Modelling on the effect of temperature on the dehydration kinetics of rapana venosa meaty (veined rapa whelk)

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Abstract: Rapana Venosa (Veined rapa whelk) is perishable bio-material because of its high systemic moisture, it decomposed easily after been harvested thereby loses it marketability and value. Therefore, drying a means of reducing moisture and increases storability and availability during off-seasons. This research work investigated the Modelling on the Effect of Temperature on the Dehydration Kinetics of Rapana Venosa (Veined rapa whelk) applied under six varying temperatures ranging from 50°C -100°C with a varying temperature of 10°C. The drying data was inputted into three different models such as Page, Henderson-pabis and Lewis model in other to predict it's drying kinetic of the meaty. The developed constants and coefficients and the effective moisture diffusivity were resulted using non-linear regression approach and linearised Fick's second law respectively. The result obtained indicated moisture reduction sharply at the sample from the beginning of the experiment but became slower exponentially at the later end. The temperature dependent effective diffusivity values range from 1.1367×10^{-7}- 3.648×10^{-7} m^2 s^{-1} with activation energy 13.03kJ/mol. It is therefore, an evident that the drying process of Rapana Venosa took place extremely at the falling rate period characteristic of drying of biomaterials. Page model, closely followed by the Lewis model and lastly Henderson-Parbis were the best models applicable for predicting the drying behaviour of the Rapana Venosa.

Keywords: Rapana Venosa, drying kinetics, thin layer, activation energy, moisture ratio and effective moisture diffusivity

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1 Introduction

Rapana venosa *(Veined rapa whelk*) was harvested alive; it's been parboiled in other to successfully removed the fleshy part from the shell which is then soaked in a brine water and inoculated with seasoned and surface-active agents and yield to stabilize, it is then cook-fried in a pot without application water or roasted and sufficient seasoned to produced creamy brown colour depending on individual sense of organoleptic properties. However, it is most times dried to very low moisture content and then traded by wholesalers or by table-top retailers in the market places. However, because of its advantages, drying Rapana venosa has been a major means of preservation and storage to reduce and prevent

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early deterioration. Aside of drying to increase the shelf life of the product it is also retain its high systemic protein, meaty, viscoelastic and high lipid content of the Rapana venosa *(Veined rapa whelk*). Technical literature is rife with such reports including tomato (Kross et al., 2004), egg-plant (Ertekin and Yaldiz, 2004), apple (Wang et al., 2006; Kaya et al., 2007), soyabean (Gely and Santalla, 2000), green pepper and Onion (Yaldiz and Ertekin, 2001), cucumber (Daun et al., 2010), african nutmeg (Burubai and Etekpe, 2014), cocoyam corm slices (Ndukwu and Karen, 2011), cocoa bean (Ndukwu et al., 2010), bitter kola (Ehiem and Simonyan, 2011), pumpkin seeds (Sacilik, 2007), plantain (Satimehin and Alabi, 2005), fresh water clam (Burubai, 2015), mud snail meat (Burubai and Bratua, 2015), sea foods (Jain and Pathare, 2007; Kilic, 2009). Palm Weevil laeva (Zibokere and Egbe, 2019), lactose powder (Mcminn, 2006) and Shrimps (Davies et al., 2020). Therefore, this researched paper is modelling the dehydration kinetics of Rapana venosa *(Veined rapa whelk*) necessary for sufficient storage and preservation of this meaty food delicacy and to fit the experimental data to an appropriate thin-layer model.

2 Materials and methods

2.1 Sample preparation

A large numbers of Rapana venosa *(Veined rapa whelk*) used for this experiment were bought on the 3rd of February 2020, all alive in Nigeria, Bayelsa State, and Southern Ijaw Local Government Area in Ondewari community. The samples were then taken to the Food Processing and Storage Laboratory of the department of Agricultural and Engineering in the Niger Delta University Wilberforce Island Baylesa State. The Niger Delta University is located from Latitude 4°51'N to 5°02'N, and from longitude 6°.04'E to 6°17'E. They were thoroughly washed to remove all debris and were keep in a fresh saline water with seasoners for about 30mins for stabilization purposes in the ambience of the laboratory just to allow uniformity in all the specimens. The cleaned and pre-osmoses sample was inserted into a transparent bag and was then put inside refrigeration for preservation. Eighteen set of the specimens were taken with an initial weight of 7 g using top digital balance with 0.01 g precision and thickness of 0.013 mm using micro screw gauge and then the initial moisture content of the samples was obtained. The specimens were oven dried using WTC binder oven Model (1718) at different temperature levels such as 50, 60, 70, 80, 90, and 100°C. Each sets of the specimen was dried to a constant final weight and was repeated 3-times for each of the temperature levels and average values was recorded. The oven drying was based on ASAE Standards (S368.41 of 2000 as reviewed). The weight differences were used to determine the final moisture content for each replicate, all measured on dry-basis as

$$M = \frac{w_i - w_f}{w_f} \times 100\% \quad (1)$$

where;

M = dry basis moisture content, %-db

W_i = initial weight of the specimen, g

W_f = initial weight of the specimen, g

Then the necessary moisture ratio was calculated using Equation 4.

2.2 Theory of Drying

Drying of biomaterials is as a result of their systemic water which causes serious damages (deterioration) on the products after been harvested. This is achieved by several layers sliced or reduced. It's mostly in a simulation studies on the thin-layer by the application of a stream of hot air passing over the layers. Drying of biomaterials is of two processes either in a constant rate period or falling rate period each adhered to different drying rates. The process of applying a hot stream air absorb moisture by means of heat and mass transfer which thereby reducing its moisture absorbing capacity. Thus, equilibrium moisture content is attained at different drying time at each layer. This assumption runs through the development of thin layer drying models applicable in predicting the drying behaviour of biomaterials.

Technical literature strongly indicates that drying of biomaterials do so mostly in the falling rate period (Brennan et al., 1969; Toledo, 2000; Earle, 2006). The molecular transport (diffusion) through a continuum of interface thin layers follows the Fick's second law as

(Bird et al., 2005; Zibokere and Egbe, 2019)

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

where;

M = moisture content at time t, kg_{H_2O}/kg_{solid}

t = drying time, min.

r = radius of an equivalent sphere (distance from the core to the surface), mm

De = effective diffusivity, mm2 min-1.

The analytical solution of Equation 2 for a number of thin spherical layers can be (Ndukwu and Karen, 2011)

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

where;

MR = moisture ratio

n = number of thin layers.

Taking natural log on both sides

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

Effective diffusivity, De can then be obtained from the slope of the plot of ln(MR) and drying time, t. From the slope De, can be deduced as

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

The moisture ratio in this context can be (Sahay and Singh, 2005)

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

where;

Me = equilibrium moisture content, kg_{H_2O}/kg_{solid}

Mo = initial moisture content, kg_{H_2O}/kg_{solid}.

If values of Me are small in relation to values of M and Mo, assumed to be zero in Robert et al. (2008) and Burubai (2015), then Equation 6 would simplified to

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

Taking n = 1 then further simplifying (3) brings about the thin layer drying equations of

the Lewis model

$$MR = e^{-kt} \quad (8)$$

the Henderson-Parbis model

$$MR = Ae^{-kt} \quad (9)$$

and when n > 1, the Page model

$$MR = e^{-kt^n} \quad (10)$$

From the Lewis model (8) above we can simplify as

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

or

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

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, De can now be deduced when the plot is normalised.

2.3 Activation energy

This is energy required to initiate moisture transport during drying of biomaterials with high bound water content. Activation energy in diffusion can be estimated from the Arrhenius type of relation given as (Burubai, 2016)

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

where;

E_a = activation energy, kJ mol^{-1}

D_e = effective diffusivity at drying time, t°K, m^2 min^{-1}.

D_o = effective diffusivity at drying time, 0°K, m^2 min^{-1}.

R = universal gas constant (8.314 × 10^{-3}, kJ mol^{-1} K^{-1})

Simplification of Equation 11 gives

$$lnD_e = lnD_o - \frac{E_a}{Rt} \quad (14)$$

where in $$E_a = ln(\frac{D_o}{D_e})Rt \quad (15)$$

The plot of lnD_e against t^{-1} is linear with intercept, lnD_o at the lnD_e axis, the slope, $\frac{E_a}{R}$ of which would give value of the activation energy of Rapana venosa *(Veined rapa whelk*)

Figure 1 A Picture of Rapana venosa *(Veined rapa whelk*)

2.4 Statistical approach

The data so obtained were fitted into the selected drying models of Equations 8, 9, and 10 for Lewis, Henderson-Parbis, and Page respectively. The non-linear regression and fitting processes were assisted by MS Excel stat 2010. Coefficient of determination, R^2 (Equation 16) was the major criterion for determining the goodness of fit at the temperature values used. The non-parametric statistics of reduced chi-square, χ^2 (Equation 17), root mean square error, RMSE (Equation 18) and mean bias error (Equation 19) were used in comparing and predicting the drying behaviour on the specimens. The statistical equations were as follows (Ndukwu and Karen, 2011; Burubai, 2015; Davies et al., 2020)

$$R^2 = 1 - [\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2] \quad (16)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{n-k} \quad (17)$$

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

$$\text{MBE} = \frac{1}{N}\sum_{i=0}^{n}(MR_{Pred} - MR_{exp}) \quad (19)$$

The model(s) with the highest R^2 and the least χ^2 and RMSE and MBE was (were) accepted as the best fitting parameter(s).

3 Results and discussions

3.1 Drying kinetics

The results from the drying on the samples are shown as drying curve in Figure 2 and 3. Figure 2 shows that the biomaterial moisture ratio is proportional with the drying time. The gradual tangential advances of the drying curves to the axis of drying duration proof bio-materials with high systemic of water and fat, oil and high protein in nature. The movement of moisture by evaporation from the bio-product was extremely dull. This is an indication that the whole drying process took place in the falling rate period. The slow method of drying also proof that drying continuous without the features of case-hardening at even a high temperature. These is with agreement with similar investigation by Burubai and Bratua (2015) on mud snail, (Zibokere and Egbe, 2019) on Palm Weevil Larvae, claim Burubai (2015) and Sankat and Mujalfar (2006) on catfish. Figure 3 is a graph of logarithmic moisture ratio as a function of drying time. The experiment shows that there was an increase in the drying process because of high water diffusion and evaporation, but later it became decrease even with an increase in temperature. At these later point of drying time much higher quantum of energy would be required in the diffusion mechanism that would unbind water in the protein based solid matrix of the bio-product. As a result drying became slower. The sharp drop of the exponential drying curves in the plot Figure 3 also a proof that drying occurred mainly in the falling rate period. This is with an agreement with the report on the thin layer drying of yoghurt (Hayaloglu et al., 2007), tomatoes, (Kross et al., 2004), fresh fish (Kilic, 2009).

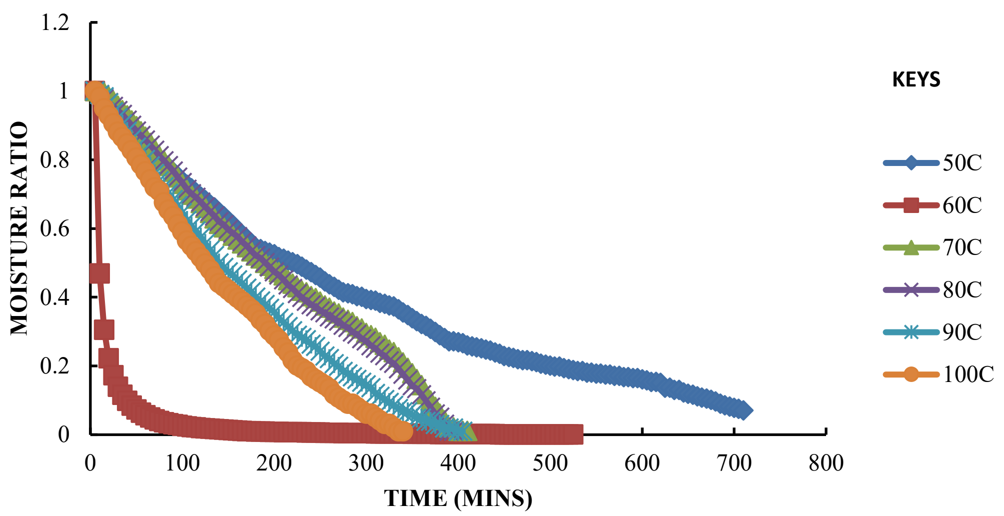

Figure 2 Drying curve at different temperatures for Rapana venosa *(Veined rapa whelk)*

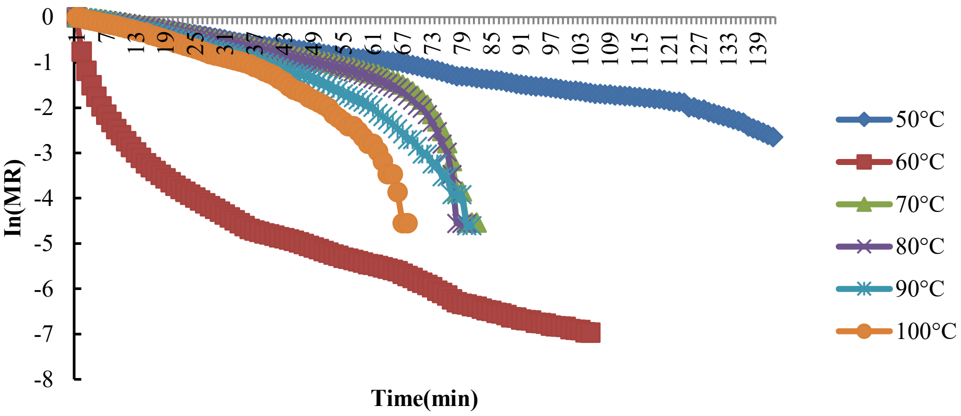

Figure 3 Drying curve of Rapana venosa *(Veined rapa whelk)*

3.2 Fitting experimental data into drying models

The three models Lewis, Henderson-Pabis, and page model were used to obtain the experimental drying data; this enables the selected model to know the best to describe dehydration kinetic of Rapana venosa *(Veined rapa whelk*). The constant 'k' and coefficient 'a' was obtained after using the approach of non-linear least square statically of (SPSS 1996 or Ms excel 2007) and were fitted into the Fick's diffusion equation (Equation 3). The obtained values were mathematical validated using coefficient of determination (R^2), and the root mean error (RMSE) and the mean bias error (MBE). The experimental Moisture ratio (MR) and the predicted moisture ratio (MRpre) were plotted at regression equation were developed which were used to obtain the reduce chi-square (X^2) as shown in Figure 4. The Table 1 represents the outcome. To describe the best drying characteristic of Rapana venosa *(Veined rapa whelk*) this is as a result of lower the root mean error (RMSE), and reduce chi-square (X^2) but higher the coefficient of determination (R^2) value. Three models applied page model closely followed by Henderson-Pabis model gives the lower the root mean error (RMSE), and lower the reduce chi-square (X^2) and higher the coefficient of determination (R^2) and are accordingly accepted.

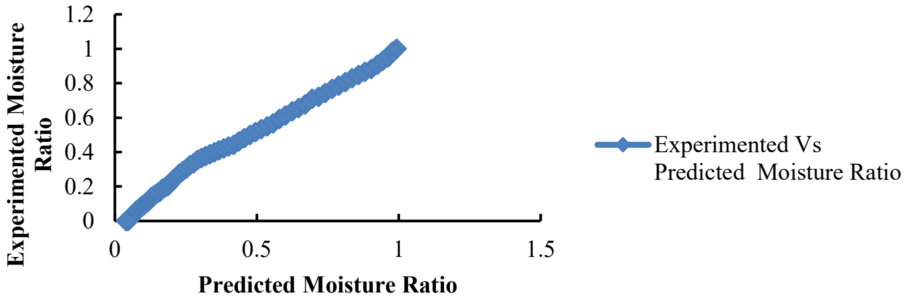

Figure 4 Relationship between experimental and predicted moisture ratio

Table 1 Statistical results of the model for Rapana venosa *(Veined rapa whelk*)

Model	Temp	Constant &Coefficient	R^2	MBE	RMSE	X^2
Page	50	k=1.0165 n=0.0029	0.9328	-0.00028061	0.0033449	0.00001134
	60	k=0.4253 n=0.4991	0.8895	-0.00009357	0.000957	9.37E-08
	70	k=1.54 n=0.00024	0.9725	-0.00022339	0.0021	0.00000439
	80	k=0.0218 n=0.0807	0.8463	0.005312	0.048687	0.002399

	90	k=1.367 n=0.009	0.9895	-0.0003544	0.002799	0.00000802
	100	k=1.3915 n=0.0009	0.9852	-9.896E-06	0.00084	0.229657
Henderson	50	k=0.0033 a=1.0440	0.9899	0.026993	0.321654	0.104939469
	60	k=0.0043 a=0.8521	0.984	0.027876	0.285645	0.083177492
	70	k=0.0076 a=1.7042	0.7228	0.1506402	1.396979	1.99801723
	80	k=0.0075 a=1.6565	0.7422	0.1369046	1.254751	1.612280116
	90	k=0.0095 a=1.7400	0.8973	0.2846339	2.624195	7.05337774
	100	k=0.0108 a=1.6864	0.8889	0.2905548	2.465439	6.252057754
Lewis	50	k=0.012	0.9899	0.02574	0.3067	0.09473092
	60	k=0.043	0.984	0.0332742	0.34096	0.117371164
	70	k=0.0076	0.7228	0.0861411	0.79884	0.645653
	80	k=0.0075	0.7422	-0.002016	0.018479	0.000346
	90	k=0.00795	0.7422	-0.00166	0.015267	0.000236
	100	k=0.0108	0.8889	0.170122	1.443536	2.113146

3.3 Effective diffusivity (D_e)

Equations 4 and 5 were experimentally used to achieved the effective diffusivity (*De*) on the three replicates of temperature were used and the average value was obtained as shown in Table 2. It shows that moisture diffusivity increases with an increase in temperature. This is reasonable as to show that diffusion mechanism while drying occurs is a function of energy applied. This is evidence and agreement with Davies et al. (2020), Burubai and Bratua (2015), and Sacilik (2007) researched on Shrimps, mud snail and pumpkin seeds respectively.

Table 2 Moisture diffusivity values of Rapana venosa *(Veined rapa whelk*)

Temp (℃)	Average effective diffusivity (m^2 sec^{-1})
50	1.1367E-07
60	3.335E-07
70	2.587E-07
80	2.582E-07
90	3.259E-07
100	3.684E-07

Note: (Based on Logarithmic moisture ratio vs drying time)

3.4 Activation energy E_a

This measured the rate of heat of heat absorb by Rapana venosa *(Veined rapa whelk*) while undergoing the process of drying. It is by linearizing the Arrhenius embodiment Equation 13-19 for the different type of temperature used in this work. To achieve particular desired moisture content (at wet basis) level, the higher the time of drying and the higher the activation energy (E_a). During the experiment, the average value of activation energy (E_a) becomes. During the experiment the average value of activation energy (E_a) was 13.03kJ/mol. This investigation falls within the discovered range of 12.7-110 kj mol^{-1} for higher moisture of bio-products (Zogzas et al., 1996), and 0-53 kj mol^{-1} for reduce moisture diffusion controlled bio- products (Toakis and Labuza, 1989)

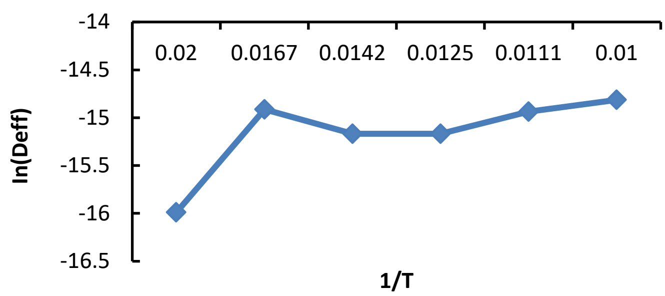

Figure 5 Estimation of Activation Energy of Rapana venosa (*Veined rapa whelk*)

4 Conclusion

The drying kinetics of *Rapana Venosa* was investigated and it was evident that the drying process falls under the falling rate period like other biological materials. Out of the three thin layer models that were investigated, the best for predicting the drying kinetics of Rapana venosa *(Veined rapa whelk*) was the Page model followed closely by the Lewis model lastly Henderson-Parbis model having undergo statistical analysis of the drying parameters and for the temperature dependent effective moisture diffusivity ranging from 1.1367×10^{-7} $m^2\ s^{-1}$-3.648×10^{-7} $m^2\ s^{-1}$ over the temperatures used in the work. The related activation energy value obtained was 13.03kJ/mol.

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