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STUDY OF DRYING CHARACTERISTICS OF BAOBAB (*Adansonia digitata L.*) LEAVES

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ABSTRACT

Drying characteristics of agricultural products such as the drying rate, effective diffusivity, diffusion coefficient, activation energy and the prediction of moisture ratio are the tools employed in the design, simulation, and optimization of drying processes. In this study, drying characteristics of baobab leave were experimentally investigated under the temperature levels of 40, 50, 60 and 70°C. The experiments were carried out so as to know the variation in moisture content of baobab leaves as a function of drying time at different temperature levels. Drying parameters that include effective diffusivity, diffusion coefficient and activation energy of baobab leaves were determined. Experimental data were fitted to existing moisture ratio models. Results show that it took 340 min to dry baobab samples at a drying temperature of 40 °C, 160 min at 50 °C, 100 min at 60 °C and 80 min for 70 °C. Effective diffusivity of baobab leaves ranged 4.0528×10^{-13} *to* $1.1753 \times 10^{-11}\ m^2/s$ *within drying temperature of 40-70 °C. The diffusion coefficient and activation energy of the baobab leaves were found to be* $2.290 \times 10^{-11}\ m^2/s$ *and 106.95 kJ/mol, respectively. Values of* R^2*, RMSE and Chi-Square of all the models fitted varied between 0.717-0.997, 0.0171– 0.2893 and 0.0003–0.1046 respectively. The logarithmic model has the highest* R^2 *and lowest RMSE and Chi-Square values. It can therefore, be concluded that the Logarithmic model could sufficiently define the thin layer drying of baobab leaves.*
Keywords: Baobab leaves, drying characteristics, temperature, moisture ratio, models.

1. INTRODUCTION

Baobab (*Adansonia digitata L.*) belongs to the Malvaceae family, Genus of Adansonia. L and it is native to Africa (Rahul *et al.,* 2015). The plant is very common in Nigerian where most of its trees grow on their own as wild trees. It is called *Ose* in Yoruba and *Kuka* in Hausa. Most parts of the baobab plant including fruits, pulps and leaves are found to be nutritious and medicinal (Rahul *et al.*, 2015). The fruit and spongy pulp inside it are processed into favourite Hausa drinks called *Kwalba da nono*. Its bark is used for fibers, dye or as fuel. Baobab leaves are usually consumed in fresh or dried (powder) form as an ingredient of soup or sauce. Its leaves are used in making the popular Hausa soup called *Miyar Kuka* that is, *Kuka* soup, corresponding to *Obè lúúrú* in Yoruba. *Kuka* is also a major constituent of Hausa food called *Danwake* (NAP, 2006). Baobab leaves have several benefits therapeutically to treat some illnesses. David (2014) and Rahul *et al*. (2015) stated that baobab acts as an expectorant for cough, diaphoretic and anti-pyretic, an astringent and relieves excessive perspiration. They also revealed that the leaves can treat certain forms of allergy with their anti-histamine and hyposensitive properties. Other benefits derive from baobab are treatment of asthma, fatigue, inflammations, insect bites, kidney diseases, gallbladder diseases and dracunculiasis and sores.

Baobab is a seasonal vegetable crop that produces leaves during the rainy season. Similar to other biological materials, fresh leaves of baobab have a very short shelf-life. The leaves deteriorate when kept for days without proper preservation. The traditional method is usually employed in extending its shelf-life against the scanty period by open sun drying. David (2014) stated that vitamin A content of baobab leaves often depends on the different tree types, the drying method and the processing method. Owing to the sensitivity of baobab leaves to uncontrolled temperature during processing, NAP (2006) advised against sun drying the leaves of baobab and urges consumers to give preference to leaves with darker green colour. The author observed that Pro vitamin A in leaves of plant degraded by overcooking. It is therefore important for the processors to apply proper drying temperature to preserve nutritive values of the product. Dried leaves or powder of baobab leaves with poor colours, taste, flavour and nutritional quality arising from inefficient drying are common in our markets.

Among the problem of processing the product is lack of substantial information on the drying characteristics that could be used for the design of it dryers. There are several thin-layer models described in the literature that are able to fit the drying kinetics of food materials (Esmaeil and Zohreh (2011), Singh *et al.* (2014) and Aviara and Igbeka (2016)). To obtain better quality of products for the consumers, the knowledge of the drying characteristics is very important so that the leaves can be dried and its nutritional constituent maintained. Information from the study will serve as a guide to engineer who might be interested in design of dryer for the leaves. Proper drying of baobab will add value to the products, ensure its availability in off seasons and minimize chemical, biochemical and microbiological deterioration.

The objective of this study was to establish the drying characteristic of baobab leaves by investigating the effect of drying time and drying air temperatures on the moisture content of baobab leave and selecting the best mathematical model for the dry curves of the leaves.

2. MATERIALS AND METHOD

2.1 Sample Preparation

Experiments were done in the processing laboratory of Department of Agricultural and Environmental Engineering, Bayero University Kano, Nigeria. Fresh baobab leaves were obtained from the new-site campus of the university. The leaves were collected in the month of August when fresh leaves of the plant are readily available. About 2 kg of the leaves was used in the experiment. Laboratory equipment used were: Citzon electronic weighing balance model CG4102 of resolution 0.01g, Thermo Fisher scientific laboratory oven, containers and a stop watch.

2.2 Initial Moisture Content Determination

Sample initial moisture content was determined using A. O. A. C. (1984) oven dried method. This was by setting laboratory oven at 105 °C. 5 g of the samples were weighed into containers of known masses. Initial moisture contents for five replicate samples were determined in dry basis using the relation in the equation 1. In addition, dynamic equilibrium moisture contents were calculated using similar method.

$$MC = \frac{M1 - M2}{M2 - M3} \times 100 \quad \ldots \quad (1)$$

Where,
MC = moisture content (% d.b)
$M1$ = mass of fresh sample plus container (g)
$M2$ = mass of dried sample plus container (g)
$M3$ = mass of container (g)

2.3 Determination of Moisture Ratio

The moisture ratio (MR, dimensionless) of baobab leaves was calculated using Equation 2 as given by Kalaivani and Chitra (2013):

$$MR = \frac{M - M_e}{M_0 - M_e} \quad \ldots \quad (2)$$

Where:
M= moisture content at any time of drying (kg water/kg dry matter)
M_0= Initial Moisture Content (kg water/kg dry matter)
M_e=Equilibrium moisture content (kg water/kg dry matter)

The equilibrium moisture contents of the leaves at different temperature used in the drying process were obtained using Equation 1.

About 5 g of samples were dried at 40, 50, 60, and 70 °C air temperature in the oven until the weight loss of sample remained constant. The equilibrium moisture content of the sample were determined and used to calculate the moisture ratio.

2.4 Determination of Effective Diffusivity, Diffusion Coefficient, and Drying Activation Energy

The effective diffusivity (De) of the baobab leaves was estimated by applying the model for diffusion in infinite slab, as given by Ajala *et al.* (2012), Chayjan *et al.* (2012) and Kamalakar *et al.* (2014):

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left(-\frac{(2n+1)^2\pi^2 D_e t}{4L^2}\right) \quad \ldots \quad (3)$$

Where:
D_e = Effective diffusivity (m²/s)
n = Positive integer
t = time (s)
L= Half of the slab thickness (m)

When L is small and t is large, first term of the series in equation 3 is considered.

Hence,

$$MR = \frac{8}{\pi^2}exp\left(-\frac{\pi^2 D_e t}{4L^2}\right) \quad \ldots \quad (4)$$

Taking natural logarithm of both sides yields a linear equation as:

$$Ln(MR) = Ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_e}{4L^2}\right)t \quad \ldots \quad (5)$$

$$Ln\,(MR) = A - Bt \quad \ldots \quad (6)$$

Where, A and B are constant, and

$$B = \frac{\pi^2 D_e}{4L^2} \quad \ldots \quad (7)$$

Plotting Ln(MR) against t and the constant B obtained as gradient of the graph was used to compute De from equation (7).

Diffusion coefficient and diffusion activation energy of baobab leaves were estimated using Arrhenius equation as given by Akpinar (2006) and Aviara and Igbeka (2016).

$$D_e = D_0 exp\left(\frac{-E_a}{RT}\right) \quad \ldots \quad (8)$$

Where,
D_0 = diffusion coefficient (m²/s),
Ea = drying activation energy (kJ/mol),
R = universal gas constant (0.0083144 kJ/mol K)

T = air absolute temperature (K).

When equation (9) was linearized through logarithmic transformation as:

$$Ln(D_e) = Ln(D_0) + \frac{-E_a}{RT} \quad \ldots \quad (9)$$

Through the plot of *Ln*(*De*) against the reciprocal of *T* a straight line graph was obtained. The diffusion activation energy (*Ea*) was obtained from the slope of the graph and the diffusion coefficient (D_0) from the intercept on the Y-axis.

2.5 Mathematical Models Fitting

Five different thin-layer models that are commonly used presented in Table 1 were fitted to the drying data of baobab leaves at different temperatures using the non-linear regression procedure of the SAS System for Windows 9.0.

Table 1: Thin-layer Drying models fitted to baobab leaves

Model name	Model	No of Eqn
Lewis	$MR = exp^{-kt}$	(10)
Henderson & Pabies	$MR = aexp^{-kt}$	(11)
Logarithmic	$MR = aexp^{-kt} + c$	(12)
Two term	$MR = aexp^{-k_0t} + bexp^{-k_1t}$	(13)
Wang & Singh	$MR = 1 + at + bt^2$	(14)

In the models, MR is the moisture ratio, *t* is time of drying (min), a, b and c are the drying coefficient and k is the drying constant (per minute). Models verification was done using root mean square error (RMSE) and Chi-square (χ^2) to evaluate the goodness of fit. These parameters were calculated using Equations (15) and (16) respectively. In model validation, the observed and predicted moisture ratios were compared and statistically analyzed to determine the best-fit equation using correlation coefficient (R^2) as presented in Equation (17) as given by Kalaivani and Chitra (2013).

$$RMSE = \left(\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{N}\right) \quad \ldots \quad (15)$$

$$\chi^2 = \left(\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{N - z}\right) \quad \ldots \quad (16)$$

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(\overline{MR}_{pre,i} - MR_{exp,i})^2}\right) \quad \ldots \quad (17)$$

Where,

N = Number of observations
z = Number of constants in the model
$MR_{exp,i}$ = experimental moisture ratio
$MR_{pre,i}$ = predicted moisture ratio
$\overline{MR}_{pre,i}$ = Average moisture ratio

3. RESULTS AND DISCUSSION

The variation in moisture content of baobab leaves as a function of drying time at different temperatures is presented in Figure 1. The results show that baobab leaves have initial moisture content of 81.85 % d.b and the moisture content of samples was found to deceased with the increase in drying time and drying temperature. This could be because water in the samples attained more energy to go out of the sample at higher temperature. The rate of moisture loss was higher at higher temperature than low temperature and then total drying time reduced substantially with the increase in temperature. Similar results were observed for *Syzygium Cumini* leaves (Kalaivani and Chitra, 2013). The curve can be applied in the determination of time required to dry baobab leaves to given moisture content at a prescribed temperature. It can be read from the curve that to dry baobab leaves to equilibrium moisture content, it took 300 min for samples at a drying temperature of 40 °C, 140 min at 50 °C, 80 min at 60 °C and 80 min for 70 °C.

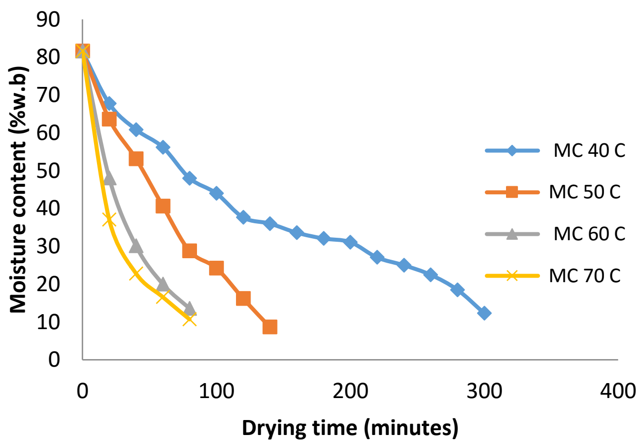

Figure 1: Effects of drying time and drying air temperatures on the moisture content of baobab leave.

3.1 Effective diffusivity, diffusion coefficient, and activation energy

Values of effective diffusivity of baobab leaves at different drying temperature is presented in Table 2.

Table 2: Variation of effective diffusivity of baobab leaves at different drying temperature

Drying temperature (°C)	Effective diffusivity (m^2/s)	R squared
40	4.0528E-13	0.9696
50	1.2159E-12	0.9685
60	7.7004E-12	0.7000
70	1.1753E-11	0.7092

From the table, it is evident that the effective diffusivity of baobab leaves ranged 4.0528×10^{-13} to $1.1753 \times 10^{-11}\ m^2/s$ within drying temperature of 40-70 °C. The values of effective diffusivity were found to increase with the drying temperature and this agrees with the findings of Chayjan *et al.*, (2012) and Aviara and Igbeka (2016). The diffusion coefficient *Do* and activation energy *Ea* of the baobab leaves were found to be $2.290 \times 10^{-11}\ m^2/s$ and 106.95 kJ/mol, respectively. These are important parameters as, moisture diffusion coefficient is needed to actuate the flow during moisture removal through drying, while the activation energy is the amount of energy needed to initiate moisture removal from a solid matrix during drying (Tanko *et al.*, 2005 and Aviara and Igbeka, 2016). The following expression therefore presents the developed relationship between the effective diffusivity and drying temperature of baobab leaves:

$$De = 2.290 \times 10^{-11} exp\left(\frac{-106.95}{8.3144 \times 10^{-3} T}\right) \quad \ldots \quad (18)$$

$\boldsymbol{R^2 = 0.959}$

3.2 Model fittings

Moisture ratios were computed from the moisture content data at the four levels of drying temperature and the variation of moisture ratio with drying time was fitted to the five selected thin-layer drying models listed in Table 2. The results of statistical analyses carried out on these models were presented in Tables 3. The best model was selected based on three decisive factors, R^2, RMSE and Chi-Square. The Table shows that values of R^2, RMSE and Chi-Square of all the models fitted varied between 0.717-0.997, 0.0171– 0.2893 and 0.0003–0.1046 respectively. Table 3 showed that the highest R^2 and lowest RMSE and Chi-Square values were obtained in the logarithmic model especially at the temperatures of 50 °C and 70 °C. It can therefore be concluded that the Logarithmic model could sufficiently define the thin layer drying of baobab leaves.

Table 3: Models constants and statistical values at various temperatures

Model	Drying Temp.(°C)	Model Constants	R^2	RMSE	Chi-Square γ
Lewis	40	*k=0.00761*	0.987	0.0293	0.0009
	50	*k=0.0149*	0.985	0.0368	0.0016
	60	*k=0.0365*	0.993	0.0282	0.0010
	70	*k=0.0469*	0.997	0.0189	0.0004
Henderson and Pabies	40	*k=0.00725, a=0.9694*	0.990	0.0258	0.0008
	50	*k=0.0153, a=1.0231*	0.986	0.0353	0.0017
	60	*k=0.0358, a=1.0094*	0.993	0.0288	0.0014
	70	*k=0.0530, a=1.0031*	0.992	0.0320	0.0017
Logarithmic	40	*k=0.00798, a=0.9308, c=0.0386*	0.991	0.0244	0.0007
	50	*k=0.00906, a=1.3408, c=-0.3456*	0.997	0.0171	0.0005
	60	*k=0.0292, a=1.1005, c=0.01019*	0.911	0.1120	0.0314
	70	*k=0.0471, a=0.9941, c=0.00237*	0.997	0.0188	0.0009
Two term	40	*k=0.00693, a=0.9227, b=0.0773, g=2.8719*	0.993	0.0206	0.0005
	50	*k=0.0164, a=1.0919, b=-0.0919, g=4.9541*	0.989	0.0308	0.0022
	60	*k=0.48619, a=0.39700, b=0.29768, g=0.90472*	0.717	0.2893	0.4185
	70	*k=0.1076, a=1.00363, b=0.11036, g=0.3171*	0.837	0.1481	0.1097
Wang and Singh	40	*a=-0.00647, b=0.000012*	0.967	0.0463	0.0025
	50	*a=-0.0116, b=0.000035*	0.996	0.0179	0.0005
	60	*a=-0.0259, b=0.000170*	0.995	0.0263	0.0012
	70	*a=-0.0306, b=0.000233*	0.968	0.0643	0.0069

4. CONCLUSION

The drying characteristics of baobab leaves were carried out in the laboratory at the drying air temperatures of 40, 50, 60 and 70 °C. The moisture content of the drying leaves was influenced by the drying air temperature. The drying time decreased with increases in drying air temperature. Effective diffusivity of baobab leaves increased with the drying temperature and its values ranged 4.0528×10^{-13} to $1.1753 \times 10^{-11}\ m^2/s$

within drying temperature of 40-70 ºC. Logarithmic model has the highest R^2 and lowest RMSE and Chi-Square values and could sufficiently define the thin layer drying of baobab leaves

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