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Estimating the Drying Kinetics of Spiced *Okpokuru* (*Oryctes rhinoceros*) with the use of some Thin-Layer Drying Models

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ABSTRACT

Okpokuru is the larvae of a red-headed palm weevil (Oryctes rhinoceros) being consumed in its cooked, dried or semi dried state. Drying is a veritable technology for storage beyond immediate consumption. This study thus, investigated the drying behaviour of the larvae in thin-layers using a laboratory convective oven dryer. A temperature range of 50 – 100 ℃ in multiples of 10 ℃ was selected and applied. Results were fitted to three thin-layer models of Page, Lewis, and Henderson-Parbis and compared using suitable statistical parameters (R^2, RMSE and χ^2) to select the suitable estimating thin-layer model. The emanating drying coefficients and the effective moisture transport process were evaluated using the linearized thin-layer drying model of Fick's second law diffusion equation. Constant rate period was observed to be completely absent during the drying process. The Page model and that of Henderson-Parbis respectively showed a reliable prediction of the drying kinetics of the red-head palm weevil's larvae at the chosen temperatures. The temperature related activation energy is 28.5 kJ/mol and the effective moisture diffusivity ranged from 3.943×10^{-7} - 1.3487×10^{-6} m^2/sec showing that the moisture reduction from the samples took place entirely in the falling rate period. Drying rate along with characterizing drying constant also increased exponentially with temperature.

1. INTRODUCTION

Orycytes rhinoceros (Izon, *Okpokuru*) is a weevil whose larvae is milky white, red-headed and prevalently C-shaped in overall physical appearance. A large-number colony of the larvae naturally occurs and lives in this metamorphic stage of growth, in decaying stems of raphia palm species. It is edible, and especially in it's cooked, dried (or semi-dried) state. Faleiro (2006), Okaraonye and Ikewuchi, (2009) all reported that it is among the stocks in the wilds that constitute unconventional sources for protein, fat and oil, and vitamins for the consuming population in the south-south region of Nigeria. It is generally marketed in its raw, cooked and dried or semi dried forms. Since it is a highly perishable meaty delicacy, microbial deterioration quickly sets in beyond its immediate consumption. Sometimes it is heavily spiced (though not usually beyond the generalized organoleptic requirement) and freeze-stored. However, a more quality/flavour preservative and generally mobile storage technique is when it is dried to an acceptable level of moisture content. In this state microbial, and biochemical deterioration (rancidity) would be halted for a rather long period, and the product's usable life-time and storage stability will increase along with its enhanced transportability (Doymaz, 2004; Figiel, 2010; Arefin et al., 2017).

Drying as a unit operation is a process of extracting moisture from a material using temperature gradient to induce moisture diffusion from the core to the surface of the product. The moisture at the surface is then removed by a slow convective air motion. Though, various methods are normally employed to achieve drying of such high moisture food biomaterial, shelf drying in close compartments using electrical heating is considered neat and compact, yielding to ease of calculating drying rates and drying economics (Onifade et al., 2016). Drying on thin layers generally employs shelf drying especially at experimental level of research and also in the food and agriculture industry. This informs its wide application in technical literature as in the reports of Akpinar et al. (2003) on red pepper, Satimehin and Alabi (2005) on plantain, Jain and Pathare (2007) on fish, Sacilik (2007) on pumpkin seeds, Kilic (2009) on fish quality, Ndukwu et al (2010) on cocoa bean, Ehiem and Simonyan (2011) on bitter kola, Ndukwu and Karen (2011) on cocoyam corm slices, Burubai and Etekpe (2014) on nutmeg and ogbono, Burubai (2015) on fresh-water clam, Burubai and Bratua (2016) on pre-osmosed fresh water frog.

Drying on thin-layers is a concept of simulating drying of a given bio-material done as if in batches of single beds or several layers each of small thickness, dx. A stream of hot air is then made to pass over the layers placed either in series or parallels, in a given direction using forced convection. As the hot air stream passes over the layers it absorbs moisture by a combined heat and mass transport processes. The process acting through a number of thin layers, each assumed to be of uniform thickness, the moisture pick-up capacity of the air stream declines one over the next layer. Drying is then described to be in stages of constant and or falling rates, each stage characterized by different drying conditions. Each layer would then attain equilibrium moisture content (EMC) at different drying periods as the exhaust air from a previous layer becomes input air to the succeeding layer and until the terminal layer is reached. Modelling the drying process in this simulated manner would of course, require that the layers are infinitesimally thin and placed in such a manner that the hot air stream exhausts through the layers undiminished in its moisture carrying capacity. The layers are therefore, seen to attain the desired equilibrium moisture content (EMC) at a given water activity at the same drying time. This assumption constitutes a major aspect in the development of thin layer drying models as an attempt to predict the drying behaviour of most food and agricultural materials (Mahmutoglu et al., 1995; Yaldiz et al., 2001; Wang et al., 2006).

For appropriate drying of *Orycytes rhinoceros* before storage therefore, a study of its drying behaviour is a necessary requirement for the design and development of the storage compartment, and to enable the development of generic drying curves and related coefficients. The objectives of this work therefore, are to investigate the drying kinetics of the red palm weevil larvae using a laboratory convective oven heating, and to validate the resulting experimental data by fitting to three mathematical predicting thin-layer drying models.

2. MATERIALS AND METHODS

2.1. Sample Preparation

Some 25 kg of the red-head palm weevil larvae was obtained from a local market at Ondewari town in Southern Ijaw Local Government Area of Bayelsa State, Nigeria. By measuring each of the larvae using 0.001 cm precision veneer calliper, they were stratified into different but equal thickness of 7 g sample groups. These samples were then suitably spiced, stabilized and stored in refrigerated cabinets in the Food Processing Laboratory, Department of Agricultural and Environmental Engineering of Niger Delta University, Bayelsa State, Nigeria. Each sample group was then oven dried using Convective oven Model WTCB 1718 at varying temperatures from 50°C – 100 °C in increments of 10 °C. The initial and other levels of moisture content values for each of the sample groups were measured using the method of ASAE standard (ASAE standards S368 41 2000). The dehydration process (weight loss) monitored at specific time intervals, to point of the equilibrium moisture content for each sample group was studied in similar manner as in the works of Burubai (2015) applied on freshwater clams, Sankat and Mujaffar (2006) on catfish, Jittanit, (2001) on pumpkin seeds and Robert et al (2008) on grape seeds. All the drying tests were replicated thrice at each temperature level and average values were recorded. The weight differences before and after drying were used to determine the final moisture content for each replicate, all measured on dry-basis as (Mohsenin, 1986).

$$M = \frac{w_i - w_f}{w_f} \tag{1}$$

Where:

M = dry basis moisture content (%-db)
W_i = initial weight of the specimen (g)
W_f = initial weight of the specimen (g)

2.2. Thin-layer Drying Models

A major concern in thin-layer drying modeling is the role of molecular transport through the layers. The general indication in technical literature is that drying of most bio-materials takes place in the falling rate period (Toledo, 2000). Following the Fick's second law on moisture diffusion, the molecular transport through a continuum of interface thin layers can be described with Equation (Crank, 1975; Zibokere and Egbe, 2019)

$$\frac{dM}{dt} = D_e\left(\frac{d^2M}{dr^2}\right) \tag{2}$$

Where:

M = moisture content at time t (kg_{H_2O}/kg_{solid})
t = drying time (min)
r = radial distance from the core to the surface (mm)
D_e = effective diffusivity (mm^2/min)

Equation (2) would solve to give moisture ratio (over a number of thin spherical layers) as (Ndukwu and Karen, 2011).

$$MR = \frac{6}{\pi^2} e^{-nD_e t\left(\frac{\pi}{r}\right)^2} \tag{3}$$

Where:

MR = moisture ratio
n = number of thin layers

Taking natural log of both sides

$$\ln(MR) = \ln\frac{6}{\pi^2} - nD_e(\frac{\pi}{r})^2 t \quad (4)$$

Whence the effective diffusivity (D_e) would be deduced from the slope of the plot of ln(MR) and drying time (t) as:

$$D_e = \frac{Slope\ of\ plot\,[r^2]}{n\pi^2} \quad (5)$$

Also, the moisture ratio can then be obtained as (Sahey and Singh, 2006):

$$MR = \frac{M - M_e}{M_o - M_e} \quad (6)$$

Where:

M_e = equilibrium moisture content (EMC) (kg_{H_2O}/kg_{solid})
M_o = initial moisture content (kg_{H_2O}/kg_{solid})

For rather small M_e (assumed to be zero in) (Robert et al., 2008) in relation to values of M and M_o, then Equation (6) would simplify to:

$$MR = \frac{M}{M_o} \quad (7)$$

2.2.1. The empirical models applied

The three chosen thin-layer models in this work, seen to be several and individual coinages from Equation (3), are as given below (Navneet et al., 2012).

i). the Lewis model:

$$MR = e^{-kt} \quad \text{(Kingly et al., 2007)} \quad (8)$$

ii). the Henderson-Parbis model:

$$MR = Ae^{-kt} \quad \text{(Chinnman, 1984)} \quad (9)$$

iii). the Page model:

$$MR = e^{-kt^n} \quad \text{(Karathanos and Belessiotis, 1999)} \quad (10)$$

A further solution of the Lewis model (Equation 8) in logarithmic form can give:

$$\ln(MR) = \ln(k) - kt \quad (11)$$

or

$$\ln\frac{M}{M_o} = \ln(k) - kt \quad (12)$$

Where:

k is the drying rate constant and A and n are empirical constants.

Equation (12) permits the plot of moisture ratio on natural logarithm axis against drying time with intercept, ln(k) on the moisture ratio axis and slope, - kt; whence the effective diffusivity, D_e can now be deduced (Suarez et al., 1980; Zibokere and Egbe, 2019).

2.3. Activation Energy

Different bio-materials naturally have high bound constituent water at different degrees of bonding. The higher the degree of bonding, the greater the amount of energy required to loosen the bond for effective moisture diffusivity during drying. The energy so required to initiate moisture transport during drying of biomaterials with high bound water content is technically referred to as activation energy in molecular transport studies. In this study, the activation energy was estimated from the Arrhenius type of relation given as (Burubai, 2015; Zibokere and Egbe, 2019).

$$D_e = D_o(e^{-E_a/Rt}) \quad (13)$$

Where:

- E_a = activation energy, (kJ/mol)
- D_e = effective diffusivity at drying time, t°K, (m^2/min)
- D_o = effective diffusivity at drying time, 0°K, (m^2/min known as the Arrhenius factor)
- R = universal gas constant (8.314 x 10^{-3}, kJ/mol.K)

Linearizing Equation (13) would give:

$$\ln D_e = \ln D_o - \frac{E_a}{Rt} \quad (14)$$

Where:

$$E_a = \ln\left(\frac{D_o}{D_e}\right)Rt \quad (15)$$

Taking drying time in relation to the absolute air temperature as t + 273, then Equation (15) will rewrite to give:

$$E_a = \ln\left(\frac{D_o}{D_e}\right)[\,0.008314(t + 273)] \quad (16)$$

The plot of $\ln D_e$ against inverse of the absolute temperature based drying time, t^{-1} will be linear with $\ln D_o$ at the $\ln D_e$ axis. The slope of the linearized plot, $\frac{E_a}{R}$ would give value of the required activation energy (Suarez et al., 1980).

2.4. Analysis of Statistical Parameters

Relevant statistical parameters are useful to validate the process when fitting experimental data to existing thin-layer drying models. Coefficient of determination (R^2) and the non-parametric reduced chi-square (χ^2) are especially useful in determining the goodness of fit for experimental data emanating from a particular drying temperature (Wang et al., 2006; Ndukwu and Karen, 2011; Zibokere and Egbe, 2019); while the root mean square error (RMSE) values are applied in selecting a suitable thin-layer drying model to estimate the drying kinetics of the specimens (Ertekin and Yaldiz, 2004). The statistical equations (Equation 17, 18 and

19) were used to calculate R^2, RMSE and X^2 respectively using the Microsoft Excel window 2010 (Ndukwu et al., 2010; Burubai, 2015)

$$R^2 = 1 - \left[\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2\right] \quad (17)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{n}} \quad (18)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{n - k} \quad (19)$$

Where:
$MR_{pre.}$ = predicted moisture ratio
$MR_{exp.}$ = experimental moisture ratio
n = number of observations
k = drying rate constant

The model(s) with the highest R^2 (approaching 1), a low RMSE and χ^2 values provided the criteria for accepting as the good estimator(s).

3. RESULTS AND DISCUSSIONS

3.1. Drying Kinetics

Figure 1 is a plot of moisture ratio of the samples against drying time for the chosen temperature levels, while Figure 2 shows the moisture ratio obtained in logarithmic form [ln(MR)] plotted as a function of drying time. The moisture ratios are all given in dry basis (db). The plots show an initial accelerated moisture loss in drying due to quick diffusion and evaporation of free water (Igbeka, 2013). Drying however, became slower at the later stages of drying time, even with increasing temperatures. The sharp drop seen in the drying curves (as in Figure 2) shows that removal of moisture from the samples decreased as time increased. This is characteristic of such animal-muscled bio-materials with high level of constituent fats/oils and protein causing less water activity even with increase in drying temperature (Jain and Pathare, 2007; Burubai and Bratua, 2016). This implies that lesser water is available for evaporation at the surface of the samples; thus, drying rate is seen to decrease with time typifying a falling rate drying proceeding without the feature of case-hardening even on the high temperatures ranges. This agrees with reports on the thin layer drying of red pepper (Akpinar et al., 2003), tomatoes (Kross et al., 2004), plantain (Satimehin and Alabi, 2005), salted catfish fillets (Sankat and Mujalfar, 2006), yoghurt (Hayaloglu et al., 2007), hull-less seed pumpkin (Sacilik, 2007), fresh fish (Kilic, 2009), bitter kola (Ehiem and Simonyan, 2011), bananas (Ganesapillai et al., 2011), pumpkin seeds (Jittanit, 2011), fresh tilapia fish (Zhiqiang et al., 2013) and clam (Burubai, 2015).

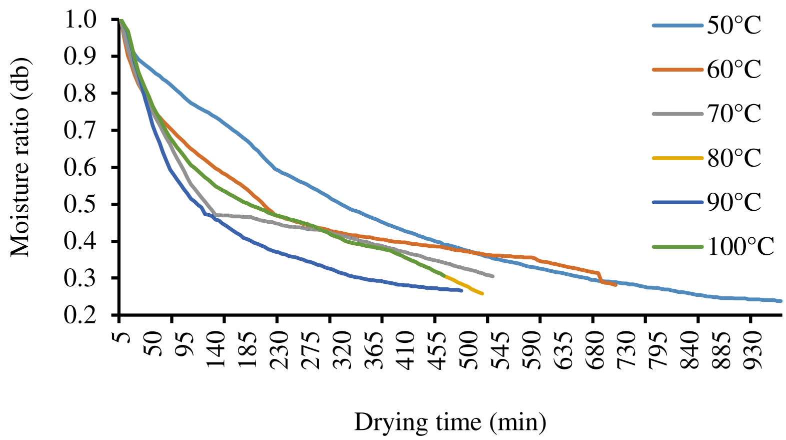

Figure 1: Drying curve at different temperature for Okpokuru *(Oryctes rhinoceros)*

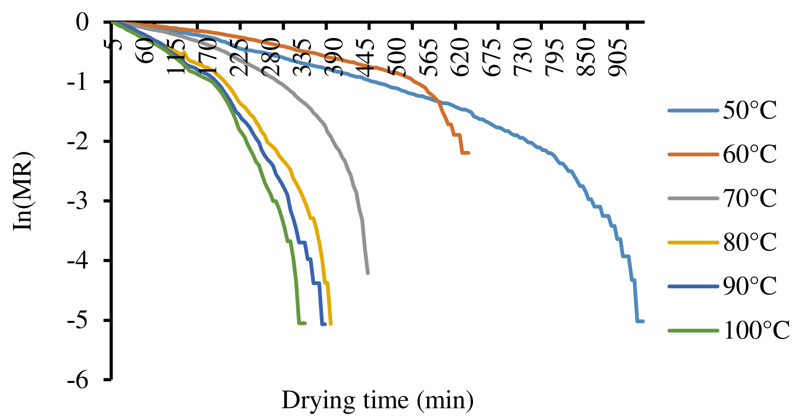

Figure 2: Drying curve of Okpokuru (*Oryctes rhinoceros)* (logarithmic moisture ratio vs drying time)

3.2. Fitting Experimental Data into Thin-Layer Drying Models

Estimating of the dry behaviour of the samples was done by fitting into the thin-layer drying models of Lewis, Henderson-Parbis and Page (Equations 8, 9 and 10). The fitting was done to enable selection of model that would best represent the drying behaviour of the specimens on thin layers. Table 1 presents the coefficient of determination, the root mean square error and the chi-square values used to validate the fitting process statistically. Fitting constants (Table 1) 'a' and 'k' were first obtained through a non-linear least square statistical analysis (SPSS, 1996) using data from the experiments fitted into the Fick's diffusion equation (Equation 2). R^2 values for the range of drying temperatures applied in this work were used as the main criteria for the determination of acceptable thin-layer drying model applicable for describing the drying data for the specimens. In Table 1 R^2 values ranged from 0.9560 - 0.9886 for the Page model, 0.9207-1.0 for Henderson model and 0.9532 - 0.9972 for Lewis model. With rather low RMSE values (0.0010127 – 0.018601) over the range of drying temperatures applied, the Page model followed closely by the Henderson-Parbis' seem to significantly represent the drying kinetics of the samples (□-level = 0.05). The respective χ^2 values ranging from 0.00000103-0.00003510 (approximately = 0), with experimental data values banded or clustered along the straight line of the plot (Figure 3), is a reasonable indication that the Page model gave a better goodness of fit than the others. Thus, the Page model was adjudged reasonably acceptable for estimating the drying characteristics of the red-head palm weevil.

Table 1: Statistical Parameters of Okpokuru *(Oryctes rhinoceros)* on the three thin-layer drying models

Model	Temperature (°C)	Fitting constants & coefficient	R^2	MBE	RMSE	χ^2
Page	50 °C	k= 0.00048, n=1.263	0.9812	-0.0138900	0.0010127	0.000001032
	60 °C	k=0.00035, n=1.2547	0.9605	0.0016370	0.0186010	0.000035100
	70 °C	k=0.000422, n=1.3824	0.9650	-0.0001100	0.0011120	0.000001260
	80 °C	k=0.00158, n=1.2622	0.9646	-0.0003100	0.0027890	0.000007980
	90 °C	k=0.000544, n=1.4885	0.9886	0.0003000	0.0027060	0.000007510
	100 °C	k=0.00171, n=1.2906	0.9631	-0.0004200	0.0035110	0.000013265
Henderson-Parbis	50 °C	k=0.0013, A=1.0060	1.000	0.0063800	0.0874600	0.007730000
	60 °C	k=0.0016, A=2.5607	0.9757	0.0318070	0.0361250	0.132559000
	70 °C	k=0.0023, a=2.8682	0.9972	0.0499340	0.4841300	0.239480000
	80 °C	k=0.0026, A=2.5204	0.9720	0.0507170	0.4564550	0.213625000
	90 °C	k=0.0028, A=2.5211	0.9532	0.0540540	0.4804430	0.236820000
	100 °C	k=0.0030, A=2.4930	0.9663	0.0576140	0.4888710	0.245824000
Lewis	50 °C	k=0.0010	0.9695	0.0067000	0.0924660	0.008600000
	60 °C	k=0.0016	0.9757	0.0104590	0.1187940	0.014212200
	70 °C	k=0.0023	0.9972	0.0139210	0.1349670	0.018411000
	80 °C	k=0.0026	0.9720	0.0172340	0.1551000	0.024315800
	90 °C	k=0.0028	0.9532	0.0186020	0.1653330	0.027686000
	100 °C	k=0.0030	0.9663	0.0199950	0.1696600	0.029192000

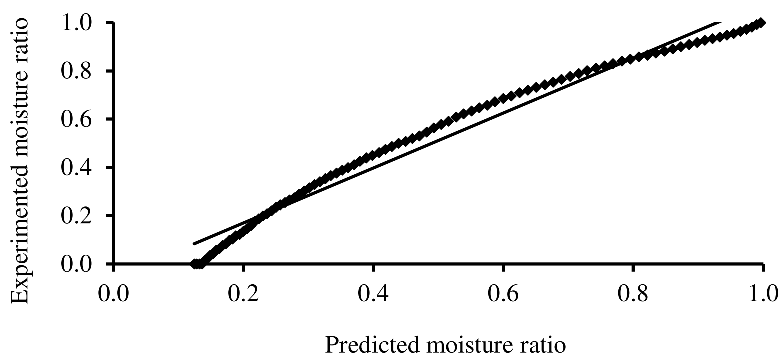

Figure 3: Relationship between experimental and predicted moisture ratio for the Page model

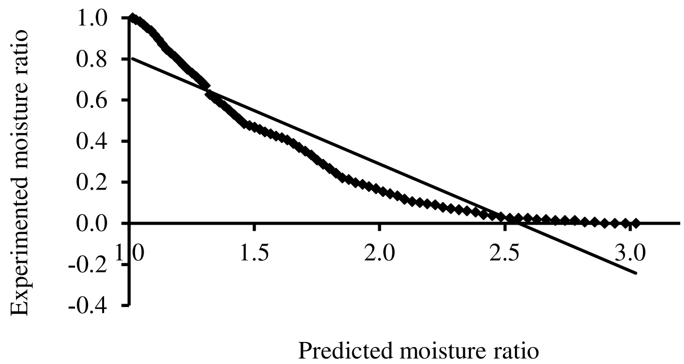

Figure 4: Relationship between experimental and predicted moisture ratio for the Lewis model

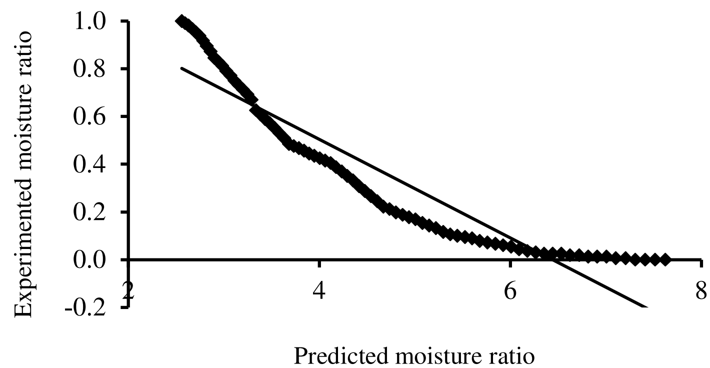

Figure 5: Relationship between experimental and predicted moisture ratio for the Henderson-Pabis model

3.3. Effective Diffusivity (D_e)

Effective diffusivity is a parameter used to describe the process of effective moisture migration from the solid matrix to the surface of the specimen. Equation 5, yielding effective diffusivity was obtained using the method of slopes. The resulting data based on average of three replications varied from 3.943×10^{-7}-1.3487×10^{-6} m^2/sec for the respective temperature values applied in this work (Table 2). It is evident that moisture diffusivity increased increase in drying temperature. This is reasonable as diffusion is seen as a temperature dependent mechanism. Robert et al. (2008), Jittanik (2011), Burubai and Bratua (2016) all reported similar results on grape seeds, pumpkin seeds, and fresh water clam respectively.

Table 2: Moisture diffusivity values of Okpokuru *(Oryctes rhinoceros)* at different drying temperatures

Temp (^{o}C)	Average effective diffusivity (m^2/s)
50	$3.943x10^{-7}$
60	$2.076\ x10^{-7}$
70	$6.744\ x10^{-7}$
80	$1.069\ x10^{-6}$
90	$1.255\ x10^{-6}$
100	$1.349\ x10^{-6}$

3.4. Activation Energy (E_a)

Activation energy describes the energy kinetics of the moisture transport process and is here reported to indicate the degree of temperature dependence of moisture diffusivity (heat sensitivity) of the specimens during the drying tests. Equation 16 linearized from the Arrhenius type relationship (Equation 13) over the temperature values used in this work (Figure 6). The calculated E_a value of 28.5 kJ/mol in this work was seen to be within the literature range of 12.7 – 110 kJ/mol for high moisture biomaterials (Zogzas *et al.,* 1996).

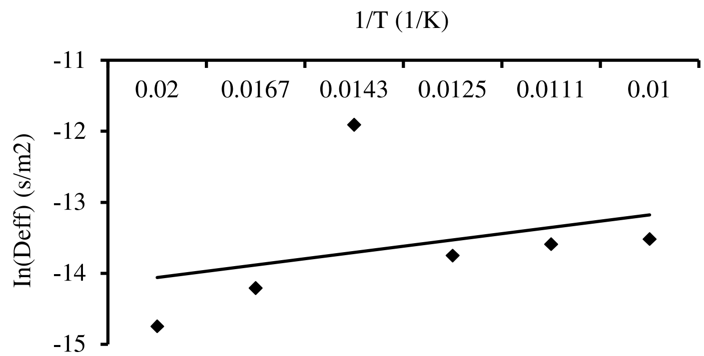

Figure 6: Estimation the activation energy for Okpokuru (*Oryctes rhinoceros* larvae)

4. CONCLUSION

An investigation was conducted to characterize the drying kinetics of the larvae of red-head palm weevil [Okpokuru (*Oryctes rhinoceros*)] on thin layers. Drying was observed to follow the falling rate period in line with several literature reports on other biological materials. Experimental data were fitted to selected three thin layer models to explore the best for predicting the drying kinetics of the specimens. The Page model followed closely by the Henderson-Parbis model were accepted as good estimators of the drying behaviour of the red-head weevil larvae over the drying temperature values applied in this work. The activation energy value was deduced to be 28.5 kJ/mol and falls within the range in technical literature over same temperature range in this report; and the effective moisture diffusivity values increased with increase of drying temperature.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Akpinar, E. K., Bicer, Y. and Yildiz, C. (2003). Thin layer drying of red pepper. *Journal of Food Engineering,* 59(1), pp. 99 – 104.

Arefin, A., Mallik, A., Sonmoy, K., Nahian, S.R.A. and Sakif, A.S.L. (2017). Drying and Dehydration Technologies: A Compact Review on Advance Food Science. *Research & Reviews: Journal of Food and Dairy Technology*, 5(4), pp. 36 – 42.

ASAE standards (S368 41). (2000). *Moisture measurement of unground grains and seeds*. ASAE Press, St. Joseph, MI, USA.

Burubai, W. (2015). Thin layer drying kinetics of freshwater clam (Tridacna maxima). *Umudike Journal of Engineering and Technology,* 1(1), pp. 79 – 90.

Burubai, W. and Bratua, I. (2016). Drying Kinetics of Pre-Osmosed Fresh Water Frog (*Dicroglossus Occipitalis). Nigerian Journal of Technology* (NIJOTECH), 35(4), pp. 935 – 939.

Burubai, W. and Etekpe, G. W. (2014). Microwave-drying behaviour of african nutmeg *(Monodora myristica)* and ogbono *(Irvinga gabonensis)* kernels. *Advanced Journal of Agricultural Research,* 2(12), pp. 189 - 196.

Chinnman, (1984). Evaluation of selected mathematical models for describing thin layer drying of in-shell pecans. *Transaction of the ASAE,* 27, pp. 610 - 615.

Crank, J. (1975). *The Mathematics of Diffusion.* 2nd ed, Oxford University Press. London, UK. p. 414.

Doymaz, I. (2004). Drying kinetics of white mulberry. *Journal of Food Engineering,* 61(3), pp. 341–346.

Ehiem, J.C. and Simonyan, K.J. (2011). Thin layer drying characteristics of bitter kola. *Proceedings of the Nigerian Institution of Agricultural. Engineers,* 32, pp. 384 – 390.

Ertekin, C. and Yaldiz, O. (2004). Drying of egg-plant and selection of a suitable thin layer drying model. *Journal of Food Engineering,* 63, pp. 349 - 359.

Faleiro, J.R.A. (2006). Review of the issues and management of the red palm weevil (*Rhynchophorus ferrugineus*) in coconut and date palm during the last one hundred years. *International Journal of Tropical Insect Science,* 26, pp. 135 – 154.

Figiel, A. (2010). Drying kinetics and quality of beetroots dehydrated by combination of convective and vacuum-microwave method. *Journal Food Engineering*. 98: 461 - 470.

Ganesapillai, M., Regpathi, L. and Murugesan, T. (2011). Modeling of thin-layer drying of banana under microwave, convective and combined microwave – convective processes. *Chemical Products and Modelling,* 6(1), pp. 1 – 10.

Hayaloglu, A. A., Karabulut, I., Alpaslan, M. and Kelbaliyev, G. (2007). Mathematical modeling of drying characteristics of strained yoghurt in a convective type 308 tray-dryer. *Journal of Food Engineering,* 78, pp. 109 – 117.

Igbeka, J.C. (2013). *Agricultural Processing and Storage Engineering*. University of Ibadan Publishing House and Press, Nigeria, pp. 145 – 155.

Jain, D. and Pathare, P. (2007). Studying the drying kinetics of open sun-drying of fish. *Journal of Food Engineering,* 78, pp. 1315 - 1319.

Jittanit, W. (2011). Kinetics and temperatures dependent moisture diffusivity of pumpkin seeds during drying. *Kasetsart Journal (Natural Science.*) 45, pp. 147 - 158.

Karathanos, V.T and Belessiotis, V. G. (1999). Application of thin layer equations to drying data of fresh and semidried fruits. *Journal of Agricultural Engineering Research*, 74, pp. 335 - 361.

Kingly, R.P., Goyal, R.K., Manikantan, M.R. and llyas, S.M. (2007). Effect of pre-treatment and drying air temperature on drying behaviour of peach slice. *International Journal of Food Science and Technolog,* 4, pp. 65 - 69.

Kilic, A. (2009). Low temperature and high velocity (LTHN) application in drying: characteristic and effects on fish quality. *Journal of Food Engineering,* 91, pp. 173 – 182.

Kross, R.K., Mata, M.E., Duarte, M.E.M. and Junior, V.S. (2004). Drying kinetics of tomatoes (*Lycopersicon esculentum*) submitted to a previous osmotic treatment. Proceedings of the *11th International Drying Symposium,1998, Halkidiki, Greece,* August 19 - 22. pp. 2133 - 2140.

Mahmutoglu, T., Pala, M. and Unah, M. (1995). Mathematical modelling of moisture, volume and temperature changes during drying. *Journal of Food Processing and Preservation,* 19, pp. 467 – 490.

Mohsenin, N. N. (1986). *Physical properties of Plant and Animal Materials.* Vol. 1. Gorgon Beach Science Publications, USA.

Navneet, K., Sarkar, B.C. and Sharma, H. K. (2012). Mathematical modelling of thin layer hot air drying of carrot pomace. *Journal of Food Science and Technology,* 49(1), pp. 33 – 41.

Ndukwu, M. C. and Karen, W. (2011). Thin layer drying kinetics of varieties of cocoyam corm slice with heated air. *Proceedings of the Nigerian Institution of Agricultural Engineers (NIAE),* 32, pp. 347 – 353.

Ndukwu, M.C., Ogunlowo, A.S. and Olukunle, O.J. (2010). Cocoa bean (*Theoboroma cacao*) drying kinetics. *Chilean Journal of Applied Agriculture,* 70(4), pp. 633 – 639.

Okaraonye, C.C. and Ikewuchi. J.C. (2009). Nutritional potential of *Orcyte rhiniceros* larva. *Pakistan Journal of Nutrition,* 8(1), pp. 35 - 38.

Onifade, T. B., Taiwo, A. and Jekayinfa, S.O. (2016). Modification of A Locally Made Electric Crop Dryer. *Innovative Systems Design and Engineering,* 7(2), pp. 40 – 51.

Onifade, T.B. (2015). Energy and Exergy Analyses of the thin layer of drying of physic nuts (*Jatropha curcas*). Unpublished Ph.D Dissertation, Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria, pp. 1-232

Robert, J.S. David, R.K. and Olga, P. (2008). Drying kinetics of pumpkin seeds, grape seeds. *Journal of Food Engineering,* 89, pp. 460 - 465.

Sacilik, K. (2007). Effect of drying methods on thin-layer drying characteristics of hull-less seed pumpkin. *Journal of Food Engineering,* 79, pp. 23 - 30.

Sahey, K. M and Singh, K. K. (2005). *Unit Operations in Agricultural Processing*. 2nd Ed. VIKAS Publishing PVT Ltd, New Delhi. pp. 125 – 130.

Sankat, C. K. and Mujaffar. S. (2006). Modelling the drying behaviour of salted catfish fillets. Proceedings of the 15th International Drying Symposium (IDS 2006), Budapest Hungary, 20 - 23 August.

Satimehin, A. A. and Alabi, T. O. (2005). Drying kinetics of plantain (*Musa paradisiaca*) chips. *Proceedings of the Nigerian Institute of Agricultural Engineers* (NIAE). 27, pp. 289 – 294.

SPSS (1996). SPSS for Windows, Release 7.5.1.

Suarez, C., Violaz, P. and Chilife, J. (1980). Diffusional analysis of air drying of grain sorghum. *Journal of Food Technology,* 15, pp. 523 - 531.

Toledo, R. T. (2000). *Fundamentals of Food Process Engineering*. CBS Publishers and Distributors, New Delhi.

Wang, Z. Sun. J., Liao-Chen, F., Zhao, G. and Wujand, H.U.X. (2006). Mathematical modelling on hot air drying of thin-layer apple pumice. *Journal of Food Engineering,* 40, pp. 39 - 46.

Yaldiz, O., Ertekin, C. and Uzum, H. I. (2001). Mathematical modelling of thin layer solar drying of sultana grapes. *Energy,* 26(5), pp. 457-465.

Zibokere, D.S. and Egbe, E.W. (2019). Thin-layer Drying Kinetics of Palm Weevil Larvae *(Rhynchophorus feruguneus* larvae*). Annals of Applied Science,* 5(2), pp. 40 – 46.

Zhiqiang, G., Wang, X., Li, M. and Jiang, X. (2013). Mathematical modeling of hot air drying of thin-layer fresh tilapia fillets. *Polish Journal of Food and Nutrition Science,* 63(1), pp. 25 – 34.

Zogzas, N. P., Maroulis, Z.B. and Marinos-Kouris, D. (1996). Moisture diffusivity complication in foodstuffs. *Drying Technology,* 14, pp. 2225 - 2253.