COMPARING THE DRYING BEHAVIOUR OF A MUDSKIPPER

Opiriari Pryse Princewill
Department of Agricultural and
Environmental Engineering,
Rivers State University
NIGERIA

Henry Oqua-solo Edet
Department of Agricultural and
Environmental Engineering,
Rivers State University
NIGERIA

ABSTRACT

The drying behaviour of a mudskipper under various drying conditions was investigated. The study was carried out to find out, among the various available drying models, which of those models best described the drying behaviour of mudskipper by statistically comparing them. Freshly harvested mature samples of a mudskipper were obtained from Fimie market, along Abuloma road, Port Harcourt, Rivers State. The samples were thoroughly washed to remove dirt and mud on its surface before it was cut into thin-layers of uniform sizes of 3cm. The samples were then subjected to three different drying conditions of $DC_{1\left(11.3\%\,\text{w.b.},60^{0}\,\text{C}\right)}$, $DC_{2\left(11.3\%\,\text{w.b.},80^{0}\,\text{C}\right)}$, $DC_{3\left(11.3\%\,\text{w.b.},100^{0}\,\text{C}\right)}$ and the data obtained from each drying condition was fitted to three (3) drying models. Non-linear regression analysis was used to determine the model parameters, while the highest value of the coefficient of determination (R^2) and the least value of the standard error of the estimate calculated from the data generated from the models formed the basis for determining the model of best fit. The Page drying model gave the best fit for the mudskipper drying.

Keywords: Mudskipper, Drying, Drying Model.

INTRODUCTION

Mudskipper (*Periophthalmus barbarous*) is an amphibious fish that provides a rich source of protein in human diet. Mudskippers are terrestrial in nature though studies (Al-Behbehani and Ebrahim, 2010; Ansari *et al*., 2014) have shown that they are more adapted to the intertidal habitat especially those found in Africa, Asia and Australia. Mudskippers usually inhabit tidal mudflats and mangroves but can be found on sandy and rocky shores. Mudskippers are air breathing gobies (Subfamily, oxudercidae) with special anatomical adaptions; such as arm-like side fins that help them to skip over the mud. This special feature makes it exhibits a wide range of territorial behaviour and shows off agonistic displays on the mudflats when the tide reseeds. Besides, some species spend more time on land than in water and climb trees, like frogs and toads, with their eyes perched high on the head, enabling them to see potential food organisms and to avoid birds, which prey on these amphibious fishes (Kutschera et al., 2008). In Nigeria, most rural areas especially, the fishing communities in Rivers State make some marine products such as the mudskipper and tilapia an essential component of their diet. The reason for the behaviour of the locals as regards the daily consumption of these fish products is not far-fetched from the findings of a research effort which reported that fishes provide up to 20% of the total animal protein intake (Teh et al., 2016). Fish is an important source of good quality protein needed in human diet (Darvishi et al., 2013). It is used in many dietary preparations after it has been harvested from its natural habitat or ponds. Basically, immediately any biological material such as fish is harvested and slaughtered, it begins to deteriorate (Ashie et al., 1996). Fish is a highly perishable food product and as a result, it has a very short shelf life. Several methods have been devised to extend the shelf life of perishable food products such as cooling and drying. Cooling is a widely used preservation technique as it serves to maintain the quality as well as prevent the further deterioration of the product after harvest. A simple method of cooling of fish is icing (Darvishi et al., 2013). This method is very useful as surplus fresh fish that is not readily utilized by consumers and converted into finish products can be immediately preserved. Cooling fish by icing is highly recommended provided the fish is held for a short period of time only since it lacks the capacity to completely keep microbial activities in the food at bay. This is because as the cooling time increases, the ice absorbs heat and melts thereby encouraging the rapid growth of microorganisms which contaminates the food through the loss of natural flavour, taste and wholesomeness.

LITERATURE REVIEW

Microorganisms in food require water to grow and multiply rapidly and as a result, any attempt that must be devised to control its activities should require a method that deprives it of the water it needs to metabolise. One way of achieving this is by the use of drying. Drying of fish is important because it preserves the fish by removing the moisture necessary for microbial growth and multiplication (Bellagha et al., 2002; Bala and Mondol, 2001; Duan et al., 2004; 2010). Dried fish is one of the most important exported marine products in many countries such as Turkey, Iran, India, Thailand, Russia, China, Malaysia and United States. Drying of fish is cheap and easy to implement. It involves the use of heat (through heat air) and the simultaneous movement of water from the product. Several methods that utilise this concept include natural drying, solar drying and artificial drying.

All of these methods have been successfully applied by several research workers (Bellagha et al., 2002; Bala and Mondol, 2001; Chukwu and Shaba, 2009; Chukwu, 2009; Duan et al., 2004; 2010) to dry fish to safe moisture content. The flavour, taste and wholesomeness of the fish associated with each of those drying methods remains varied even as efforts are consistently being made to understand the reasons for the differences. Considering a technical solution to the problem, a number of innovative research efforts (Chukwu and Shaba, 2009; Chukwu, 2009; Darvishi et al., 2013; Bala and Mondol, 2001) have been carried out to advance reasons for the differences by linking the flavour, taste and wholesomeness of the fish to the method of drying. While this view is still relevant, some other researchers believe that modelling the drying behaviour of the fish under each drying method and comparing them remains the best approach in solving the problem. In this regard, a number of thin-layer drying models like the Lewis, Page, modified Page, Henderson and Pabis, modified Henderson and Pabis, Logarithmic and the Two term drying models have being developed and fitted against experimental data with a view to finding the model that best describes the drying behaviour of the product. Taking a look at the various reports in the foregoing, it becomes extremely important to ask whether the response of the fish in terms of its flavour, taste and wholesomeness is actually dependent on the method of drying? And if so, would it not have been an advancement of the existing preservation techniques if more intellectual resources are technically applied to improving the already established drying methods? Or, could it be that all of those responses have been properly accounted for in each of those drying models thus making it the prime tool for comparison among itself? These questions point to the fact that a drying model should, at least, contain most of the variables that influence the behaviour of the product it intends to predict and considering that most of the existing drying models were developed for seeds and grains, it remains a subject of research to evaluate whether the differences between crop and animal tissues play any significant role in determining the drying model that best describes the drying behaviour of mudskipper. In the absence of such a research finding, the objectives of this research work will be to determine the drying responses of mudskipper samples under different drying conditions, to explore some suitable thin-layer drying models that can describe the drying behaviour of mudskipper samples, to determine the correlation coefficient of some drying models that will be fitted against experimental data, to compare those values statistically and to choose the drying models that best describes the drying behaviour of mudskipper based on the values of the models.

METHODOLOGY

Experimental procedures

Mature samples of mudskipper whose colours were a mixture of grey and brown (when the mud was washed away) were procured from the market (Fimie market) along Abuloma road, Port Harcourt, Rivers State. Before it was subjected to further experimental work, the samples were all thoroughly washed to remove dirt and mud on the surface. The mudskipper samples ranged from 7cm (2.75 inches) to 25cm (9.75 inches) in length. Each sample was transversally cut to have a thin-layer of uniform sizes of 3cm. The cut samples were then weighed. With the dryer (oven) being turned on and allowed to reach thermal equilibrium at each of the desired drying conditions $[\mathrm{DC}_{1(11.3\%\ \mathrm{w.b.},60^{0}\mathrm{C})}$, $\mathrm{DC}_{2(11.3\%\ \mathrm{w.b.},80^{0}\mathrm{C})}$, $\mathrm{DC}_{3(11.3\%\ \mathrm{w.b.},100^{0}\mathrm{C})}]$, the weighed samples were then inserted into it for the drying process to commence. At a specified drying interval, the samples were continuously withdrawn from the oven and its weight taken until the drying data signifies an end to the experiment. Once this is achieved, the experiment is terminated and the dried sample is withdrawn from the dryer (oven). Each experiment was replicated thrice (3) and average values were taken for further analysis. One of such analysis will be carried out using Table 1 as shown below.

Table 1: Statistical Analysis and Expected Outcome

S/N	Statistical Analysis	Components of the Analysis	Expected Statistical Outcome
1	Statistical analysis 1	Comparison between $MR_{\mathrm{DC1}(11.3\%,60^{\mathrm{O}}\mathrm{C})}$ and $MR_{\mathrm{DC2}(11.3\%,80^{\mathrm{O}}\mathrm{C})}$	It is either statistically significant or not statistically significant
2	Statistical analysis 2	Comparison between $MR_{\mathrm{DC1}(11.3\%,60^{\mathrm{O}}\mathrm{C})}$ and $MR_{\mathrm{DC3}(11.3\%,100^{\mathrm{O}}\mathrm{C})}$	It is either statistically significant or not statistically significant
3	Statistical analysis 3	Comparison between $MR_{\mathrm{DC2}(11.3\%,80^{\mathrm{O}}\mathrm{C})}$ and $MR_{\mathrm{DC3}(11.3\%,100^{\mathrm{O}}\mathrm{C})}$	It is either statistically significant or not statistically significant

Where (DC1), (DC2), and (DC3) represents the drying conditions at the first, second and third instances respectively.

If the expected statistical outcome is not significant, the moisture ratio from any of the drying conditions will be used to fit against the data emanating from the chosen thin-layer drying models. However, if the expected statistical outcome is significant, the moisture ratios from the three (3) different drying conditions will be checked against the predicted moisture ratios of each of the chosen thin-layer drying models. Literally, the statistical analysis tends to indicate whether the moisture ratios emanating from each drying condition will be fitted against each of the chosen thin-layer drying models or a moisture ratio emanating from any of the drying conditions is representative of those drying conditions and at such, it can be used to fit against any of the chosen thin-layer drying models. When this is accomplished, it now remains to find out which of those chosen thin-layer drying models best fit the experimental data. To do this, there are several frequently used criteria as stated in literatures (Noomhorm and Verma, 1986; Zhao and Gao, 2016) that can be used to evaluate the suitability of a model to experimental data such as the correlation coefficient (r), the mean bias error (MBE), the reduced chi-squared (χ^2) and the standard error (SE). In this research work, the correlation coefficient (r) and the standard error will be the only judgement tool to be used. Thereafter, the coefficient of determination (r^2) and the standard error of the chosen thin-layer drying models will be compared and the thin-layer drying model with the highest value of r^2 and the least value of the standard error of the estimate will be chosen as the drying model that describes the drying behaviour of mudskipper.

Experimental Determinations

Determination of Initial and Subsequent Sample Weights

Given that the chosen size of the mudskipper samples was small, the initial and subsequent sample weights were determined by using an electronic weighing balance of high sensitivity. All measurements taken with the weighing balance were designated as $(w_i)_{t=0}$ and $(w_s)_{t=x_1,x_2,x_3,...x_n}$.

Where,

$(w_i)_{t=0}$ = initial weight of the sample

$(w_s)_{t=x_1,x_2,x_3,...x_n}$ = subsequent weights of the sample taken at the specified drying interval.

Determination of Initial and Subsequent Moisture Contents

The initial moisture content of the mudskipper samples was determined by the air oven drying method as stated by Association of Official Analytical Chemists (2005) and it is designated as $(MC_{wb})_i$ while the subsequent moisture content of the mudskipper samples undergoing drying was determined by using an equation developed by the authors of this research work and it is given as:

$$\left[(MC_{wb})_s\right]_{t=x_1,x_2x_3,..x_n} = \left[(MC_{wb})_i\right]_{t=0} + \frac{(d)_{t=0} \times \left[(w_s)_{t=x_1,x_2,x_3,..x_n} - (w_i)_{t=0}\right]}{(w_s)_{t=x_1,x_2,x_3,..x_n} \times (w_i)_{t=0}}$$

Where,

$(MC_{wb})_i$ = initial moisture content of the mudskipper sample before the commencement of drying.

$(w_i)_{t=0}$ = initial weight of the mudskipper sample before the commencement of drying.

$(d)_{t=0}$ = oven dry weight of the sample

$\left[(MC_{wb})_s\right]_{t=x_1,x_2,x_3,...x_n}$ = subsequent moisture content of the sample computed at the specified drying interval.

Determination of Drying Interval and Drying Time of Mudskipper

Experimental drying operation is basically symbolized by the duration in which the biological material is allowed to stay in the dryer before it is brought out for weight measurements and re- inserted into the dryer again for continuation of the drying process as well as the total time the entire drying process takes before the product dries to safe moisture content. The duration in which the biological material is allowed to stay in the dryer (oven) before it is brought out for subsequent weight measurements is called drying interval while the total time it takes the product to dry to safe storage moisture content is called drying time. Following these explanations, both drying interval and drying time will be used in this work. Consequently, a drying interval of 10minutes is chosen while the drying time for each drying condition will depend on when $(w_{sn})_{t=n} = (w_{sn+1})_{t=n+1}$. However, both parameters will be determined using a stopwatch.

Determination of Drying Responses of Mudskipper

Determination of Subsequent Moisture Content of Mudskipper Samples

With the drying interval chosen (10mins) and the dryer adjusted to the set drying condition [$\mathrm{DC}_{1\left(11.3\%\,\mathrm{w.b.},60^0\mathrm{C}\right)}$, $\mathrm{DC}_{2\left(11.3\%\,\mathrm{w.b.},80^0\mathrm{C}\right)}$, $\mathrm{DC}_{3\left(11.3\%\,\mathrm{w.b.},100^0\mathrm{C}\right)}$], a sample of the mudskipper whose initial weight and initial moisture content are taken as $(w_i)_{t=0}$ and $(MC_{wb})_i$, respectively, is loaded into the dryer for actual drying. At the end of each drying interval, the sample is withdrawn from the dryer (oven) and weighed. As the drying proceeds, it will get to a point where $(w_{sn})_{t=n} = (w_{sn+1})_{t=n+1}$. When this condition is established, the experiment is terminated and the dried sample is withdrawn from the oven. The subsequent moisture content which is taken as one of the drying responses of the mudskipper samples will be computed using the equation given below:

$$\left[(MC_{wb})_s\right]_{t=10,\,20,\,30,\ldots x_n} = \left[(MC_{wb})_i\right]_{t=0} + \frac{(d)_{t=0} \times \left[(w_s)_{t=10,\,20,\,30,\ldots x_n} - (w_i)_{t=0}\right]}{(w_s)_{t=10,\,20,\,30,\ldots x_n} \times (w_i)_{t=0}}$$

Determination of Moisture Ratio of Mudskipper Samples

Moisture ratio is used to analyse drying data. Like in most cases, the moisture ratio is used as the main response of the biological material and it is plotted against time (Hashemi et al., 2009; Jaiyeoba and Raji, 2012; Ndukwu, 2009). Mathematically, it is given as:

$$MR \quad = \frac{M - M_e}{M_i - M_e}$$

Where

M = subsequent moisture content at any time (% d.b.)
M_i = initial moisture content (% d.b.)
M_e = equilibrium moisture content (% d.b.)

In this research work, the moisture ratio will be computed the main drying response of the mudskipper samples.

The experimental determinations for each of the chosen variables were carried out at the Department of Food science and technology Laboratory, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, between August 2, 2016 to August 24, 2016.

Choosing a Thin-layer Drying Model to Describe the Drying Behaviour of Mudskipper Samples

A lot of thin-layer drying models to describe the drying behaviours of several biological materials exist today. Of this number, a few of them are presented in Table 2.

Table 2: A List of some Thin-layer Drying Models

S/N	Names	Models	Remarks
1	Lewis	$MR = e^{-kt}$	Lewis (1921)
2	Page	$MR = e^{-kt^n}$	Page (1949)
3	Modified Page	$MR = e^{(-kt)^n}$	Overhults et al (1973)
4	Henderson and Pabis	$MR = ae^{-kt}$	Henderson and Pabis (1961)
5	Two-term	$MR = ae^{-k_0 t} + be^{-k_1 t}$	Pabis (1974)

Based on the models presented in Table 2, the Lewis, Page and Modified Page thin-layer drying models are chosen to be used to fit the experimental data for mudskipper samples.

Determination of Statistical Variables

The three (3) chosen thin-layer drying models will be evaluated for its suitability to fit experimental data correctly based on the values of the preferred statistical judgement tools. These are the correlation coefficient (r), the coefficient of determination (r^2) and the least standard error of estimate. The statistic of these judgement tools can be described as follows:

Coefficient of Correlation (r)

The coefficient of correlation is a statistic that measures how strong a relationship is between two variables and in this research work, it will be used to estimate how closely related the moisture ratios emanating from the various experiments are to the values of the moisture ratios generated from the chosen thin-layer drying models. The statistic was earlier used by Alibas (2014) and it is put in simplified form as given below:

$$r = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{[n\sum x^2 - \left(\sum x\right)^2][n\sum y^2 - \left(\sum y\right)^2]}}$$

Where

x = $MR_{\exp eriment}$

y = $MR_{predicted}$

n = number of observations

Coefficient of Determination (r^2)

A high value of the coefficient of correlation is good but it does not tell how well the chosen thin-layer drying models fit the experimental data. In other words, the coefficient of determination is the statistic needed to tell exactly how well the chosen thin-layer drying models fit the experimental data. A simple form of this statistic as previously used by Alibas (2014) is given as:

$$r^2 = \left(\frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{\sqrt{[n\sum x^2 - \left(\sum x\right)^2][n\sum y^2 - \left(\sum y\right)^2]}}\right)^2$$

Standard Error of the Estimate (SEE)

As good as the coefficient of correlation is in helping one choose the model with the best fit, it does not tell exactly how far the experimental data points are from the predicted values. One statistic that gives an exact measure of the distance between the experimental data points and the predicted values is the standard error of estimate. According to Saeed et al (2008), the standard error of the estimate is given as:

$$SEE = \sqrt{\frac{\sum_{i=1}^{N}(MR_{[exp]i} - MR_{[cal]i})}{N - n_p}}$$

Where:

SEE = standard error of estimate

$MR_{(exp)}i$ = experimental moisture ratio of the i^{th} term for which i takes up values from 1, 2, 3,…N

$MR_{(cal)}i$ = Predicted moisture ratio of the i^{th} term for which i takes up values from 1, 2, 3,…N

N = the number of observation
n_p = number of constants used in the model

RESULTS

Reports from several experimental determinations for mudskipper samples and those closely related to it, such as the statistical analysis needed to aid the selection of the correct drying model that truly represents the drying behaviour of mudskipper samples, are presented for discussion in the section following. The results are arranged in tabular form and as a figure as shown in Tables 1-7 and Figure 1 respectively.

Table 1: Mudskipper Sample Dried at $DC_{1\left(11.3\%\text{ w.b.},60^0\text{C}\right)}$

Subsequent drying time (mins)	Subsequent weights of sample (g)	Subsequent moisture content of sample (% w.b.)	Subsequent moisture content of sample (% d.b.)	Moisture ratio (dimensionless)
10	$(w_s)_{t=10} = 241.57$	11.1	12.5	0.98
20	$(w_s)_{t=20} = 240.63$	10.8	12.1	0.94
30	$(w_s)_{t=30} = 239.82$	10.5	11.7	0.91
40	$(w_s)_{t=40} = 238.44$	10.0	11.1	0.85
50	$(w_s)_{t=50} = 237.50$	9.6	10.6	0.81
60	$(w_s)_{t=60} = 236.66$	9.3	10.3	0.78
70	$(w_s)_{t=70} = 235.41$	8.8	9.6	0.72
80	$(w_s)_{t=80} = 234.32$	8.3	9.1	0.67
90	$(w_s)_{t=90} = 233.12$	7.9	8.6	0.62
100	$(w_s)_{t=100} = 232.62$	7.7	8.3	0.60
110	$(w_s)_{t=110} = 231.17$	7.1	7.6	0.53
120	$(w_s)_{t=120} = 230.83$	6.9	7.4	0.51
130	$(w_s)_{t=130} = 230.39$	6.8	7.3	0.50
140	$(w_s)_{t=140} = 229.73$	6.5	7.0	0.48
150	$(w_s)_{t=150} = 229.11$	6.2	6.6	0.44
160	$(w_s)_{t=160} = 227.55$	5.6	5.9	0.40
170	$(w_s)_{t=170} = 225.42$	4.7	4.9	0.28
180	$(w_s)_{t=180} = 224.19$	4.1	4.3	0.23
190	$(w_s)_{t=190} = 222.65$	3.5	3.6	0.20
200	$(w_s)_{t=200} = 221.93$	3.2	3.3	0.14
210	$(w_s)_{t=210} = 220.51$	2.5	2.6	0.07
220	$(w_s)_{t=220} = 219.84$	2.2	2.2	0.04
230	$(w_s)_{t=230} = 218.66$	1.8	1.8	0.00
240	$(w_s)_{t=240} = 218.66$	1.8	1.8	0.00

$(w_i)_{t=0} = 242.00\text{g},\ (d)_{t=0} = 217.86\text{g},\ (MC_{wb})_i = 11.3\%,\ (MC_{wb})_e = 1.8\%$

Table 2: Mudskipper Sample Dried at $\mathrm{DC}_{2(11.3\%\ \mathrm{w.b.},80^{0}\mathrm{C})}$

Subsequent drying time (mins)	Subsequent weights of sample (g)	Subsequent moisture content (% w.b.)	Subsequent moisture content of sample (% d.b.)	Moisture ratio (dimensionless)
10	$(w_s)_{t=10} = 237.16$	10.4	11.6	0.90
20	$(w_s)_{t=20} = 236.21$	10.1	11.2	0.86
30	$(w_s)_{t=30} = 235.96$	10.0	11.1	0.85
40	$(w_s)_{t=40} = 233.59$	9.1	10.0	0.76
50	$(w_s)_{t=50} = 231.87$	8.4	9.2	0.68
60	$(w_s)_{t=60} = 230.42$	7.8	8.5	0.62
70	$(w_s)_{t=70} = 229.75$	7.5	8.1	0.58
80	$(w_s)_{t=80} = 228.58$	7.1	7.6	0.54
90	$(w_s)_{t=90} = 226.01$	6.0	6.4	0.43
100	$(w_s)_{t=100} = 225.19$	5.7	6.0	0.39
110	$(w_s)_{t=110} = 223.94$	5.1	5.4	0.34
120	$(w_s)_{t=120} = 222.46$	4.5	4.7	0.27
130	$(w_s)_{t=130} = 221.73$	4.2	4.4	0.25
140	$(w_s)_{t=140} = 220.90$	3.8	4.0	0.21
150	$(w_s)_{t=150} = 219.61$	3.3	3.4	0.16
160	$(w_s)_{t=160} = 218.18$	2.6	2.7	0.09
170	$(w_s)_{t=170} = 217.91$	2.5	2.6	0.08
180	$(w_s)_{t=180} = 217.60$	2.4	2.5	0.08
190	$(w_s)_{t=190} = 216.95$	2.1	2.1	0.04
200	$(w_s)_{t=200} = 216.73$	2.0	2.0	0.03
210	$(w_s)_{t=210} = 215.97$	1.6	1.6	0.00
220	$(w_s)_{t=220} = 215.97$	1.6	1.6	0.00
230	$(w_s)_{t=230} = 215.97$	1.6	1.6	0.00
240	$(w_s)_{t=240} = 215.97$	1.6	1.6	0.00

$$(w_i)_{t=0} = 239.49\mathrm{g},\ (d)_{t=0} = 212.43\mathrm{g},\ (MC_{wb})_i = 11.3\%,\ (MC_{wb})_e = 1.64\%$$

Table 3: Mudskipper Sample Dried at $\mathrm{DC}_{3(11.3\%\,\mathrm{w.b.},100^0\mathrm{C})}$

Subsequent drying time (mins)	Subsequent weights of sample (g)	Subsequent moisture content (% w.b.)	Subsequent moisture content of sample (% d.b.)	Moisture ratio (dimensionless)
10	$(w_s)_{t=10} = 245.82$	10.5	11.7	0.91
20	$(w_s)_{t=20} = 241.65$	8.9	9.8	0.74
30	$(w_s)_{t=30} = 238.18$	7.6	8.2	0.60
40	$(w_s)_{t=40} = 236.51$	7.0	7.5	0.54
50	$(w_s)_{t=50} = 234.11$	6.0	6.4	0.44
60	$(w_s)_{t=60} = 233.76$	5.9	6.3	0.43
70	$(w_s)_{t=70} = 232.12$	5.2	5.5	0.40
80	$(w_s)_{t=80} = 231.93$	5.1	5.4	0.35
90	$(w_s)_{t=90} = 231.53$	5.0	5.3	0.34
100	$(w_s)_{t=100} = 230.04$	4.4	4.6	0.30
110	$(w_s)_{t=110} = 229.55$	4.1	4.3	0.25
120	$(w_s)_{t=120} = 228.46$	3.7	3.8	0.21
130	$(w_s)_{t=130} = 228.01$	3.5	3.6	0.20
140	$(w_s)_{t=140} = 227.60$	3.3	3.4	0.17
150	$(w_s)_{t=150} = 227.11$	3.1	3.2	0.16
160	$(w_s)_{t=160} = 226.96$	3.1	3.2	0.16
170	$(w_s)_{t=170} = 225.13$	2.3	2.4	0.08
180	$(w_s)_{t=180} = 224.58$	2.0	2.0	0.05
190	$(w_s)_{t=190} = 223.20$	1.4	1.4	0.00
200	$(w_s)_{t=200} = 223.20$	1.4	1.4	0.00
210	$(w_s)_{t=210} = 223.20$	1.4	1.4	0.00
220	$(w_s)_{t=220} = 223.20$	1.4	1.4	0.00
230	$(w_s)_{t=230} = 223.20$	1.4	1.4	0.00
240	$(w_s)_{t=240} = 223.20$	1.4	1.4	0.00

$(w_i)_{t=0} = 248.06\mathrm{g},\ (d)_{t=0} = 220.03\mathrm{g},\ (MC_{wb})_i = 11.3\%,\ (MC_{wb})_e = 1.42\%$

Table 4: **Computed Values of Moisture Ratio for Mudskipper Samples Dried at** $DC_{1(11.3\%\ \text{w.b.},60^0\text{C})}$, $DC_{2(11.3\%\ \text{w.b.},80^0\text{C})}$, and $DC_{3(11.3\%\ \text{w.b.},100^0\text{C})}$

Sub drying time (mins)	$MR_{DC1(11.3\%,60^O\text{C})}$	$MR_{DC2(11.3\%,80^O\text{C})}$	$MR_{DC3(11.3\%,100^O\text{C})}$
10	0.98	0.90	0.91
20	0.94	0.86	0.74
30	0.91	0.85	0.60
40	0.85	0.76	0.54
50	0.81	0.68	0.44
60	0.78	0.62	0.43
70	0.72	0.58	0.40
80	0.67	0.54	0.35
90	0.62	0.43	0.34
100	0.60	0.39	0.30
110	0.53	0.34	0.25
120	0.51	0.27	0.21
130	0.50	0.25	0.20
140	0.48	0.21	0.17
150	0.44	0.16	0.16
160	0.40	0.09	0.16
170	0.28	0.08	0.08
180	0.23	0.08	0.05
190	0.20	0.04	0.00
200	0.14	0.03	0.00
210	0.07	0.00	0.00
220	0.04	0.00	0.00
230	0.00	0.00	0.00
240	0.00	0.00	0.00

Where Sub drying time refers to the subsequent drying time.

Table 5: **Statistical Analysis for Moisture Ratio Data at three Different Drying Conditions**

S/N	**MEAN DIFFERENCE**	**DFW**	**MSW**	**1/N1+1/N2**	**Alpha**	$t_{v,a}$	**LSD**	**Expected Statistical Outcome**
1	0.148	69.000	0.086	0.083	0.05	1.995	0.169	Not Significant
2	0.224	69.000	0.086	0.083	0.05	1.995	0.169	Significant
3	0.076	69.000	0.086	0.083	0.05	1.995	0.169	Not Significant

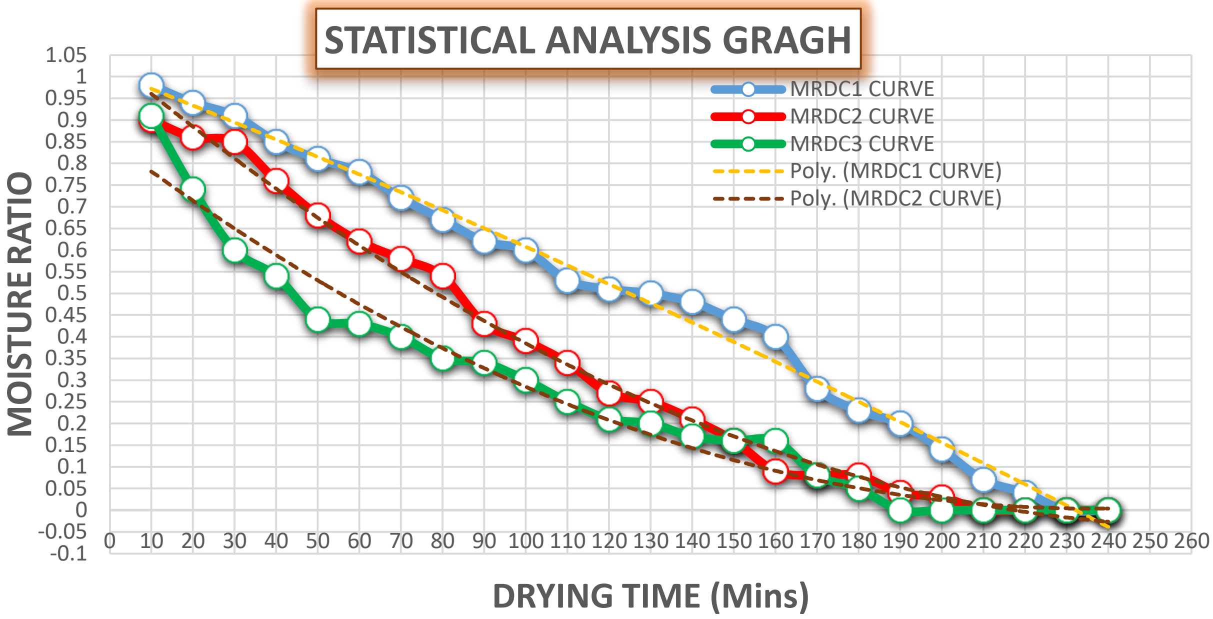

Figure 1: Statistical Curve of Moisture Ratio Against Drying Time.

Table 5: Experimental and Predicted Moisture Ratios for Mudskipper Sample Dried at $DC_{2(11.3\% w.b, 80^0 C)}$

Moisture Ratio Obtained from Experimental Data $MR_{DC2(11.3\%,80^O C)}$	Moisture Ratio Obtained from three (3) Different Thin-layer Drying Models and Juxtaposed against Data from $MR_{DC2(11.3\%,80^O C)}$		
	Lewis	**Page**	**Modified Page**
0.90	0.95	0.94	0.95
0.86	0.91	0.87	0.88
0.85	0.87	0.79	0.81
0.76	0.83	0.72	0.73
0.68	0.79	0.64	0.65
0.62	0.75	0.57	0.58
0.58	0.72	0.51	0.51
0.54	0.68	0.45	0.45
0.43	0.65	0.39	0.39
0.39	0.62	0.34	0.34
0.34	0.59	0.30	0.29
0.27	0.57	0.26	0.25
0.25	0.54	0.22	0.22
0.21	0.51	0.19	0.18
0.16	0.49	0.17	0.16
0.09	0.47	0.14	0.13
0.08	0.45	0.12	0.11
0.08	0.42	0.10	0.09
0.04	0.40	0.09	0.08
0.03	0.37	0.08	0.07
0.00	0.37	0.06	0.05
0.00	0.35	0.05	0.04
0.00	0.33	0.05	0.04
0.00	0.32	0.04	0.03

Table 6: Computed Values of Coefficient of Correlation (R) for the Three (3) Thin-layer Drying Models and Experimental Results

	Experimental	*Lewis*	*Page*	*Modified Page*
Experimental	1			
Lewis	0.993114298	1		
Page	0.991688446	0.986652	1	
Modified Page	0.991982255	0.986324	0.999922	1

(R^2) and Standard Models

R^2	0.992028	0.994898	0.992028
SEE	1.14E-04	4.55E-06	1.82E-05

DISCUSSION

At the end of the various experimental determinations, it becomes expedient to carry out the much needed statistical analyses that will be required in determining the model that truly describes the drying behaviour of mudskipper samples. The first of these analyses is to find out whether the moisture ratios of the three different experiments are statistically significant or not. Table 4, Table 5 and Figure 1 show the computed values of moisture ratio for three different samples of mudskipper dried at $DC_{1\left(11.3\%\,\text{w.b.},60^{0}\text{C}\right)}$, $DC_{2\left(11.3\%\,\text{w.b.},80^{0}\text{C}\right)}$ and $DC_{3\left(11.3\%\,\text{w.b.},100^{0}\text{C}\right)}$, the results of the comparison analysis as well as the statistical analysis graph.

Figure 1 shows that the moisture ratios (MR) of the three different mudskipper samples decrease as the drying time increases. The plot of moisture ratio against drying time at $DC_{1\left(11.3\%\,\text{w.b.},60^{0}\text{C}\right)}$ shows that the trend line curve is a linear curve while for both $DC_{2\left(11.3\%\,\text{w.b.},80^{0}\text{C}\right)}$ and $DC_{3\left(11.3\%\,\text{w.b.},100^{0}\text{C}\right)}$, the trend line reveals that a non-linear curve exist there. This implies that there is no significant difference between the moisture ratios of mudskipper samples dried at $DC_{2\left(11.3\%\,\text{w.b.},80^{0}\text{C}\right)}$ and $DC_{3\left(11.3\%\,\text{w.b.},100^{0}\text{C}\right)}$. However, there is a significant difference between the moisture ratios of mudskipper samples dried at $DC_{1\left(11.3\%\,\text{w.b.},60^{0}\text{C}\right)}$ and those dried at $DC_{3\left(11.3\%\,\text{w.b.},100^{0}\text{C}\right)}$. It was thought earlier that the results of the statistical analysis would show that the moisture ratio data at the three different drying conditions would not be statistically different when compared among themselves. However, this notion has been discarded going by the obvious revelations of the statistical analysis. One way of choosing the right moisture ratio data to be used for the validation of the descriptive thin-layer drying model is to make an additional consideration for energy consumption. Since it has been statistically proven that there is no significant difference between $MR_{\text{DC2}\left(11.3\%,80^{0}\text{C}\right)}$ and $MR_{\text{DC3}\left(11.3\%,100^{0}\text{C}\right)}$, meaning that the drying effect showed by the mudskipper samples were the same, and considering that energy consumed by the dryer at $DC_{3\left(11.3\%\,\text{w.b.},100^{0}\text{C}\right)}$ is more than that consumed at $DC_{2\left(11.3\%\,\text{w.b.},80^{0}\text{C}\right)}$; it becomes clear that using $MR_{\text{DC2}\left(11.3\%,80^{0}\text{C}\right)}$ as the data for the model analysis is better. It is on the basis of this that Table 5 is being formed.

The results of the moisture ratio computations carried out for the three (3) thin-layer drying models together with those obtained from experiment are presented in Table 5 above. The results presented in Table 5 was further subjected to statistical interpretation to allow for the selection of the drying model that best describes the thin-layer drying behaviour of mudskipper samples based on the results of the preferred statistical judgement tools earlier mentioned in this work. The results of the statistical judgement tools are presented in Tables 6 and 7 above.

From Table 6, the values of the coefficient of correlation (R) for the Lewis, Page and Modified Page models are 0.993114298, 0.991688446, 0.991982255, respectively while those for the coefficient of determination (R^2) and the standard error of estimate for the three (3) listed models above are 0.992028, 0.994898, 0.992028; 0.000114, 0.00000455, 0.0000182, respectively. Judging from the statistical point of view, a model that best fits an experimental data is one with the highest value of the coefficient of determination (R^2) and the least value of the standard error of estimate (SEE). Based on this, the Page model is chosen as the thin-layer drying model that describes the drying behaviour of mudskipper.

CONCLUSIONS

Several thin-layer drying models were compared with experimental data emanating from the drying response of mudskipper samples and with the data generated from the models itself. This was done so that a representative kinetic equation that best describes the thin-layer drying behaviour of the product can be chosen based on some statistical judgement tools like the coefficient of determination (R^2) and the standard error of estimate whose values for the models when calculated would be the highest and least respectively. On the basis of this, the Page model was found to have the best goodness of fit with the highest value of (R^2) of 0.991688446 and the least value of the SEE of 0.00000455 and as a result, it was chosen as the thin-layer drying model which describes the drying behavior of mudskipper samples.

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REFERENCES

Al-Behbehani, B. E. & Ebrahim, H. M. A. (2010) Environmental Studies on the Mudskippers in the Intertidal Zone of Kuwait Bay. Nature and Science. 8(5): 79-89.

Alibas, I. (2014). Mathematical Modeling of Microwave Dried Celery Leaves and Determination of the Effective Moisture Diffusivities and Activation Energy. Food Science and Technology, 34(2):394-401. https://dx.doi.org/10.1590/S0101-20612014005000030

Ansari, A. A., Trivedi, S., Saggu, S. & Rehman, H. (2014). Mudskipper: A biological indicator for environmental monitoring and assessment of coastal waters. Journal of Entomology and Zoology Studies. 2(6): 22-33.

AOAC. (Association of Official Analytical Chemists) (2005) Official Methods of Analysis of the Association of Analytical Chemists International, 18th ed. Gathersburg, MD U.S.A Official methods, 2005.08.

Ashie, I. N. A., Smith, J. P., Simpson, B. K., & Haard, N. F. (1996) Spoilage and shelf life extension of fresh fish and shellfish. Critical Reviews in Food Science and Nutrition, 36:1-2, 87-121, DOI: 10.1080/10408399609527720.

Bala, B.K. & Mondol, M.R.A. (2001) Experimental investigation on solar drying of fish using solar tunnel dryer Drying Technology, 19(2): 427-436. http://doi.org/10.1081/DRT-100102915.

Bellagha, S., Amami, E., Farhat, A. & Kechaou, N. (2002) Drying kinetics and characteristic drying curve of lightly salted Sardine (*Sardinella aurita*).Drying Technology, 20(7): 1527-1538. . http://doi.org/10.1081/DRT-120005866.

Chukwu, O. (2009) Influences of drying methods on nutritional properties of tilapia fish (*Oreochromis nilotieus*) World J. Agri. Sci., 5 (2): 256-258.

Chukwu, O. & Shaba, M. I. (2009) Effects of drying methods on proximate compositions of catfish (*Clarias gariepinus*). World J. Agri. Sci., 5 (1): 114-116.

Darvishi, H., Azadbakht, M., Rezaeiasl, A., & Farhang, A. (2013) Drying Characteristics of Sardine Fish Dried with Microwave Heating. Journal of the Saudi Society of Agricultural Sciences. 12(2): 121-127. https://doi.org/10.1016/j.jssas.2012.09.002.

Duan, Z. H., Jiang, L. N., Wang, J. L., Yu, X.Y. & Wang, T. (2010) Drying and quality characteristics of tilapia fish fillets dried with hot air-microwave heating. Food Bioprod. Process. http://dx.doi.org/10.1016/j.fbp. 2010.11.005.

Duan, Z.H., Zhang, M., & Tang, J. (2004) Thin layer hot-air drying of bighead carp Fish. Sci., 23(3): 29-32.

Hashemi, G., Mowla, D. & Kazemeini, M. (2009) Moisture diffusivity and shrinkage of broad beans during bulk drying in an inert medium fluidized bed dryer assisted by dielectric heating. Journal of Food Engineering, 92(3):331-338. https://doi.org/10.1016/j.jfoodeng.2008.12.004.

Henderson, S. M. & Pabis, S. (1961) Grain drying theory. II. Temperature effects on drying coefficients. J. Agr. Eng. Res. 6, 169–174.

Jaiyeoba, K. F. & Raji, A. O. (2012) Effects of Drying Temperature on the Effective Coefficient of Moisture Diffusivity and Activation Energy in Ibadan- Local Tomato Variety (*lycopersicum esculentum*). Journal of Information Engineering and Applications. 2(4): 24-39.

Kutschera, U., Burghagen, H. & Ewert, J. P. (2008) Prey-catching Behaviour in Mudskippers and Toads: A Comparative Analysis. Online Journal of Biological Science, 8: 41-43.

Lewis, W. K. (1921) The rate of drying of solid materials. J. Industrial Engineering Chemistry, 13: 427-432.

Ndukwu, M. C. (2009) Effects of Drying Temperature and Drying Air Velocity on the Drying Rate and Drying Constant of Cocoa Bean. Agricultural Engineering International: the CIGR Ejournal Manuscript 1091. (XI): 1-7.

Noomhorm, A. & Verma, L. R. (1986) Generalized Single Layer Rice Drying Models. Trans ASAE.:29: 587–591.

Overhults, D. G., White, H. E., Hamilton, H. E. & Ross, I. J. (1973) “Drying soybeans with heated air”. Trans. of the ASAE, 16: 112-113.

Pabis, U. K. (1974) Physical Changes in Bamboo (*Bambusa phyllostachys*) Shoot During Hot-air Drying: Shrinkage, Density and Porosity. Drying Technology.

Page, G.E. (1949) Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin Layers. M.S. Thesis. Department of Mechanical Engineering, Purdue University, Purdue, USA.

Saeed, I. E., Sopian, K. & Zainol, A. Z. (2008) Drying characteristics of Roselle: Study of Two-term Exponential Model and Drying Parameters. Agricultural Engineering International: the CIGR Ejournal. Manuscript FP 08 016. (X): 1-27.

Ter, L.S. L., Lam, V. W. Y., Cheung, W.W. L., Miller, D., Ter, L. C. L. & Sumaila, U. R. (2016) Impact of High Seas Closure on Food Security in Low Income Fish Dependent Countries. PLOS ONE 11(12): 1-27. : DOI: 10.1371/journal.pone.0168529.

Zhao, R. & Gao, T. (2016) Research Progress of Hot Air Drying Technology for Fruits and Vegetables. Advance Journal of Food Science and Technology. 10(3): 160-166.