MODELING DRYING CHARACTERISTICS OF MORINGA (*MORINGA OLEIFERA*) LEAVES UNDER A MECHANICAL CONVECTIVE CABINET DRYER

Ayoola Patrick Olalusi*, Goodluck Ehis Odiase
Department of Agricultural and Environmental Engineering, Federal University of Technology, P.M.B. 704, Akure, Ondo State, Nigeria
* E-mail: apolalusi@futa.edu.ng

Abstract
Moringa oleifera leaves is known for its nutritive and medicinal relevance especially because almost every part of the plant can be used as medicine, food or other beneficial applications. In this study, drying characteristics of Moringa oleifera leaves were investigated using a Mechanical Convective Cabinet dryer at temperature of 45, 55, 65 and 75°C and at constant air velocity of 0.9 m/s. Thirteen (13) Mathematical models were fitted to the experimental data and the performance of these models was evaluated by comparing the coefficient of determination (R^2), Root Mean Square Error (RSME) and reduced chi-square (χ^2) between the observed and predicted moisture ratio for all conditions of drying. Results indicated that drying took place in the falling rate period as there was only a very short or no constant rate period in the drying curves. Also, there was a reduction in drying time and an increase in drying rate as the drying air temperature increased. Mathematical modeling of the drying characteristics showed that diffusion model gave the best for Moringa oleifera samples dried at 45 and 55°C while the Simplified Fick's (SFFD) diffusion was the best model for 65 and 75°C. The dried vegetables can be rehydrated and used in ready to eat foods.

Keywords: drying, Mathematical models, falling rate period, drying temperature, air velocity

Submitted: 14.04.2015 Reviewed: 21.05.2015 Accepted: 18.06.2015

1.INTRODUCTION

Moringa oleifera is the most widely cultivated species of the genus *Moringa*. It is the only genus in the family *Moringaceae.* Almost every part of the *Moringa* tree can be used for food or medicine. Due to its vast application, people also often called 'Miracle Tree'. Some nutritional and medicinal properties of *Moringa oleifera* leaves have been reported (Fahey, 2005). Drying is a very important way of preserving foods of all variety and it has been utilized for this purpose for several years now. Drying involves the removal of moisture from a material by the application of heat (Ching *et al.,* 2012). This is done so that the product can attain a safe moisture content which is necessary for longer shelf life in storage. It is energy intensive. In other words, drying can also be considered as a combined simultaneous heat and mass transfer operation which involves a continuous supply of energy. The major objectives of drying are to extended shelf life as well as enhance quality, ease handling, for further processing and for sanity of operations. It is one of the oldest methods of preserving food which has been practiced by mankind (Mujumdar, 2007). The drying process of agricultural products can be undertaken in closed equipment such as a solar or industrial dryer to improve the quality of the final product (Ertekin and Yaldiz, 2004). In Engineering, it is important to develop a good understanding of the controlling parameters of this complex process. Hence, mathematical models of the drying processes are used for designing new drying systems or improving existing ones as well as control the drying process. Many mathematical models have used to describe the drying process of the thin-layer drying models of several agricultural materials. Some of the thin-layer drying models, available in literature for explaining drying characteristics of agricultural products, have been highlighted here. These models can be classified as theoretical, semi-theoretical

(Lewis, Page, Henderson and Pabis, Modified Page, Logarithmic, Two-term, Two-term exponential, Approximation of diffusion), and empirical (Wang and Singh model) (McMinn, 2006). Several researchers have undertaken many studies on mathematical modeling and kinetics of vegetable drying process. For instance, eggplant (Akpinar and Bicer, 2004; Ertekin and Yaldiz, 2004), red chilli (Kaleemullah and Kailappan, 2005), green bean (Yaldiz *et al.,* 2001), okra (Doymaz, 2005a; Gogus and Maskan, 1999), tomato (Sacilik *et al.,* 2006) and green pea (Simal *et al.,* 1996). However, there is limited information and research on drying of Moringa oleifera leaves in literature.

Various methods of drying fruits and vegetables exist such as the direct sun drying, solar drying, convective or mechanical cabinet drying, freeze drying, oven drying, shadow drying, green-house drying etc. The present study was undertaken with the following objectives:

i. conduct thin layer drying experiment on *Moringa oleifera* using the mechanical cabinet dryer for four (4) temperatures: 45, 55, 65 and 75°C at constant air velocity of 0.9m/s

ii. evaluate the effect of drying temperatures on the drying characteristics of *Moringa oleifera* leaves;

iii. fit the experimental data to thirteen (13) mathematical models in order to determine an appropriate drying model for the *Moringa oleifera* leaves using relevant statistical methods

2. MATERIAL AND METHODS

The *Moringa oleifera* leaves used for this experiment was obtained from a commercial at farm Akure, Nigeria and used immediately for the drying experiments. After collecting the Moringa oleifera leaves samples, they were sorted and properly rinsed with water to removed dust and other foreign materials that might be present. The mechanical cabinet dryer were operated at temperatures 45, 55, 65 and 75°C and at air velocity 1.9 m/s. The drying system was first run for about 30 minutes to obtain a stable condition before placing samples in the chamber. The initial moisture content of the samples were determined using the oven method as used by several authors (Owoso and Ogunmoyela, 2001). In this method the material is placed in the oven and set at 102°C to dry for about 24 hours after which the final weight is taken. The initial weights of the *Moringa oleifera* leaves were about 100±5g and the drying operation started with an initial moisture content of about 75.46% (wet basis) and continued until no further changes in their mass were observed i.e. to the final moisture content of about < 10% (w.b) which was taken as the equilibrium moisture content. This method has earlier been used by McMinn (2006), Setwase *et al*., (2013) and Karim *et al.,* (2013). Drying tests were conducted in triplicates at each air temperature.

Analysis of drying data

The experimental drying data obtained were fitted to the thirteen (13) thin layer drying models shown in Table 1. The moisture ratio was obtained from equation (1)

$$MR = \frac{M - M_e}{M_0 - M_e} \qquad (1)$$

Where M, M_0 and M_e are present, initial and dynamic equilibrium moisture contents.

This has been used and simplified by many researchers (Togrul and Pehlivan, 2004; Akpinar, 2006) to the Equation 2 below

$$MR = \frac{M_t}{M_0} \qquad (2)$$

Where MR= Moisture ratio, M_t= Moisture content at any time, t., M_o= Initial Moisture content, M_e = Equilibrium moisture content

The drying rate (DR) can be expressed below as reported by Ceylan *et al.*(2007), Doymaz, (2007), and O"zbek and Dadali (2007).

$$DR = \frac{M_t + d_t - M_t}{d_t} \qquad (3)$$

where Mt+dt and Mt are moisture content at t+dt (kg water/kg dry matter) and moisture content at time t respectively and t is drying time (min).

Table1: Thin-layer drying models most frequently used by various authors.

S/N	Model Name	Model	References
1.	Newton	$MR = \exp^{(-kt)}$	Ayensu, (1997); Togrul and Pehlivan, (2004); Upadhyay *et al.,* 2008
2.	Page	$MR = \exp^{(-ktn)}$	Kaleemullah and Kailappan,(2006); Saeed *et al.*, (2006); Senadeera *et al.*, (2003)
3.	Modified Page	$MR = \exp(^{(kt)n})$	Goyal *et al.*, (2007); Ceylan *et al.*, (2007); Sogi *et al.*, (2003)
4	Modified Page II	$MR = \exp(-k(t/L^2)^n)$	Midilli *et al.* (2002); Wang *et al.*(2007)
5	Henderson and Pabis	$MR = a.\exp(-kt)$	Kashaninejad and Tabil (2004); Saeed *et al.* (2006); Ozdemir and Devres, (1999)
6	Modified Hend. andPabis	$MR = a.\exp(-kt)+b.\exp(-gt) +c.\exp(-ht)$	Karathanos, (1999); Kaya *et al.*, (2007b); Yaldiz *et al.,* (2001)
7	Simplified Fick's (SFFD) diffusion	$MR = a.\exp(-kt)+c$	Babalis *et al.*, (2006); Celma *et al.*, 2007; Lahsasni *et al.*, (2004b)
8	Logarithmic	$MR = a.\exp^{(-c(t/L2))}$	Togrul and Pehlivan, (2002; 2003); Wang *et al.*, (2007)
9	Two-term	$MR = a.\exp^{(-kt)}+ b.\exp^{(k1t)}$	Lahsasni *et al.*, (2004b); Rahman *et al.*, (1998); Wang *et al.*, (2007)
10	Two-term Exponential	$MR = a.\exp^{(-kt)}+(1-a)\exp^{(-kat)}$	Midilli and Kucuk, (2003); Sacilik *et al.*, (2006); Tarigan *et al.*, (2007)
11	Verma *et al*	$MR = a.\exp^{(-kt)}+(1-a)\exp^{(-gt)}$	Doymaz, (2005b); Karathanos, (1999); Yaldiz and Ertekin, (2001)
12	Diffusion approach	$MR = a.\exp^{(-kt)}+(1-a)\exp^{(-kbt)}$	Wang *et al.*, (2007); Yaldiz and Ertekin, (2001); Togrul and Pehlivan, (2002)
13	Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh, 1978
14	Thomson	$t = a.\ln(MR) + b[\ln(MR)]^2$	Paulsen and Thomson (1973); Thomson *et al.*, (1968)
15	Midilli and Kucuk	$MR = a\exp^{(ktn)} + bt$	(Midilli and Kucuk ,2003)
16	Hii *et al.*	$MR = a \exp^{(-kt\,n)} + c \exp^{(-gt\,n)}$	Hii *et al.*, 2009

Moisture ratio(MR)=dependent variable, Drying constant (k)=independent variable

Regression analysis was performed using Microsoft Excel Solva version 2007. The coefficient of determination (R^2) was the primary criterion used for selecting the best model to describe the drying curves. In addition to R^2, the deviations between experimental and predicted values for the models and root mean square error analysis (RMSE) were used to determine the goodness of the fit. The higher the values of R^2 and the lower the values of $\chi 2$ and RMSE, the better the goodness of the fit (Midilli and Kucuk, 2003). They were calculated as

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{pre,i}) * (MR_i - MR_{exp,i})}{\sqrt{[\sum_{i=1}^{N}[MR_i - MR_{pre,i}]^2 * [\sum_{i=1}^{N}(MR_i - MR_{exp,i})^2]}} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{cal,i})^2}{N}} \quad (5)$$

2.

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{cal,i})^2}{N-n} \quad (6)$$

where R^2 is called the coefficient of determination, $MR_{exp,i}$ stands for the experimental moisture ratio found in any measurement, $MR_{pre,i}$ is the predicted moisture ratio for this measurement and N is the total number of observations (Demir *et al.*, 2007; Doymaz, 2005b; Wang *et al.*, 2007).

Modeling the drying behaviour of different agricultural products often requires the statistical methods of regression models and correlation analysis. Linear and non-linear regression models are important tools to find relationship between different variables, especially for which no established empirical relationship exists.

3. RESULTS AND DISCUSSION

Drying curves

Figures 1 and 2 show the variation of moisture ratios with the drying time and the drying rates versus drying time respectively for *Moringa oleifera* leaves. It is obvious that increasing the drying temperature resulted in an increase in the drying rate, therefore decreasing the drying time. The time required to decrease the moisture contentto the given level was dependent on the drying condition, being highest at 45°C (5hrs) and lowest at 75°C (4hrs). It is observed that there was only a short constant rate drying period in the drying of *Moringa oleifera* leaves. Though drying rate was initially low at the start of drying, it suddenly increased sharply and then consistently reduced till the end of the drying period. Majority of the drying took place in the falling rate period. This indicates that diffusion is the main physical mechanism governing moisture migration in the samples. Similar results were obtained by Doymaz (2013) for broccoli, Wankhade *et al.,* (2013) for okra, Lee and Kim (2009) for radish, Kaleemullah and Kailappan (2006) for red chillies, and Togrul and Pehlivan (2003) for apricots. The effect of temperature used for the drying process was most remarkable with moisture content reducing rapidly with increased temperature.

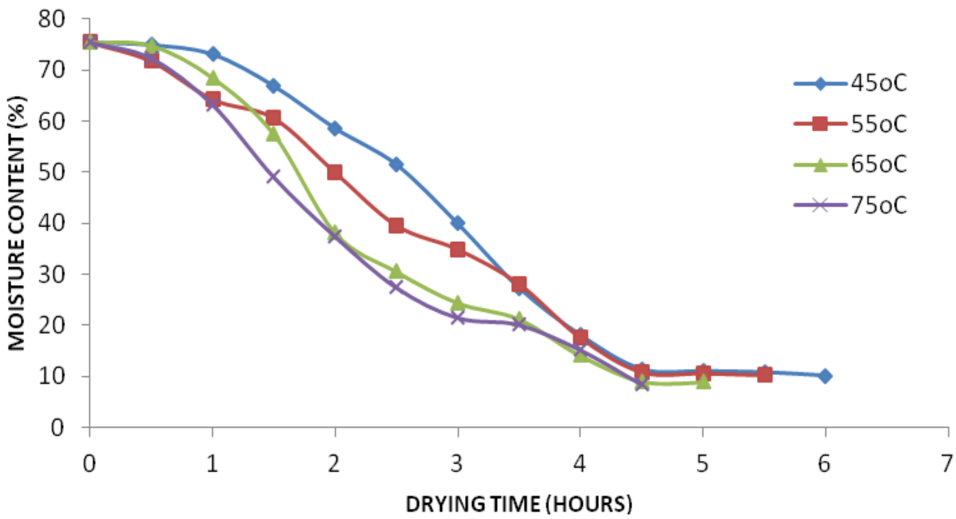

Figure 1: Variation of moisture content with drying time for Mechanically dried *Moringa oleifera* Leaves

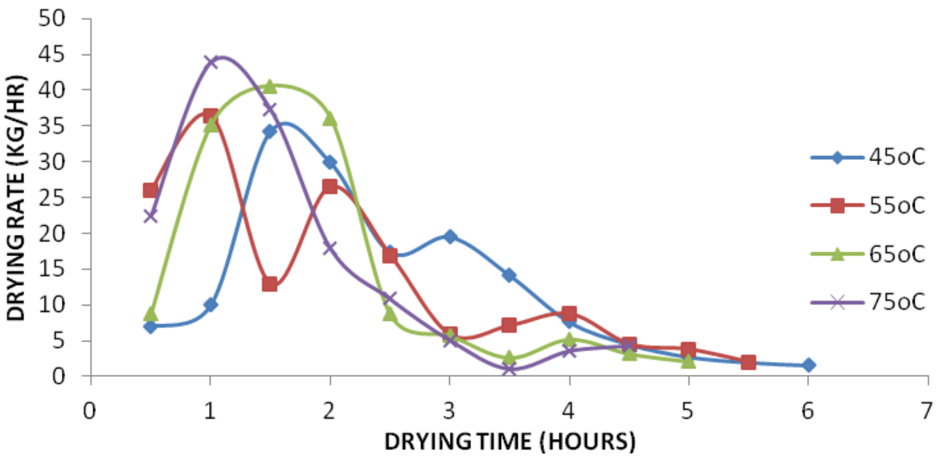

Figure 2: Variation of drying rate with drying time for Mechanically dried *Moringa oleifera* Leaves

This agrees with reports from several researchers who have also reported a significant increase in the drying rates when higher temperatures were used for drying various agricultural products such as chili (Zhao *et. al.,* 2013), pepino fruit (Uribe *et. al.,* 2011), canola (Gazor and Mohsenimanesh, 2010), okra (Doymaz, 2005a), eggplant (Ertekin and Yaldiz, 2004), and red pepper (Doymaz and Pala, 2002).

Fitting of the drying curves

Table 2, presents the results of non-linear regression analysis of the thirteen models. The entire model gave consistently high coefficient of determination (R^2) values in the range of 0.803 to 0.994. Table 2 shows the summary of statistical results obtained from mathematical models. The best model describing the thin-layer drying characteristics of *Moringa oleifera* using the mechanical dryer was chosen as the one with the highest R^2 values and the lowest $\chi 2$ and RMSE values. Four different temperatures were considered which are 45, 55, 65 and 75°C. The statistical parameter estimations showed that R^2, $\chi 2$ and RMSE values ranged from 0.817 to 0.994, 0.0001 to 0.002448, and 0.009761 to 0.046934 respectively for sample dried at 45°C. Also R^2, $\chi 2$ and RMSE values ranged from 0.9600 to 0.985, 0.000922 to 0.002904, and 0.0254 to 0.0417 respectively for samples dried at 55°C.

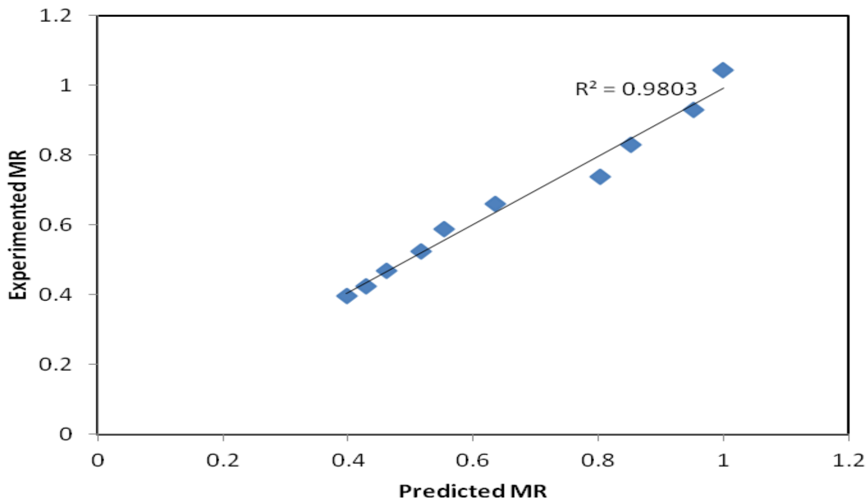

Figure 3: Plot of Experimented MR against Predicted MR using the Diffusion model for *Moringa oleifera* for the Mechanical Cabinet dryer of the leaves at 45°C

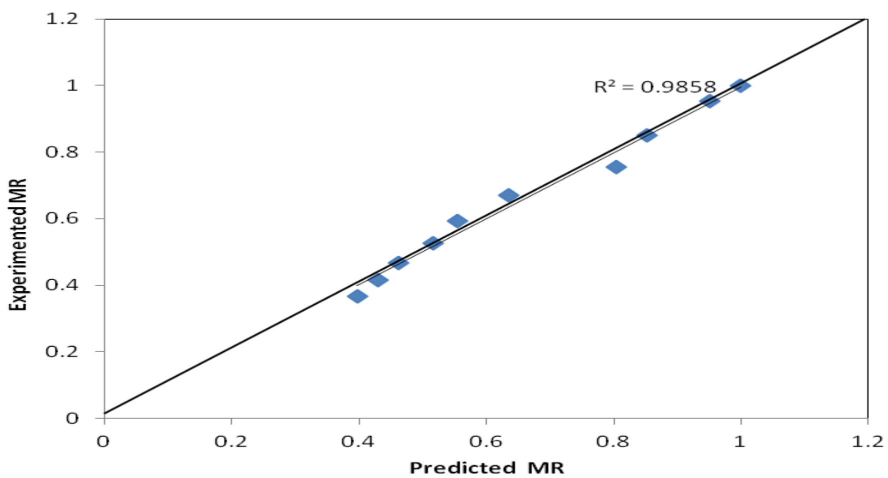

Figure 4: Plot of Experimented MR against Predicted MR using the Diffusion model for *Moringa oleifera* for the Mechanical Cabinet dryer of the leaves at 55°C

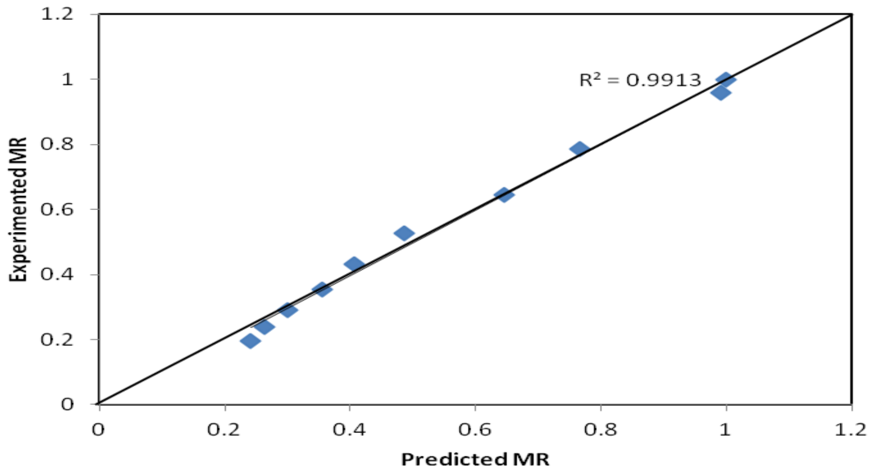

Figure 5: Plot of Experimented MR against Predicted MR using the Simplified Fick's (SFFD) diffusion model for *Moringa oleifera* for the Mechanical Cabinet dryer of the leaves at 65°C

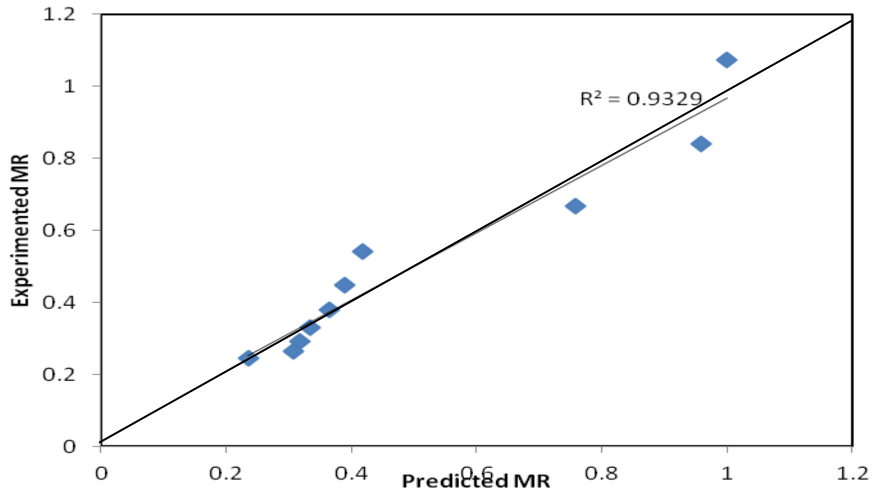

Figure 6: Comparism of Experimented MR against Predicted MR using the Simplified Fick's (SFFD) diffusion model for *Moringa oleifera* for the Mechanical drying of the leaves at 75°C

For samples dried at 65°C, R^2, χ2 and RMSE values were ranged from 0.9260 to 0.9910, 0.000981 to 0.008842, and 0.9260 to 0.991000 respectively and for 75°C dried samples, R^2, χ2 and RMSE values were ranged from 0.803 to 0.936, 0.007018 to 0.02255, and 0.06826 to 0.13431 respectively. Of all the models tested, the Hii *et al.*, Diffusion approach, Diffusion approach, Simplified Fick's (SFFD) diffusion model gave the highest value of R^2 and the lowest values of χ2 and RMSE for 45, 55, 65 and 75°C respectively.

Figure 3, 4, 5 and 6 compares experimental data with those predicted with the respective models for *Moringa oleifera* leaves samples for mechanical drying at 45, 55, 65 and 75°C. The prediction using the model showed *MR* values banded along the straight line with a very high value of R^2 (0.994, 0.985, 0.9910 and 0.936 for 45, 55, 65 and 75°C), which showed the suitability of these models in describing mechanical drying characteristics of *Moringa oleifera*. Tables 2 showed that drying rate constants increase with increase in drying air temperature. An increase in rate constant with increasing drying air temperature has been reported by Kaleemullah and Kailappan, (2006) for the drying of red chillies and Olurin *et al.*, (2012) for the drying of Blanched field pumpkin.

Table 2: Drying constants and coefficients of the non-linear regression model for Moringa oleifera leaves

MODEL	DRYING AIR TEMP	MODEL CONSTANTS	R^2	$\chi 2$	RMSE
Page	45	k=0.027695053, n=1.920405329	0.9860	0.0003	0.0157
	55	k=0.176017134, n=1.162769975	0.9810	0.0011	0.0296
	65	k=0.268073577, n=1.208579121	0.9770	0.0022	0.0420
	75	k=0.382582626, n=0.958268636	0.9140	0.0071	0.98
Simplified Fick's (SFFD) diffusion	45	a=20.98391905, k=0.004291747, c=-19.93668123	0.9430	0.0010	0.0306
	55	a=1.0916321, k=0.20639945, c=-0.056499528	0.9790	0.0013	0.0305
	65	a=1.085766549, k=0.344036694, c=-0.019115405	0.9750	0.0026	0.0428
	75	a=0.884942581, k=0.612433944, c=0.188500848	0.9320	0.0070	0.0701
Logarithmic	45	a=5.84300648, k=0.015721535, c=-4.794755587	0.9390	0.0011	0.0315
	55	a=1.091563208, k=0.206419304, c=-0.056428285	0.9790	0.0013	0.0305
	65	a=1.085766549, k=0.344036527, c=-0.019115535	0.9750	0.0026	0.0428
	75	a=0.884942904, k=0.612432769, c=0.188500237	0.9320	0.0070	0.0701
Two-term	45	a=1.022330586, k=0.042469505, c=-0.011270812, g=-0.695614876	0.9940	0.0001	0.0098
	55	a=1.042825911, k=0.229427604, c=1.12306E-06, g=-2.231160196	0.9800	0.0015	0.0299
	65	a=1.076262139, k=0.364410195, c=2.35415E-06, g=-2.098724234	0.9760	0.0029	0.0419
	75	a=1.052141717, k=0.490670397, c=0.018461501, g=-0.47128668	0.9360	0.0078	0.0683
Wang and Singh	45	a=-0.074620416, b=0.008	0.8910	0.0017	0.0395
	55	a=-0.14934306 b=0.008,	0.9600	0.0023	0.0427
	65	a=-0.197093389 b=0.008,	0.9260	0.0075	0.0776
	75	a=-0.204165925 b=0.008,	0.8030	0.0226	0.1343
Midilli and Kucuk	45	a=1.00012635, b=-0.097284146, k=-0.069183629	0.965	0.00064	0.02409
	55	a=1.000129587, b=-0.142926849, k=0.020656897, n=1.122828	0.961	0.00290	0.04174
	65	a=1.000130981, b=-0.177701975, k=0.063502711, n=1.122828	0.929	0.00884	0.07283
	75	a=1.000132255, b=-0.15026308, k=0.187296328, n=1.122828	0.829	0.02086	0.11189
Henderson and Pabis	45	a=1.05390941, k=0.10243577	0.906	0.0016	0.03794
	55	a=1.038352669, k=0.223982503	0.979	0.00117	0.03062
	65	a=1.069077983, k=0.35590392	0.975	0.00229	0.04283
	75	a=1.027861633, k=0.382182971	0.915	0.00786	0.07934
Verma *et al*	45	a=-1.792723734, k=0.393731015, g=0.245394454	0.979	0.00039	0.01875
	55	a=4.892425659, k=0.083769707, g=0.101838487	0.978	0.00159	0.03337
	65	a=-2.274411937, k=0.149287254, g=0.194263153	0.973	0.00348	0.04938
	75	a=-1.297563265, k=0.368841823, g=0.368848747	0.932	0.00701	0.07009
Diffusion approach	45	a=1.950079632, k=0.386160317, b=0.643794761	0.979	0.00039	0.01873
	55	a=-0.08148581, k=5.016710235, b=0.047801456	0.985	0.00092	0.02540
	65	a=-0.169169291, k=15.13743505, b=0.026279186	0.991	0.00098	0.02620
	75	a=-1.792868627, k=0.368863268, b=0.999995044	0.913	0.00917	0.08013
Hii *et al*	45	a=1.019139413, k=0.09270472, c=-0.006211406, g=-1.516737712, n=0.530718763	0.994	0.00010	0.00976
	55	a=1.043063059, k=0.19515418, c=1.11176E-06, g=-1.89882714, n=1.176140563	0.98	0.00178	0.02985
	65	a=1.074521563, k=0.312668865, c=2.54841E-06, g=-1.778422147, n=1.161951917	0.976	0.00351	0.04191
	75	a=1.052011525, k=0.991493567, c=0.018830064, g=-0.943548258, n=0.4953915	0.936	0.00932	0.06826

Table 2					
Modified Hend. and Pabis	45	a=0.351303414, b=0.223982466, c=0.351303379, g=0.102436192, h=0.102436213, k=0.102436213,	0.906	0.0016	0.03794
	55	a=0.346117475, b=0.346117542, c=0.346117475, g=0.223982069, k=0.223982466, h=0.102436213	0.979	0.00234	0.03062
	65	a=0.356359275, b=0.356359213, c=0.356359274, g=0.355903807, h=0.355904063, k=0.355904063	0.975	0.00458	0.04283
	75	a=0.342620508, b=0.342620424, c=0.342620508, g=0.382182517, h=0.382183075, k=0.382183075	0.915	0.01573	0.07934
Two-term Exponential	45	a=0.001190524, k=70.88617164	0.817	0.00244	0.04693
	55	a=0.000861751, k=242.7219801	0.979	0.00156	0.03540
	65	a=0.996689027, k=0.326455278	0.975	0.00334	0.05176
	75	a=0.367778611, k=0.70128672	0.921	0.00749	0.07741
NEWTON	45	k=0.0848002686749533	0.923	0.00241	0.04658
	55	k=0.209512193495314	0.979	0.00137	0.03521
	65	k=0.326472214291968	0.975	0.00297	0.05176
	75	k=0.368858097872436	0.913	0.00713	0.08013

Moisture ratio(MR)=dependent variable, Drying constant (k)=independent variable

4. CONCLUSIONS

In this study, the drying behaviour of *Moringa oleifera* leaves was investigated in a mechanical cabinet dryer with forced convection mode. The following submission are made

(1) Drying air temperature is a significant factor in drying of *Moringa Oleifera* leaves.

(2) Higher drying air temperature resulted in a shorter drying time.

(3) Drying of the leaves takes place in the falling rate period and there was no constant rate period in most of the dried materials

(4) The diffusion model gave the best for *Moringa oleifera* samples dried at 45 and 55^{o}C while the Simplified Fick's (SFFD) diffusion was the best model for 65 and 75^{o}C.

5. REFERENCES

[1] Fahey J.W., (2005). *Moringa oleifera*: A review of the medical evidence for its nutritional, therapeutic and prophylactic properties. Part 1. Trees Life J., 1(1):8-9

[2] Ching L. H., S. V. Jangam, S. P. Ong and A. S. Mujumdar (2012). Solar Drying: Fundamentals, Applications and Innovations. Pg 4-8.

[3] Mujumdar, A.S., (2007), *Handbook of Industrial drying*, Taylor and Francis group, U.K.

[4] Ertekin, C., and Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. Journal of Food Engineering, 63, 349–359

[5] Akpinar, E. K., and Bicer, Y. (2004). Modelling of the drying of eggplants in thin-layers. International Journal of Food Science and Technology, 39, 1–9.

[6] Kaleemullah, S., and Kailappan, R. (2005). Drying kinetics of red chillies in rotary dryer. Biosystems Engineering, 92, 15–23.

[7] Yaldiz, O., Ertekin C. and Uzan H. E. (2001). Mathematical modeling of thin layer solar drying of sultana grapes. Energy, 26(5): 457-465.

[8] Doymaz, I. (2005a). Drying characteristics and kinetics of okra. Journal of Food Engineering, 69, 275–279.

[9] Gogus F., and Maskan, M. (1999). Water adsorption and drying characteristics of okra (Hibiscus esculentus L.). Drying Technology, 17, 883–894.

[10] Sacilik, K., Keskin, R., and Elicin, A. K. (2006). Mathematical modeling of solar tunnel drying of thin layer organic tomato. Journal of Food Engineering, 73, 231–238.

[11] Simal S., Mulet A., Tarrazo J., and Rosello C., (1996). Drying models for green peas. Food Chemistry, 55, 121–128.

[12] Owoso, O. and Ogunmoyela, O. A. (2001). Proximate Constituents of Food. In: Chemical Analysis of Foods- an outline. Concept Publishers Limited, Lagos Nigeria.

[13] McMinn, W. A. M. (2006). Thin-layer modeling of the convective, microwave, microwave-convective and microwave-vacuum drying of lactose powder. Journal of Food Engineering, 72, 113–123.

[14] Satwase A.N, Pandhre G.R, Sirsat P.G, and Wade Y.R (2013). Studies on Drying Characteristic and Nutritional Composition of Drumstick Leaves by Using Sun, Shadow, Cabinet and Oven Drying Methods. 2:584 doi:10.4172/scientificreports.584

[15] Karim O.R., Kayode R. M., Oyeyinka S. A., and Oyeyinka, A. T., (2013). Proximate, Mineral and Sensory Qualities of 'Amala' Prepared from Yam flour fortified with Moringa leaf powder. Journal of Food Science and Quality Management 12:2-4

[16] Ayensu, A. (1997). Dehydration of food crops using a solar dryer with convective heat flow. *Solar Energy* 59:121-126.

[17] Togrul, I.T. and Pehlivan D., (2004). Modeling of thin layer drying kinetics of some fruits under open air sun drying process. *Journal of Food Engineering*, 65 (3): 413-425.

[18] Upadhyay A.H.K, Sharma, and Sarkar B.C., (2008). "Characterization and Dehydration Kinetics of Carrot Pomace". Agricultural Engineering International: The CIGR Ejournal Manuscript.

[19] Kaleemullah S., and Kailappan R. (2006). Modelling of thin layer drying kinetics of red chillies. *Journal of Food Engineering*, 76(4): 531-537.

[20] Saeed, I.E, K. Sopian and Z. Zainol Abidin, (2006). Drying kinetics of Roselle (*Hibiscus sabdariffa* L.): dried in constant temperature and humidity chamber. *Proceeding, of SPS 2006*. Ed Muchtar *et al.* 29-30 Aug. Permata, Bangi, Malaysia, 2006, pp: 143-148.

[21] Senadeera W., Bhandari, B. R., Young, G., and Wijesinghe, B. (2003). Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying. Journal of Food Engineering, 58, 277–283.

[22] Goyal R. K., Kingsly, A. R. P., Manikantan, M. R. and Ilyas, S. M. (2007). Mathematical modelling of thin layer drying kinetics of plum in a tunnel dryer. *Journal of Food Engineering* 79: 176-180.

[23] Ceylan, I., Aktas, M. and Dog˘an, H. (2007). Mathematical modeling of drying characteristics of tropical fruits. *Applied Thermal Engineering* 27: 1931-1936.

[24] Sogi D. S., Shivhare U. S., Garg S. K., and Bawa, A. S. (2003). Water sorption isotherms and drying characteristics of tomato seeds. Biosystems Engineering, 84, 297–301.

[25] Midilli, A., H. Kucuk and Z. Yapar, (2002). A new model for single-layer drying. *Drying Technology*, 20: 1503-1513.

[26] Wang, Z, Sun J., Liao X., Chen F., Zhao G., Wu J. and Hu X., (2007). Mathematical modeling on hot air drying of thin layer apple pomace. *Food Research International*, 40: 39–46

[27] Kashaninejad, M., and Tabil, L. G. (2004). Drying characteristics of purslane (Portulaca oleraceae L.). Drying Technology, 22, 2183–2200.

[28] Ozdemir, M., and Devres, Y. O. (1999). The thin layer drying characteristics of hazelnuts during roasting. Journal of Food Engineering, 42, 225–233.

[29] Karathanos, V.T., (1999). Determination of water content of dried fruits by drying kinetics. *Journal of Food Engineering*, 39: 337-344.

[30] Kaya, A., Aydin, O., Demirtas, C. and Akgün, M. (2007). An experimental study on the drying kinetics of quince. *Desalination* 212: 328-343.

[31] Yaldiz, O. and Ertekyn, C. (2001). Thin layer solar drying of some vegetables. *Drying Technology* 19(3-4): 583-597.

[32] Babalis J.S, and Belessiotis G.V (2006). Influence of drying condition on the drying constants and moisture diffusivity during the thin layer drying of figs. Journal of Food Eng., 65: 449- 458

[33] Celma, A.R, S. Rojas, F. Lo´pez, I. Montero and T.Miranda, (2007). Thin-layer drying behavior of sludge of olive oil extraction. *Journal of Food Engineering*, 80: 1261-1271

[34] Lahsasni, S., Kouhila, M., Mahrouz, M. and Jaouhari J. T. (2004b). Drying kinetics of prickly pear fruit (Opuntia ficus indica). *Journal of Food Engineering* 61: 173-179.

[35] Togrul I.T. and Pehlivan D. (2002). Mathematical modeling of solar drying of apricots in thin layer dryers. *Journal of Food Engineering* 55: 209-216.

[36] Togrul I. T. and Pehlivan D. (2003). Modeling of drying kinetics of single apricot. *Journal of Food Engineering* 58:23–32.

[37] Rahman M.S, Perera C.O, Theband C. (1998) Desorption isoterm and heat pump drying kinetics of peas. Food Res Int 30:485–91.

[38] Midilli, A. and H. Kucuk, (2003). Mathematical modeling of thin layer drying of pistachio by using solar energy. *Energy Conversion and Management*, 44(7):1111-1122.

[39] Sacilik, K., Keskin, R., and Elicin, A. K. (2006). Mathematical modeling of solar tunnel drying of thin layer organic tomato. Journal of Food Engineering, 73, 231–238.

[40] Tarigan, E., Prateepchaikul G., Yamsaengsung R., Sirichote, A. and Tekasakul, P., (2007). Drying characteristics of unshelled kernels of candle nuts. *Journal of Food Engineering*, 79: 828–833.

[41] Doymaz, I. (2005b). Sun drying of figs: an experimental study. *Journal of Food Engineering* 71:403-407.

[42] Wang C.Y., and Singh R.P., (1978). A single layer drying equation for rough rice. ASAE, paper no. 3001.

[43] Paulsen, M. R and Thomson, T. L. (1973). Drying endysus of grain sorghum. Trans ASAE 1973;16:537–40.

[44] Thomson, T. L, Peart P.M, and Foster, G.H. (1968). Mathematical simulation of corn drying: A new model. Trans ASAE; 11:582–6.

[45] Hii, C. L., Law, C. L. and Cloke, M. (2009). Modeling using a new thin layer drying model and product quality of cocoa. Journal of Food Engineering, 90, 191 – 198.

[46] Togrul, I.T. and Pehlivan, D.(2004). Modeling of thin layer drying kinetics of some fruits under open air sun drying process. *Journal of Food Engineering*, 65 (3): 413-425.
[47] Akpinar, E. K. (2006). Determination of suitable thin layer drying curve model for some vegetables and fruits. *Journal of Food Engineering* 73: 75-84.
[48] Doymaz, I., (2007). The kinetics of forced convective air-drying of pumpkin slices. *Journal of Food Engineering*, 79: 243-248.
[49] Demir, V., Gunhan, T. and Yagcioglu, A. K. (2007). Mathematical modelling of convection drying of green table olives. *Biosystems Engineering* 98: 47-53.
[50] Doymaz, I. (2013). Effect of blanching temperature and dipping time on drying time of broccoli. Food Sci Technol Int 20(2): 149-157.
[51] Wankhade P, Sapkal R and Sapkal V (2013). Drying characteristics of okra slices on drying in hot air dryer. *Procedia Engineering* 51: 371-374.
[52] Lee J.H., and Kim H.J., (2009). Vacuum Drying Kinetics of Asian White Radish (Raphanus sativus L.) Slices, LWT - Food Science and Technology, 42, p. 180
[53] Togrul I. T. and Pehlivan D. (2003). Modeling of drying kinetics of single apricot. *Journal of Food Engineering* 58:23–32.
[54] Zhao, D, Zhao C, Tao, H, An, K. and Ding S (2013) The effect of osmosis pretreatment on hot-air drying and microwave drying characteristics of chili (*Capsicum annuum* L.) flesh. International Journal of Food Science & Technology 48(8): 1589-1595.
[55] Uribe, E, Vega-Galvez, A, Di Scala, K., Oyanadel R. and Torrico J. S., (2011) Characteristics of convective drying of pepino fruit (*Solanum muricatum* Ait.): application of weibull distribution. Food and Bioprocess Technology 4(8): 1349-1356.
[56] Gazor, H. R. and Mohsenimanesh, A. (2010): Modelling the drying kinetics of canola in fluidised bed dryer. Czech J. Food Sci., 28: 531–537
[57] Doymaz, I. and Pala, M. (2002). The effects of dipping pretreatments on air-drying rates of the seedless grapes. *Journal of Food Engineering*, 52: 413-417.
[58] Olurin, T. O., A. O. Adelekan, and W. A. Olosunde. (2012). Mathematical modelling of drying characteristics of blanched field pumpkin (*Cucurbita pepo* L) slices. Agric Eng Int: CIGR Journal, 14(4): 246－254.