DRYING KINETICS OF IBADAN-LOCAL TOMATO (*Lycopersicum esculentum* cv)

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ABSTRACT

There are several tomato cultivars grown in Nigeria, but their production is seasonal and availability geographical in spite of their importance in the daily dietary intake. They are usually in short supply in the dry season and effective storage in the fresh state still poses a challenge. Among these available cultivars in the southwestern Nigeria is Ibadan-Local (*Lycopersicum esculentum* CV*)*, a variety with higher fruit yield and longer fruiting tendency which has received little or no significant attention because of the higher preference of other cultivars to it. Pre-treatment methods have been reported to improve drying characteristics of fruits and vegetables generally but there is dearth of information on drying of Ibadan-Local variety of tomato despite its high nutritional value.

Sixteen grams (16g) of Ibadan-Local variety was sorted for complete ripeness, firm and void of injury/bruises and osmotically pre-treated in a binary osmotic solution containing 45g of sugar and 15g of salt and a solution temperature of 50^{o}C previously prepared to have a solution to fruit ratio of 10:1 and the experiment was conducted in triplicate. Osmosized samples were removed, drained and the surface mopped up to eliminate posterior weight at 30 minutes interval and weighed electronically until a constant weight was attained (Water loss at infinity). These osmotically pre-treated and fresh samples were then subjected to drying at 40, 45 and 50^{o}C in an oven that was previously run on a no-load mode for 30minutes. Mechanism of mass transfer phenomena was thus studied. Five thin layer drying models (Exponential, Henderson and Pabis, Page, Modified Page and Logarithmic) were compared and fitted into the experimental moisture ratio. Adequacy of fit was based on highest R^2, χ^2 and least RMSE. Effective coefficient of moisture diffusivity and Activation energy were determined using Arrhenius equation.

Results of water loss and solid gains were significant ($p<0.05$) for all variables considered. Different models fit at different temperatures. The Exponential model fitted at 40 &45^{o}C with R^2 value range of 0.8291-0.8981 and 0.9352-0.981 for treated, 0.9453-0.9829 and 0.8281-0.9224 for untreated tomato having the best fit in Page and Modified Page and RMSE value range of 0.07966-0.10089,0.0464-0.364 (treated) and 0.0301-0.0538(untreated). At 50^{0}C, R^2 value ranged between 0.8461-0.8981 (treated) and 0.8281-0.9224 (untreated), with RMSE value of 0.07984-0.09659 and 0.0778-0.1008. Calculated values of effective moisture diffusivity varied from 1.17-3.51x10^{-8} and 1.25-3.13x10^{-8} and activation energy varied from a maximum of 52.61-46.81 KJ/mol in treated and untreated tomato. The present study has shown that the proposed empirical models were able to describe mass transfer process during osmotic dehydration of tomato as the values calculated using the proposed empirical models were in good agreement with the experimental data.

KEYWORDS: Tomato, models, effective diffusion coefficient, pre-treatment, activation energy.

1. INTRODUCTION

Drying is the commonest form of food preservation that extends the shelf life of fruits and vegetables (Doymaz, 2007). Ojediran and Raji, (2010) reported that it is an important unit operation in the food processing industry. The major objective in drying agricultural products is the removal of water in the solid up to a certain level at which microbial spoilage, deterioration and chemical reactions are greatly minimized (Krocxida and Marinos-Kouris, 2003). This allows for safe storage over an extended period, and also brings about substantial reduction in weight and volume, minimizing packaging, storage and transportation costs (Jaiyeoba and Raji, 2012).

Drying of most fruits and vegetables are done in thin layer using different conventional drying methods but these methods have been found to be deficient as most of the nutritional and sensory properties are reportedly lost after drying but pre-treatment of fruits/vegetables have been reported to improve the drying characteristics of dried products. Although much information has been given on the effective moisture diffusivity and activation energy for various agricultural products as some researchers have studied the moisture diffusion and activation energy in the thin layer drying of various agricultural products such as Seedless grapes (Doymaz and Pala, 2002), Plums (Goyal *et al.,* 2007), grapes (Pahlavanzadeh *et al*., 2001), candle nuts (Tarigan *et al.,* 2006), potato slices (Akpinar *et al.,* 2003) and onion slices (Pathare and Sharma, 2006). Very little published literature is available on the effective moisture diffusivity and activation energy data for local varieties most especially Ibadan-Local Tomato during drying.

One of the several tomato cultivars grown in Nigeria is Ibadan-Local which is indigenous to the southwestern part of Nigeria with higher fruit yield and longer fruiting tendency (Adedeji *et al*., 2006) when compared with other varieties but has received little or no significant acceptability because of the higher preference of other cultivars to it because of inadequate information on the drying characteristics of this variety (Jaiyeoba and Raji, 2012).

The local variety, from literatures and preliminary investigation has shown to contain a very high percentage of titratable acid and pH values(because of the presence of citric and malic acids which are required for best flavour , palatability and its influence on the brightness of color, stability, consistency and the keeping quality of the product (Kaur *et al.,* 1996). This is a pointer to the fact that the local variety has better qualities that are yet to be harnessed. Published literatures are available on the drying kinetics (effective moisture diffusivity and activation energy) data for different fruits and vegetables including tomato but there is still a dearth of information on the drying kinetics of Ibadan-Local tomato.

This study therefore investigated the drying kinetics of Ibadan-Local variety of tomato. This is with a view to identifying the effect of the optimum processing conditions on the local variety and its drying characteristics.

2. METHODOLOGY

2.1 Experimental Methods

Ibadan-Local (*Lycopersicum esculentum* CV*)* tomato fruits previously sorted for complete ripeness, firm and void of injury/bruises were used for this experiment. Binary osmotic solution containing 45g of sugar and 15g of salt in 100ml of distilled water i.e. (60g/100g) was prepared on a heat stirrer (Stuart model CB162, U.K) previously prepared to have a solution to fruit ratio of 10:1 at a solution temperature of 50^{o}C- Optimum processing condition, (Jaiyeoba and Raji, 2012). Sixteen grams (16g) of Ibadan-Local variety was osmotically pre-treated in the sucrose-salt solutions in a water bath (10 shaker Tecnal TE 421 Model, Germany) previously brought to a relatively higher temperature (to compensate for heat loss when samples were introduced to the solution) and kept at 30, 40, and 50^{o}C temperatures. The temperature within the water bath was maintained thermostatistically, wherein temperature variation was maintained not more than ±1^{o}C and the experiment was conducted in triplicate. Samples were removed, drained and the surface mopped up to remove posterior weight at 30 minutes interval and weighed until a constant

weight was attained (Water loss at infinity). These osmotically pretreated samples were then subjected to oven drying at 40, 45 and 50°C while untreated (Fresh) samples of this tomato variety were also subjected to the same drying temperature in an oven that was previously run on a no-load mode for 30minutes and the results were used to find the moisture ratio at different temperatures. The moisture ratio, MR is the ratio of free water still to be removed at time t, to the total free water initially available in the food.
The moisture ratio, MR is given by Nieto *et al*., (2001) as:

$$MR = \frac{Mt - Me}{Mo - Me} \quad \text{...} (1)$$

Where, M_t is the moisture content of tomato slab after time, t; M_e is the moisture content of tomato slab at equilibrium (gH_2O/g dry solid); and M_o is the moisture content of tomato slab prior to O.D (g H_2O/g dry solid)

The drying time was thereafter plotted against time. The dimensionless moisture Ratio, MR was also plotted against Time at the different drying temperatures. The drying rate against time graph at the three temperatures and the MR plot against Time were further used for the drying kinetics.

Data was hence generated and analyzed. Simulation of results was done and fitted into five existing semi-theoretical models namely: (Exponential (Newton) model, Henderson and Pabis model, Page model, Modified Page model and the Logarithmic model (Table 1**)** to predict mass transfer in the samples.

2.2 Mathematical Modelling of the Drying Process

Moisture ratio data obtained from the drying experiment were fitted to five of the most commonly used thin layer drying models (Table 1) using the non linear regression procedure in SPSS for Windows 14.0 released in 2005. In order to estimate and select the appropriate drying model between five of the commonly used thin layer drying models for grains and legumes were tested. The fit was statistically determined by fitting experimental data to the model equation.

Table 1: Mathematical models used for drying characteristics

Model	**Model Equation**	**References**
Exponential (Newton)	MR = exp (-kt)	Liu and Bakker-Arkema, 1997
Henderson and Pabis	MR = a.exp (-kt)	Henderson and Pabis, 1961
Page	MR= exp ($-kt^n$)	Zhangn and Litchfield, 1991
Modified Page	MR = exp [$-(kt)^n$]	Overhaults *et al., 1973*
Logarithmic	MR = a. exp (-kt)+c	Yaldiz *et al*., 2001

Source: Akpinar and Bicer (2006)

The initial parameter estimates were obtained by linearization of the models through logarithmic transformation and application of linear regression analysis. The least-squares estimates or coefficients of the terms were used as initial parameter estimates in the non-linear regression procedure. Model parameters were estimated by taking the moisture ratio (MR) to be the dependent variable. The Coefficient of determination (R^2), χ^2 and Root Mean Square Error (RMSE) were used as criteria for adequacy of fit. The best model describing the thin layer drying characteristics of tomato samples was chosen as the one with the highest R^2 χ^2 and the least RMSE (Ozdemir and Devres, 1999; Doymaz *et al*., 2004; Ertekin and Yaldiz, 2004; Ojediran and Raji, 2010).

2.3 Effective Coefficient of Moisture Diffusivity

Drying process of food materials generally occurs in the falling rate period (Wang and Berennan, 1992). To predict the moisture transfer during the falling rate period, several mathematical models have been proposed using Fick's second law. By using Fick's second law and considering the following assumptions, proposed equ (1) for the effective diffusivity for an infinite slab (Crank, 1975).

1. Moisture is initially distributed uniformly throughout the mass of a sample
2. Mass transfer is symmetric with respect to the center.
3. Surface moisture content of the sample instantaneously reaches equilibrium with the condition of surrounding air.
4. Resistance to the mass transfer at the surface is negligible compared to internal resistance of the sample.
5. Mass transfer is by diffusion only. Mathematical modeling and simulation of drying carries under different conditions is important to obtain a better control of this unit operation and an overall improvement of the quality of the final product.
6. Diffusion coefficient is constant and shrinkage in negligible

The experimental drying data for the determination of effective diffusivity coefficient (D_{eff}) were interpreted using Fick's second law for spherical bodies according to Geankoplis (1983) and Doymaz (2004a). This is because the shape of the tomato fruits are closer to being spherical than the commonly used flat object (slab assumption). The diffusivity coefficient (Deff) was obtained from the equation for spherical bodies and the moisture diffusivity coefficient (D_{eff}) was calculated at different temperatures using the slope derived from the linear regression of *ln*(MR) against time data.

The effective radius (R) was calculated using the equation given by Aseogwu *et al*., (2006). The activation energy is a measure of the temperature sensitivity of D_{eff} and it is the energy needed to initiate the moisture diffusion within the seed. It was obtained by linearising Equation (5).

$$MR = \frac{M}{M_0} = \frac{8}{\pi^2}\sum_{n-1}^{\infty}\exp\left[-\frac{(2n-1)^2\pi^2}{4L^2}Dt\right] \text{.....................................} (2)$$

Where MR is moisture ratio, M is the moisture content at any time (kg water/kg dry matter), M_0 is the initial moisture (kg water/kg dry solid), n = 1, 2, 3,…. the number of terms taken into consideration, t is the time of drying in second, D is the effective moisture diffusivity in M^2/s and L is the thickness of slice (m).

Only the first term of Equation (2) is used for long drying times (Lopez *et al*., 2000),

$$MR = \frac{8}{\pi^2}\exp\left[-\frac{\pi^2 Dt}{4L^2}\right] \text{..} (3)$$

The slope (K_0) is calculated by plotting in MR versus time according to equation (4)

$$K_0 = \frac{\pi^2 D}{4L^2} \text{..} (4)$$

2.4 Energy of Activation

The energy of activation was calculated by using an Arrhenius type equation (Lopez *et al*., 2000; Akpinar *et al*., 2003).

$$D = D_0 \exp\left[-\frac{E_a}{RT_a}\right] \text{...(5)}$$

Where: E_a is the energy of activation (kJ/mol), R is universal gas constant (8.3143kJ/mol), T_a is the absolute air temperature (K), and D_0 is the pre-exponential factor of the Arrhenius equation (m^2/s).
The activation energy can be determined from the slope of the Arrhenius plot, Ln (D) versus $1/_{Ta}$.

Models are often used to study the variables involved in the process, predict drying kinetics of the product and to optimize the operating parameters and conditions (Karathanos and Bellesiotis, 1999).

From Equ (5), a plot of Ln D versus $1/_{Ta}$ gives a straight slope of K_1.

$$K_1 = {E_a}/{R} \text{..(6)}$$

The linear regression analysis was performed using statistic computer program to fit the equation to the exponential data to obtain correlation coefficient (R^2).

The drying process was stopped after no further change in weight was observed. At this point, moisture content decreased from 96.5% to 10.23% (w.b). Moisture content data were converted to moisture ratio and then fitted to the 5 thin layer drying models.

In MR was then plotted against time and the effective diffusivity (D_{eff}) was obtained from the slope of the graph.

The diffusivity coefficient at different temperatures is often found to be well predicted by the Arrhenius equation given by Equation (7) as follows:

$$D_{eff} = \frac{DoeEa}{Rg(T + 273.15)} \text{...(7)}$$

Where, D_{eff} is the effective diffusivity coefficient m^2/s, D_o is the maximum diffusion coefficient (at infinite temperature), E_a is the activation energy for diffusion (kJ/mol), T is the temperature (°C) and R_g is the gas constant.

Linearization the equation gives:

$$\ln Deff = -\left[\frac{1}{Rg(T + 273.15)} Ea\right] + \ln Do \text{..(8)}$$

D_o and E_a were obtained by plotting ln D_{eff} against $\left[\frac{1}{Rg(T + 273.15)}\right]$

The drying data were used to obtain the following plots:

i. The drying curve of moisture content against drying time at different temperatures
ii. Drying rate against time at different temperatures
iii. Drying rate against moisture content at different temperatures

3. RESULTS AND DISCUSSION

Tables 2 – 4 and Figs 2 – 4 show the results of the fitting statistics of various thin layer models at different drying temperatures. Model constants were derived by linearising the model equation,

Table 2 Results of the fitting statistics of thin layer models of pre-treated Ibadan-Local tomato at 40°C

Model no	Model name	Coefficients and constants	R^2	χ^2	RMSE
i.	Exponential	k = 0.001	0.8981	380.02	0.0797
ii.	Henderson & Pabis	k = 0.001, a = 1.002	0.8981	380.02	0.0798
iii.	Page	k = 0.001, n = 0.980	0.8260	199.37	0.8260
iv.	Modified page	k = 0.001, n = 0.980	0.8219	199.40	0.1009
v.	Logarithmic	k = 0.001, a = 1.002, c = 0.001	0.8981	380.02	0.0798

The result of the fitted model at 40°C showed that the Henderson and Pabis and the Logarithmic model shared the same level of fit.

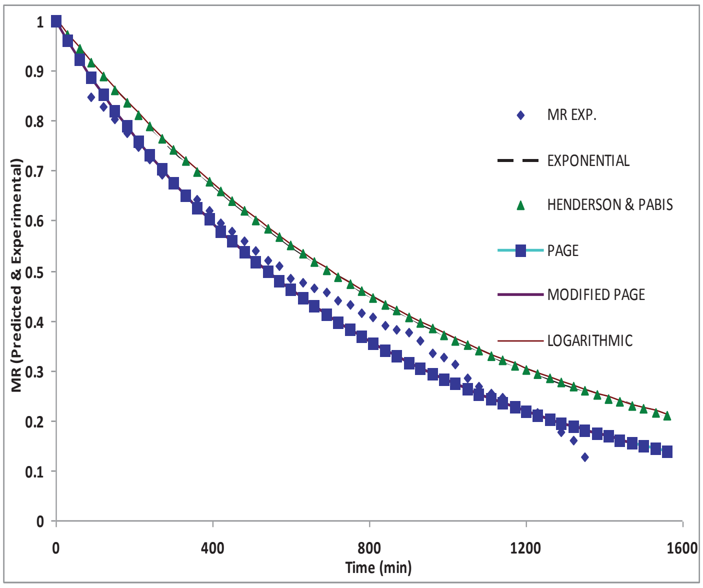

Fig. 2 Experimental and predicted MR for treated tomato at 45/15/50 dried at 40°C

Table 3 Results of the fitting statistics of thin layer models of pre-treated Ibadan-Local tomato at 45°C

Model no.	Model name	Coefficients and constants	R^2	χ^2	RMSE
i	Exponential	k= 0.002	**0.981**	**2706.82**	**0.364**
ii	Henderson & Pabis	a = 1.002, k = 0.002	0.9595	1233.91	0.0464
iii	Page	k = 0.004, n = 0.943	0.9352	735.88	0.06351
iv	Modified page	k = 0.003, n = 0.943	0.9352	735.49	0.06353
v	Logarithm	a = 1.002, k = 0.002, c = 0.002	0.9595	1233.91	0.04652

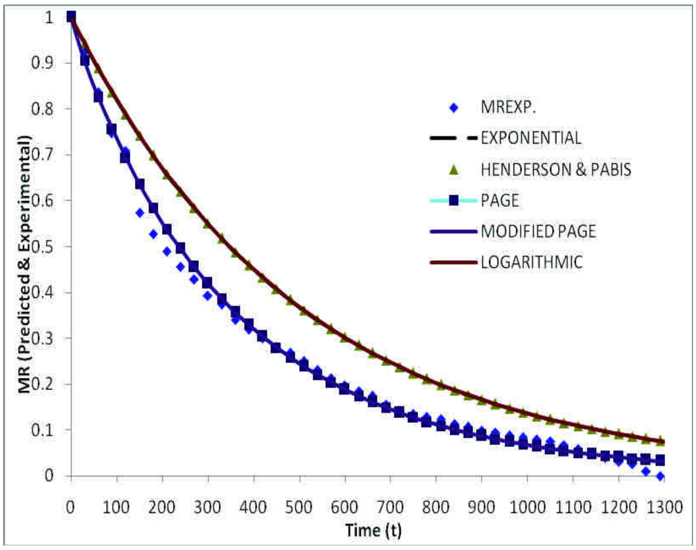

Fig. 3 Experimental and predicted MR for treated tomato at 45/15/50 dried at 45°C

Table 4 Results of the fitting statistics of thin layer models of pre-treated Ibadan-Local tomato at 50°C

Model no	Model name	Coefficients and constants	R^2	χ^2	RMSE
i	Exponential	k = 0.003	0.8664	214.04	0.09241
ii	Henderson and Pabis	k = 0.003, a = 1.023	0.8981	380.02	0.07984
iii	Page	k = 0.003, n = 0.987	0.8624	214.04	0.0945
iv	Modified page	k = 0.003, n = 0.987	0.8461	187.87	0.09659
v	Logarithmic	k = 0.003, a = 1.023, c = 0.003	0.8624	214.04	0.09479

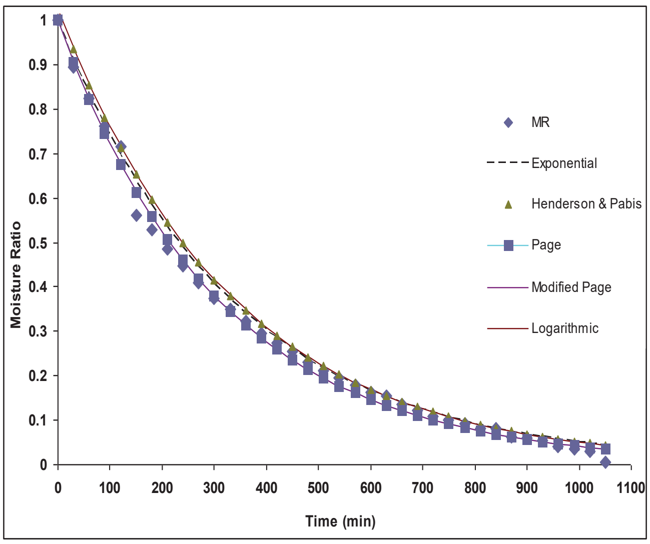

Fig. 4 Experimental and predicted MR for treated tomato at 45/15/50 dried at 50°C

Table 5 Estimated effective moisture diffusivity at different temperature of drying for osmotically pre-treated tomato

Samples	**Diffusion**	**Coefficient**	**10^{-8}(m^2/s)**
	40°C	**45°C**	**50°C**
Pre-treated tomato	1.17	2.34	3.51
Untreated tomato	1.25	2.50	3.13

Table 6 Estimated activation energy and moisture diffusivity constant

Sample	**Diffusion**	**Coefficient**	**10^{-8}(m^2/s)**
	Do (m^2/s)	Ea (KJmol)	R^2
Pre-treated	3.96	52.61	0.977
Untreated	3.85	46.81	0.919

Calculations of the moisture diffusivity and activation energy from Tables 5 and 6 indicated that there is a direct relationship between temperature and the effective spread, which depicts that increase in temperature leads to increase in the effective distribution coefficient. Using the Arrhenius relationship, the dependence of effective coefficient moisture diffusivity to temperature was described correctly. Activation energy and constant effective coefficient diffusivity were calculated from the slope of Arrhenius (Ln (D_{eff}) against $1/T_{abs}$. Changes of effective coefficient moisture diffusivity for tomato were gained from 1.17 x 10^{-8} to 3.52 x 10^{-8} in the temperature range of 40 to 50°C for osmotically pretreated samples of local variety and 1.25 x 10^{-8} to 3.12 x 10^{-8} m^2/s in the same temperature range for untreated local variety of tomato.

4. CONCLUSIONS

All the models used seem to fit but the Henderson and Pabis fitted best for osmotically pretreated tomato and modified page for untreated/fresh tomato as models with the highest value of RMSE, X^2 and R^2 were chosen (These three were the criteria used to determine the degree of fitness of the models). The present study has shown that the proposed empirical models were able to describe mass transfer process during osmotic dehydration of tomato as the values calculated using the proposed empirical models were in good agreement with the experimental data. Diffusivity constant value of 3.96 and 3.85 x10^{-8} m^2/s were obtained for treated and untreated samples. Activation energy is higher in osmotically pre-treated sample (52.61 KJ/mol), Untreated sample of tomato has an activation energy value of (46.81 KJ/mol) and R^2 value of 0.919.

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