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Thin Layer Drying Kinetics of Salt Water Crab (*Cardisoma Guanhumi*)

Jonathan, B. J[1*], Egbe, E. W[1]

[1]Department of Agricultural and Environmental Engineering, Faculty of Engineering, PMB 071, Niger Delta University Wilberforce Island Amassoma, Bayelsa State, Nigeria

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***Corresponding author:** Jonathan, B. J
Department of Agricultural and Environmental Engineering, Faculty of Engineering, PMB 071, Niger Delta University Wilberforce Island Amassoma, Bayelsa State, Nigeria

Abstract

Crab meat undergoes rapid microbial deterioration after death, placing it in the category of highly perishable sea foods (the Crayfish and lobsters alike) Thus, this affects its economic value. Drying is one of the techniques that will provide consumers with ready-to-use dried crabmeat to incorporate into daily meals such as soups, sauces, and so on. This study thus, investigated the drying behavior of the crab on thin-layers. A laboratory convective oven dryer was used as the heating source, on the temperature (range of 60 - 100°C) applied in a varying manner on multiples of 10°C. The layer thickness was about 45-mm. as with high moisture sea foods, the drying profile showed a typical falling rate period with no distinct constant rate period for all the temperature levels used in this work. Moisture loss (diffusion) data obtained from the experiments were fitted to three popular semi-empirical thin-layer models of Lewis, Henderson-Pabis, and Page, and their suitability was validated using statistical parameters such as Root Mean Square,(R^2), X^2 and RSME. This was done to select thin-layer model that would suitably describe the drying kinetics of the samples over the range of temperature levels chosen in this work. Consequently, the Henderson-Pabis model and that of Page model were taken to have reliably predicted the drying behavior of the samples at the chosen temperature levels.

Keywords: Salt-water crabs, thin-layer drying, drying kinetics, modelling, effective, diffusivity, activation energy.

1. INTRODUCTION

Crabs are crustaceans that belong to the infra order Brachyuran and have thick exoskeletons (shells) as well as a single pair of pincers. A hidden tail under the thorax is another subtle feature. Their habitats include all of the world's oceans, fresh water, and land. They are commercially important to humans as a traditional food item because they have a high average meat yield and a high meat-to-shell ratio when fresh (Martin 2020). Humans are the primary predators of crab meat in general because they are shelled and highly toxic to most sea or river creatures. In the ocean belts of Nigeria's Niger Delta region, they are primarily marketed alive, as crab meat can be consumed whole (shell and all) when cut in their molten state or picked (picking as a processing term refers to removing meat from the shell and claws either by hand or with the use of a machine) and eaten seasoned and cooked to taste, as in the case of adult crabs.

Seafood is widely recognized for its nutritional value. Crabmeat, in fact, is high in essential proteins and minerals, particularly calcium, iron, phosphorus and potassium (Premarathna *et al.*, 2015; Zotti *et al.*, 2016). According to Zotti *et al.*, 2016); Gökoðlu *et al.*, 2013); Wu *et al.*, (2010) Crabmeat have a high protein content (14 to 22.6%) as well as a high mineral content. Crabmeat contains less than 2% lipids (Ayas, 2016), The majority of which contains polyunsaturated fatty acids (PUFAs), accounting for 32 to 52 percent of the total fatty acid content, compared to 20 to 28 percent of the total fatty acid content (Bejaoui *et al.*, 2017; Gokoolu *et al.*, 2013; Wu *et al.*, 2010). Investigation shows that several fish species to a crab species (P. pelagicus), and their study revealed that PUFAs and monounsaturated fatty acids (MUFAs) were significantly higher in crabmeat than in fish flesh, while saturated fatty acids (SFAs) were lower in crabmeat (Premarathna *et al.*, 2015). Because of the large number of crabs that are currently present on the southern coast of Nigeria, as well as the high nutritional value of crabmeat, this decapod should be valorized and preserved using a variety of techniques in order to establish new food products with a high nutritional value that consumers value.

Drying is one of these techniques that will provide consumers with ready-to-use dried crabmeat to incorporate into daily meals such as soups, sauces, and so on. However, both traditional and innovative drying processes, regardless of mode like microwave, convective, infrared etc frequently result in product overheating, which causes significant organoleptic degradation, nutrient denaturation and crack formation. Heat treatments do, in fact, have a negative impact on the proximate composition of seafood and alter its sensory properties.

Crab meat, on the other hand, undergoes rapid microbial deterioration after death, placing it in the category of highly perishable sea foods (the Cray fish and lobsters alike) Thus, this affects its economic value thus, endogenous enzymes and chemical reactions such as Millard browning and oxidative discoloration are a primary influence to the color of the crab meat during processing (Boon 1975). Browning also occurs during the cooking process. Nutrients may be lost in processes like canning which involves storage of animal muscled biomaterial in wet form, hence the need to prolong the shelf life of this product while retaining its physiochemical and qualitative characteristics, harvested quantities in excess of immediate consumption will necessitate proper and prompt post-harvest handling, preservation, and storage (Crandal 2016) While techniques such as freezing, salting, chilling, cooked-canning, and frying are useful for wet storage, dry preservation and storage is a well-known method for extending the shell life of animal muscle bio-material. Drying does not deplete, but rather retains required flavor, color, and nutritive value, as well as influencing the physiochemical and quality characteristics of the products.

The goal of this research is to extend the shelf life of crab meat while retaining its flavor, color, and nutritional value. If widely implemented, this study will propose increased demand for crab meat, as crab meat is one of the most consumed and valued meats on the market today, and may be regarded as the king of seafood due to its exceptional taste and flavors. Drying will also aid in better packaging, which will serve as a marketing tool. Dried food is always more intensely flavored as well as being highly nutritive and most at time can be consumed solo, hence crab meat in dried form will be a form of delicacy on its own, and an absolute delight when added to other meals as a side serve or in-recipe.

Therefore, in this work the drying behavior of the salt water crab was investigated on thin-layers and the resulting experimental data were fitted to the selected thin-layer drying models to characterize the drying kinetics of the crab. This would also create a good database or improved equipment design of the drying processes.

1.1 THEORETICAL FRAMEWORK

Thin layer as a concept refers to a layer of a product that is sufficiently thin in thickness that its characteristics can be considered identically uniform throughout the layer with no observable variations. All individual particles of the material should be fully exposed to the drying air. Thin layer drying conditions are frequently divided into two drying periods: constant rates and falling rate periods. Thin-layer drying was carried out in batches of single beds or layers split to different small but uniform thicknesses. It is common practice to arrange the various splits in vertical series so that hot air in a forced convective stream can pass over them. The hot air stream can then be seen absorbing moisture from the first split through the others, such that the exhaust from one split becomes input air to the next split, and so on until it reaches the final or terminal split. Passing through a number of thin splits in this manner, it is clear that the air stream's ability to pick up moisture decreases from one layer to the next.

To ensure the success of such simulation work, the splits (now referred to as thin-layers) must be made infinitesimally thin and arranged in such a way that the inlet hot air stream simply exhausts through the layers with no reduction in moisture carrying capacity. Drying would then occur in all of the splits, with each batch characterized by different drying rates at the various temperature levels used (Zibokere and Egbe, 2019). Fick's second law governs the entire rate period of the drying process, which is known to be a diffusion (molecular transport) phenomenon through a continuum of interface slits (moisture flux proportional to the moisture gradient) (Bird *et al*., 2005; Suarez *et al*., 1980).

2.0 MATERIALS AND METHODS

2.1 MATERIALS

Some freshly harvested Ruth Bun crab (Cadisoma Guanhumi) were purchased from a local market located at Yenagoa, Yenagoa local government area of Bayelsa state, Nigeria. The crabs were taken to the food processing laboratory in the department of Agricultural and Environmental Engineering in Niger Delta University, Bayelsa State to study the drying kinetics. Using a 0.001-cm precision veneer calliper, each of the Rath bun crab (Cadisoma Guanhumi) meat (plate 1) to be used in the drying tests was measured of the basic dimensions, stratified into groups of different but equal thickness and length, re-stabilized and stored without any further treatment in refrigerated cabinets. The samples were weighed with a digital balance to obtain a uniform weight of 32-g in five (5) distinct places. The samples were then oven dried in a thin-layered form, to a constant final weight using WTC binder oven (Model WTCB).

2.2 DESCRIPTION OF THE OVEN DRYER

The oven dryer is designed to remove moisture from the oven chamber so as to dry the samples as quick as possible. The drying oven process introduces fresh dry air to the chamber and expels the warm moist air simulataneously allowing to rapidly dry the samples. The oven dryer provides high-performance drying and heating. The samples are to be dried for a defined period of time at constant temperatures. The moisture content is determined by weighing the sample before and after drying See plate 2.

Plate 1: Salt water blue crab (*Cardisoma Guanhumi*) a.k.a the Rathbun crab

Plate 2: Electric Oven Dryer

2.3 METHOD

The summary of the experimental data used in this study is represented in equ 2-4. Three Models were used, Lewis, Henderson and Page.

2.3.1 DRYING PROCEDURE

Thin layer experiments were conducted at six (6) levels of temperature (60, 70, 80, 90 and 100, 110°C respectively). The samples were introduced into the electric oven drier. The initial and all other moisture content values were taken using the digital balance with 0.01-g precision. The moisture reduction process (i.e. weight loss) for each sample was monitored at specific time intervals (of about 10min) to point of equilibrium and in a manner as described in the works of (Zibokere and Egbe, 2020) on Spiced Okpokuru (*Orycles rhinoceros*), and on catfish (Sankat and Mujaffar, 2006).

2.3.2 DATA COLLECTION

As earlier stated by definition, drying is a progressive moisture reduction phenomenon until a final level is reached. Therefore, data collected in the work included initial and final weight of samples, initial and final moisture contents measured in %db. All weight measurements were done using a laboratory-type top digital balance with 0.01-g precision. The initial and all other moisture content values were taken using the oven method of ASAE standard (ASAE standard, 2000, (S368 41 2000). 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 interval, all measured on dry-basis as (Mohsenin, 1986).

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

Where;

M= dry basis moisture content, %-db.

W_i = initial weight of the specimen, g

W_f = initial weight of the specimen, g.

2.4 THIN LAYER MATHMATICAL DRYING MODELS

The use of mathematical models in estimating the behaviour of agricultural and other biomaterials during drying is common in technical literature. Several of such thin-layer drying models are listed in equation 2, 3 & 4 (the Lewis, page and Henderson-Pabis models) are selected for validation in this work on Rathbun crab (Cadisoma Guanhumi).

a) Lewis Model

$$MR = e^{-kt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

b) Henderson-Pabis Model

$$MR = Ae^{-kt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

c) Page Model
$MR=e^{-kt^n}$ ……………………….. 4

Taking natural logarithm of both sides deduced equation 8
In(MR)=In(k) – kt ……………………….. 5

Where k is kinetic (drying) rate constant and a, b, n are model constants.

2.5 OBTAINING DRYING CURVES

The control of drying rates is critical in describing thin layer drying. Drying time can be reduced by increasing the drying rate at various drying temperatures. However, drying at high temperatures (say, above 80°C) in a variety of drying conditions may have a negative impact on the final quality of high body-moisture materials (Shi *et al.*, 2008, Chen *et al.*, 2013). The reduction of moisture in the drying process may be related to the drying time in a cubic polynomial form in the following direction Y in a given split for a given drying temperature (Hayder *et al.*, 2014).

$$y = C_0 + C_1t + C_2t^2 + C_3t^3 + C_4t^4 \text{ ……………….. 6}$$

Where the C's are constant, caring for the intrinsic factors in the drying process. Differentiating Eq. 6 with respect to time will yield drying rate as follows:

$$\frac{dy}{dt} = -(c_1 + 2c_2t + 3c_3t^2 + 4c_4t^3 \ldots) \text{ …………….. 7}$$

The negative sign indicates decay in the drying rate with passage of drying time. Considering higher powers of ***t*** as negligible, Eq. 7 can be reduced to:

$$\text{Drying rate}\left(\frac{dy}{dt}\right) = -(c_1 + 2c_2t + 3c_3t^2 \ldots) \text{ …….. 8}$$

Eq. 8 is a semi parabolic on a drying rate vs drying time plot, yielding drying curves for the different drying temperatures chosen in this work.

2.6 DRYING KINETICS

Drying kinetics show good information about the drying process of crab meat. (Omori *et al.*, 2018).

$$\frac{dM}{dt} = D_e\left(\frac{d^2M}{dr^2}\right) \text{ ……………………….. 9}$$

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
D_e= effective diffusivity, mm^2/min.

The moisture ratio (MR) prevalent in the drying system can be expressed as (Sahey and Singh 2005).

$$MR = \frac{M-M_e}{M_0-M_e} \text{ ……………………….. 10}$$

Where
M_e = equilibrium moisture content (emc),
M_0 = initial moisture content,
M is as previously defined
The drying rate was calculated using 10 (Ju *et al.*, 2016)

$$DR = \frac{\Delta M}{\Delta T} \text{ ……………………….. 11}$$

Where
ΔM = Change in moisture content at wet base
ΔT = Change in time

2.7 STATISTICAL FITTING OF EXPERIMENTED DATA

In order to find best suitable model to explain drying behaviour of any product, thin-layer drying models can normally be evaluated and the quality of fit compared using certain statistical indicators such as coefficient of determination (R^2), the non-parametric reduced chi square (x^2), and the Root Mean Square Error (RMSE)the usual criteria is that an acceptable goodness of fit is said to have occurred in describing the drying curve of a given model if R^2 is high and the value of other indicators, x^2 and RMSE are low. In this work, the experimental drying data of the samples obtained at different temperature were used to fit into the three commonly used thin-layer drying models. The goodness of fit of the selected mathematical models to experimental data was evaluated using the given criteria. The statistical parameters as the indicators were calculated as described:

$$R^2 = 1-\left[\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2\right] \text{ ……………… 12}$$

$$X^2 = \frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{n-k} \text{ ………………… 13}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{n}} \text{ ………………… 14}$$

NOTE:
Where
$MR_{pre.}$= predicted moisture ratio
$MR_{exp.}$ = experimental moisture ratio
n = number of observations
k = Constant

3.0 RESULTS AND DISCUSSION

3.1 CHARACTERIZING DRYING KINETICS

It was necessary to transform the drying data obtained from experiments into dimensionless moisture ratios (MR). These MR values were then plotted as a function of the drying time (Figure 1) for the Rathbun crab (*Cadisoma Guanhumi*) at the selected temperature while it has variations in the humidity ratios given in the logarithmic form drawn according to the drying system. It is known that the activation energy promotes the molecular transport phenomenon (diffusion) that derives the drying process. Moisture ratios are all given to dry (DB). It is observed that the plots figure 2 followed the general trend of the drying curves as reported for many bio-materials. The curves presented a stronger initial slope, an indication of an initial increase and a loss of accelerated moisture in drying. This could be due to increased water activity in the samples resulting from faster moisture migration to the surface of evaporation and evacuation, helping to shorten the drying time. The drying process, however, because more slowly (curves have become flattened) at subsequent stages, even with increasing temperature as lower and lesser water becomes available for evaporation on the surface of the samples.

3.2 Fitting Experimental Data into Thing-Layer Drying Models

The transformed dimensionless moisture ratios were used to fit the empirical models of Lewis, Henderson, and Page, and for all the different drying temperatures chosen in this work. The parameters were subjected to statistical analysis for all the drying conditions (Table 1). The fitting results in concurrence with the statistical analysis showed that the coefficient of determination, R^2 values were consistently high in the range of 0.743547 – 0.999421 for all the models. The indication here is that all the used empirical models could satisfactorily describe the drying behavior of the samples. When tuned further with the other statistical parameters, the model expression of Henderson and Pabis followed by that of Page had the highest R^2 values and the lowest X^2 and RMSE values in the temperature range of the work. This showed the suitability of these models in describing the drying kinetics of the samples. It was therefore, satisfactory to select the Henderson-Pabis model to predict the drying kinetics of the Salt water crab on the drying temperatures applied in this work.

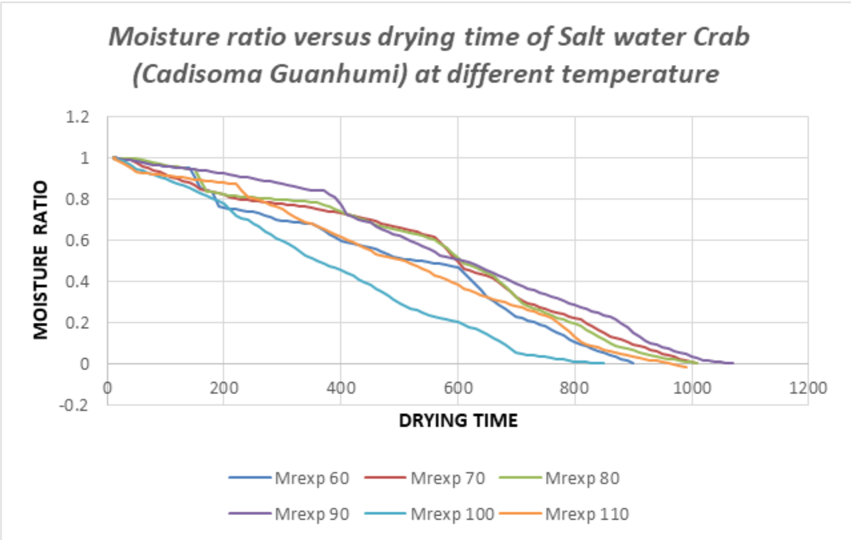

Fig 1: Moisture ratio versus drying time of Salt Water Crab *(Cadisoma Guanhumi)* at different temperature

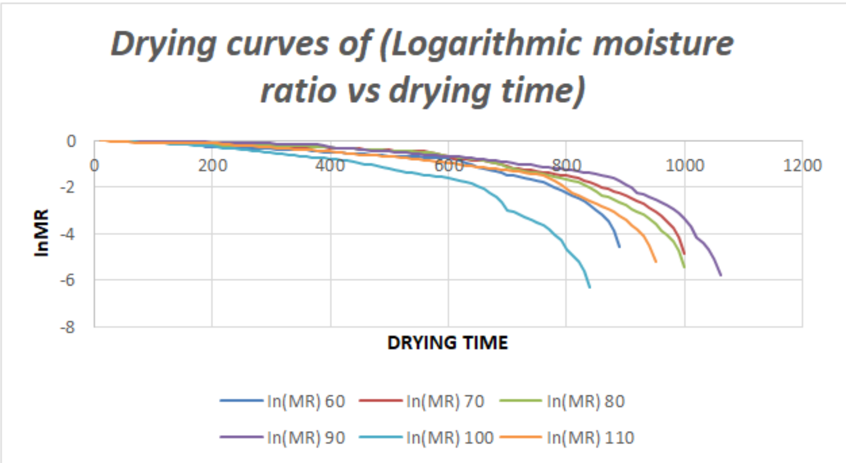

Fig 2: Drying curves of (Logarithmic moisture ratio vs drying time)

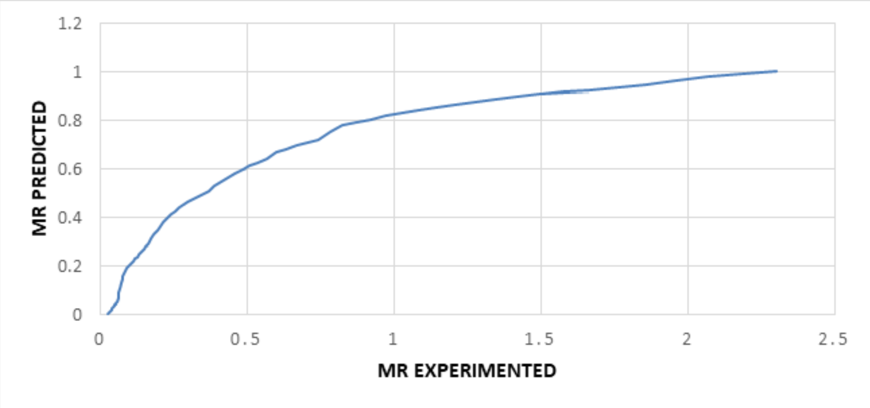

Fig 3: Relationship between Experimented Moisture ratio and Henderson's Model Moisture Ratio Prediction at 100°C

Table 1: Statistical Parameters of Salt Water Crab *(Cadisoma Guanhumi)* on three selected Thin-layer Drying Models

MODEL NAME	TEMPERATURE (◦C)	R2	X2	RMSE	K	a	N
LEWIS	60	0.743547	0.002881	0.053381	0.031800		
	70	0.941214	0.000588	0.24125	0.003000		
	80	0.923490	0.000765	0.027523	0.003500		
	90	0.919173	0.000763	0.274840	0.003300		
	100	0.949162	0.000061	0.007734	0.005400		
	110	0.777529	0.00227	0.014991	0.035800		
HENDERSON	60	0.765410	0.002636	0.051054	0.031800	1.743509	
	70	0.999452	0.000005	0.002329	0.003000	1.063984	
	80	0.997805	0.000022	0.004662	0.003500	2.188027	
	90	0.998356	0.000016	0.003920	0.003300	2.191311	
	100	0.993914	0.000007	0.002676	0.005400	2.429778	
	110	0.791713	0.002125	0.014505	0.034400	2.018188	
PAGE	60	0.812852	0.002103	0.045601	0.031800		0.000019
	70	0.902831	0.000972	0.031017	1.425700		0.000099
	80	0.858765	0.001412	0.037395	1.754000		0.000012
	90	0.869739	0.001229	0.034891	1.629100		0.000023
	100	0.957394	0.000051	0.007080	1.462600		0.00016
	110	0.938203	0.000631	0.007901	1.3536		0.000172

4.0 CONCLUSION AND RECOMMENDATION

This study so far has investigated the kinetic behavior of heat and its effect on our selected specimen which is the Rathbun salt water crab (*Cadisoma Guanhumi*). The drying process was observed to have followed the falling rate period model, in line with other related literature. Data from the experiment were fitted into three thin layer models (Lewis, Henderson-Pabis, and Page) to determine the best model that will predict the drying kinetics of the sample. The Henderson-Pabis model followed closely by the Page model were observed to present good estimators of the drying behavior of the of the salt water crab over drying temperatures so applied. The work can be useful in the design and development of drying equipment for the preservation of salt water crab. The work however limited the selection of thin-layer drying models to only three. An attempt could be made to extend the selection base beyond the limit applied in this work to obtain a higher degree of exactness of the drying data for an improved drying system design

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