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Modelling of Thin Layer Drying of Dika Kernel and Dika Nut Using Different Drying Methods

John ISA

Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria
jisa@futa.edu.ng

Corresponding Author: jisa@futa.edu.ng

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Abstract: *In this study, the thin layer drying characteristics of dika kernel and dika nut were investigated using two drying methods viz; mechanical drying methods with three temperature parameters (50 ^{O}C, 60 ^{O}C and 70 ^{O}C) at drying air velocity of 0.9 m/s and open sun drying method. All the readings for the experiment were taken at 30 minutes interval. The experimental data obtained were converted to the dimensionless moisture ratio and were fitted into fourteen thin layer drying models. In order to select the best model that can best describe the drying characteristics of dika kernel and dika nut, coefficient of determination, (R^2), reduced chi-square (χ^2), mean bias error (MBE) and root mean square error (RMSE) were used. Results showed that the Hii et al. model was able to describe the drying of dika nut using mechanical method with R^2, χ^2, MBE and RMSE values of 0.9997, 0.000017,0.0000035 and 0.038595 respectively, Modified Henderson was able to describe the mechanical drying for dika kernel with the R^2, χ^2, MBE and RMSE values of 0.9996, 0.000023,0.0000094 and 0.00395 respectively. For the sun drying method, the model that best described the dika nut is Midili-Kucuk, with R^2, χ^2, MBE and RMSE values of 0.9988, 0.000072,0.0000085 and 0.0078 respectively, Hi et al model was able to describe dika kernel with the R^2, χ^2, MBE and RMSE values of 0.9980, 0.00016,0.0003 and 0.011 respectively. It is expected that this study will be beneficial to those involved in modelling, design, optimization, and analysis of food drying.*

Keywords: Thin Layer drying, drying Methods, dika nuts, dika kernel, modelling.

1. INTRODUCTION

Drying of agricultural products is a widely spread method offering physic-chemical stabilization by taking away part of the moisture content, producing different product with new qualitative properties and different nutritional and economic value. Considerable percentages of those agricultural crops are dried artificially in heated air mechanical drying system. [1-3]. Dika "*Irvingia Gabonensis*" fruit is obtained from a plant classified in the *Irvingiacea* family of plants and it is popularly called dika fruits or bush mango in Nigeria. It is either cultivated or grows naturally in most parts of West and Central Africa. The tree is considered to be one of the most important fruits trees in these regions because of the usefulness of its fruits. The study of drying behaviour of various vegetables has been subject of interest of different various researchers. There have been many studies on the drying behaviour of various fruits and vegetables such as carrot [4], green beans and onion [5].

The Dika fruit is a drupe with a thin epicarp, a yellow, soft and fleshy mesocarp which is fibrous in nature and a stony endocarp (nut) encasing a soft dicotyledonous kernel locally called ogbono in Nigeria. The kernel is widely used for food, as a pharmaceutical binder and in the manufacture of soap and cosmetics. Thus, the Dika kernel has market value locally, nationally and internationally, mostly in West and Central Africa countries. The tree has been identified as one of the most important fruit trees for domestication in the region, because of its relative importance to the food industry [6-8]. The most common drying method for fruits and vegetable in the world is sun drying. However, this drying technique has some disadvantages like the slowness of process and the exposure to environmental contamination. Furthermore, direct exposure to solar radiation will lead to colour changes. There is also quality of the dried products which may be lowered significantly. Therefore, using hot air dryers, which are far more rapid, providing uniformity and hygiene, are inevitable for industrial food drying processes [9, 10].

Drying kinetics of food crops are generally affected by factors which include drying temperature, pretreatment method, relative humidity, and product sizes [11, 12] and are crop specific. Thus, research has been carried out on the drying characteristics and kinetics of various food crops [13-16]. Physical and thermal properties of agricultural products such as heat and mass transfer, moisture diffusion, energy of activation, and energy consumption are required for ideal dryer design. Several researchers are known to calculate the moisture diffusion, and the energy of activation of agriculture products and the evaluation of the effect of the drying conditions on the thin-layer drying characteristics [17, 18, 15]. This study was carried out to determine and model the drying kinetics of dika kernel and dika nut in a hot-air mechanical dryer and sun drying.

2. MATERIALS AND METHODS

The materials used for this project include dika fruits (*Irvingia gabonensis*), thermocouple, weighing balance, thermometer, oven, and mechanical dryer. The fruits were purchased from Owena market, Owena, Nigeria. The mechanical dryer which was used for the drying was fabricated in the Department of Agricultural Engineering, Federal University of Technology Akure, Nigeria. The basic design of the mechanical dryer was an insulated rectangular box. It operates independently of the weather. The heat was supplied via electricity.

2.1 Drying Procedure

The selection of the edible dika fruits was carried out and they were divided into two parts. The first part, only the fruit pulp was removed to get the nuts. After the removal, the nuts were placed inside an air-tight leather for homogeneity of the moisture; it was later stored under a room temperature before the drying process commenced. In order to obtain the kernel, the second half of the bought *Irvingia gabonensis* was used, the fruits pulp was removed and the dika nut was cracked. The process of extraction of the kernel (cracking of the nut) was done manually, In the wet state, the nuts were split open by placing them on a hard surface and slitting with a machete along the natural line of cleavage of the nut. After the separation, the kernels were packed inside leather to preserve the moisture, and were stored at room temperature.

A rectangular shaped (1m x 1m x 0.9m) mechanical dryer was used in this study, the dryer consist of control unit, blowing unit, heating unit, drying chamber and the outlet vent. The air velocity and temperature in the drying chamber of the dryer were controlled by variac and a thermostat respectively. The air enters the bottom of the system and move the heat from the heating unit to the drying chamber, the heated air was circulated (convectively) in the drying chamber and exits from the chamber through the outlet vent situated at the top of the chamber

Prior to the commencement of the drying process, the mechanical dryer was tested and certified fit for the work. Out of the four drying trays of known weight inside the drying chamber only two trays were utilised. Thin stainless sheets were measured and dika nut and the dika kernel were placed in a thin layer on the thin stainless sheet for easy accessibility of the sample during drying. The dika nuts and the dika kernels were weighed before putting on the trays in the drying chamber of the dryer.

The air temperature was the main factor considered for the mechanical dryer and three levels of temperature used were; 50°C, 60°C and 70°C at constant air velocity 0.75 m/s. Also, dika kernel and dika nut was sundried for 12 hrs daily. The reduction in the weight of the dika kernel and the dika nut was monitored at 30min in. The temperature and the relative humidity were taken during the drying. 1st day, the readings were taken at 30min interval while in the second day, 60mins interval. The moisture content of the sample at every time was calculated using the following relationship.

$$Mc = \frac{M_w - M_d}{M_w} \quad (1)$$

Where,
Mc = moisture content on wet basis,
M_w = wet mass of the sample and
M_d = dry mass of the sample

2.2 Mathematical Modelling

In order to describe the behaviour of dika, and its prediction under different drying conditions, it is necessary to model the drying process. The modelling was done by using the software ‘sigma plot’. The experimental values for moisture content were converted to moisture ratio using the equation below, which has been used and simplified by many researchers [19].

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

Where,
MR = moisture ratio,
M_t = moisture content at any time,
M_e = initial moisture content,
M_0 = equilibrium moisture content.

The data of the moisture ratio were then fitted to the thin layer drying models of Table 1 to select the best model that can suitably predict the drying characteristics of dika kernel and dika nut. The coefficient of determination (R^2) was the primary criterion for selecting the best model to describe the drying characteristic. The reduced chi square (X^2), the mean bias error (MBE) and the root mean square error (RMSE) was used for the modelling.

The equations are;

$$R^2 = \frac{\sum_{i=1}^{n}(MR_i - MR_{pre,i})\sum_{i=1}^{n}(MR_i - MR_{pre,i})}{\sqrt{\sum_{i=1}^{n}(MR_i - MR_{pre,i})}\sqrt{\sum_{i=1}^{n}(MR_i - MR_{pre,i})}} \quad (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_i - MR_{pre,i})^2}{N-n} \quad (4)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{n}(MR_{pre,i} - MR_{esp,i}) \quad (5)$$

RMSE $= \left[1/N \sum_{i=1}^{n} (MR_i - MR_{pre,i})^2\right]^{1/2}$ (6)

where N = no. of observations, z = no. of constants, MRexp,i = i experimental data, MRpre,i =ithe predicted data. In general, the higher the R^2 values and the lower the χ^2 and RMSE values indicate that the model is best fitted. Non-linear Regression analysis was performed using Microsoft Excel Solver (Microsoft Office, USA).

Table 1: Thin layer drying models tested for the drying of dika kernel and dika nut

Model Name	Model Equation	Equation No.	References
Newton	MR $=\exp^{(-kt)}$	1	[20]
Henderson and Pabis	MR = a$\exp^{(-kt)}$	2	[21]
Page	MR = $\exp^{(-kt^n)}$	3	[22]
Logarithmic	MR = a $\exp^{(-kt)}$ + C	4	[5]
Two term model	MR = a $\exp^{(-kt)}$ + c $\exp^{(-gt)}$	5	[23]
Two term exponential	MR = a $\exp^{(-kt)}$ + (1+ a)$\exp^{(-kat)}$	6	[13, 24]
Verma *et al.*	MR = a $\exp^{(-kt)}$ + (1 +a)$\exp^{(-gt)}$	7	[25]
Diffusion approach	MR = a $\exp^{(-kt)}$ + (1 - a)$\exp^{(-kgt)}$	8	[26]
Midili-Kucuk	MR = a $\exp^{(-kt^n)}$ + bt	9	[27]
Wang and smith	MR = 1 + at + bt	10	[28]
Hii *et al*	MR = a $\exp^{(-kt^n)}$ + c $\exp^{(-gt^n)}$	11	[29]
Modified page	MR = a $\exp^{(-kt^n)}$	12	[30]
Modified Haderson and Pabis	MR = a $\exp^{(-kt)}$ + b$\exp^{(-gt)}$ + c$\exp^{(-bt)}$	13	[10]
Approximation of diffusion	MR = a $\exp^{(-kt)}$ + (1 - a)$\exp^{(-kbt)}$	14	[31, 5]

3. RESULTS AND DISCUSSION

3.1 Drying Curves

Figure 1 and 2 shows the drying curves of the artificial drying processes (Mechanical dryer) for dika kernel and nut respectively and the natural drying processes (Sun drying) was shown in Figure 3. It is apparent that the moisture content decreased steadily with drying time. The initial moisture content of dika kernel and nut were 38.18 and 43.36% (wet basis) respectively. The higher drying rate was observed in the mechanical dryer and resulted in the reduction of the drying time. However, the low drying rate of the sun drying process can be attributed to the fluctuations in two fundamental factors (temperature and humidity). The temperature of typical drying day was found fluctuating between 26°C and 33°C while the relative humidity fluctuated between 56% and 82%. The temperatures recorded in the were all well below 60°C and this shows that the drying took place within the range of a safe temperature.

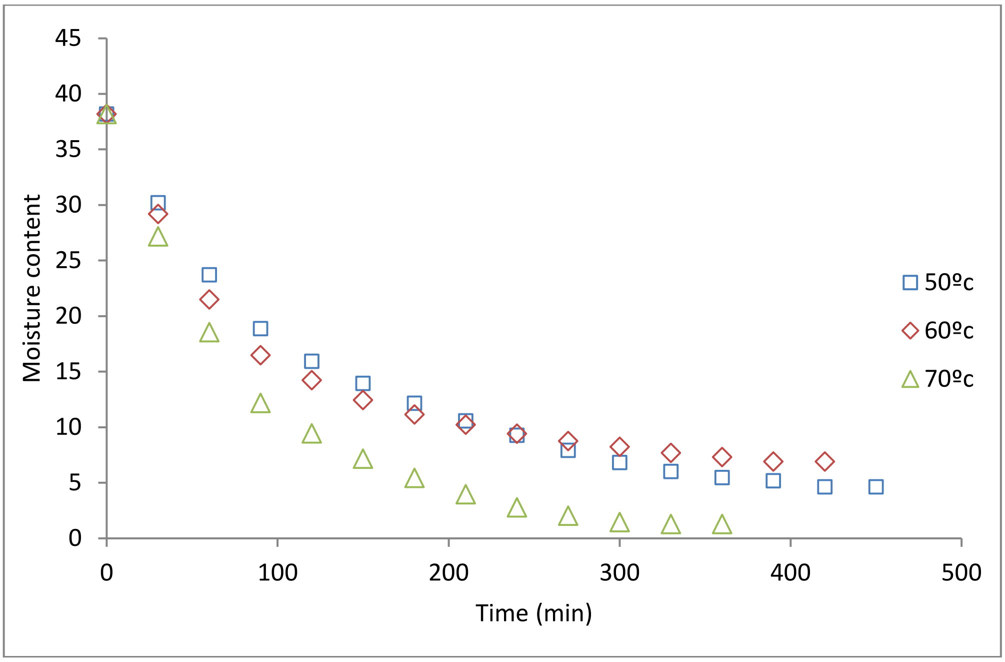

Figure 1: Drying curve of mechanical drying of dika kernel at selected temperatures with (0.9m/s) air velocity

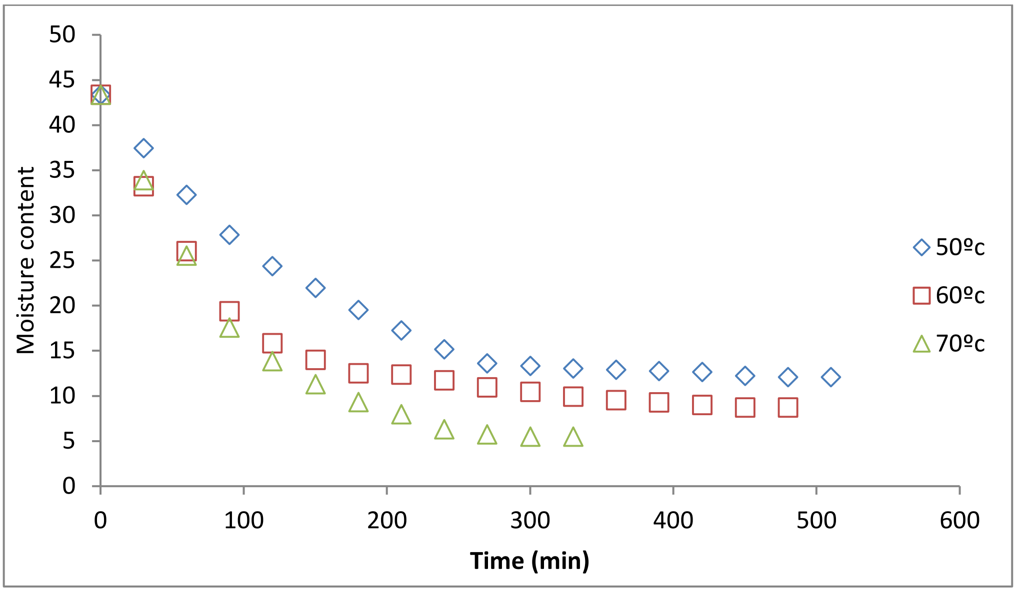

Figure 2: Drying curve of mechanical drying of dika nut at selected temperatures with (0.9m/s) air velocity

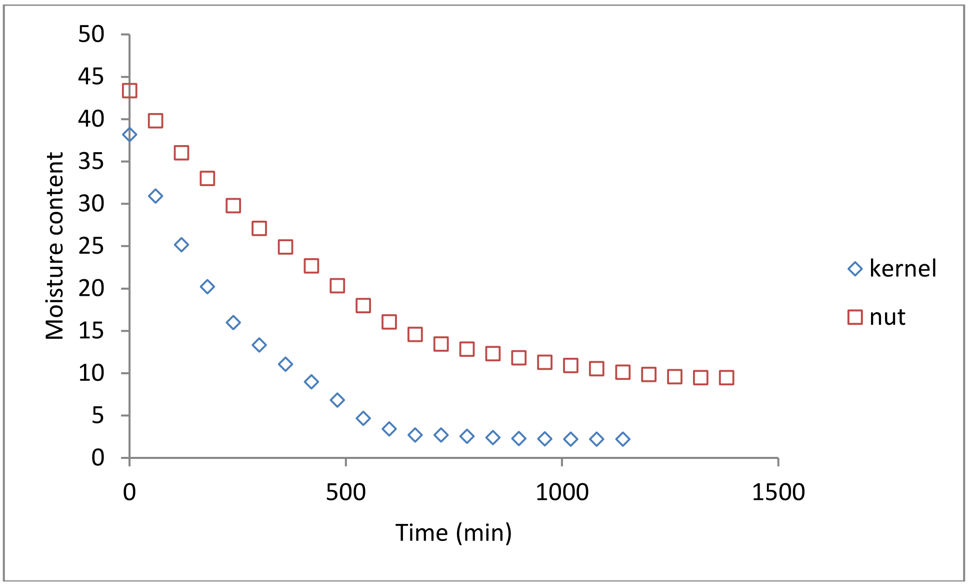

Figure 3: Drying curve of sun drying method of dika nut and dika kernel

3.2 Mathematical Modelling

The statistical parameter estimations showed that R^2, χ^2, MBE and RMSE values ranged from, 0.9990 to 0.9997, 0.000023 to 0.000017, -0000094 to -0.0000035 and 0.0028 to 0.0035, for dika kernel and dika nut respectively (Table 2-5). The best model that described the thin layer drying characteristic was selected based on the highest R^2, the lowest χ^2 and RMSE values. In turn, The Modified Henderson was chosen as best mathematical model for the description of the dika kernel and the Hii *et al.* model for dika nut (Figure 4 and 5).

For the sun drying method, Hii *et al.* model with $\mathbf{R^2, \chi^2,}$ MBE and RMSE values of 0.9988, 0.000072, -0.0000083 and 0.0078 respectively, was selected as the best model for predicting the drying behaviour of dika nut and Midili-Kucuk model with $\mathbf{R^2, \chi^2,}$ MBE and RMSE values of 0.9980, 0.00016, 0.0003 and 0.011 respectively, for dika kernel (Figure 6 and 7).

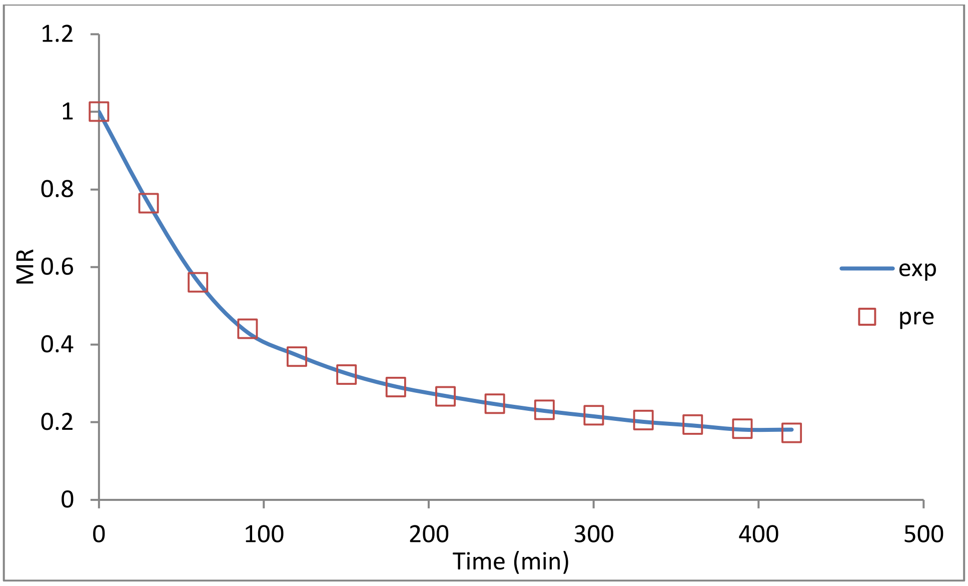

Figure 4: Dika kernel (Modified Handerson)

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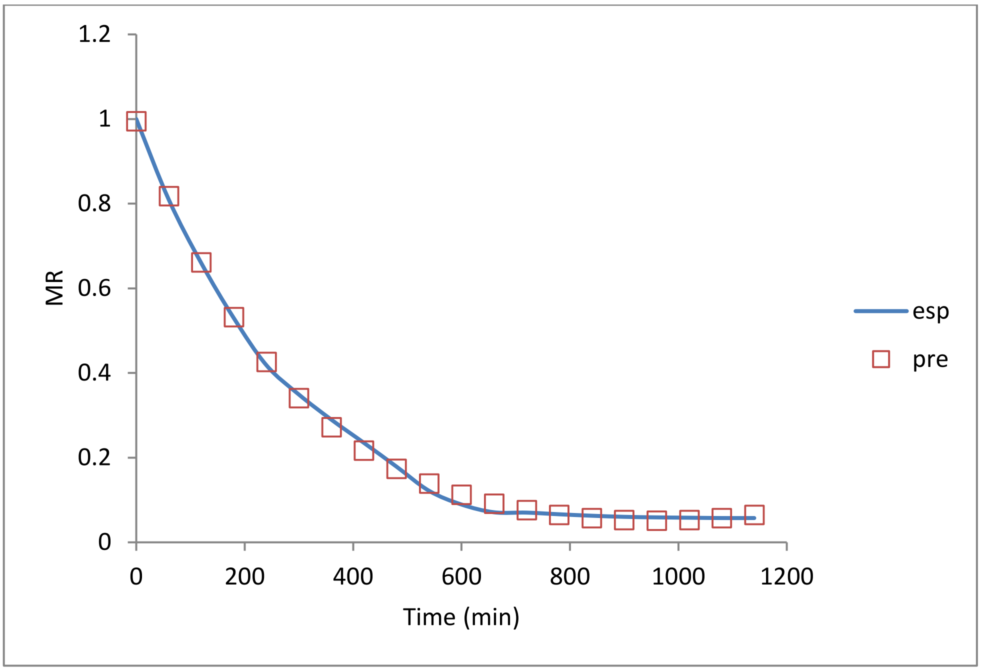

Figure 5: Dika kernel sun drying (Hii *et al.* model)

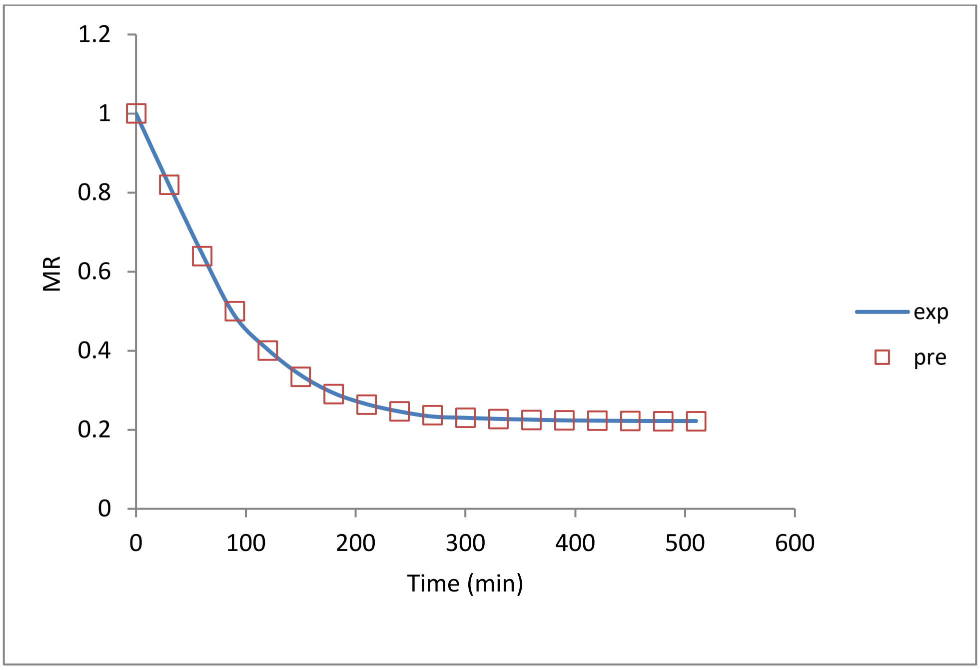

Figure 6: Dika nut (Hii *et al.* model)

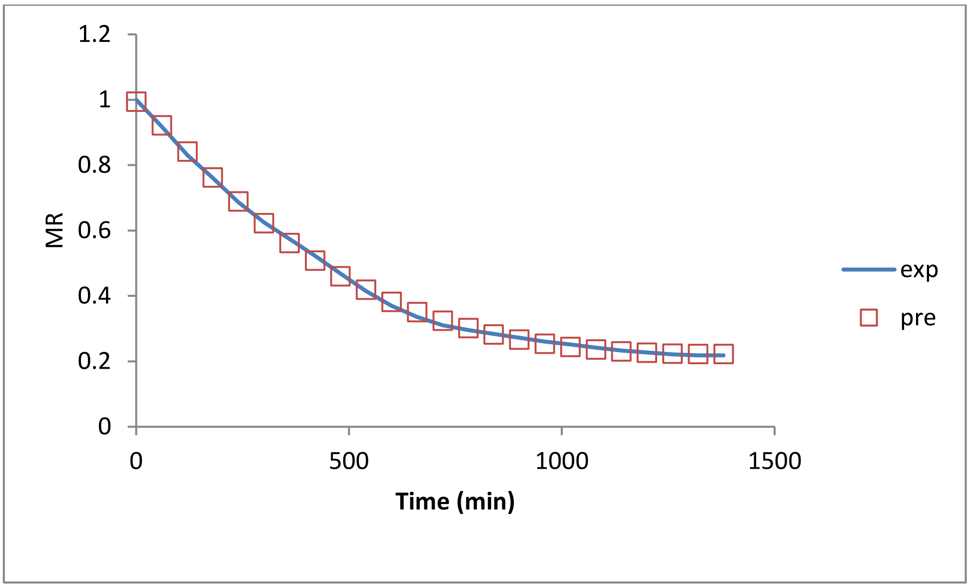

Figure 7: Dika nut sun drying (Midili-Kucuk)

Table 2: The performance of the selected thin layer models on drying dika nut using mechanical dryer

Model	COEFFICIENT	Adj R^2	X^2	MBE	RMSE	Rank
Newton	k=0.0312	0.8234	0.0095	-0.0139	0.0945	12
Page	k=0.0312, n=3.0000	0.9416	0.0031	-0.0051	0.0528	9
Logaritmic	k=0.0623, a=1.5000, c=1.5000	0.9946	0.0003	1.10E-17	0.0156	6
Wang and Singh	a=1.1669, b=0.0208	0.8993	0.0054	0.01504	0.0692	10
Modified page	k=0.0312, n=3.0000	0.8124	0.0101	-0.0139	0.0945	13
Henderson and Pebis	k= 0.0312, a=1.8740	0.848	0.0081	-0.0159	0.0851	11
Two term	a= 1.5000, k=0.0623, c=1.5000, g=1.0000	0.9965	0.0002	5.60E-06	0.0121	4
Verma	a= 1.5000, k=0.0623, g=1.0000	0.996	0.0002	-0.0015	0.0133	2
Diffusion approach	a= 1.5000, k=0.0623, g=1.0000	0.996	0.0002	-0.0015	0.0133	2
Midili-Kucuk	a= 1.5000, k=0.0623, b= 0.0208, n=3.0000	0.9954	0.0002	-0.0004	0.0138	5
Hii *et al.*	a= 1.5000, k=0.0623, b= 0.0208, n=3.0000, g=1.0000	0.9997	2.00E-05	-6.00E-06	0.0035	1
Modefied Henderson	a= 1.0000, k=0.0623, b= 0.0208, c=1.0000, g=1.0000	0.9993	4.00E-05	-6.00E-06	0.005	7
Two term exponential	a= 1.5000, k=0.0623	0.9000	0.0569	-6.00E-06	0.225	14
Approximation of diff	a= 1.5000, k=0.0623, b= 0.0208	0.9933	0.0004	-0.0021	0.0173	7

Table 3: The performance of the selected thin layer models on drying dika kernel using mechanical dryer

Model	COEFFICIENT	Adj R^2	X^2	MBE	RMSE	Rank
Newton	k=0.0363	0.9132	0.00521	-0.0107	0.06987	11
Page	k=0.0363, n=3.0000	0.9872	0.00077	-0.0029	0.02588	9
Logaritmic	k=0.0725, a=1.5000, c=1.5000	0.9949	0.0003	6.70E-06	0.01571	7
Wang and Singh	a= 1.2847, b=0.0242	0.8858	0.00685	0.01896	0.07744	13
Modified page	k=0.0363, n=3.0000	0.907	0.00558	-0.0107	0.06987	12
Henderson and Pebis	k=0.0363, a=2.0589	0.9304	0.00418	-0.0135	0.06045	10
Two term	k=0.0725, a=1.5000, c=1.5000, g=1.0000	0.9983	0.0001	4.30E-07	0.00882	3
Verma	k=0.0725, a=1.5000, g=1.0000	0.9983	0.0001	-0.0005	0.00907	3
Diffusion approach	k=0.0725, a=1.5000, g=1.0000	0.9983	0.0001	-0.0005	0.00907	3
Midili-Kucuk	k=0.0725, a=1.5000, b=0.0242, n=3.0000	0.9949	0.00031	-0.0002	0.0152	7
Hii *et al.*	k=0.0725, a=1.5000, c=1.5000, g=1.0000, n=3.0000	0.9996	2.40E-05	-2.00E-05	0.0046	1

Modified Henderson	k=0.0725, a=1.5000, b=0.0363, c=1.5000, g=1.0000	0.9994	3.40E-05	-6.00E-05	0.0048	2
Two term exponential	k=0.0725, a=1.5000	0.9000	0.0643	-1.00E-05	0.2372	14
Approximation of diff	k=0.0725, a=1.5000, b=0.0242	0.9983	0.0001	-0.0005	0.00907	3

Table 4: The performance of the selected thin layer models on drying dika kernel using sun drying method

Models	**COEFFICIENT**	**Adj R^2**	**X^2**	**MBE**	**RMSE**	**Rank**
Newton	k=0.0115	0.995	0.0004	-0.0047	0.01949	10
Page	k=0.0115, n=3.0000	0.9948	0.00042	-0.0044	0.01944	11
Logarithmic	k=0.0230, a=1.5000, c=1.5000	0.9961	0.00031	5.00E-06	0.01624	7
Wang and Singh	a=1.4140, b=0.0077	0.9653	0.00278	0.01198	0.05006	9
Modified page	k=0.0115, n=3.0000	0.9947	0.00042	-0.0047	0.01949	12
Henderson and Pebis	a=2.2670, k= 0.0115	0.9947	0.00042	-0.0047	0.01949	12
Two term	a=1.5000, k=0.0230, c=1.5000, g=1.0000	0.9977	0.00018	0.00084	0.01213	4
Verma	a=1.5000, k=0.0230, g=1.0000	0.9978	0.00018	0.00032	0.01234	2
Diffusion approach	a=1.5000, k=0.0230, g=1.0000	0.9978	0.00018	0.00032	0.01234	2
Midili-Kucuk	a=1.5000, k= 0.0230, b=0.0077, =3.0000	0.9975	0.0002	0.0003	0.01259	5
Hii *et al.*	a=1.5000, k=0.0230, c= 1.0000, g=1.5000, n=3.0000	0.998	0.00016	0.00025	0.011	1
Modified Henderson	a=1.0000, k=0.0230, b=0.0115, c= 1.0000, g=1.0000	0.9971	0.00023	0.00124	0.01319	6
Two term exponential	a=1.5000, k=0.0230	0.9000	0.08459	3.50E-05	0.27591	14
Approximation of diff	a=1.5000, k= 0.0230, b=0.0077	0.9959	0.00032	-0.001	0.01661	8

Table 5: The performance of the selected thin layer models on drying dika nut using sun drying method

Model	**COEFFICIENT**	**Adj R^2**	**X^2**	**MBE**	**RMSE**	**Rank**
Newton	k=0.0065	0.9753	0.0015	-0.0019	0.0375	12
Page	k=0.0065, n=3.0000	0.9849	0.0009	-0.0036	0.0287	10
Logaritmic	k= 0.0130, a=1.5000, c=1.5000	0.9955	0.0003	-6.00E-18	0.0153	7
Wang and Singh	a= 1.1724, b=0.0043	0.9949	0.0003	0.00227	0.0166	8
Modified page	k=0.0065, n=3.0000	0.9742	0.0015	-0.0019	0.0375	13
Henderson and Pebis	k=0.0065, a=2.5867	0.9765	0.0014	-0.0045	0.0357	11
Two term	k= 0.0130, a=1.5000, c=1.5000, g=1.0000	0.9978	0.0001	7.10E-05	0.0104	4

Verma	k= 0.0130, a=1.5000, g=1.0000	0.9976	0.0001	-0.0012	0.0113	5
Diffusion approach	k= 0.0130, a=1.5000, g=1.0000	0.9976	0.0001	-0.0012	0.0113	5
Midili-Kucuk	a=1.5000, k=0.0130, b=0.0043, n=3.0000	0.9988	7.00E-05	-8.00E-06	0.0078	1
Hii *et al.*	k= 0.0130, a=1.5000, c=1.5000, g=1.0000, n=3.0000	0.9987	8.00E-05	-8.00E-06	0.0078	2
Modefied Henderson	k= 0.0130, a=1.0000, b=0.0065, c=1.0000, g=1.0000	0.9983	0.0001	-7.00E-05	0.0089	3
Two term exponential	k= 0.0130, a=1.5000	0.9000	0.0621	-4.00E-05	0.2386	14
Approximation of diff	a=1.5000, k=0.0130, b=0.0043	0.9944	0.0003	-0.0023	0.0171	9

4. CONCLUSION

The performance of some thin layer drying models on the experimental drying data of dika nut and dika kernel were evaluated. The experimental data were fitted into the thin layer dying model and were statistically compared to the values predicted by the models. Analyses were carried out to select the thin layer models that best described the mechanical drying and natural sun drying of dika nut and dika kernel. Results showed that the Hii *et al.* model was able to describe the drying using mechanical method for dika nut with R^2, χ^2, MBE and RMSE values of 0.9997, 0.000017,0.0000035 and 0.038595 respectively, Modified Henderson was able to describe the mechanical drying for dika kernel with R^2, χ^2, MBE and RMSE values of 0.9996, 0.000023,0.0000094 and 0.00395 respectively. For the sun drying method, the model that best described for dika nut is Midili-Kucuk, with R^2, χ^2, MBE and RMSE values of 0.9988, 0.000072,0.0000085 and 0.0078 respectively, Hii *et al.* model was able to describe for dika kernel with the R^2, χ^2 ,MBE and RMSE values of 0.9980, 0.00016,0.0003 and 0.011 respectively.

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