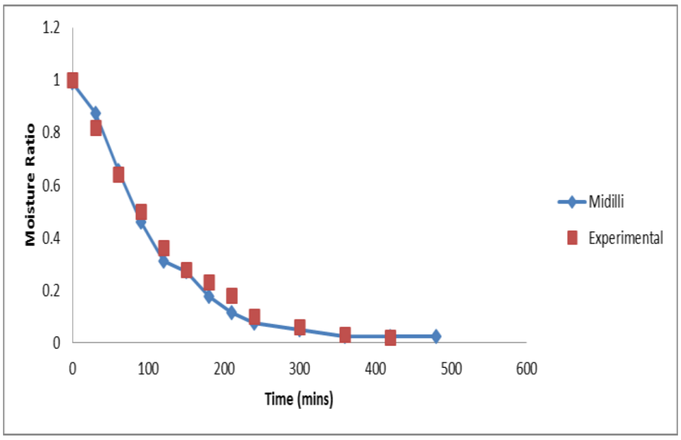

Figure. 5: Moisture ratio versus drying time for experimental values and Midilli at 60^{O}C

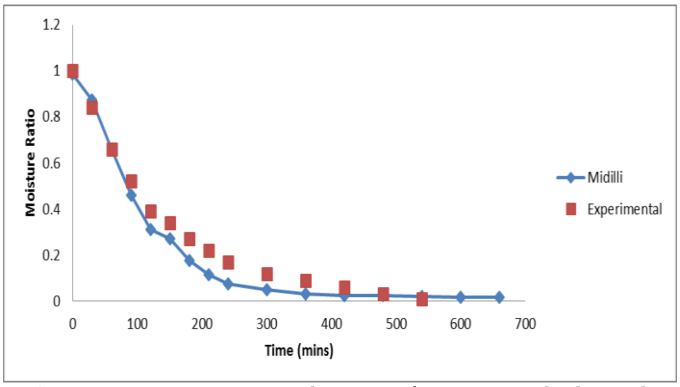

Figure. 6: Moisture ratio versus drying time for experimental values and Midilli at 50^{O}C

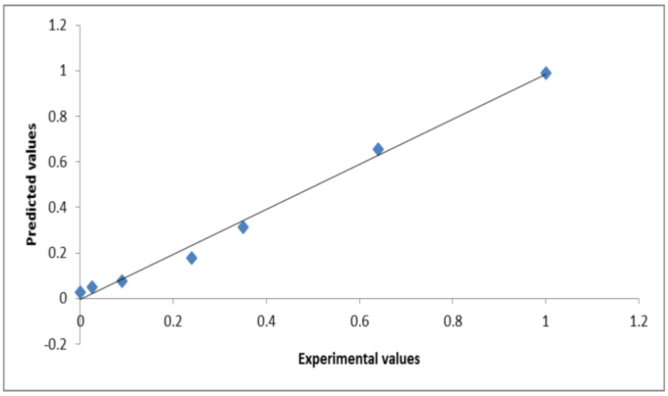

Figure. 7: Variation of experimental and predicted moisture ratio by using Midilli model at 70^{O}C

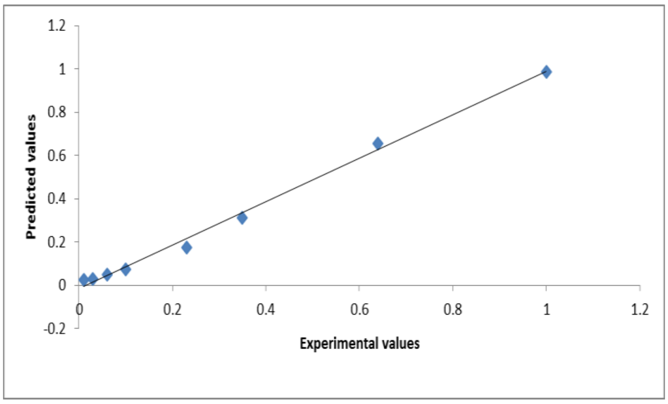

Figure. 8: Variation of experimental and predicted moisture ratio by using Midilli model at 60^{O}C

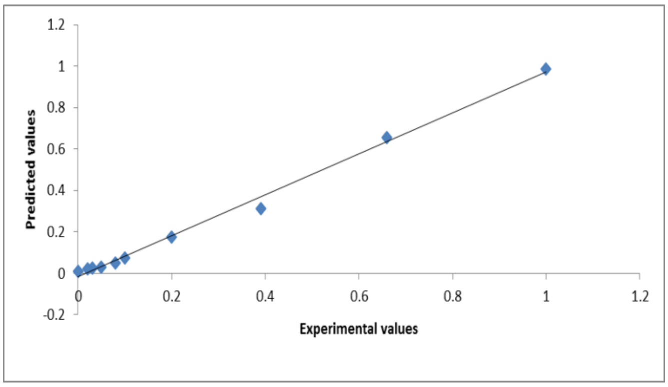

Figure. 9: Variation of experimental and predicted moisture ratio by using Midilli model at 50^{O}C

5. Conclusion

Conclusively, the results of moisture content versus drying time for this study showed that drying process exist in the decreasing proportion period, no constant proportion period and the time to reach the dynamic equilibrium moisture content reduced with increasing temperature shown that temperature clearly has a marked outcome on musa balbisiana. The Midilli model best describe the experimental drying data among the models considered for the study. The effective diffusivity values deduced were between 6.75 x 10^{-9} and 1.03 x 10^{-8}m^2/s while activation energy was calculated to be 30.76 kJ/mol.

Conflict of Interest
No conflict of Interest

Authors' Contributions
Fawohunre A. J. researched literature, conceived the study, analyze the data and wrote the first draft of the manuscript.
Obolo A. A. involved in proof reading and gaining ethical approval
Ologunagba F. O. involved in protocol development and contributed in reviewing and editing of the manuscript. All authors approved the final version of the manuscript.

References

[1].T.B. Onifade, A. Taiwo, S.O. Jekayinfa, ''Modification of a Locally Made Electric Crop Dryer,'' *Innovation System Design and Engineering*, Vol. **7**, Issue. **2**, pp.**4 – 50**, **2016**.
[2].Y.T. Osman, E.F. Fatma, ''Modelling and Characteristics of Thin Layer Convective Air – Drying of Thyme (Thymus vulgaris) Leaves,'' *CZECH Journal of Food Sciences*, Vol. **37**, pp.**128-134**, **2019**.
[3].M.M. Muliterno, D. Rodrigues, F.S. De-Lima, E.I. Ida, L.E. Kurozawa, ''Conversion/ Degration of Isoflavones and Color Alteration During the Drying of Okra'' *LWT- Food Science and Technology*, Vol. **75**, pp.**512-519**. **2016**.
[4].B.C. Oforkansi, M.K. Oduola, ''Determination of Thin-Layer Drying Characteristics of a Plantain Sample at Different Temperatures,'' *International Journal of Engineering Research*. Vol. **5**, Issue. **5**, pp.**367-372**, **2016**.
[5].A.J. Fawohunre, B.A. Adewumi, O.U. Dairo, O.P. Sobukola, ''Fitting Model for the Thin Layer Drying of Plantain (Musa Acuminata),'' *American Journal of Engineering Research*. Vol. **8**, Issue. **8**, pp.**160-166**, **2019**.
[6].A.A. Satimehin, J.S. Alkal, O.T. Alabi, ''Thin Layer Drying Characteristics of Plantain,'' *Journal of Tropical Agriculture, Food, Environmental and Extension*. Vol. **9**, Issue. **1**, pp.**31-37**, **2010**.
[7].T. Karikarisei, E.W. Egbe, ''Thin Layer Drying Characteristics of Ripe Plantain Slices (Musa Paradisaca),'' *Rivers State University Journal of Biology and Applied Science*, Vol. **2**, Issue. **1**, pp.**11-17**, **2023**.
[8].T. Babatunde, K. Oseni, R.B. Taiwo, ''Modelling of Thin Layer Drying Characteristics of Unripe Cardaba Banana (Musa ABB) Slices,'' *Cogent Food and Agriculture*, Vol.**3**, Issue. **1**, pp.**1-6**, **2017**.
[9].A.O. Omolola, A.I. Jideani, P.F. Kapila, ''Modeling Microwave Drying Kinetics and Moisture Diffusivity of Mabonde Banana Variety,'' *International Journal of Agricultural and Biological Engineering*, Vol.**7**, Issue. **6**, pp.**107-113**, **2014**.
[10].S.K. Kumar, ''Drying Kinetics of Banana Peel,'' *Journal of Food Processing and Technology*, Vol.**6**, Issue. **11**, pp.**514-520**, **2015**.
[11].J.A.V. Famurewa, ''Drying Kinetics of Unripe Plantain Chips Using Charcoal Fuelled Cabinet Dryer,'' *Agricultural Engineering International: CIGR Journal*, Vol. **17**, Issue. **1**, pp.**21-27**, **2015**.
[12].A. Kushwah, A. Kumar, M.K. Gaur, ''Drying Kinetics, Performance, and Quality Assessment of Banana Slices Using Heat – Assisted Drying System,'' *Journal of Food Process Engineering*, Vol. **45**, Issue. **3**, pp.**32-38**, **2022**.
[13].O.K. Oni, A.S. Ajala, A.O. Oloye, ''Effect of Different Drying Methods on the Drying Kinetics of Fermented Cardaba Banana Peels,'' *FOUYE Journal of Engineering and Technology*, Vol. **6**, Issue. **2**, pp.**5-9**, **2021**.
[14].AOAC, ''Official method of analysis,''Association of Official Analytical Chemist, Washington, DC **934.06**, February, **1990**.
[15].I. Doymaz, ''Convective Air Drying Characteristics of Thin Layer Drying of Carrots,'' *Journal of Food Engineering*, Vol. **61**, pp.**359-364**, **2004**.
[16].S. Jena, H. Das, ''Modelling for Vacuum Drying Characteristics of Coconut Presscake,'' *Journal of Food Engineering*, Vol. **7**, Issue. **1**, pp.**92-99**, **2007**.
[17].O.P. Sobukola, O.U. Dairo, ''Modeling Drying Kinectics of Fever Leaves (Ocimenviride) in a Convective Hot Air Drier,'' *Nigerian Food Journal*, Vol. **25**, Issue. **1**, pp.**145-153**, **2007**.
[18].Datafit Oakdale, ''Data fit version 9.0.59,'' Oakdale Engineering, Oakdale, USA PA **15070**, March, **2008**.
[19].J.O. Ojediran, A.O. Raji, ''Thin Layer Drying of Millet and Effect of Temperature on Drying Characteristics,'' *Internationl Food Journal*, Vol. **17**, pp.**1095-1106**, **2010**.
[20].O.P. Sobukola, O.U. Dairo, L.O. Sanni, A.B. Odunewu, B.O. Fatiolu, ''Thin Layer Drying Process of Some Leafy Vegetables Under Open Sun Drying,'' *Food Science and Technology Interntional*, Vol. **13**, Issue. **1**, pp.**35-40**, **2007**.
[21].I. Doymaz, ''Thin Layer Behavior of Mint Leaves,'' *Journal of Food Engineering*, Vol. **74**, pp.**370-375**, **2007**.

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