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Full Length Research Paper

Modelling of drying pattern of cassava chips at different air velocity and temperature using fluidizied bed dryer

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This study investigated the drying kinetics of cassava chips using fluidized bed dryer with a view to predicting the most suitable drying model for the drying of cassava (TMS30572 and TMS98/0581). The experiment was carried out using a 4x4x2 factorial; (air velocities, air temperatures, and varieties of cassava) with three replications for each treatment.. Fresh cassava tubers were peeled, washed, drained and chipped using manual slicer. A 100 g of the wet chips was then subjected to drying using pre heated fluidized bed drier at a specific temperature and varied air velocity. The change in mass was recorded at constant time interval of 20 minutes until constant weight was achieved Twelve different mathematical drying models were fitted to the experimental data of the moisture ratio against the time using nonlinear regression analysis by Sigma Plot 10.0 and Microsoft Excel (2010). The models were compared based on their coefficients of determination (R^2), reduced chi-squares (χ^2), root mean square errors (RMSE), and mean bias error (MBE). Modified Henderson and Pabis model was found to be the best mathematical model for describing the drying kinetics of cassava chips for TMS30572 and TMS98/0581 respectively having highest value of R^2, least values of χ^2, RMSE and MBE.

Key words: Cassava, fluidized bed dryer, modeling, drying.

INTRODUCTION

Drying is an energy intensive operation of some industrial significance, in most industrialized countries 7–15% of the nation's industrial energy is used for drying and often times with relatively low thermal efficiencies ranging from 25% to 50% (Chua *et al.,* 2001). It is the separation operation method of converting a solid, semi-solid or liquid feedstock into a solid product by evaporation of the liquid into a vapor phase through the application of heat (Jayamaran and Gupta, 2006). It occurs by effecting vaporization of the liquid by supplying heat which could be either supplied by convection (direct dryers), by conduction (contact or indirect dryers) and radiation (direct or indirect dryers). The essential features include phase change and production of a solid phase as end product. The process involves a heat and mass transfer phenomenon where moisture migrates from the interior to the surface of the drying product from which it evaporates. Heat is transferred from the surrounding air to the surface of the product. Part of this heat is transferred to the interior of the product, resulting to rise in temperature, formation of water vapor, while the remaining amount of heat is utilized in evaporation of the moisture from the surface (El-Ghetany, 2006). Drying behaviour is basically influenced by a number of internal characteristics and thermo physical properties (such as density, permeability, porosity, sorption-desorption) and external parameters (such as temperature, velocity, and relative humidity of the drying medium) (Kaya *et al.,* 2007).

About 88% of cassava produced in Africa is consumed by humans, 50 percent of which is processed. Cassava roots cannot be stored for a long period since they rot within 3 to 4 days after harvesting; this means that roots greater than 48 hours old have little market value and limits the range over which fresh roots can be marketed. The roots are usually bulky with about 60-70 % moisture which makes transportation of the tubers to urban market and exportation difficult and expensive therefore drying is used as means to reduce spoilage and ease of transportation. Cassava chips are unfermented white dried

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products of cassava with an average diameter of 3 to 5 mm often used as a carbohydrate base, for human consumption, in the animal feed industry, milled into flour for other uses such as in the production of ethanol, cakes, dough-nut and biscuits. Traditionally, it is processed into dried whole roots with undesirable colour, irregular shapes and often contaminated with moulds (Balagopalan *et al.,* 1988).

The quality of the dried chips produced is determined mainly in the drying stage. Undesirable biochemical changes and subsequent contamination and spoilage of the chips can only be prevented if the drying process is fast enough and the final product is dry enough (Maskan, 2000). Heat application to food during drying helps to achieve this. Though sun drying is the common method of drying of cassava in the tropics, has a main disadvantage of slowness of the drying process due to ambient temperature that is used for drying. Therefore there is need for alternative drying methods that will dry the product faster which has an extra advantage of providing uniformity of drying (Minguez-Mosquera *et al*., 1994; Tiris *et al.*, 1994; Ayensu 1997).

The application of heat during processing for drying affect these qualities, the drying kinetics for cassava chips need to be determined in order to stabilize variation in the quality of dried cassava chips. Drying kinetics of food crops are generally affected by factors which include drying temperature, pretreatment method, relative humidity, and product sizes (Ade-Omowaye *et al*., 2002; Kudra, 2004) and are crop specific. Manyresearchers have carried out studies on the drying characteristics and kinetics of various food crops (Sacilik *et al*., 2006; Doymaz, 2007; Vengaiah and Pandey, 2007; Goyal *et al*., 2008; Therdthai and Zhou, 2009). Physical and thermal properties of agriculture products such as heat and mass transfer, moisture diffusion, energy of activation, and energy consumption are required for ideal dryer design (Akpinar *et al*., 2003 a&b; Babalis and Belessiotis, 2004; Goyal *et al*., 2007). Mathematical modelling of drying processes and equipment is an important aspect of drying technology; its purpose is to allow design engineers to choose the most suitable operating conditions, size of the drying equipment and drying chamber accordingly to meet desired operating conditions.

MATERIALS AND METHODS

Sample Preparation

TMS 30572 and TMS 98/0581varieties were obtained fr om Ado-Ekiti, Ekiti State.

Freshly harvested cassava were peeled washed, drained, chipped and dried at varying temperature and air velocity to obtain dried cassava chips from each of the cassava varieties.

Drying Operation

100g of cassava chips was thinly loaded into the drying glass chamber of the Laboratory size fluidized bed dryer (Arm field, mode: Mark II,;,serial number: FBD/,240/90/5428) for TMS30572 and TMS98/0581 respectively. The sample weight was being monitored using an electronic weighing balance (Sartorious Tare: Model BS323S) with accuracy of 0.01g at interval of 20 minutes until constant weight was observed which indicated equilibrium condition. Different drying temperatures used were 40, 50, 60 and 70 ^{o}C at air velocity of 2.03, 2.25, 2.45 and 2.75 m/s. Each experiment was carried out in triplicate and average values were determined. The initial average moisture content which was about 64 % wet basis was obtained following the method of AOAC (1990).

ANALYTICAL PROCEDURE OF THE THIN LAYER DRYING

The analytical procedure for the thin layer drying of the dried cassava chips was done by determining the moisture content of the dried chips from both varieties, calculation of the moisture ratio, correlation coefficient, mean bias error, random mean square error and fitting the values generated into drying models as shown in Table 1.

Moisture Ratio

The change in mass data recorded from the experiment was converted to dry basis data using the moisture content value of the dried sample. The values were converted into moisture ratio using the equation 1a:

$$MR = \frac{[\![(M]\!]_t - M_e)}{(M_0 - M_e)}$$

which was simplified by some investigators (Yaldiz *et al.,* 2001; Togrul and Pehlivan, 2002; Midilli and Kucuk, 2003) because of the continuous fluctuations occurring during drying processes to:

$$MR = \frac{M_t}{M_0}$$

where:
MR: moisture ratio, dimensionless;
M_0: initial moisture content (kg water/kg dry mater);
M_t: moisture content at time t (kg water/kg dry mater);
Me: equilibrium moisture content, (kg water/kg dry mater).

Mathematical Modelling of the Drying Curve

The drying curves obtained were processed to find the most suitable model for describing the drying process of

Table 1. Mathematical Models as Investigated by Various Authors.

No	Model name	Model equation	Model equation References
1	Newton or Lewis	MR = exp(−kt)	Kingsly *et al*., (2007) Ayensu (1997) Liu and Bakker-Arkema (1997) O'Callaghan *et al*., (1971)
2	Page	MR = exp(−kt^n)	Lopez *et al* (2000) Zhang and Litchfield (1991) Akpinar, 2006
3	Modified page	MR = exp(−$(kt)^n$)	Babalis *et al.,* (2006)
4	Henderson and Pabis	MR = a exp(−kt)	Henderson and Pabis(1961) Chinnman (1984) Aghbashlo *et al*., (2009)
5	Logarithmic	MR = a exp(−kt) + c	Doymaz (2004) Yaldiz *et al*., (2001)
6	Two term	MR = a exp(−bt) + c exp(−dt)	
7	Two term exponential	MR = a exp(−kt) + (1− a) exp(−kat)	Ertekin & Yaldiz (2004)
8	Wang and Singh	MR = 1+ at + bt^2	Ertekin &Yaldiz (2004)
9	Midilli and Kucuk	MR = aexp(−kt^n) + bt	Midilli *et al.,* (2002)
10	Diffusion approach	MR = a exp(−kt) + (1− a) exp(−kbt)	Togrul & Pehlivan (2002)
11	Verma*et al.*	MR = a exp(−kt) + (1− a) exp(−gt)	Lopez *et a*l., (2000) Zhang and Litchfield (1991)
12	Modified Henderson and Pabis	MR = a exp(−kt) + b exp(−gt) + c exp(−ht)	Babalis *et al.,* (2006)

cassava chips. Drying curves were fitted with twelve (12) thin-layer drying equations as given in Table 1 by several investigators. 96 runs of drying experiments were done at varied temperatures (40, 50, 60 and 70 ^oC) with air velocity of 2.03, 2.25, 2.45 and 2.75 m/s respectively.

The experimented moisture ratio was subjected to non-linear analysis using sigma10 plot and Microsoft Excel 2010 software packages to generate the constants and predicted moisture ratio for each model equation. The R^2 (coefficient of determination) was the main criterion for selecting the best equation. Also the goodness of fit was determined by lowest values for various statistical parameters such as χ^2 (chi square), RMSE (root mean square error) and MBE (mean bias error) (Goyal *et al*., 2006; Erenturk *et al*., 2004; Demir *et al*., 2004; Ertekin and Yaldiz , 2004; Akpinar *et al.*, 2003; Togrul and Pehlivan, 2002; Midilli *et al.*, 2002; Yagcioglu *et al.,* 2001.; Sarsavadia *et al.*, 1999 ; Yagcioglu *et al.*, 1999; Lui and Bakker-Arkema, 1997; Yaldiz and Ertekin , 1991; O'Callaghan *et al.,* 1971).

The drying curves obtained were processed to find the most convenient one among 12 different expressions defining drying behaviour as given in Table 1. The statistical test methods used to evaluate the performance of the drying models were calculated as:

$$R^2 = \frac{\sum_{i=1}^{N}\left(MR_i - MR_{pre,i}\right) * \left(MR_i - MR_{exp,i}\right)}{\left[\left[\sum_{i=1}^{N} \left(MR_i - MR_{pre,i}\right)^2\right] * \left[\sum_{i=1}^{N} \left(MR_i - MR_{pre}\right.\right.\right.}$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)$$

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

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

Where;

$MR_{exp,i}$ stands for theith experimental moisture

$MR_{pre,i}$ is the ith predicted model moisture ratio

N is the number of sampling times

n is the number of constants in the drying model.

RESULTS AND DISCUSSIONS

Mathematical Modeling of Drying Curves

The drying data obtained (moisture ratio against drying time) for the different dried chips (TMS30572 and TMS98/0581) samples from varied drying condition were fitted into the selected models shown in Table 1. R^2 for 40 ^oC varied from 0.7585 to 0.9995 at 2.03 m/s, from 0.4886 to 1.0000 at 2.2 5m/s, from 0.6339 to 0.9997 at 2.45 m/s, 0.4859 to 1.0000 at 2.75 m/s. At 50 ^oC R^2 varied from 0.5503 to 1.0000 at 2.03 m/s, from 0.4335 to 0.9956 at 2.25 m/s, from 0.2639 to 0.9978 at 2.45 m/s, from 0.0832 to 0.9989 at 2.75 m/s. At 60 ^oC R^2 varied from 0.0658 to 1.0000 at 2.03 m/s, from 0.1475 to 1.0000 at 2.25 m/s, from 0.0681to 0.9988 at 2.45 m/s, from 0 to 0.9999 at 2.75 m/s. Also at 70 ^oC R^2 varied from 0.2036 to 1.0000 at 2.03 m/s, from 0.2091to 1.0000 at 2.25 m/s, from 0.1474 to 1.0000 at 2.45 m/s, from 0.0111 to 1.0000 from 2.75 m/s.

The χ^2 values varied from 1.03 x 10^{-4} to 8.31 x 10^{-5}, 1.09 x 10^{-4} to 7.46 x 10^{-5}, 1.10 x 10^{-4} to 3.31 x 10^{-2} and 1.13 x 10^{-4} to 8.49 x 10^{-5} for temperature 40 ^oC and air velocity (2.03, 2.25, 2.45, 2.75 m/s respectively); at 50 ^oC and air velocity (2.03, 2.25, 2.45, 2.75 m/s respectively) values varied from 1.90 x 10^{-3} to 6.31 x 10^{-4}, 1.46 x 10^{-3} to 4.14 x 10^{-4}, 2.12 x 10^{-4} to 6.40 x 10^{-4} and 1.02 x 10^{-3} to 9.64 x 10^{-5}; it varied from 1.03 x 10^{-4} to 9.15 x 10^{-5}, 1.27 x 10^{-4} to 7.53 x 10^{-5}, 1.23 x 10^{-3} to 5.97 x 10^{-2} and 1.44 x 10^{-4} to 9.16 x 10^{-6} for 60 ^oC and air velocity (2.03, 2.25, 2.45, 2.75 m/s respectively); at 70 ^oC and air velocity (2.03, 2.25, 2.45, 2.75 m/s respectively) the values varied from 2.99 x 10^{-3} to 6.78 x 10^{-7}, 5.69 x 10^{-2} to 2.81 x 10^{-7}, 7.87 x 10^{-2} to 3.56 x 10^{-7} and 6.96 x 10^{-2} to 9.819 x 10^{-6} for the tested models for TMS30572 samples.

The non linear analysis result of TMS98/0581 dried chips, the R^2 for 40 ^oC and 2.03m/s varied from 0.1849 to 0.9994, from 0.0473 to 0.9999 2.25 m/s, from 0.4324 to 0.9986 at 2.45 m/s, from 0.2743 to 1.0000 at 2.75 m/s. For 50 ^oC, it varied from 0.6498 to 0.9998 at 2.03 m/s, from 0.6055 to 0.9993 at 2.25 m/s, from 0.6158 to 0.9998 at 2.45 m/s and from 0.3702 to 1.0000 at 2.75 m/s. at 60^oC it varied from 0.4566 to 1.0000 at 2.03 m/s, from 0.4033 to 0.9991 at 2.25 m/s, from 0.2538 to 0.9974 at 2.45m/s and 0.0000 to 1.0000 at 2.75 m/. At 70 ^oC it varied from 0.5338 to 0.9998 at 2.03 m/s, from 0.1271 to 1.0000 at 2.25 m/s, from 0.1109 to 1.0000 at 2.45 m/s and 0.0000 to 0.9999 at 2.75 m/s.

The χ^2 values which varied from 1.36 x 10^{-4} to 9.99 x 10^{-4}, 1.00 x 10^{-4} to 7.52 x 10^{-5}, 1.10 x 10^{-4} to 4.22 x 10^{-2} and 1.22 x 10^{-4} to 9.87 x 10^{-5} for temperature 40^oC and air velocity (2.03, 2.25, 2.45, 2.75 m/s respectively); at 50^oC and air velocity (2.03, 2.25, 2.45, 2.75 m/s respectively) values varied from 1.25 x 10^{-4} to 3.37 x 10^{-2}, 1.01 x 10^{-3} to 9.18 x 10^{-4}, 1.03 x 10^{-4} to 6.67 x 10^{-5} and 2.48 x 10^{-4} to 8.20 x 10^{-4}; it varied from 1.06 x 10^{-4} to 9.81 x 10^{-5}, 1.05 x 10^{-4} to 9.27 x 10^{-5}, 1.02 x 10^{-3} to 5.30 x 10^{-2} and 1.44 x 10^{-4} to 8.70 x 10^{-5} for 60 ^oC and air velocity (2.03, 2.25, 2.45, 2.75 m/s respectively); at 70^oC and air velocity (2.03, 2.25, 2.45, 2.75 m/s respectively) the values varied from 2.34 x 10^{-3} to 6.04 x 10^{-4}, 1.06 x 10^{-4} to 6.46 x 10^{-2}, 1.34 x 10^{-4} to 6.15 x 10^{-2} and 1.78 x 10^{-4} to 9.88 x 10^{-6} for the tested models.

The higher value in each of the range indicates the R^2 value also the lowest χ^2, RMSE and MBE for Modified Henderson and Pabis model. Values of R^2 greater than 0.99 were obtained for all the models, except the Wang & Singh model. The selection of the best model to describe the drying behavior of pretreated cassava chips was based on the highest R^2 and lowest χ^2, RMSE and MBE values respectively. At all levels of temperature considered, Modified Henderson and Pabis has highest values of R^2 and lowest χ^2, RMSE and MBE. The results of best fit for Modified Henderson and Pabis model values at various air velocity and temperature for TMS 30572 and TMS98/0581 chips are shown in Tables 2 and 3.

The coefficients of determination; chi-square, RMSE and MBE of all the thin layer drying models for all drying conditions (varying temperature and air velocity), the Modified Henderson and Pabis model gave the lowest values and thus satisfy the condition to represent the model for thin layer hot-air drying of the cassava chips of both cassava varieties.

Validation of the established model was made by comparing the experimental moisture ratio values with the predicted ones as shown in Figure 1a to Figure 1d for TMS30572 and Figure 2a to Figure 2d for TMS98/0581 respectively. There was good agreement between the experimental and predicted variables which indicates that the Modified Henderson and Pabis model could be used satisfactorily to predict the thin layer hot-air drying of cassava chips from TMS30572 and TMS98/0581 although all models had R^2 higher than 0.99 except for Wangh and Singh model for both varieties, which is acceptable as reported by Madamba *et al.* (1996).

Drying Behaviour of Dried Cassava Chips

The drying curves shown by Figures 3a to 3d show the changes in the experimental moisture ratio data of the cassava chips with drying time at specific air velocity with

Table 2. Best fit of drying (Modified Henderson and Pabis) model values at various air velocity and temperature for dried TMS 30572 chips.

Air velocity (m/s)	**Temperature (°C)**	**R^2**	**χ^2**	**RMSE**	**MBE**
2.03	40	0.9995	5.16e-5	0.006223	-1.58e-3
	50	1.0000	4.30e-6	0.001639	1.87e-5
	60	1.0000	4.07e-7	0.000505	1.04e-5
	70	1.0000	6.78e-7	0.000651	5.43e-6
2.25	40	1.0000	0.003619	0.047558	0.002955
	50	0.9956	4.14e-4	0.016079	1.06e-4
	60	1.0000	5.79e-7	0.000602	3.17e-5
	70	1.0000	2.81e-7	0.000419	2.54e-5
2.45	40	0.9997	3.29e-05	0.004531	9.12e-05
	50	0.9978	2.31e-4	2.23e-5	-1.40e-2
	60	0.9988	1.12e-4	0.008352	-5.28e-5
	70	1.0000	3.56e-7	0.000472	-4.94e5
2.75	40	1.0000	1.35e-1	0.148891	-5.14e-2
	50	0.9989	9.64e-5	0.007761	1.16e-4
	60	0.9999	9.16e-6	0.002393	2.90e-4
	70	1.0000	1.47e-6	0.000939	9.70e-5

Table 3. Best fit of drying (Modified Henderson and Pabis) model values at various air velocity and temperature for dried TMS 98/ 0581 chips.

Air velocity (m/s)	Temperature (oC)	R^2	χ^2	RMSE	MBE
2.03	40	0.9994	5.72e-5	0.005861	-1.60e-4
	50	0.9998	3.27e-5	0.004426	8.55e-5
	60	1.0000	4.07e-7	0.000505	1.04e-5
	70	0.9998	2.40e-5	0.003795	-2.76e-4
2.25	40	0.9999	1.00e-5	0.002452	2.14e-5
	50	0.9993	9.15e-5	0.007553	-1.2e-4
	60	0.9991	1.05e-4	0.007951	-7.09e-6
	70	1.0000	4.35e-6	0.001616	-6.86e-5
2.45	40	0.9986	1.62e-4	0.009863	-1.28e-4
	50	0.9998	2.16e-5	0.003603	-1.24e-4
	60	0.9974	2.64e-4	0.012581	3.78e-4
	70	1.0000	3.06e-4	0.001356	1.61e-5
2.75	40	1.0000	3.53e-7	0.00046	-9.50e-6
	50	1.0000	4.84e-6	0.001704	1.26e-4
	60	1.0000	2.76e-6	0.001286	8.36e-5
	70	0.9999	9.88e-6	0.002434	-3.75e-5

varied temperature (40, 50, 60 and 70 °C) for TMS30572 and TMS98/0581 respectively. The drying of the cassava chips at varied temperature and specific air velocity exhibited the characteristic moisture desorption behavior. Initially, high rate of moisture removal was observed, followed by slower moisture removal in the latter stages. This characteristic behaviour can be attributed to the various forms in which water is present in food products. As the drying was progressing, the moisture ratio was observed to be decreasing non linearly in respective of the drying time for all the samples. Doymaz, 2004, 2007b & 2008; Ertekin and Yaldiz, 2004; Kingsly *et al*., 2007; Vengaiah and Pandey, 2007 also reported that it is a general trend adopted by other food products such as sweet pepper, tomatoes, egg plant, mulberry and peach slices. Figures 3a to 4d confirmed that air velocity is important during cassava drying because it affects the rate of moisture removal. It also shows that as air velocity increases from 2.03 m/s to 2.75 m/s the rate of drying that is moisture removal increases irrespective of the increase in temperature as demonstrated by Figures 3a to 4d for cassava chips from TMS30572 and TMS98/0581 respectively. Air velocity therefore reduces the resistance to moisture transport thereby increasing the drying rate.

The drying rate for cassava chips (TMS30572) at air velocity of 2.03 m/s and varied temperature (40, 50, 60 & 70 °C) were 4.41×10^{-5}, 3.05×10^{-5}, 3.61×10^{-5} and 3.27×10^{-5} kg water per kg dry matter per hour, followed by 2.25 m/s having 4.65×10^{-5}, 3.63×10^{-5}, 4.35×10^{-5} and

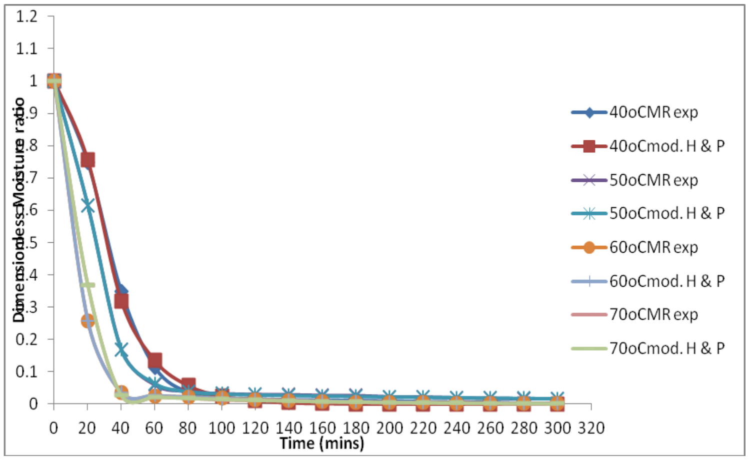

Figure 1a. Experimental and predicted moisture ratio by the Modified Henderson and Pabis model versus drying time for air velocity of 2.03m/s for TMS30572.

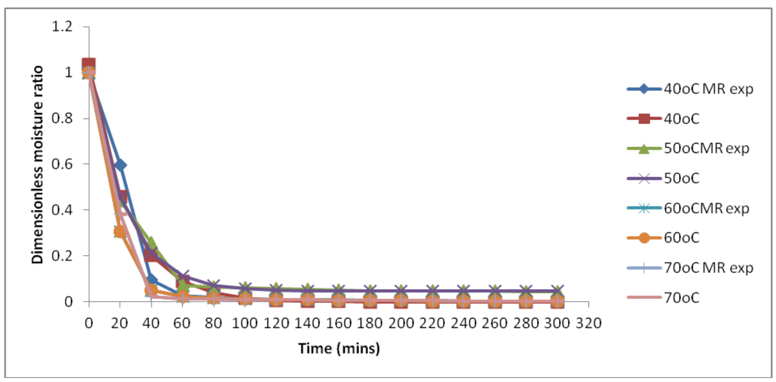

Figure 1b. Experimental and predicted moisture ratio by the Modified Henderson and Pabis model versus drying time for air velocity of 2.25m/s for TMS30572.

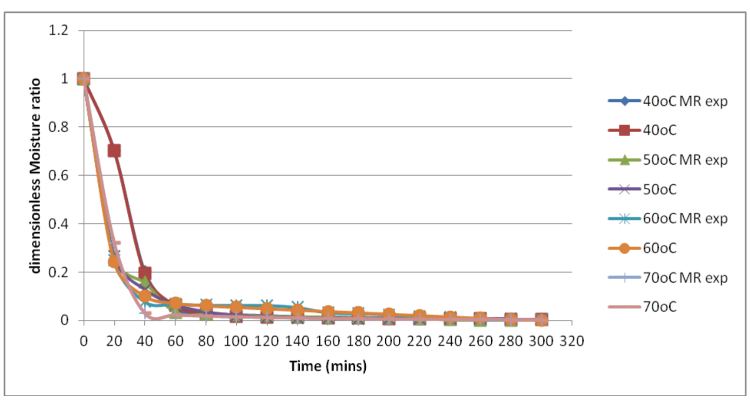

Figure 1c. Experimental and predicted moisture ratio by the Modified Henderson and Pabis model versus drying time for air velocity of 2.45m/s for TMS30572.

4.68 x 10^{-5} kg water per kg dry matter per hour while that for cassava chips dried at air velocity of 2.45 m/s which were 4.07 x 10^{-5}, 3.46 x 10^{-5}, 4.79 x 10^{-5} and 4.74 x 10^{-5} kg water per kg dry matter per hour and at 2.75 m/s the rate were 4.43 x 10^{-5}, 4.37 x 10^{-5}, 5.18 x 10^{-5} and 5.28 x 10^{-5} which indicates that increase in air velocity irrespec-

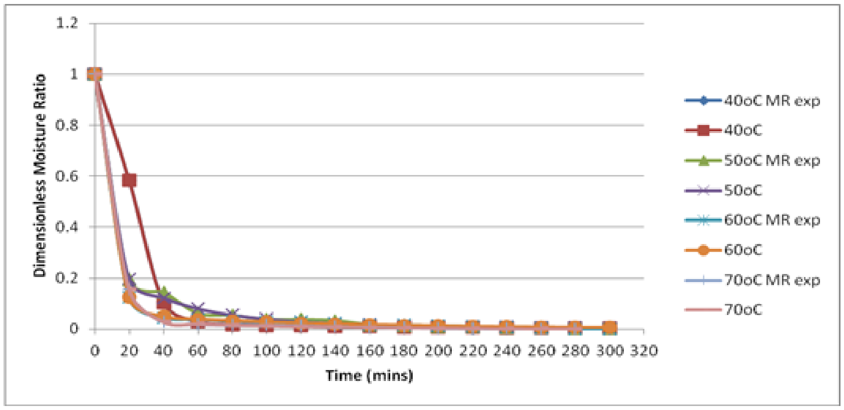

Figure 1d. Experimental and predicted moisture ratio by the Modified Henderson and Pabis model versus drying time for air velocity of 2.75m/s.

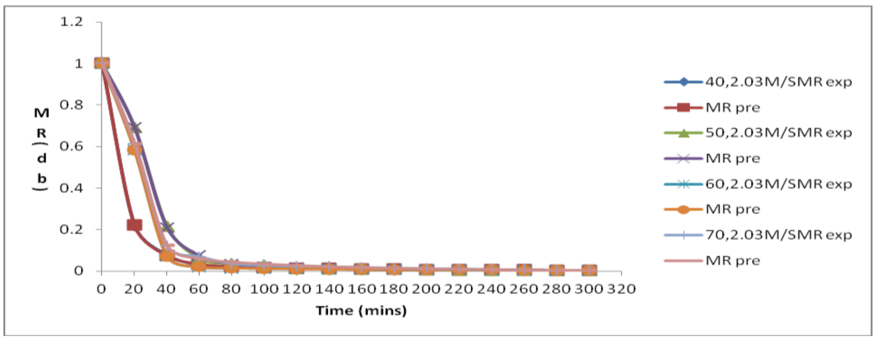

Figure 2a. Experimental and predicted moisture ratio by the Modified Henderson and Pabis model versus drying time for air velocity of 2.03m/s TMS98/0581 .

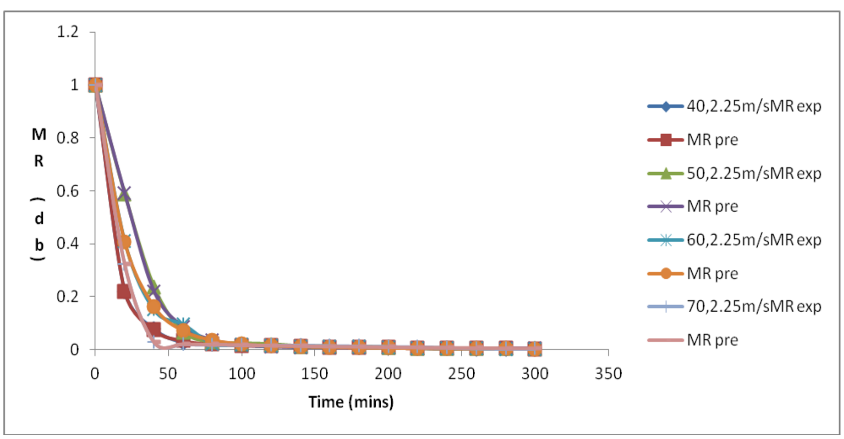

Figure 2b. Experimental and predicted moisture ratio by the Modified Henderson and Pabis model versus drying time for air velocity of 2.25m/s TMS98/0581.

tive of the temperature has significant effect on drying rate. Drying rates decreased with decreasing moisture contents and drying occurred in the falling rate period. The drying was also characterized by no constant rate (at the early part of the drying processes) or a short constant rate (at the end of the drying). Maskan, 2000; Damirel and Turhan, 2003 reported similar observations during studies on the convective drying of banana.

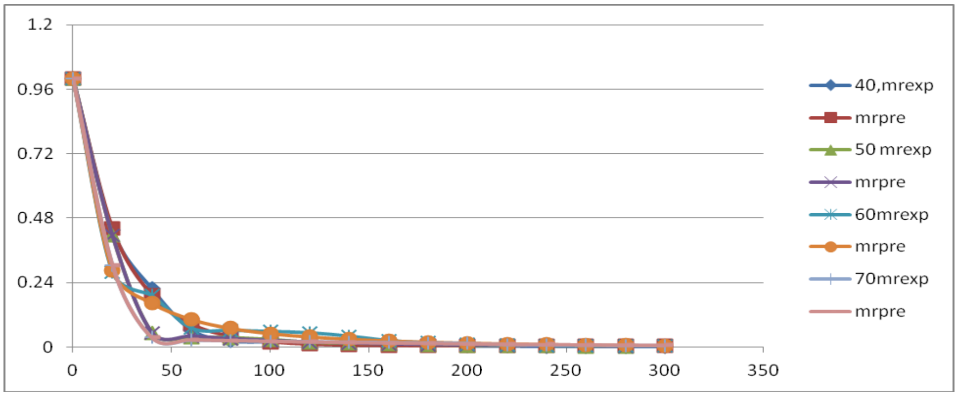

Figure 2c. Experimental and predicted moisture ratio by the Modified Henderson and Pabis model versus drying time for air velocity of 2.45m/s TMS98/0581.

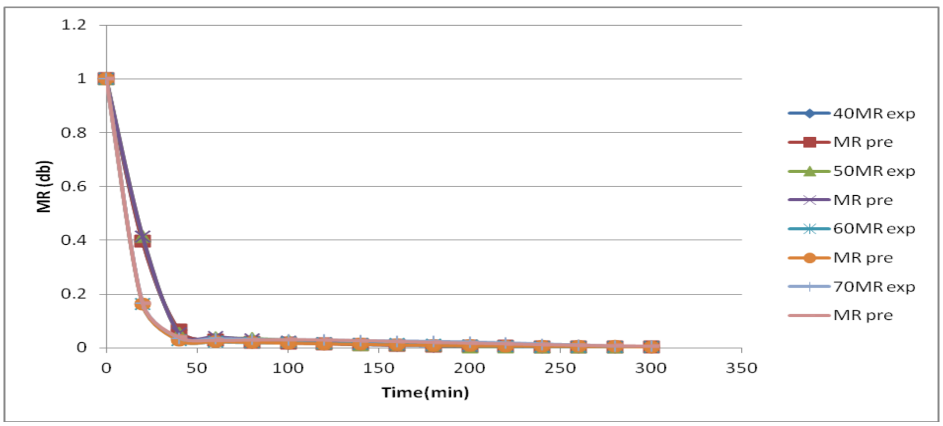

Figure 2d. Experimental and predicted moisture ratio by the Modified Henderson and Pabis model versus drying time for air velocity of 2.75m/s TMS98/0581.

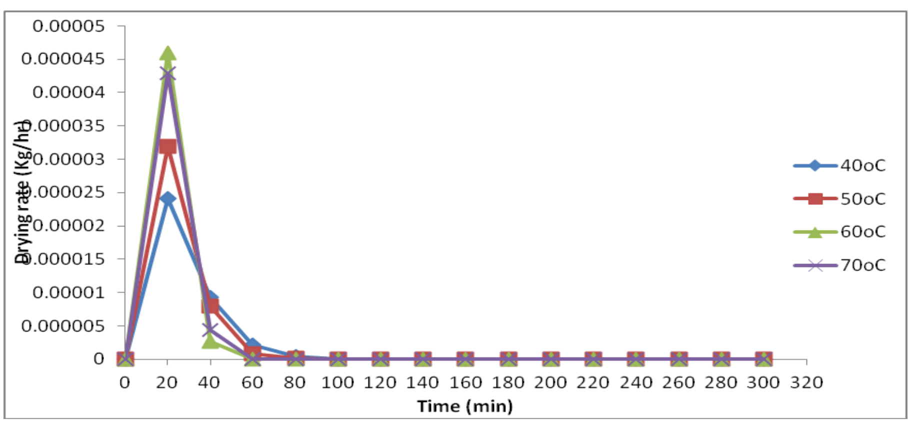

Figure 3a. Drying rate dynamics of cassava chips at air velocity of 2.03m/s and different temperature (^oC) for TMS 30572.

The mean drying rate for cassava chips (TMS98/0581) at air velocity of 2.03m/s and varied temperature (40, 50, 60 & 70 ^oC) respectively were 2.41 x 10^{-5}, 3.20 x 10^{-5}, 4.59 x $10^{-5}$and 4.29 x 10^{-5} kg water per kg dry matter per hour, followed by 2.25m/s having 3.36 x 10^{-5}, 4.43 x 10^{-5}, 4.56 x $10^{-5}$and 4.45 x 10^{-5} kg water per kg dry matter per hour while that for cassava chips dried at air velocity of 2.45m/s which were 3.10 x 10^{-5}, 4.93 x 10^{-5}, 4.78 x $10^{-5}$and 4.71 x 10^{-5} kg water per kg dry matter per hour and at 2.75m/s the rate were 3.83 x 10^{-5}, 5.09 x 10^{-5}, 5.13 x

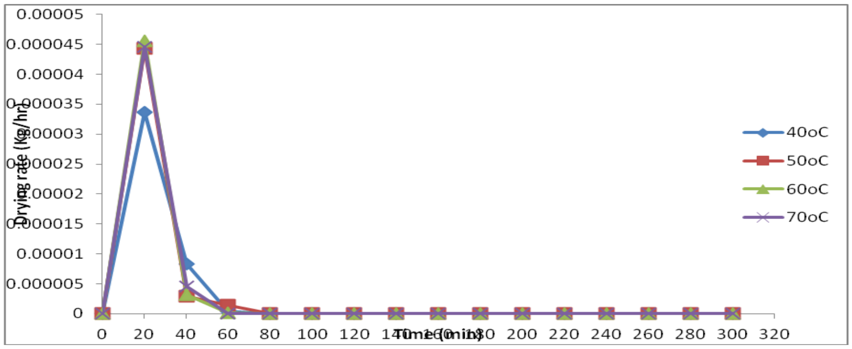

Figure 3b. Drying rate dynamics of cassava chips at air velocity of 2.25m/s and different temperature (^{o}C) for TMS 30572.

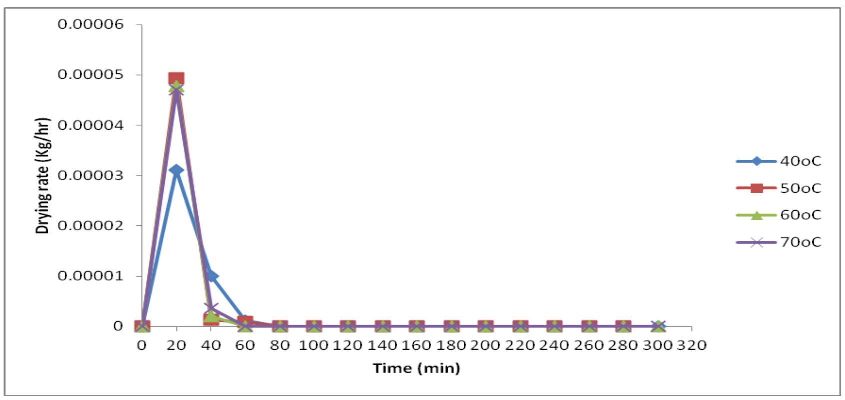

Figure 3c. Drying rate dynamics of cassava chips at air velocity of 2.45m/s and different temperature (^{o}C) for TMS 30572.

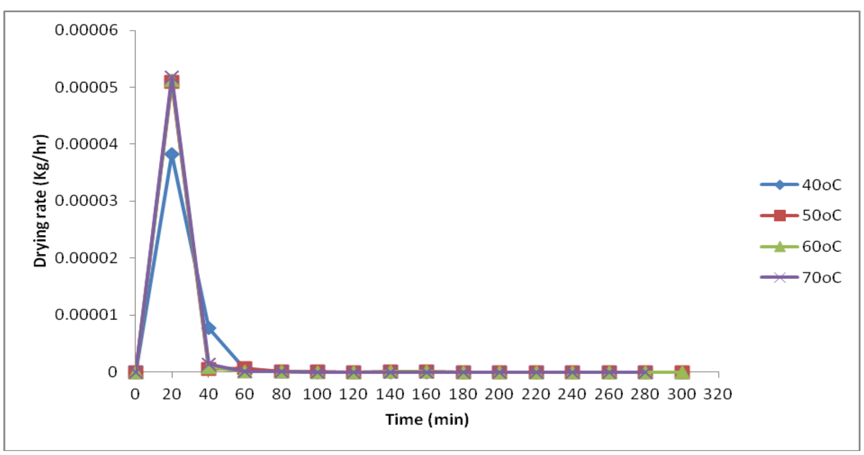

Figure 3d. Drying rate dynamics of cassava chips at air velocity of 2.75m/s and different temperature (^{o}C) for TMS 30572.

$10^{-5}$and 5.18 x 10^{-5} which indicates that increase in air velocity irrespective of the temperature has significant effect on drying rate.

There was no constant rate-drying period in the entire drying process from the curves as shown in Figure 3a to Figure 4d, all drying processes occurred in falling rate-

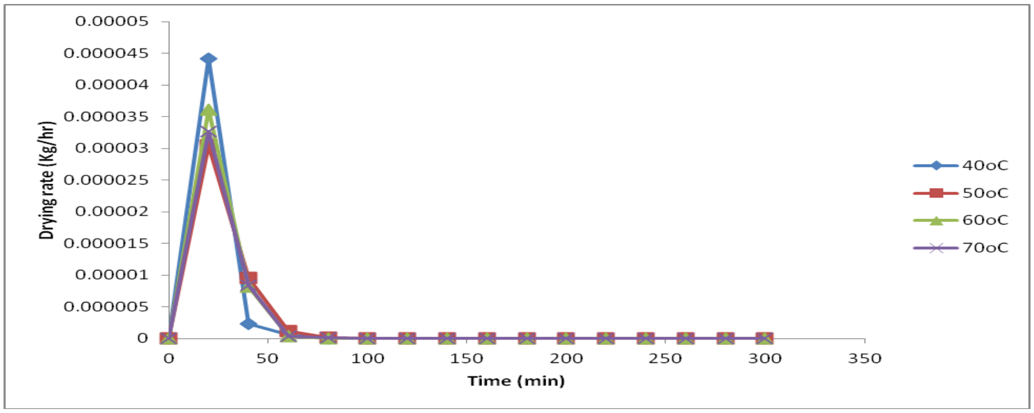

Figure 4a. Drying rate dynamics of cassava chips at air velocity of 2.03m/s and different temperature (^{o}C)TMS 98/0581.

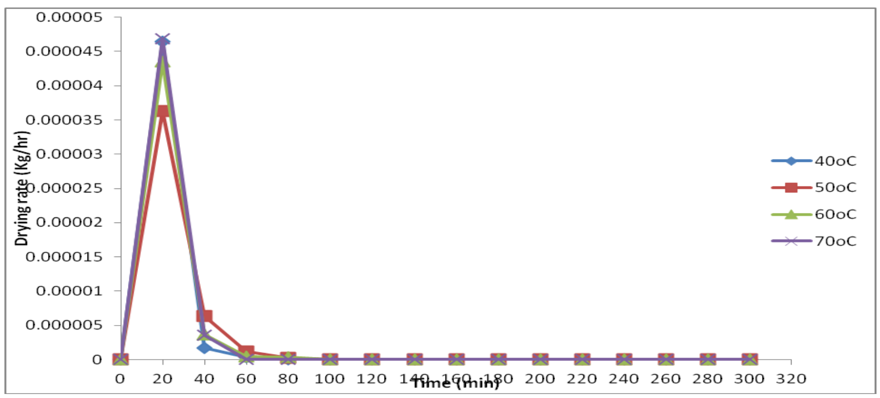

Figure 4b. Drying rate dynamics of cassava chips at air velocity of 2.25m/s and different temperature (^{o}C)TMS 98/0581.

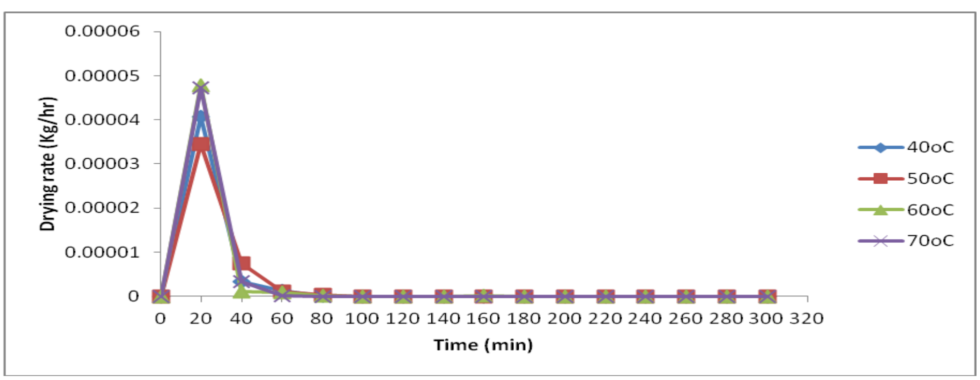

Figure 4c. Drying rate dynamics of cassava chips at air velocity of 2.45m/s and different temperature (^{o}C)TMS 98/0581.

drying period and during the period, the drying process of cassava chips from TMS30572 and TMS98/0581 respectively were mainly controlled by diffusion mechanisms.

Lopez *et al.* 2000; Ertekin and Yaldiz, 2004; Piga *et al*., 2004; Doymaz, 2004, 2005; Akanbi *et al*., 2006; Sacilik *et al*., 2006; Kingsly *et al*., 2007 also reported same in earlier research work.

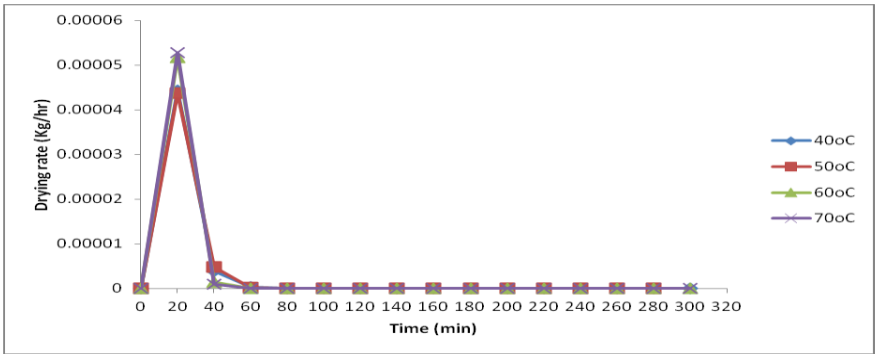

Figure 4d. Drying rate dynamics of cassava chips at air velocity of 2.75m/s and different temperature (^oC)TMS 98/0581.

CONCLUSION AND RECOMMENDATION

Based on the results obtained from this study, the following conclusions could be drawn :

- Cassava (TMS98/0581) chips at particular air velocity for varied temperature had higher dryinrates than samples from TMS30572,
- drying curves of dried cassava chips showed a falling rate-drying period only under the experimental conditions employed for both varieties,
- the highest R^2 value, lowest value of χ^2, RMSE and MBE for the thin layer drying process for cassava chips from TMS30572 and TMS98/0581 was obtained from the Modified Henderson and Pabis model at constant air velocity and varied temperature (40, 50, 60 and 70^oC) as shown in Tables 4.5 and 4.6 respectively. Therefore, the Modified Henderson and Pabis model could adequately describe drying characteristics of cassava chips from TMS 30572 and TMS98/0581 than the other models and that
- air velocity has effect on the drying process of the chips from both varieties as moisture ratio decreases with increase in air velocity at specific temperature.

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