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The dehydration kinetics of curry leaves (*Murraya koenigii rataceae*)

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ABSTRACT

The dehydration kinetics of curry leaves were investigated. Convective oven dry method was employed at four different temperature such as 70, 80, 90 and 100°C the resulting experimental values were input into three thin layer model such as Henderson-Pabis, Page and Lewis Model. Henderson-Pabis model ranges from 0.9992-0.999, 1.657x10^{-5} – 7.1 x10^{-5} and 0.000832437-0.003683804 for R^2, X^2 and RMSE respectively. Investigation indicates that drying process falls under the falling rate period like other biological materials. Amongst the three different model evaluated Henderson-Pabis model gives perfect description for predicting the curry leaves closely related to the Lewis model after subjected to mathematical analysis of the drying sample and within the temperature studied in this research, the dependent effective moisture diffusivity ranges from 6.99x10^{-8} - 3.93 x10^{-7}m/s. The related activation energy value obtained was 42.49-kJ/mol.

1. INTRODUCTION

Curry leaf is a very vital vegetable which is believed to have originated from India, widely known for flavoring food. Its presently cultivated in many parts of the world including Nigeria, China, Australia, Burma Africa etc. Curry is cultivated from seeds. Curry leaves oil has some level of volatility and has its very useful in the soap production industry. It has Slightly pungent, bitter and acidic taste and has quality of retaining its flavor and other properties even after drying (Khatoon et al., 2011) Based on reports, curry leaf possesses various vital medicinal functionalities such as anti-aging, anti-diabetic, anti-oxidant, anticarcinogenic, anti- inflammatory (Ghasemizadeh et al., 2014). Hence the extension of the self-life of this vital vegetable is of paramount importance with the predominance of diabetes mellitus.

Drying is one predominant method of food processing that is accessible to almost all category of people in the society. Drying lowers the moisture content of food and other essential products with the intention of reducing the amount of microbial and enzymatic activity that is sparked by a high moisture presence, hence increasing the self-life of the aforementioned product. Drying: Minimizes packaging and haulage costs, ensures availability of product beyond harvest season, improves appearance of products, retains flavor and nutritional value (Saeed et al., 2008; Bijaya, 2018). Curry leaves can be harvested on demand by plucking the leaves or branches can as well be cut off in interval two months especially in the growing season (Deng et al., 2018). The nutritional composition of curry leaf is as follows: Carbohydrates (18.7gm), energy (108Kcal), Fiber (6.4gm), protein (6.1gm), fat (1gm), Calcium (830mg) and minerals (4gm) reported by (Priti et al., 2017).

The most accessible and low-cost method of drying is sun drying which fall under open air-drying method characterized by contamination with dust and microbes. Improved mechanical methods such as convective oven drying and other options are used where the weather is not favorable and where there is buoyancy of finance. Food and vegetable drying have been the subject of numerous studies for example, Mahmoud *et al.,* (2018) researched the kinetics and mathematical modeling of infrared thin layer drying of garlic slices and Egbe et al., (2020) investigated the thin layer drying kinetics of African giant snail. This study investigated the drying attributes of curry leaves on thin layers and the experimental output was fitted into three selected thin layer drying models to characterize the drying kinetics of curry leaves, consequently will avail us information on the development of improved equipment for its processing.

Theory of Study

Drying is simultaneous hat and mass transfer process, vital for the preservation of food materials and other medicinal products. It does this by reducing the moisture content to a safe level, so as to minimize harmful microbiological and enzymatic activities, triggered by high moisture presence, with the goal of extending the self-life of the biomaterial drying also has the pluses of: reduction of haulage and packaging costs, improvement of storability and appearance; retention of flavor and nutritional value of respective product (Saeed et al., 2008). Thin layer as a concept represents a configuration of products adequately thin in thickness, so that infinitesimal difference in characteristics observed throughout the layer of product. Drying carried out with such infinitesimal thickness of products connotes what is refers to as thin layer drying. Numerous empirical models are already widely available in the literature for the prediction of moisture migration during the drying of various types of biomaterials. Equation (1) was used to calculate the dimensionless moisture ratio (MR) of the product being dried (Sahay and Singh, 2005):

$$MR = \frac{M - Me}{M0 - Me} \quad (1)$$

$$MR = \frac{M}{Mo} \quad (2)$$

The rate of dehydration was estimated by equation (3) (Juo et al., 2016).

$$D_R = \frac{Change\ in\ mass}{Change\ in\ Time} \quad (3)$$

2. MATERIALS AND METHODS

Sample Collection

Curry leaf samples were purchased in the Swali ultramodern market in the Nigerian Bayelsa State local government of Yenagoa. The samples were delivered to the food processing laboratory at the Niger Delta University in Bayelsa State. In accordance with ASAE Standards (S368.4 of 2000 as reviewed), they were cleaned and washed to eliminate extraneous objects like stones and dust before being weighed with a laboratory-style top digital scale with a precision of 0.01g to get a uniform weight of 4 grams across five repetitions. The samples were then dried in a WTC binder oven to a consistent weight (model WTCB). The weight loss of the specimen was tracked and recorded every five minutes throughout the drying process.

Procedure of experiment

The samples after preliminary preparations were admitted into WTC Binder Electric oven (model WTCB) at five different temperatures such as 60˚C, 70˚C, 80˚C, 90˚C and 100˚C. The weight loss caused by dehydration was tracked and recorded during the drying experiment at intervals of 5 minutes until equilibrium moisture content was reached, which was indicated by a constant weight (Zibokere and Egbe, 2020; Sankat and Mujaffar, 1986). For each temperature, the process was repeated three times and the average was determined. To determine the ultimate moisture content for each period, the weight difference between before and after drying was employed (Mohsenin, 1986); (Kongdej Limpaiboon 2011).

$$M = \frac{Wi-Wf}{Wf} \quad (4)$$

Where

Wi = initial weight of sample in grams;

Wf = final weight of sample in grams.

Evaluation of Effective Moisture Diffusivity

There is evidence in the literature that most biomaterials dry out throughout the period of falling rate (Brennam et al., I969; Earle, 2006; Toledo, 2000). Fick's second law of diffusion is observed when moisture diffuses through a sequence of thin layer surfaces (Bird et al., 2005). According to Crank (1975), the ficks second law of diffusion is modified for slab-shaped particles that are dried for a long time.

$$MR = \frac{8}{\pi^2} \exp\left(-\pi^2 D_{eff} t/4L^2\right) \quad (5)$$

Where: t = time in minutes and L = is half the slab thickness in meters when drying takes place from both sides of the slab. A further simplification of equation (5) give rise to equation (6):

$$MR = 0.8099 \exp \frac{-2.4694}{L^2} \quad (6)$$

Taken as the natural logarithm of both sides, equation (6) can be linearized as follows:

$$\text{Ln (MR)} = \text{Ln } 0.8099 - \frac{2.4694t}{L^2} \quad (7)$$

By drawing a graph of ln (MR) against (t), ln (0.8099) coincides with the intercept on ln (MR) axis and effective moisture diffusivity resulted from the gradient of the graph

$$\text{Gradient of plot} = \frac{-2.4694Deff}{L^2} \quad (8)$$

$$Deff = \frac{Gradient\ of\ plot * L^2}{-2.4694} \quad (9)$$

Deff is useful in describing the effective diffusivity of the biomaterials.

Derivation of Activation Energy

Activation energy (E_a) is the threshold energy that must be reached to initiate water molecular transport through a sample. By the recommendations of (Akgun and Doymaz, 2005; Robert et al., 2018; Burubai, 2015; Sanjuan et al., 2003). Following is an example of how effective diffusivity and temperature can be linked using an Arrhenius-type relationship:

$$Deff = Do \exp\left(-\frac{E_a}{R*T}\right) \quad (10)$$

By taking natural logarithm of both sides of equation (10) we have equation (11):

$$\ln Deff = lnDo - \left(\frac{E_a}{R*T}\right) \quad (11)$$

By Plotting on a graph $\ln D_{eff}$ against T^{-1}, the intercept of this graph equal $\ln D_o$ and the activation energy can be evaluated from the slope or gradient of graph ($-E_a/R$) as follows:

$$\text{Gradient of plot} = -E_a/R \quad (12)$$

$$E_a = \text{Gradient of plot} * R \quad (13)$$

Determination of Goodness of Fit of Thin Layer Models

(R^2), (X^2) and RMSE can all be used to assess how well a thin layer model can predict how an agricultural product would dry. A model suitability was assessed for each one and if it had the highest R^2 value and the lowest values of X^2 and RMSE, it is deemed to be appropriate (Midilli and kucuk, 2003; Egbe and Jonathan, 2022). Equations 14 to 16 were utilized to calculate the statistical indices indicated above.

$$R^2 = 1 - \left[\sum_{i=1}^{n} (MRpre\ i - MRexp\ i)^2\right] \quad (14)$$

$$X^2 = \frac{\sum_{i=1}^{n} (MRpre\ i - MRexp\ i)^2}{n-k} \quad (15)$$

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n} (MRpre\ i - MRexp\ i)^2}}{n} \quad (16)$$

Where n is number of observations, k is number of constants associated with a given model, $MR_{pre\ I}$ is predicted moisture ratio and $MR_{exp\ I}$ moisture ratio from experiment.

Mathematical thin layers applied

Mathematical model often used in literatures to predict the drying characteristics biomaterials. For the current study Lewis, Handerson and page models were used to predict the drying behavior of curry leaves under the above specified temperatures.

Table 1 List of Thin-layer Drying Models with Reference

Model Name	Mathematical Expression	References
Lewis model	$MR_{pred} = \exp(-kt)$	
Handerson model	$MR_{pred} = a\exp(-kt)$	
Page Model	$MR_{pred} = \exp(-kt^n)$	Vegas-Galvez, (201)

3. RESULTS AND DISCUSSIONS

Drying Kinetics

Drying data obtained on the samples are presented as drying curves in Figures 1 and 2. It is obvious from Figure 1 that moisture ratio of the samples reduced (increased drying) as drying time increased. The transport of moisture from the core to the surface for evaporation was rather sluggish. This suggested that the drying process did not take place during the constant rate period and that the entire procedure took place during the falling rate interval. The case-hardening characteristic of drying did not develop even at high temperatures, according to the sluggish pattern of the drying curves. These effects agree with similar reports made by Burubai and Bratua (2015) on mud sail; Zhiqiang et al., (2013) on tilapia; Sankat and Mujalfar, (2008) on catfish and, on clam (Burubai, 2015).

The logarithmic moisture ratio (n (MR)) is plotted as a function of drying time in Figure 2. The plot demonstrates that unrestricted water diffusion and evaporation initially boosted the drying process; but, as drying time progressed, even with rising temperatures, the rate of drying slowed down. The diffusion mechanism that would unbind water from the protein-based solid matrix of the samples would need a substantially higher quantum of energy at these later stages of drying time. Difficulty in drying resulted. The sharp drop of the exponential drying curves in the plot (Figure 2) is an indication also, is that drying occurred mainly within the falling rate period. This agrees with reports on the thin layer drying of yoghurt (Hayaloglu et al, 2007), potatoes (Akpinar et al, 2003), bananas, (Ganesapillai et al, 2011), plantain (Satimehin and Alabi, 2005), pumpkin seeds (Jattanit, 2011), fresh fish (Kilic, 2009), tomatoes (Kross et al, 2004) and bitter kola (Ehiem and Simonyan, 2011).

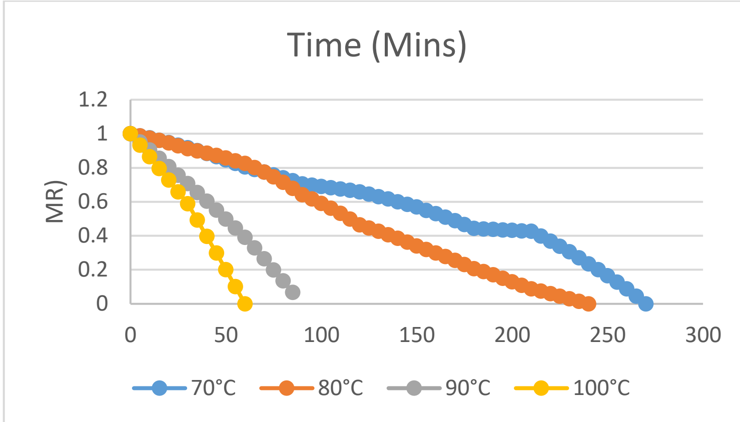

Figure 1 Drying curve at different temperature for Curry leaf (*Murraya Koenigii Rataceae*)

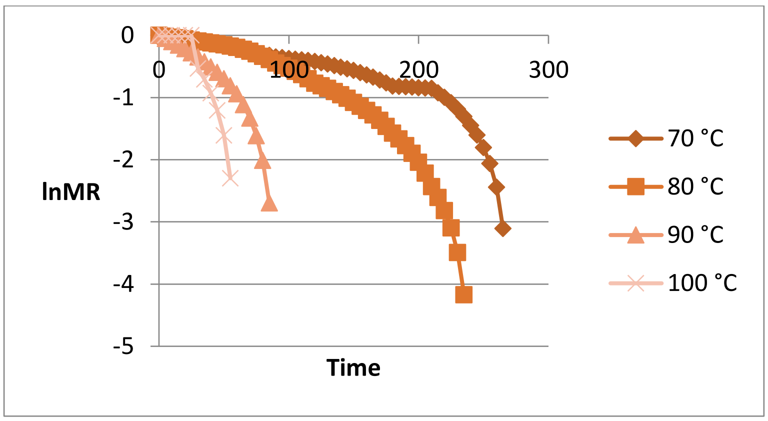

Figure 2 Drying curves of Curry leaf (*Murraya Koenigii Rataceae* (Logarithmic moisture ratio vs drying time)

Fitting Experimental Data into Drying Models

The experimental drying data were fitted into three thin layer drying models of Lewis, Henderson-Parbis and Page. This is to enable selection of model that would best describe the kinetics of curry leaves. The data were first fitted into the Ficks diffusion using the approach of non-linear least square statistic of SPSS, (1996) to satisfactorily obtain constants 'a' and 'k'. Values obtained were then statistically validated using coefficient of determination (R^2) and the root mean square error (RMSE). The model with the lowest RMSE, χ^2 and highest R^2 was selected as best fit model to describe the drying characteristics of the red palm weevil. It can be seen that of the three models applied in this work, the Page and closely to it, the Henderson-Parbis models that give the lowest RMSE and χ^2, and highest R^2 values and are accordingly accepted as representing the dry characteristics of the curry leaves.

Thin Layer Model and Their Associated Statistical Indices Values

Thin layer models used for this study with other related information are given below:

Table 2 Values of statistical indexes and constants based on models

LEWIS MODEL = MR_{pred} = exp (-kt)						
Temp.°C	R^2	X^2	RMSE	K	a	n
70°C	0.6577	6.33951×10^{-3}	0.078893899	0.0069		
80°C	0.9618	7.94934×10^{-4}	0.027905395	-0.00133		
90°C	0.9826	9.67504×10^{-4}	0.030275125	-0.0255		
100°C	0 9516	4.03085×10^{-3}	0.060998225	-0 0388		
HANDERSON'S MODEL = MR_{pred} = aexp (-kt)						
70°C	0.9999	7.19×10^{-7}	0.000832437	0.0069	1.297319	
80°C	0.9992	1.68652×10^{-5}	0.004022038	-0.00133	1.732733	

90°C	0.9997	$1.51669 x 10^{-5}$	0.003683804	-0.0255	1.369437	
100°C	0.9998	$2.00096 x 10^{-5}$	0.00411755	-0 0388	1.585183	
PAGE MODEL = MR_{pred} = exp $(-kt^n)$						
70°C	09155	$1.72734 x 10^{-2}$	0.129016509	1.2612		0.001201
80°C	0.8236	$3.75328 x 10^{-3}$	0.060000665	2.7829		0.000865
90°C	0.9452	$3.22415 x 10^{-3}$	0.053710023	1.348		0.004141
100°C	0.7914	$1.89605 x 10^{-2}$	0.126663067	2.356		0.000165

Effective Diffusivity (D_e)

Equations 8 and 9 were used to obtain the effective diffusivity, D_e on three replicates each of the temperatures applied in this work. Average values are presented in Table 3. The values show that moisture diffusivity increased as temperatures increased. This is reasonable as diffusion mechanism upon which drying occurs is seen to proceed as a function of applied energy level. This confirms the position of Burubai and Bratua, (2015) and Sacilik, (2007) working on mud sail and pumpkin seeds respectively.

Table 3 Moisture diffusivity values of Curry leaf

Temperature °C	Average effective moisture diffusivity
70	$6.99 x 10^{-8}$
80	$1.35 x 10^{-7}$
90	$2.58\ x 10^{-7}$
100	$3.93\ x 10^{-7}$

Activation Energy E_a

This is a measure of heat sensitivity of the curry leaves when undergoing drying. It is a temperature dependent moisture transport parameter that is obtainable by linearizing the Arrhenius type equation (equation 12 through 13) for the different temperature levels chosen in this work. The higher the E_a the longer the drying time to achieve a particular desired level moisture content (dry basis). In this work, the average value of E_a was 42.49-kJ/mol. This result falls within the literature range of 12.7-110-kJ/mol for high moisture biomaterials (Zogzas et al., 1996); and 0-53-kJ/mol for low moisture, diffusion-controlled biomaterials (Toakis and Labuza, 1989).

4. CONCLUSION

Curry leaf drying kinetics were examined and it became clear that drying occurs during the falling rate period just like other biological materials. After underwent statistical analysis of the drying parameters the effective moisture diffusivity ranges from 6.99 x 10-8- 3.93 x 10-7m/s over the temperatures used in the work, Henderson model was the best for predicting the drying kinetics of curry leaves amongst the three thin layer models that were investigated, the Lewis model was a close second. The associated activation energy measurement yielded a value of 42.49 kJ/mol.

Ethical issues

Curry leaf samples were obtained from Swali ultramodern market in the Nigerian Bayelsa State local government of Yenagoa. The ethical guidelines for plants & plant materials are followed in the study for experimentation.

Informed consent: Not applicable.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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