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Drying Kinetics of Oven Dried *Pellonula leonensis* Fish from Congo River

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Abstract: The populations of the riparian areas of the Congo River, have fishing as their main activity. The majority of fish caught and regularly consumed consists of a small fish called *Pellonula leonensis* or “Nsangui”. This species is of significant economic interest and is marketed in dried form. However, there does not appear to be any scientific information available on the drying of *Pellonula leonensis* fish in Congo. Thus, the objective of this work was to study the drying characteristics in a laboratory oven of *Pellonula leonensis* fish and to fit the drying data into five mathematical models to determine which one is better validated by experimental data. *Pellonula leonensis* fish were dried at two different air temperatures (50 and 70°C) in a natural convection oven. Fish moisture loss was systematically recorded, converted to moisture content, and fitted to five semi-theoretical mathematical drying models: the Lewis, Page, Henderson and Pabis, Avhad and Marchetti, and Diffusion Approach models. Chi-square (χ^2), coefficient of determination (R^2), root mean square error (RMSE), and mean bias error (MBE) are statistical parameters used to determine the quality of the model fit. It was found that the drying temperature of 70°C is the best temperature because it dries the *Pellonula leonensis* fish at 14 hours of drying time which is faster compared to the drying temperature of 50°C. This result shows that the *increase* in air temperature leads to a reduction in the drying time of the fish, so the moisture content decreases sharply with the increase in drying temperature. The drying rate decreased continuously with time. The drying process exhibited a period of decreasing drying speed and a period of constant speed. Among the models tested, the models of Avhad and Marchetti and that of Page showed the best fit to the experimental data with coefficient of determination values equal to 0.99911 and 0.99910, respectively when analyzing the 70°C temperature. The drying rate constants, coefficients and statistical parameters were determined by nonlinear regression analysis, and as a result, it could be observed that there was a good correlation between the experimental and predicted data of Avhad and Marchetti and Page models.

Keywords: Drying Kinetics, Mathematical Modeling, Rate Constant, *Pellonula Leonnensis*, Statistical Measurements, Drying Temperature, Water Content

1. Introduction

Fish is the main source of food for people in the riparian areas of sub-Saharan Africa. This is the case of the Congo where the populations of the areas bordering the Congo River, the Loueme, Sounda and Lake Nianga,… have fishing as their main activity, hence the high consumption of fish in these areas. In Congo (Brazzaville), man is therefore a large consumer of fish in general. It is especially fond of that of rivers in all its forms (fresh, smoked, dried, etc.).

The majority of the fish transported from the Congo River, Lake Nianga, the Sounda and Louémé rivers and regularly consumed by the urban communities of the cities of Pointe-Noire and Brazzaville and the rural communities consists of the fish called *Pellonula leonensis* or "Nsangui".

Pellonula leonensis is the most widespread freshwater clupeid in West and West Africa according to Gourene &

Teugels [1]. The species is found in lagoons, lakes [2] as well as in the lower and upper rivers of Senegal up to the Cross. *Pellonula leonensis* is also present in lower and upper rivers of coastal basins from Cameroon to DR Congo. The fish *Pellonula leonensis* consumed in Congo Brazzaville comes mainly from the Congo River and Lake Nianga. This species is of significant economic interest in the localities of Boko and Nianga where it is marketed in dried form. Drying is a unit operation that involves the simultaneous transfer of heat and moisture to reduce the moisture content of products to a safe level [3]. In other words, drying can be defined as the process of removing moisture due to heat and mass transfer between the biological product and the drying air by evaporation, and usually caused by temperature and air convection forces [4].

Simal et al [5] defined drying kinetics as the description of variations in the moisture content of the material during drying. These kinetics can be expressed in the form of a drying curve or a drying rate curve [6]. Many of the researches have reported on the drying characteristics of different food products [6]. We can mention as an example the work of Aremu et al [7] who studied the effect of thickness and temperature on the drying kinetics of Mangoes; the work of Premi et al [8] which focused on the drying kinetics of drumstick leaves during convection drying; Gampoula's work on modeling the drying kinetics of two extreme parts of Gamboma yam pulp, the yellow part (head) and the white part (tail), with the aim of evaluating the behavior of these two parts during drying [9]. In addition, Simal et al [5] proposed a mathematical model for simulating drying curves after evaluating the effects of drying air temperature on the functional properties of dehydrated Aloe Vera.

Drying is one of the most energy-consuming processes in the food industry, however, it is an effective method to reduce post-harvest losses [10]. In order to model the drying curves, several authors have developed numerous kinetic models. Mathematical modeling of the drying process helps predict the moisture removal behavior of materials, reduces drying time and costs, and helps in the invention of suitable drying equipment [11].

Using experimental data, model variables can be determined to better represent drying curves [10]. When performing an efficient drying process, information on the moisture removal mechanism during the drying process and modeling expressions would be useful for the design and optimization of dryers [12].

Efficient optimization of the drying operation can also be brought about by understanding the drying process and the characteristics of the raw materials [10].

The drying process can be described using theoretical and empirical models available in the literature. Different drying models are analyzed and the model best suited to the drying kinetics of the product under consideration is selected. The appropriate model is important not only for the type of equipment, but for the level of experimental data available and the type of results required [10]. However, there does not appear to be any information available on the drying kinetics of *Pellonula leonensis* fish. Therefore, this work aims to study the characteristics of drying in an oven through the effect of temperature and drying time on the fish *Pellonula leonensis* and to fit the drying data into five mathematical models to determine the one that is better validated by experimental data.

2. Materials and Methods

2.1. Material

Pellonula leonensis is known under the vernacular names of Nsangui in southern Congo in the departments of Brazzaville and Pool. *Pellonula leonensis* is a freshwater clupeid with a maximum size of 102.8 mm present in the Congo River (Figure 1).

Figure 1. *Pellonula leonensis fish from the Congo River.*

Pellonula leonensis fish were caught in the Congo River south of Congo–Brazzaville in the localities of Kombé (Brazzaville) (4°13′44″ South and 15°7′52″ East).

The fishing took place in August 2021. After receipt, the fish were cleaned, washed in water, weighed and stored in the freezer.

2.2. Drying Experiments

In this work, the drying kinetics of *Pellonula leonensis* fish were studied as a function of drying time with two variable temperatures (50 and 70°C). A laboratory oven with natural convection of Memmert brand and type UN30 was used for the study of this drying kinetics.

Whole *Pellonula leonensis* fish were used for each drying experiment. Fish mass readings were obtained every 30 minutes for several hours until the moisture content was nearly constant. Weighing was done using a CONSTANT analytical balance with a resolution of d=0.01g.

The parameters of the drying kinetics used to draw the drying curves are represented either by the moisture content X as a function of time t or by the drying rate as a function of time t or moisture content X.

The experimental curves are obtained by the evolution of the wet mass m of the product during drying by successive weighing until reaching the stability of the product.

Using the measured product mass, the moisture content in relation to the dry matter is calculated by the following equation (1):

$$X = \frac{m - DM}{DM} \quad (1)$$

With X: moisture content; m: mass of the product in grams; DM: mass of dry matter.

The instantaneous drying rate as a function of time t is determined by the following equation (2):

$$-\frac{dX}{dt} = \frac{-[X(t+\Delta t)-X(t)]}{\Delta t} \quad (2)$$

With dx/dt: drying rate; X: moisture content; t: time, Δt: time variation.

2.3. Mathematical Modelling of Drying Curves

Mathematical modelling is used to predict the drying process of *Pellonula leonensis* fish and to determine the optimal drying parameters and process performance. In this study five mathematical models were used to determine the drying curves and predict the drying kinetics of the fish studied. The mass loss data of the studied fish samples at different time intervals were converted into moisture loss data. From the initial moisture content (M_0) of the fish, the moisture content data at different time intervals (M_t), and the equilibrium moisture content (M_e) for both temperatures (50 and 70°C), the dimensionless moisture content (Moisture Ratio, MR) was calculated. Then the MR as a function of time was used to fit the mathematical models. The expression used to calculate the MR of the fish samples was written using the following equation (3):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (3)$$

Where M_0: the initial moisture content, M_t: the moisture content at time t, Me: the equilibrium moisture content.

The equilibrium moisture content (M_e) of the samples studied at each temperature was obtained experimentally by drying the fish samples in an oven until no change in mass occurred for three successive mass measurements [13].

In this study, the experimental drying curves of *Pellonula leonensis* fish were modeled using the thin-film models of Lewis (Equation 4), Page (Equation 5), Henderson-Pabis (Equation 6), Avhade and Marchetti (Equation 7) and the diffusion approach (Equation 8) [14].

$$MR = \exp(-kt) \quad (4)$$

$$MR = \exp(-kt^n) \quad (5)$$

$$MR = a.\exp(-kt) \quad (6)$$

$$MR = a.\exp(-kt^n) \quad (7)$$

$$MR = a.\exp(-kt) + (1-a)exp(-kbt) \quad (8)$$

These models are the most commonly used mathematical models to predict the drying process of different biological materials [15].

2.4. Statistical Analysis

Mathematical modeling has been used by several authors for drying analysis of various foods. For modeling drying kinetics, we used Origin Pro 8 software that allowed us to automatically determine the R^2 (coefficient to predict the best equation that describes the drying curves) and the reduced chi-square (χ^2). However, the mean bias error (MBE) and root mean square error (RMSE) are calculated by the following equations (9) [16] and (10) [17] respectively:

$$RMSE = \left[\sum_{i=1}^{n} \frac{1}{n}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]^{\frac{1}{2}} \quad (9)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(MR_{exp,i} - MR_{pre,i}\right) \quad (10)$$

Where n is the total number of observations, $MR_{exp,\ i}$ and $MR_{pre,\ i}$ are the experimental and predicted moisture ratio at any observation i.

Chi-square (χ^2), coefficient of determination (R^2), root mean square error (RMSE), and mean bias error (MBE) are statistical parameters used to determine how well the model fits. The highest R^2 value that is closer to 1 represents the best model fit [18, 19]. However, the best-fitting model should have the smallest values of χ^2, RMSE, and MBE [20, 21]. The RMSE is a measure of short-term efficiency and its value is always positive, whereas the MBE is a measure of the long-term efficiency of the correlations by comparing the actual difference between the predicted and experimental values on a term-by-term basis [22]. The ideal value for RMSE and MBE is "zero" [22].

3. Results and Discussion

3.1. Drying Characteristics

Drying curves were obtained by measuring (plotting) the moisture content of the material against drying time. These drying curves were used to determine the effect of temperature on the drying process of *Pellonula leonensis* fish using the experimental drying data obtained by varying the temperature (50 and 70°C) during the drying time. Figure 2 presents the result of the drying process and clearly shows that the drying kinetics of *Pellonula leonensis* fish depends mainly on the drying temperature.

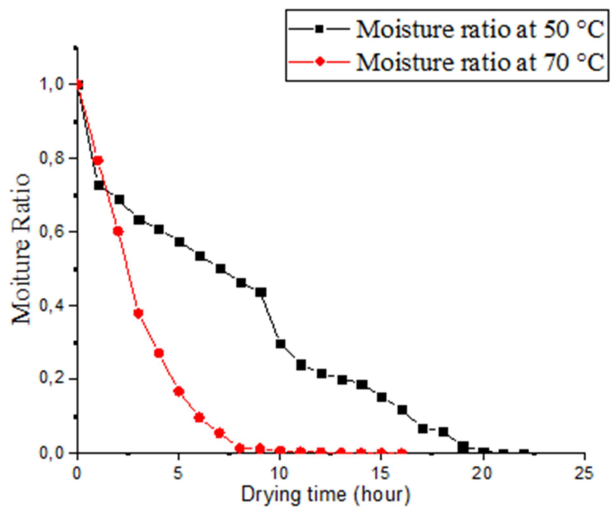

Figure 2. *Drying Curves of Pellonula Leonensis fish at Temperatures of 50°C and 70°C.*

Variations in the experimental moisture ratio as a function of drying time of *Pellonula leonensis* fish at two different drying temperatures (50°C to 70°C) showed that the drying time required to reduce the moisture from initial to final moisture was 14 and 20 hours at drying temperatures of 50 and 70°C, respectively. A moisture content value of approximately zero indicates the end of the drying process. This means that there is no change in the moisture content. The moisture content shows an exponential decrease over time at a temperature of 70°C. This behaviour of the moisture content observed for the drying of *Pellonula leonensis* fish is very similar to that of other biological materials [4].

The drying temperature of 70°C reflects the best temperature because it dries *Pellonula leonensis* fish at 14 hours of drying time which is faster compared to the drying temperature of 50°C. This result shows that increasing the air temperature leads to a reduction in the drying time of the fish, so that the moisture ratio decreases sharply with increasing the drying temperature [27].

Figure 3 Shows the Variation of the Drying rate as a Function of the Drying Time.

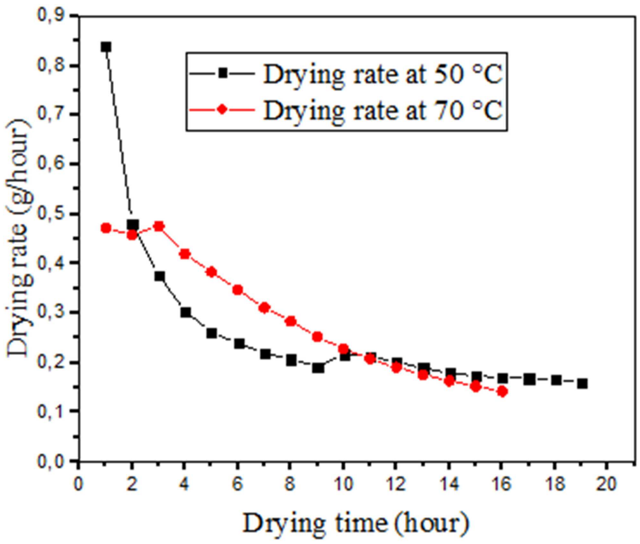

Figure 3. *Drying Rate Versus Drying time of Pellonula Leonensis Fish.*

The drying rate continuously decreases with time. The observation in Figure 3 reveals a period of decreasing drying rate and a period of constant rate in the drying process of *Pellonula leonensis* fish at considered drying temperatures. The process started with the initial moisture content and gradually decreases over time until it reaches a point of constant drying rate corresponding to the attainment of the equilibrium moisture content. These phenomena satisfy Fick's law of diffusion where the concentrated particle in a stationary medium diffuses in the direction proportional to the concentration gradient [10]. Ismail et al [10] made the same finding in the process of oven drying of *Hibiscus sabdariffa* seeds. This shows that diffusion is the dominant physical mechanism governing the movement of moisture in *Pellonula leonensis* [23]. Therefore, the drying rate is controlled by the internal diffusion phenomenon according to the mass transfer control process [24].

The higher the drying temperature, the greater the difference between the saturation and partial pressure of water vapor in the drying air. At the beginning, the drying rate is fast because of the large amounts of water that is present. As the drying process proceeds, the water content decreases. In the final stages, only small amounts of water are available and therefore the process becomes slow [10]. Several authors working on drying and in particular seed drying have reported similar behavior [10, 23, 25, 26]. This shows that a higher temperature implies a greater driving force for heat transfer and accelerates the drying of the material, as the temperature provides a significant water vapor pressure deficit [10]. The increase in drying temperature contributed positively to the drying rate and negatively to the total drying time. This was caused by the increased heat transfer and mass transfer between the air and fish sample [28].

3.2. Mathematical Modeling of Drying Kinetics

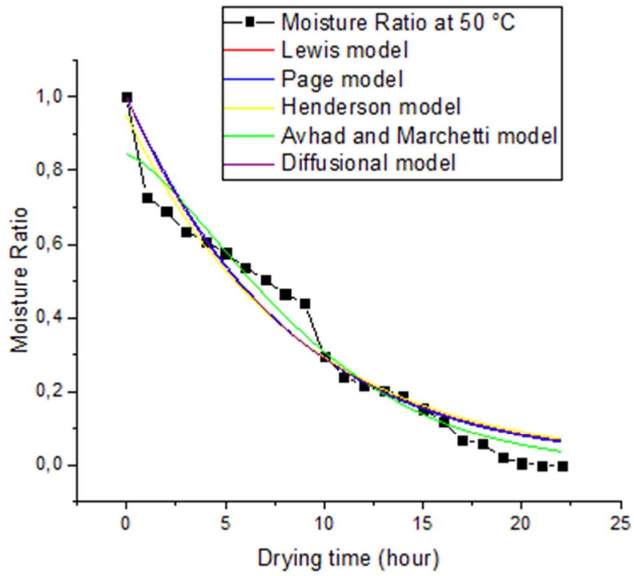

Figure 4. *Modelling of drying kinetics at 50°C for Pellonula leonensis fish.*

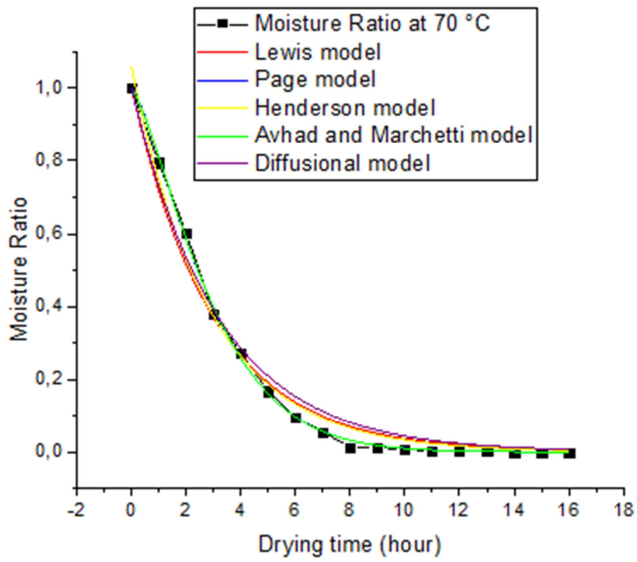

Figure 5. *Modelling of drying kinetics at 70°C for Pellonula leonensis fish.*

To predict the drying kinetics of *Pellonula leonensis* Fish, mathematical modeling of the fish moisture evaporation process is required [11]. Modeling of the drying kinetics of *Pellonula leonensis* was used to determine the optimal drying parameters and process performance. For this purpose, modeling was performed with Origin Pro 2018 software while following five models: the Lewis model, Page model, Henderson and Pabis model, Avhad and Marchetti model and Diffusion Approach model. It is essential to select the mathematical drying model that best fits the drying curves under different conditions [29]. The data predicted by the mathematical models were fitted to the drying curves of the experimental data to select a model that best describes the drying process of *Pellonula leonensis* fish. The fitted drying models can be evaluated according to different criteria to determine the quality of the models.

The results are shown in Figures 4 and 5, which show the comparison of the five mathematical drying models and the experimental data obtained for *Pellonula leonensis* fish, respectively at drying temperatures of 50°C and 70°C. From these graphical representations, we can see that all the models employed can describe the drying kinetics of *Pellonula leonensis* fish, the better the temperature is raised to 70°C. The models of Avhad and Marchetti and that of Page are the ones that best fit the experimental data. However, the selection of the best-fitting mathematical model is based on the R^2, X^2, RMSE and MBE values. However, the selection of the best fit is mainly based on the R^2 values [30] and Perea-Flores et al [11] accepted the mathematical models with R^2 values greater than 0.97 as suitable models for the experimental data in their study.

The statistical parameters calculated for the five *Pellonula leonensis* fish models at drying air temperatures of 50 and 70°C are presented in Table 1. As shown in this table, the values of R^2, X^2, RMSE, and MBE for all drying models and drying temperatures ranged from 0.94565 to 0.9991; 9.43825 × 10-5 to 454.000 × 10-5; 0.00932 to 0.83705; and 0.00121 to 0.73985, respectively. However, no mathematical model is accepted at the drying temperature of 50°C because all R^2 values are less than 0.97.

Table 1. *Results Obtained from the Statistical Analysis of the Five Selected Mathematical Drying Models at Temperatures of 50°C and 70°C for Pellonula Leonensis Fish.*

Temperature	Models	Constants	R^2	χ^2	RMSE	MBE
50°C	Lewis	k: 0,12396	0,94565	436,000E-5	0,06595	0,01441
	Page	k: 0,11658 n: 1,02674	0,94592	454,000E-5	0,06440	0,01554
	Henderson & Pabis	a: 0,95081 k: 0,11785	0,94686	426,000E-5	0,06237	0,01016
	Avhad et Marchetti	a: 0,84209 k: 0,03665 n: 1,43922	0,96206	335,000E-5	0,05395	0,00551
	Diffusion approach	a: 1,00000 k: 0,12396 b: 1,00000	0,94565	479,000E-5	0,06456	0,01441
70°C	Lewis	k: 0,33116	0,98456	152,000E-5	0,83705	0,73985
	Page	k: 0,21171 n: 1,33955	0,99910	9,43825E-5	0,00941	0,00160
	Henderson & Pabis	a: 1,05775 k: 0,34754	0,98757	130,000E-5	0,03388	0,01092
	Avhad et Marchetti	a: 0,99527 k: 0,20828 n: 1,34829	0,99911	9,93111E-5	0,00932	0,00121
	Diffusion approach	a: 1,52136 k: 0,31339 b: 1,00000	0,98284	192,000E-5	0,04103	0,01714

From the five mathematical models, the Avhad and Marchetti and Page models were found to best fit the experimental data, with coefficient of determination values equal to 0.99911 and 0.99910, respectively when analyzing the 70°C temperature. These R^2 values for the Avhad and Marchetti and Page models at the 70°C temperature are closest to 1 compared to all other models used. The smallest values of χ^2 (9.43825×10-5 for Page's model and 9.93111×10-5 for Avhad and Marchetti's model), RMSE (0.00941 for Page's model and 0.00932 for Avhad and Marchetti's model) and MBE (0, 00160 for Page's model and 0.00121 for Avhad and Marchetti's model) indicate a satisfactory representation of the drying process of *Pellonula leonensis* fish by these models. These statistical parameter values are related to the goodness of fit of the model to the experimental data. Therefore, the models of Avhad and Marchetti and Page are selected for the study of the oven drying process of Pellonula fish at 70°C. These models are presented by equations (5) and (7). These expressions are used to estimate the moisture content of *Pellonula leonensis* fish at any time during the drying process.

The values of the constants (k, a, and n) obtained for the Avhad and Marchetti and Page models are also presented in Table 1. As we see in this table, the values of the drying rate constants k (moisture release rate constant) increase with drying temperature. The estimated values for the parameters a and n of these two models also vary with drying air temperature.

Figures 6 and 7 show the fits of the Avhad and Marchetti and Page models with the experimental data for the temperature of 70°C, respectively.

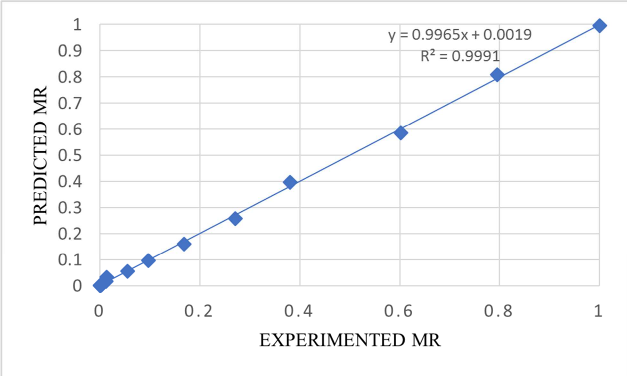

Figure 6. *Experimental Data and Estimated Moisture Content, Calculated by the Avhad and Marchetti Model.*

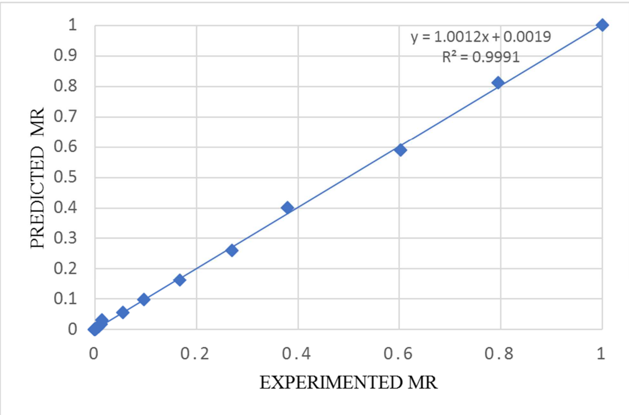

Figure 7. *Experimental Data and Estimated Moisture Content, Calculated by Page Model.*

Examination of Figures 6 and 7 shows that the experimental data appear to be closely scattered around the line representing the computational data. This indicates the suitability of both models to describe the drying behavior of *Pellonula leonensis* fish.

From these results, it can be concluded that the models of Avhad and Marchetti and Page better represent the oven drying process of *Pellonula leonensis* fish than other drying models. In addition to their simplicity, the experimental data most closely align with the predicted drying data, as shown in Figures 6 and 7. It can be observed that there is a good correlation between the experimental and predicted data. Our findings are in agreement with several works [32, 33] who showed that fishes drying were closely represented by Page mathematical model.

4. Conclusion

The little fish named "Nsangui" get great impotence for us. Previuously we are carried out the bioavailability of Docosahexaenoic (DHA) and Eicosapentaenoic (EPA) acids in its Oil [34]. In the present work, we studied its drying. The drying process of *Pellonula leonensis* fish exhibited a period of decreasing drying rate and a period of constant rate. The drying time required to remove moisture content was 20 and 10 hours at temperatures of 50 and 70°C respectively. From this result it is concluded that increasing the drying temperature leads to a reduction in the drying time of fish. Therefore, 70°C is a suitable drying temperature for drying *Pellonula leonensis* fish because, a low drying temperature of 30-50°C may protect the sensitive active ingredient, but it may promote the growth of fungi due to longer drying time [31, 10]. Meanwhile, a higher drying temperature may reduce the quality of the product due to the degradation process [10].

To study the drying kinetics, the Lewis, Page, Henderson and Pabis, Avhad and Marchetti and Diffusion Approach models were used and compared using the four statistical parameters namely coefficient of determination, chi-square test, mean square error and mean bias error. The Avhad and Marchetti model and the Page model gave a better and more comparable fit to the experimental data than the other models.

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