Determination of drying kinetics of periwinkle meat (*Turritella communis*) by application of some thin layer models

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Abstract: Drying is an important process that increases the shelf life of agricultural products. It is a process whereby the activities of most decay causing microbes are either deactivated or reduced to safe levels. This work determined the drying kinetics of Periwinkle Meaty within the drying temperature range of 50˚C through to 100°C using a laboratory convective oven. Drying data was fitted to five thin layer drying models such as artificial neural network (ANN), page, Henderson-pabis, Lewis and a newly developed model (NDM). The various related thin layer drying model constants and coefficients were obtained using non-linear regression statistical methods. The result shows that drying took place almost entirely within the falling rate period. The temperature dependent effective diffusivity was shown to be in values that ranged from 1.49×10^{-6} to 6.30×10^{-7} m^2 s^{-1} in the temperature range applied in this work. And the related activation energy was found to be 15.43 kJ mol^{-1}. The fitting results also showed the ANN and NDM closely followed by the Henderson-Parbis' as suitable for predicting the thin layer drying kinetics of periwinkle meaty.

Keyswords: periwinkle meaty, drying kinetic, artificial neural network, activation energy, effective moisture diffusivity

Citation: Egbe E.W. 2023. Determination of drying kinetics of periwinkle meat (*Turritella communis*) by application of some thin layer models. Agricultural Engineering International: CIGR Journal, 25 (4):196-206.

1 Introduction

Periwinkle Snail (*Turritella communis),* is locally known as in Izon language (see Figure 1). It is a sea food, usually harvested (mainly hand-picked) at the tidal shore areas of a sea estuary. It constitutes a very vital meaty ingredient in the preparation of different delicacies of people living along the coastal areas in Nigeria and perhaps, beyond. Adekanmbi, (2015) reported that periwinkle meat is a good source of protein for the consuming locals. It is also known that dried periwinkle meat is nutritionally richer than the fresh ones (Adebayo and Ogunjobe, 2008). Adebayo and Ogunjobe (2008) reported that fresh periwinkle meat undergo rapid deterioration and decay, thus requires preservative attention almost immediately after dislodging the meat from the shell.

Drying has been shown to be a distinctly veritable method for the preservation and storage of fresh fish and other sea foods (Jones and Disney, 1967; Bostock et al., 1987). Drying on thin layers is especially employed for small size biomaterials to achieve rapid and uniform drying as to avoid rancidity and occurrence of offensive odours. Thus, several workers deploy thin layer principles in characterizing the drying behaviour of various biomaterial products Burubai and Etekpe (2014) on nutmeg and ogbono; (Davies et al., 2020) on Shrimps; (Zibokere and Egbe, 2019) on Red palm weevil larvae; Ndukwu and Karen (2011) on cocoyam corm slices; on cocoa bean (Ndukwu et al., 2010); bitter kola (Ehiem and Ben,

Received date: 2022-06-15 **Accepted date**: 2023-10-01

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2011); pumpkin seeds (Sacilik, 2007); red pepper (Akpinar et al., 2003); plantain (Satimehin and Alabi, 2005); fresh-water clam (Burubai, 2015); freshwater frog (Burubai and Bratua, 2015); and on fish and other sea foods (Jain and Pathare, 2007; Kilic, 2009). In this work therefore, the desiccation characteristics of periwinkle meat was examined on thin layers and the emerging experiential data was inputted to the five thin layer drying models to determine the model that would suitably describe the drying kinetics of the periwinkle meat. This would also create a robust data base for the required process design.

(a) Group of single meaty part of the periwinkle snails

(b) Auger-shaped periwinkle snails with the tail nipped to dislodge the meat

(c) Full and adult auger-shaped periwinkle snails.

Figure 1 Periwinkle Snail (*Turritella communis)*

Thin layer drying is the process of removing moisture from a porous biomaterial by diffusion (moisture loss) which hot air moved through a layer of sufficiently small thickness with identified uniform without variation. Hydroscopic product dry at both constant rate and falling rate period due to the application of heat and mass transfer to a point which microbial activities are reduced. The falling rate begins when agricultural biomaterial appears dried to the critical moisture content, internal state of the bio-product such as atmosphere, moisture content and the bio-structure play essential function because it is controlled by diffusion mechanism, whereas the constant rate period is controlled by the temperature, relative humidity, air velocity and direction of air flow. The entire rate period drying process is a molecular transport phenomenon (diffusion) by the fick's second law given as Bird et al. (2015), Suarez et al. (1980) and Tulagha and Egbe (2023).

2 Materials and method

2.1 Sample preparation

An eighty kilogram (80 kg) worth periwinkle snails (Figure 1c) as purchased from Ondewari market in Southern Ijaw Local Government Area (SILGA) of Bayelsa State, South-South part of Nigeria. They were properly group-washed with clean water and parboiled for about 15 minutes. This was done to weaken the bond between the meat and the shell as to ease separation of the meat from each shell in a process known as *tweaking*. Tweaking was done using sterilized needles after the tail part of each of the auger-shaped periwinkle snails was cut away manually with a cutlass (Plate 1 b). The group of meat so obtained (Plate 1 a) then parked in plastic containers and stored in a refrigerator for stabilizing in the Processing Laboratory of the Department of Agricultural and Environmental Engineering, Niger Delta University, Bayelsa State, Nigeria. The initial moisture content of the meat was determined by an oven drying method (ASAE Standard S368.41 2000) using 100-g samples after being immersed in 5% NaCl solution with the oven set at a temperature range of 50^{o}C–100^{o}C on a 5^{o}C increment. All experiments were replicated thrice. WTC binder oven (Model WTCB 1718) was used for the drying process, and all the weight measurements of each sample were taken with a 0.01-mm precision digital scale (Max cap: 210g, Power requirements: 8-14.5V, 50/60Hz, 60V). See similar approach/method was applied by Zibokere and Egbe (2019) on red palm weevil larvae, Burubai and Bratua (2015) on acute mud-snail, and Sankat and Mujaffar (2006) on catfish. Moisture contents were measured on dry-basis using (Mohsenin, 1986). Using equation (1)

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

where,

M = sample dry basis moisture content, %

w_i = initial weight of the specimen, g

w_f = final weight of the specimen, g

2.2 Thin-layer drying models

A major concern in the modeling of thin-layer drying is the process 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). The movement of moisture over a continuum of spherical thin layers is governed by the second law of molecular diffusion, also known as the Fick's law (placed either in series or parallels) can be described with the equation 2 (Crank, 1975; Zibokere and Egbe, 2021)

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

where,

M = M = sample dry basis moisture content, %

t = drying time, min

r = radial distance from the core to the surface, mm

D_e = effective diffusivity, $mm^2\ min^{-1}$.

Equation 2 can be analyzed to deduced equation 3 (Ndukwu and Karen, 2011).

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

where

MR = moisture ratio, dimensionless

n = number of thin layers

Taking natural log on both sides,

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

A plot of *ln*(*MR*) and drying time (*t*) in other to develop a slope to derive *De* as

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

Then, the moisture ratio can be obtained as (Sahey and Singh, 2005)

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

Where,

M_e = equilibrium moisture content (emc), kg_{H_2O}/kg_{solid}

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

Equation 6 can be reduced to produce Equation 7, if M_e is assumed to be zero.

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

Taking n = 1, Equation 3 would simplify to give the thin layer drying as in the Lewis model:

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

When n = 2, Equation 3 will give the Henderson-Parbis model:

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

The log of both sides of Equations 8 and 9 and plotting respectively yield k as the slope of the linearized plot.

When n = 3, the Page model is obtained as

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

Plotting-*ln(MR)* against *t* on a logarithmic axes the constant '*k*' and coefficient '*n*' will be obtain a further solution of the Lewis model (Equation 8) in logarithmic form can give

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

or

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

Equation12 permits the plot of moisture ratio on natural logarithm axis against drying time giving the intercept, *ln(k)* and slope,-*k* whence the effective diffusivity, D_e can now be deduced (Zibokere and Egbe, 2019).

2.3 Activation energy

This is the minimum amount of energy required for the periwinkle meat to undergo drying**.** All bio-materials have different systemic water capacity, the higher the moisture contained in any of them the higher the activation energy needed to loosen the bond to have 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 our case, we can estimate the activation energy from the Arrhenius type relation to give (Burubai, 2015; Tariebi and Egbe 2023).

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

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} (known as the Arrhenius factor)

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

Linearizing Equation 13 would give

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

whence

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

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

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

Equation 16 can be recognized as a logarithmic expression to obtain the activation energy in the drying system.

Also, from Equation 14 the plot of $\ln(D_e)$ against drying time, t^{-1} will linearize the expression the slope, $\frac{E_a}{R}$ of which would provide value for the required activation energy. (Suarez et al., 1980).

2.4 Analysis of statistical parameters

In this work, experimental data would be fitted to five (5) thin-layer models as a process to selecting one that would best describe the drying kinetics of periwinkle meat. Introduction of relevant statistical parameters would be useful in order to validate the fitting process. 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 of a particular drying temperature (Wang et al., 2006; Ndukwu and Karen, 2011, Egbe et al., 2021a); while the root mean square error, RMSE values were applied in selecting the suitable thin-layer drying model (Ertekin and Yaldiz, 2004). The statistical equations used were as follows (Ndukwu et al., 2010; Burubai, 2015; Egbe and Zibokere, 2021).

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

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

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

Where,

$MR_{pre.}$ = predicted moisture ratio

$MR_{exp.}$ = experimental moisture ratio

n = number of observations

k= Number of constants

A high R^2 (approaching 1), alongside low RMSE and χ^2 values was used as basic criteria for selecting the suitable model(s).

2.5 Formulation and derivation of a developed model

Table 1 Formulation and derivation of a developed model

S/n	Variables	Dimension
1	Specific volume	L^3M^{-1}
2	Time	T
3	Length/thickness	L
4	Drying Ratio	M^1T^{-1}

π-terms = m-n = 4-3 =1

$$\pi 1 = (Dr, L, V, T) \quad (20)$$

$$\pi 1 = Dra. Lb. Vc. T \quad (21)$$

$$\pi 1 = (M1T-1)a. (L)b. (L3M-1)c.T \quad (22)$$

Therefore,

$$M0T0L0 = (M1T-1)a. (L)b. (L3M-1)c.T \quad (23)$$

Equating the exponentials

a = 1, b = -3, C = 1

Thus,

π1= Dra. Lb. Vc. t

$$\pi_1 = \frac{Dr.V.t}{L^3} \quad (24)$$

$$\text{Therefore, } MR = A \left(\frac{Dr.V.t}{L^3}\right) + C \quad (25)$$

Where,

A = Coefficient, $\pi_1 = \frac{Dr.V.t}{L^3}$ and C = Constant

v = specific volume

Dr = Drying ratio

A graph of MR against π_1 the coefficient A and constant C is deduced from the graph

2.6 Model validation

The accuracy and the performance of the model were demonstrated by comparing the MR experimented values and MR predicted values based on regression analysis (Mirhosseini et al., 2008). To measure how perfect the suggested model was able to fit the experimental data parameters such as correlation coefficient, coefficient of determination, chi-square (x^2) was used to determine the goodness of fit test.

2.6.1 The ANN model

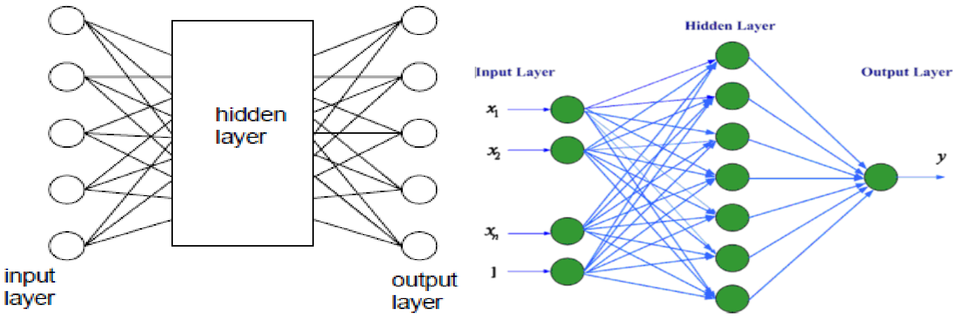


Figure 1 A schematic daigram displaying multilayer feed forward neural network (Kalogirou, 2003)

ANN suggests that artificial neurons have the same interconnected structure as biological neurons. Artificial neurons are used to mimic the learning and functioning processes of the human brain in the architecture of the ANN. Human neurons, which have dendrites, somas, axons, and synapses, were modeled after artificial neural networks (ANNs). Also known as chemical receptors, dendrites are the parts of neurons that receive information from other neurons. But the processing of the information, known as soma, is one of the components that makes up the cell. Next, the signals that have been processed are released into the vicinity of nearby neurons along the axon. In conclusion, synapses connect the neurons and regulate the way messages are transmitted between them. This straightforward artificial neuronal architecture is far from the real, biological neuron's structure and function (Levstek and Lakota, 2010; Huang et al., 2007).

2.6.2 Feed forward back-propagation neural networks (BPNN)

It made use of a feed forward back-propagation neural network (BPNN). This kind of network has been explored in great detail; the performance outcome is decreased. According to Sadrzadeh et al., (2008) and Marchitan et al., (2010), this network is generally an application-based multilayer perception (MLP) architecture. The problem has an input layer and an output variable in the MLP. consists of one or more hidden layers, an output layer with nodes representing the dependent variable (what is modelled), and an input layer with nodes representing the problem's input variable. The network can find challenging models in the data set thanks to supervised learning. The theory of feed forward back-propagation describes how errors and output are transmitted to the hidden layer and then to the input layer. These networks allow for either full or partial neuronal connectivity, and data are transmitted forward into the network without any feedback (Levstek and Lakota, 2010; Huang et al., 2007). The aim of adjusting the weights and biases during training is to conform the anticipated response more closely to the experimental response, as described by Sadrzadeh et al., (2008). According to Desai et al., (2008), BPNNs are flexible and can be used for process control and data modelling in forensic science, biotechnology, health, weather forecasting, finance, and investing.

3 Results and dissussion

3.1 Dehydration kinetics of periwinkle (*Turritellacommunis)* meat

The drying values obtained in the sample are shown in Figure 2 and Figure 3 which indicates that the moisture ratio of the sample reduced as drying time increased. It shows slow in tangential approach of the drying curve to the drying time because of high systemic water and meaty in the periwinkle meat. The slow pattern of the curve also indicated that dying process is without a case-hardening in the high temperature ranges. The drying of periwinkle meaty fall under the falling rate period, which shows that the drying rate is controlled by internal diffusion. This attributed same with the research work carried out by (Burubai and Bratua, 2015) on fresh water frog, (Zibokere and Egbe, 2019) on red palm weevil Larvae, (Davies et al., 2020) on shrimps, youghour (Hayaloglu et al., 2007), Red pepper (Akpinar et al., 2003), Fresh fish (Kilic, 2009) and (Egbe et al., 2021b) on Rapana venosa meat.

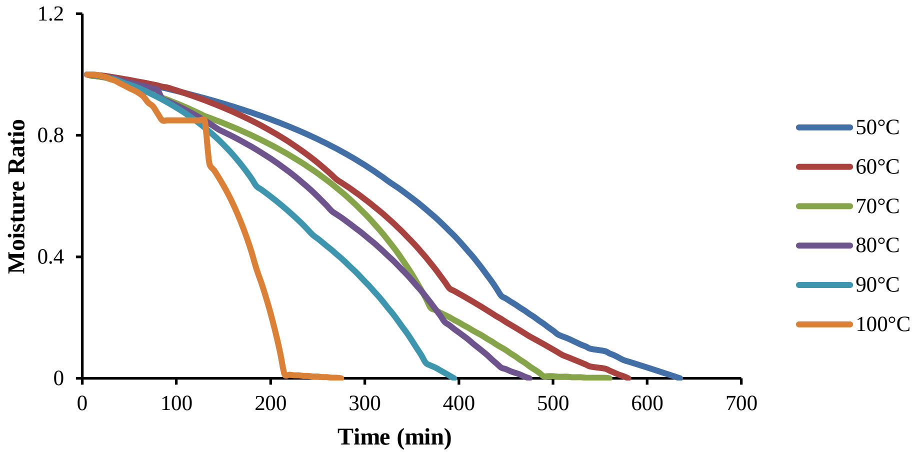
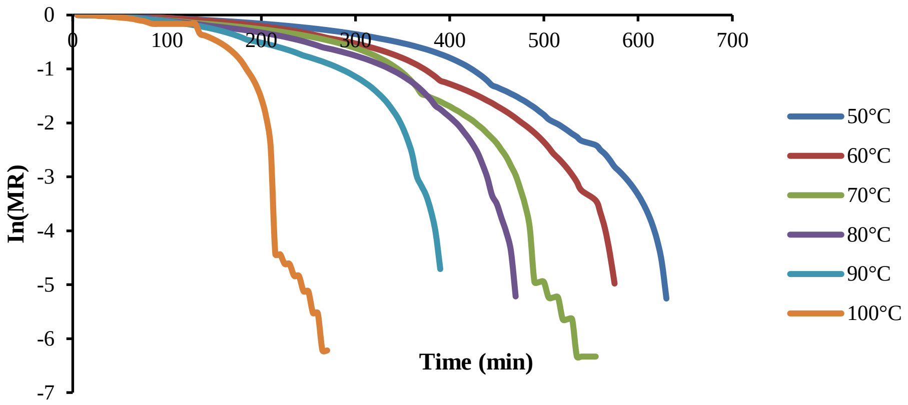


Figure 2 Drying curve at different temperature for Periwinkle Meaty (*Turritellacommunis)*



(Logarithmic moisture ratio vs drying time)

Figure 3 Drying curve of Periwinkle Meaty (*Turritellacommunis)*

3.2 Fitting experimental data into drying curve for periwinkle (*Turritellacommunis)* meat

The experimental drying values were done by fitting into five different models such as Newly developed model, ANN, Page, Henderson-pabis and Lewis models. The fitting was carried out to determine the appropriate model best represent the periwinkle meaty. The data were fitted into Ficks second law of diffusion equation and the constant 'k' and coefficient 'a' and 'n' were evaluated with the approach of non- linear least square statistic (SPSS 1996). The statistical analysis obtained from the plot of Moisture ratio experimental against Moisture ratio predicted see (Figures 3-5) were then validated in calculating the coefficient of determination (R^2), the root mean square (*RMSE*), mean bias error (*MBE*) ,and the reduced square error (X^2) as given in (Table 2, 3 and 4). The model containing the lowest RMSE, X^2, and Highest R^2 was chosen to be most appropriate model to depict the drying characteristic of the specimen. It is observed that amongst the five models applied in this work ANN and NDM closely followed by Henderson-pabis model described the best fit to predict the drying characteristic of periwinkle meaty.

Table 2 Statistical parameters periwinkle meaty (*turritellacommunis) on the* three thin-layer drying models

MODEL	TEMP◦C	MBE	R²	RMSE	X²	K	A	N
	50°C	0.083541	0.9165	0.0256852	0.00067919	0.0053		
	60°C	0.0784488	0.9216	0.026233	0.0007	0.0059		
LEWSIS	70°C	0.1101166	0.8899	0.03164	0.01019598	0.0092		
	80°C	0.078136	0.9218	0.028679	0.00084	0.0068		
	90°C	0.0724097	0.9276	0.030275	0.0009403	0.0076		
	100°C	0.14	0.86	0.006242	0.002338	0.0216		
HENDERSON	50°C	0.001577	0.9984	0.003537	0.000013	0.0055	2.218652	
	60°C	0.00001	1	0.0000055	0.00000035	0.0059	2.012746	
	70°C	0.0054723	0.999	0.009609	0.000051	0.0092	3.114909	
	80°C	0.000000076	0.991	0.000028	8E-10	0.0068	1.957171	
	90°C	0.000155	0.9998	0.001401	0.000002	0.0076	1.826314	
	100°C	0.0045563	0.9987	0.009102	0.000084	0.0219	4.036589	
	50°C	0.17772	0.8223	0.037707	0.001445	1.8694		0.0000121
PAGE	60°C	0.000582	0.9994	0.002259	0.0000052	2.1151		0.00000368
	70°C	0.03736295	0.9626	0.01843	0.000035	1.762		0.0000399
	80°C	0.053310103	0.9467	0.023689	0.00057	1.8298		0.0000271
	90°C	0.01061521	0.8938	0.036656	0.001378	1.9597		0.0000182
	100°C	0.197938	0.8021	0.059991	0.0036655	2.4803		0.0000035

Table 3 ANN for periwinkle (*Turritellacommunis)* meat

Temperature/°C	R²	MBE	X²	RMSE	ANN type	ANN structure
50	1	2.90E-11	2.30E-13	4.82E-07	FFBP	4-1-1
60	1	1.10E-09	1.19E-11	3.44E-06	FFBP	4-1-1
70	1	1.45E-12	1.32E-14	1.15E-07	FFBP	4-1-1
80	1	3.64E-10	3.83E-12	1.96E-06	FFBP	4-1-1
90	1	2.41E-08	3.05E-10	1.75E-05	FFBP	4-1-1
100	0.9999	1.96E-09	3.58E-11	5.98E-06	FFBP	4-1-1

Table 4 Newly developed model for periwinkle (*Turritellacommunis)* meat

Temperature/°C	RMSE	X²	A	K	MBE	R²
50	7.03E-07	4.99E-13	0.8022	0.9544	9.32864E-11	1
60	3.36E-06	1.14E-11	0.7736	1.1473	1.60228E-09	1
70	3.80E-06	1.47E-11	0.7529	1.8105	1.54374E-09	1
80	3.94E-06	1.58E-11	0.8816	5.7202	1.61272E-09	1
90	0.000155	2.45E-08	0.7832	5.9666	2.34936E-06	0.999998
100	0.047096	0.002267	0.8192	0.0097	0.206279451	0.793721

3.3 Effective moisture diffusivity (De.) periwinkle (*Turritellacommunis)* meat

The effective diffusivity, De is an important input variable to depict the effective migration of moisture from the surface of the specimen. A plot of *ln (MR)* against drying time which yielded a slope and was calculated with the measured thickness 0.013 m. The resulting average from three replications varies from 1.49×10^{-6} to 6.30×10^{-7} m^2 sec^{-1} as the temperature increases from 50°C to 100°C. The average values stated in Table 5. It is a clear investigation that moisture diffusion increases with increase in temperature. This is an evident with Jittanit (2011), Robert et al. (2008), and Burubai and Bratua, (2015) and Egbe and Davies (2021) all have similar results on pumpkin seeds, grape seeds and fresh water claim respectively.

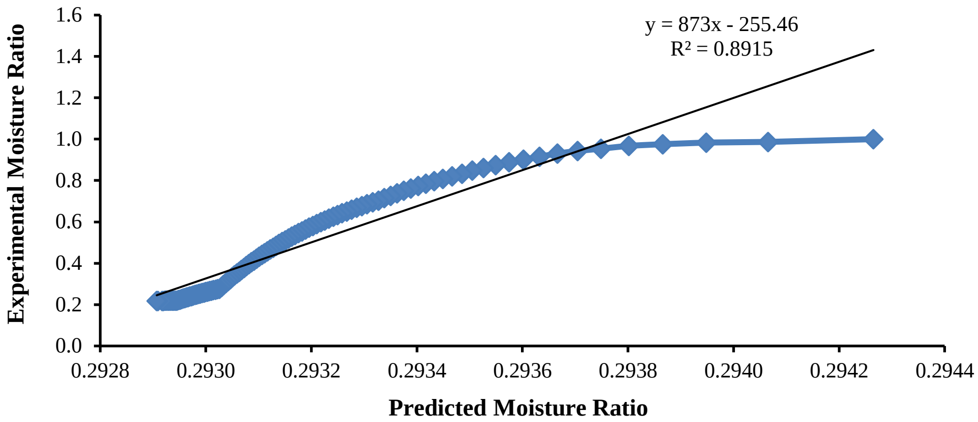


Figure 4 Relationship between experimental and predicted moisture ratio for the Henderon model for periwinkle (*Turritellacommunis)* meat at 50°C

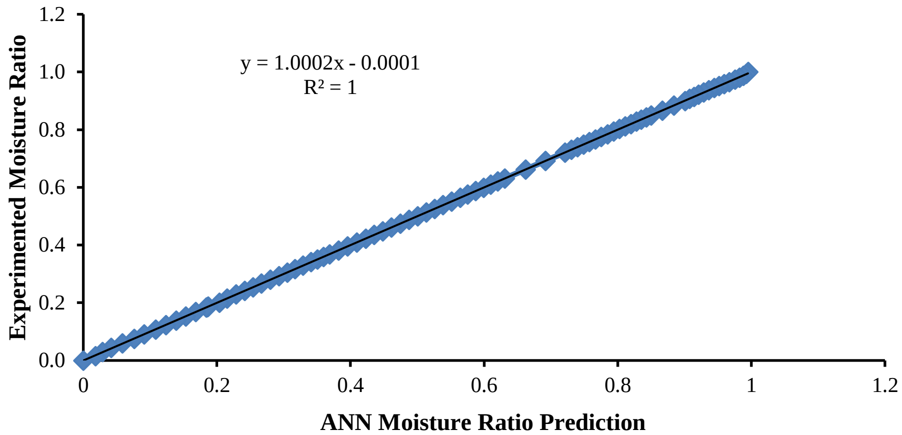


Figure 5 Showing graph experimented moisture ratio against prediction moisture ratio for Fresh-water prawn (*Macrobrachium rosenbergii*) at 50°C

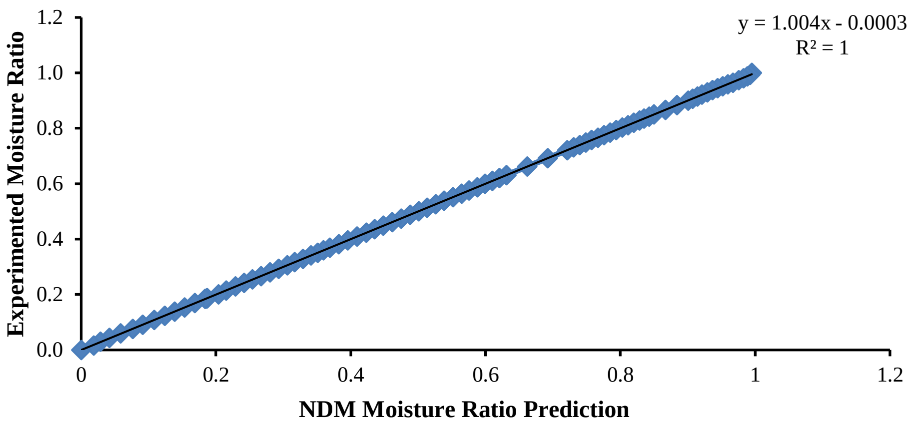


Figure 6 Showing graph experimented moisture ratio against NDM predicted moisture ratio for Fresh-water prawn (*Macrobrachium rosenbergii*) at 50°C

Table 5 Moisture diffusivity values of periwinkle (*Turritellacommunis)* meat

Temperature/°C	Average effective moisture diffusivity/ m^2 s^{-1}
50	5.20E-07
60	5.20E-07
70	6.30 E-07
80	4.66 E-07
90	5.20E-07
100	1.499E-06

3.4 Activation Energy (Ea) for Periwinkle (*Turritellacommunis)* Meat

This is the minimum amount of energy required for periwinkle meaty to undergo drying. It is obtainable by linearizing the Arrhenius equation within the temperature variation chosen for this research work. The higher '*Ea*' the drying time to archived desired moisture level. In this research work the *Ea* and R^2 was found out to be 15.43 kJ mol^{-1} and 0.9918 respectively Figure 7. In literature, the result fall within moisture level of bio-materials ranging from 12.7-110 kJ mol^{-1} for high moisture biomaterials (Zogzas et al, 1996) while 0-53 kJ mol^{-1} for low moisture biomaterials (Toakis and Labuza, 1989).

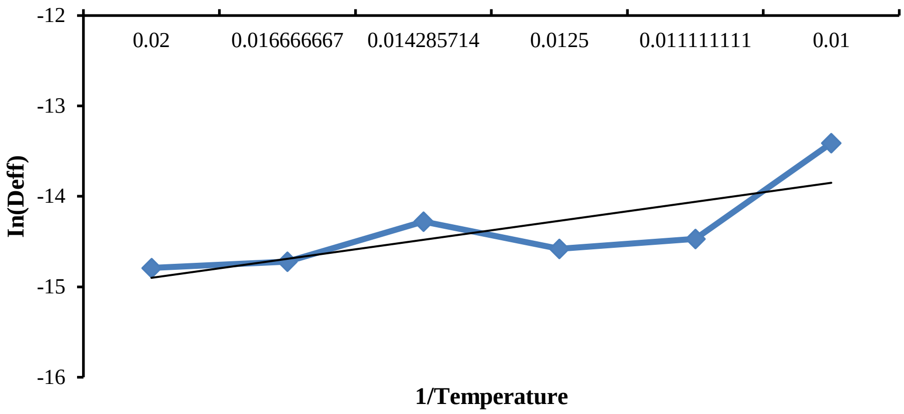


Figure 7 Estimation of activation energy in the thin layer drying of periwinkle meat

4 Conclusion

Determination of drying kinetics of periwinkle meat (Turritella communis) by application of some thin layer models was investigated from the results it shows the specimen fall under the falling rate period like other biomaterials. Amongst the five models investigated artificial neural network and newly developed mode was the best predicting the drying kinetics of periwinkle meaty closely followed by Henderson-pabis model having undergo statistical analysis of the drying parameters and for the temperature dependent effective moisture diffusivity ranging from 1.49×10^{-6} to 6.30×10^{-7} m^2 sec^{-1} as the temperature increases from 50°C to 100°C. The related activation energy value obtained was 15.43 kJ mol^{-1}.

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