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SINGLE LAYER DRYING CHARACTERISTICS OF HOSPITAL TOO FAR LEAVES (*JATROPHA TANJORENSIS*) UNDER OPEN SUN AND IN SOLAR DRYER

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Abstract: The desire for cheap and proper drying methods, the need to obtain quality dried products and understanding of drying parameters of leafy vegetables have necessitated the evaluation of drying methods. In this study, Hospital too far leaves were obtained and cleaned with distilled water. The leaves were divided in two samples each weighing 20grams. The first sample was spread in a single layer on a mesh wire attached to a rack under open sun and the second sample was also spread in single layer on drying mesh of a solar dryer. The drying starts from 8:00 am to 4:30pm. Weights of the samples were measured after every 30 minutes. Ambient air temperature and drying chamber temperature were also measured. Moisture diffusivity coefficient was found to vary from 3.55x 10^{-8} to 4.22x 10^{-7} and 3.55x10^{-8} to 3.94x10^{-7} for open sun dried sample and solar dried samples respectively. The experimental drying curves exhibit only falling drying rate period. Solar drying method has shorter drying time against open sun drying method. Nine mathematical models were fitted to the experimental drying curves. The Page model was found to decently describe both open sun drying curve and solar drying curve.
Keywords: drying curves, effective moisture diffusivity, mathematical drying models

INTRODUCTION

Hospital too far belongs to the family Euphrobiacae and show physical appearance akin to *Jatropha Gossypifolia and Jatropha Curcas* (Parabakan and Siyatha, 1999).The plant originates from Central America and is very popular in Mexico, it has been introduced in the United State of America as potential leafy vegetable and or as medicinal plant (Kuti,1996). In Nigeria, the leaf is popularly called 'Ugu oyibo' in the east and 'Iyana ipaja' in the west, predominantly consumed as leafy vegetable and medicament for diabetes mellitus, treatment of malaria, blood building herb, antioxidant and supports spermatogenesis (Olayiwola *et al*., 2004; Mordi and Akanji, 2012; Gilbert, 2017; Omigie *et al*., 2013; Osuchukwu *et al*., 2016).

Drying increases the shelf life of farm produce by reducing the moisture content to a safe level. In Nigeria, fruits and vegetables are largely dried under open sun to harness the abundant solar radiation, however, open sun drying predisposes food to potential contaminant, rain damage and characterised by variation in drying time (Werner and Josef, 2012) and is not suitable for vegetables at temperatures below 30°C because they contain lower sugar and acid; this increases the risk for food spoilage (Naseer *et al*., 2013), solar dryers made up the shortcomings of open sun by providing increased drying temperature and lower humidity at the drying chamber thus providing more marketable products and efficient drying alternative to open sun (Werner and Josef, 2012) however, the geometry of the product also affects its drying rate (Lewicki, 2006) thus, vegetables and fruits are better dried in thin layer or single layer (Mursalim and Dewi, 2002). During crude organic compounds extraction from leaves especially for medicinal purposes, the leaves need to be dried for easy pulverization to obtain larger surface area and to obtain compounds in their natural and unaltered state due to inhibited biochemical reaction (Ravi, 2015).

Some studies carried out on the drying behaviour of some leaves under different drying conditions are documented in the literature: Vernonia amygdalina leaves (Alara, Abdulrahman and Olalere, 2017) Mint, Parsely and Basil leaves (Akpinar, 2006), Coriander leaves (Ahmed and Singh, 2001), Peppermint leaves (Alireza, 2016). Aramanth leaves (Papu *et al*., 2014) and red chilly leaves (Subahana et al., 2014) However, no study was reported on the drying characteristics of hospital too far leaves, thus the experimental investigation of the effective moisture diffusivity coefficient, drying curve and mathematical modelling of drying curves of hospital too far leaves forms the objectives of this study.

MATERIALS AND METHOD

Hospital too far leaves were detached from the plant, the leaves were then washed with distilled water to rid it of any dust or dirt and were allowed to rid off the water under ambient condition. The leaves' thickness was measured using SONGQI SQ-SXQFC25 digital micrometer screw gauge at different locations and the average was computed. The leaves were detached from the stalk and were divided into two samples weighing 20 grams each. The first sample was spread on mesh wire fixed to a rack forming single layer under open sun, the second sample was placed in a natural draft solar dryer chamber forming single layer on a mesh wire rack as well. The experiment started around 8:00 am and the mass of the leaves were measured after every 30 minutes till no further change in mass of the leaves was recorded, the air drying temperature under open sun and in the drying chamber were measured using MexTech digital multi-thermometers and the changes in mass of the leaves were measured using KERRO BL3002 electronic compact scale with precision of ±0.01g.

The moisture content was computed using eq. 1 on wet basis

$$Mc=\frac{Mi-Mf}{Mi}x\ 100 \quad (1)$$

M_i is the mass of sample before drying; M_f is the mass of sample after drying

For the purpose of performing mathematical modelling to obtain model equation(s) that best describe the drying characteristics of hospital too far leaves, the moisture ratio was computed using eq. 2

$$MR=\frac{Mt-Me}{Mo-Me} \quad (2)$$

The drying rate was estimated using eq. 3:

$$\frac{dR}{dt}=\frac{Mt+dt-Mt}{dt} \quad (3)$$

M_t is the moisture content at a particular dying time (%); M_e is the equilibrium moisture content (%); M_o is the initial moisture content (%); dt is the change in drying time; M_{t+dt} is the instantaneous moisture content as the drying time changes.

Nine (9) single layer drying models presented in Table 1 were fitted to the moisture ratio drying curves using MATLAB R2009b. Highest R^2 and lowest MSE and RMSE values were used as the performance function of the models.

Table 1: Single layer mathematical models for describing drying characteristics

S/N	Model name	Model equation
1	Newton	MR=exp(-kt)
2	Page	MR=exp(-kt^n)
3	Henderson and Pabis	MR=a exp(-kt)
4	logarithmic	MR=a exp(-kt)+b
5	Approximation of difusion	MR=a exp(-kt)+(1-a) exp(-kbt)
6	Modified Henderson and Pabis	MR=a exp(-kt)+b exp(-k_ot)+c exp(-k_1t)
7	Midilli-Kucuk	MR=a exp(-kt^n)+bt
8	Wang and Singh	MR=1+at+bt^2
9	Verma et al.	MR=a exp(-kt)+(1-a) exp(-k_ot)

RESULT AND DISCUSSION

— Drying Curves

For open sun and solar dried samples, as the drying temperature increases, the drying rate also increases and consequently the moisture content and moisture ratio decreases (Figs. 1, 2, 3, 5 and 6). It was observed that solar dried samples have shorter drying time compared to open sun dried sample, this was further substantiated by Midilli (2001) and Belghit *et al.*, (2000) with the explanation that this could be possible owing to higher drying chamber temperature and lower relative humidity (Fig. 3). The two samples reached their maximum drying rate at 43.64 % (Open sun) and 27.76% (Solar dryer) moisture level at 270th minute drying time which was succeeded by falling drying rate period (Figs. 5 and 6), according to Earle and Earle (1966) at the point of maximum drying rate followed by falling drying rate period, the water stops behaving as if it was a free water due to changes in energy binding pattern between the water molecules, thus negates a predominantly temperature controlled water diffusion to the surface of the leaves, hence, moisture content changes controls the drying rate. A similar drying result was reported by (Akpinar, 2011) for drying Parsley leaves under open sun and in solar dryer.

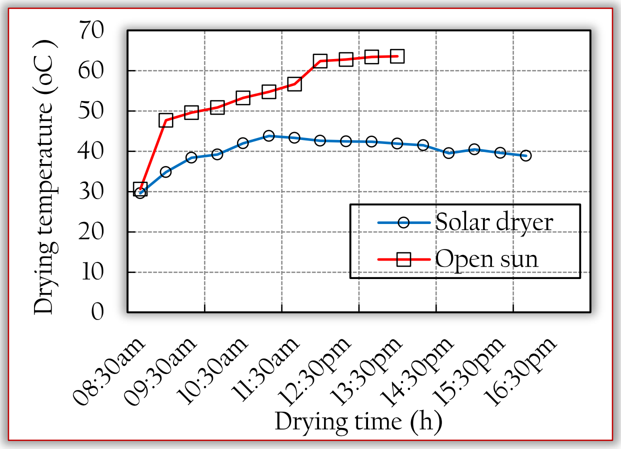

Figure 1. Variation of drying temperature with drying time

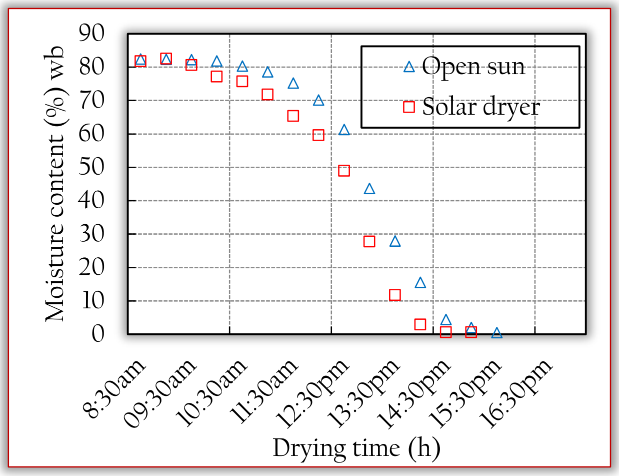

Figure 2. Variation of moisture content with drying time

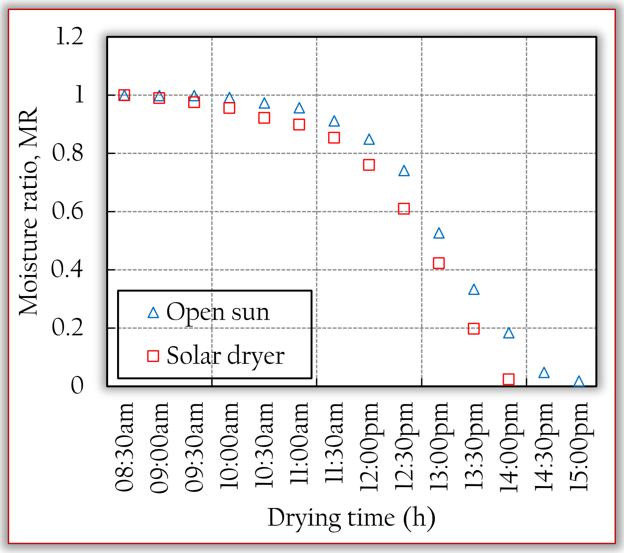

Figure 3. Variation of moisture ratio with drying time

It can also be seen from Figs. 5 and 6 that the drying rate curve of solar dried sample exhibits multiple negative and positive gradient at the early stage as moisture escapes the surface of the leaves, Keey (2011) imputed such behaviour to periodic discontinuities in drying causing selective moisture evaporation as the leaves' composition alters and also the build-up and cracking of the leaves' surface crust caused by disturbances (temperature changes during removal of samples from drying chamber) during sample weighing. The solar dried leaves appear greener to the eye against the open sun dried sample, this inferred superior product quality as more chlorophyll is retained in the leaves.


(a)
(b)
(c)

Figure 4. Fresh and dried hospital too far leaves: (a) fresh leaves sample: (b) open sun dried sample; (c) solar dried sample

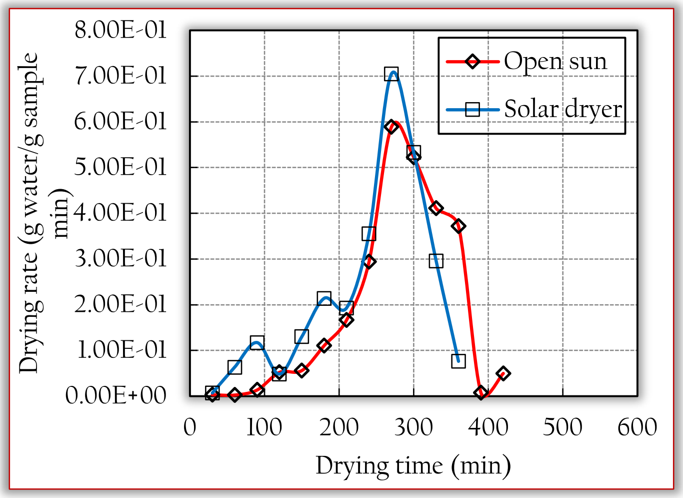

Figure 5. Plot of drying rate with changes in drying time

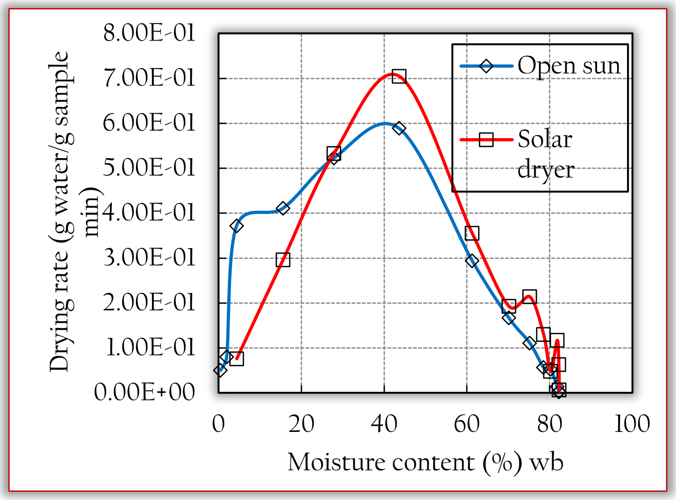

Figure 6. Variation of drying rate with changes in moisture content

— Effective Moisture Diffusivity (D_{eff})

During food drying, drying takes place in either falling rate period or constant rate period and it is govern by heat and mass transfer. During falling drying period, the rate of moisture migration in hygroscopic and isentropic matters could be represented by effective moisture diffusivity (Wang *et al.*, 2007). Moisture diffusivity can be explained in terms of the magnitude of the molar flux through the surface of the drying material per unit moisture concentration gradient away from the plane geometry (COMSOL, 2017). Effective moisture diffusivity is dependent on temperature, moisture content, porosity of material and pressure (Abe and Afzal, 1997; COMSOL, 2017). However, explaining how mass transfer occur in fruits and vegetables is quite difficult hence, Fick's second law expressed in eq. 1(Crank, 1975) is widely adopted to best describe the drying kinetics.

$$MR=\frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}\exp\left[\frac{-(2n+1)^2\pi^2 D_{eff}t}{4l^2}\right] \qquad (4)$$

MR is the dimensionless moisture ratio, D_{eff} is the effective moisture diffusivity (m^2/s), l is half the slap thickness of the material (m), t is the drying time (s) and n is the number of terms taken. Effective moisture diffusivity is determined by taking the slope of the plot of lnMR/t, the slope is presented in eq. 5 (Lamharrar et al., 2017).

$$K_o=\frac{\pi^2 D_{eff}}{4l^2} \qquad (5)$$

In this study, the effective moisture diffusivity was estimated at a given moisture ratio, drying time and drying air temperature neglecting shrinkage in the leaves thickness. The leaves were assumed to be infinite slabs.

It can be seen in Figure 7, that the effective moisture diffusivity of Hospital too far leaves ranges from 3.55x 10^{-8} to 4.22x 10^{-7} and 3.55x10^{-8} to 3.94x10^{-7} for open sun dried sample and solar dried sample respectively. The values fall between 10^{-7} to 10^{-12} for food materials as reported in Ashton (2013), Dincer and Hussain (2002) and Hosain *et al* (2014). From Figures 8 and 9, at the initial stage, as drying temperature increases, the effective moisture diffusivity of both open sun dried sample and solar dried sample gradually increases, however, toward the end of the drying time, when drying temperature changes was minimal and moisture content is low, diffusion coefficient increases sharply, this may signify that moisture content decrease results in vapour permeability increase (Hosain *et al*., 2013).

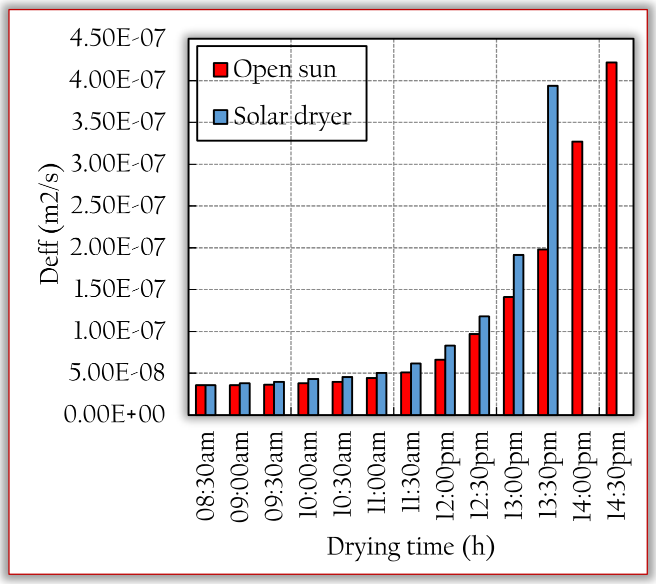

Figure 7. Plot of effective moisture diffusivity versus drying time

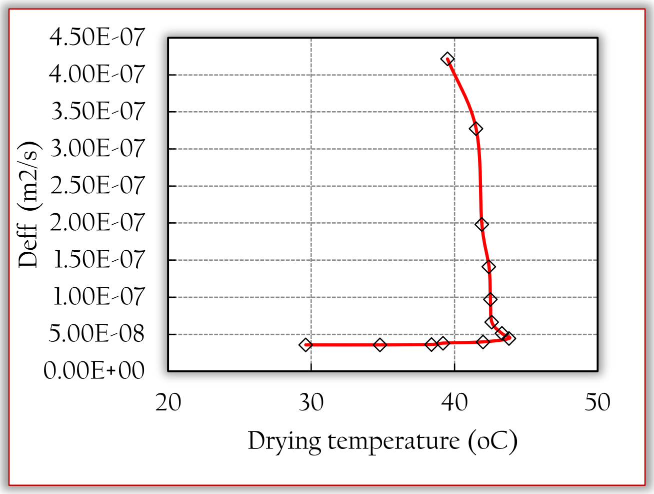

Figure 8. Variation of effective moisture diffusivity of open sun drying method with drying temperature

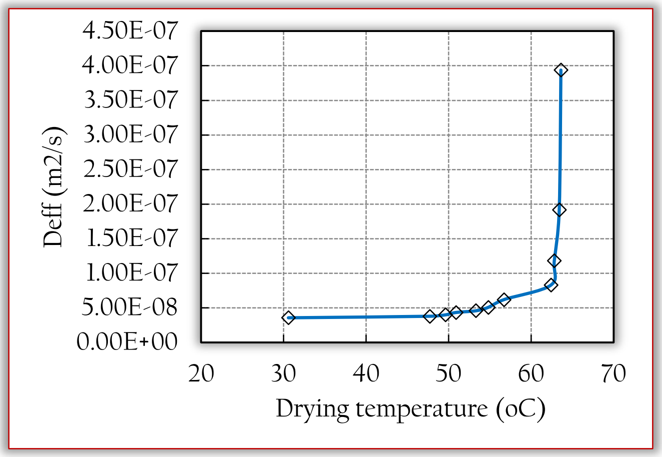

Figure 9. Variation of effective moisture diffusivity of solar drying method with drying temperature

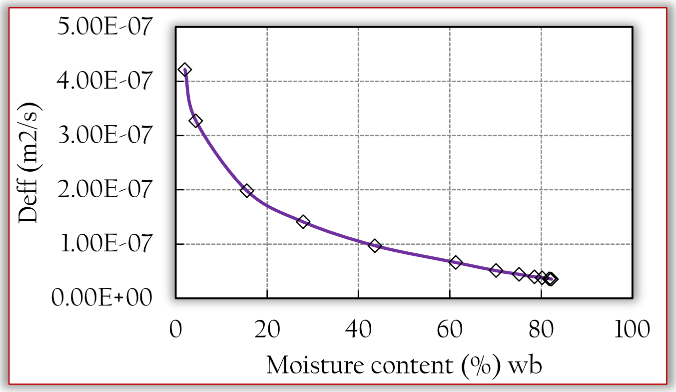

Figure 10. Variation of effective moisture diffusivity of open sun drying method with changes in moisture content

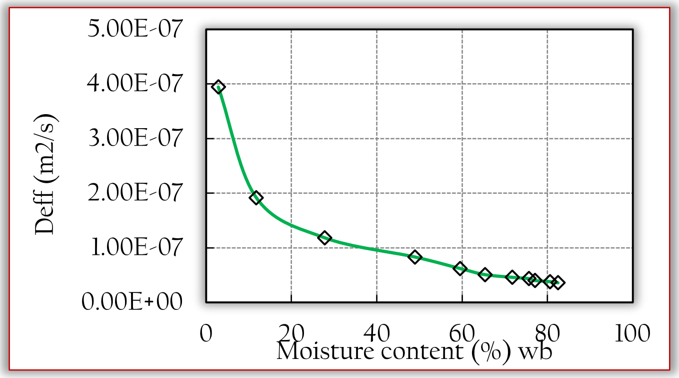

Figure 11. Variation of effective moisture diffusivity of solar drying method with changes in moisture content

From Figs. 10 and 11, the plot of D_{eff} against moisture content gave an exponential curve. Similar result was reported by Jen *et al.* (2001) and Hosain *et al.* (2013) with the explanation that it implies that effective moisture diffusivity is dominantly a function of moisture content of the leaves. Curve fitting was carried out using MATLAB R2009b and correlation equation was obtained for estimating moisture content dependent moisture diffusivity for both drying methods and is presented in eq. 6 below:

$$D_{eff} = 2.245\times10^{-7}\exp(-0.1817MC) + 2.245\times10^{-7}\exp(-0.0243MC) \quad (6)$$

MC is the moisture content, (wb).

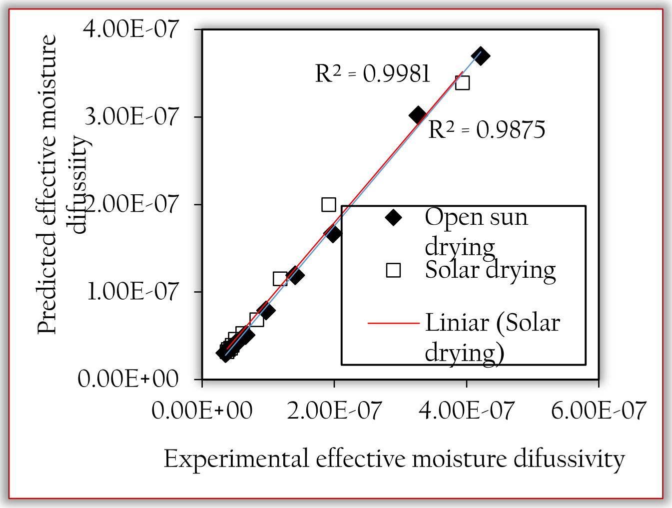

Figure 12. Experimental and predicted moisture diffusivity coefficient

— Fitting drying curves to mathematical drying models

Modelling is the most appropriate tool used in describing the drying characteristics and drying curves of fruits and vegetables. The results of fitted drying models presented in Tables 2 and 3 show that the Page model best describes the drying performance of both open sun and solar dried hospital too far leaves samples with R^2=0.9989, SSE=0.001879 and RMSE=0.01251 and R^2=0.9901, SSE=0.01214 and RMSE=0.03484 respectively.

Table 2: Open sun drying statistical parameters for each drying model

S/N	Model name	Coefficient	R^2	SSE	RMSE
1	Newton	k=0.06438	0.5695	0.8093	0.2495
2	Page	k=9.27x10^{-7} n= 5.821	0.9989	0.001879	0.01251
3	Henderson and Pabis	a= 1.359; k=0.1003	0.7028	0.5587	0.2158
4	Logarithmic	a= 369.7; k= 0.0002; b= -368.5	0.8338	0.3124	0.1685
5	Midilli-Kucuk	a= 239.8; k= 5.363; b=-0.2039; n=-0.07199	0.9533	0.06757	0.0822
6	Wang and Singh	a=0.0376; k=0.008227	0.9749	0.04715	0.06268
7	Approximation of diffusion	a= -169.7; k= 0.2357; b= 0.9899	0.8357	0.3089	0.1676
8.	Modified Henderson and Pabis	a= 54.54; k_o= 0.1659; k_1= 0.8834; b= 0.9842; c= -24.26	0.8666	0.2507	0.177
9	Verma et al.	a= 54.54; k= 0.2289; k_o= 0.2362	0.8355	0.3092	0.1676

Table 3: Solar drying statistical parameters for each drying model

S/N	Model name	Coefficient	R^2	SSE	RMSE
1	Newton	k= 0.06331	0.5710	0.5269	0.2189
2	Page	k=3.293e-006; n= 5.457	0.9901	0.01214	0.03484
3	Henderson and Pabis	a= 1.302; k= 0.0986	0.6995	0.3691	0.1921
4	Logarithmic	a=327.1; k=0.0002318; b= -326	0.8149	0.2274	0.1589
5	Midilli-Kucuk	a= 45.76; k= 3.7; b= -0.2079; n= -0.1035	0.9493	0.0235	0.0882
6	Wang and Singh	a= 0.04133; c=-0.01001	0.9809	0.04715	0.04847
7	Approximation of diffusion	a= -1.131; k= 0.06314; b=0.9794	0.571	0.5269	0.242
8.	Modified Henderson and Pabis	a= 1.897; k_o=0.001765; k_1= 0.2876; k_2= 0.4087; b=- 1.098; c= 0.3376	0.9490	0.06269	0.1022
9	Verma et al.	a= 127.9; k= 0.2034; k_o= 0.2056	0.8019	0.2433	0.1644

CONCLUSION

Study on drying characteristics of hospital too far leaves has been carried out, the experimental drying curves exhibit only falling drying rate period and solar drying method has shorter drying time against open sun drying method hence the advantage of solar drying approach against open sun drying. The effective moisture diffusivity coefficient of hospital too far leaves ranges from 3.55x 10^{-8} to 4.22x 10^{-7} and 3.55x10^{-8} to 3.94x10^{-7} for open sun dried sample and solar dried samples respectively. The Page model was found to decently describe both open sun drying curve and solar drying curve.

References

[1] Ahmed J., Singh G: Drying characteristics and product quality of coriander leaves. Food and bio products processing. Vol. 79, Issue 2, 103-106, 2001.
[2] Akpina, E. K.: Drying of parsley leaves in a solar dryer and under open sun: Modelling, energy and exergy aspects. Journal of food process engineering. 77-67, 2011.
[3] Ashton, A.: Issues in general food research. Scholarly Editions, Atlanta, Georgia. ISBN: 978-1-490-10951-0, 279-282, 2013.
[4] Alizera S., Seyed-Hassan, M. A., Mahmood R. G.: Comparison of drying characteristics of peppermint using different drying methods. Journal of Food Processing and Preservation. Vol. 41, Issue 3, 2016.
[5] Alara O. R., Abdulrahman O. A., Olalere O. A.: Mathematical modelling and morphological properties of thin layer oven drying of Vernonia Amygalina leaves. Journal of the Saudi Society of Agricultural Science. 2017.
[6] Akpinar, E. K.: Mathematical modelling of thin layer drying process under open sun of some aromatic plants. Journal of Food Engineering. 77, 864-870, 2006.
[7] Abe, T., Afzal, T. M.: Thin-layer infrared radiation drying of rough rice. Journal of Agricultural Engineering Research 67, 289-297, 1997.
[8] Belghi, A, Kouhila, M., Bouteleb, B, C.: Experimental study of drying kinetics by forced convection of aromatic plants. Energy Conservation and Management. Vol. 44, 1303-1321, 2000.
[9] COMSOL: Multiphysics Cyclopedia, available at http://www.comsol.com/multiphysics/diffusion-coefficient, 2017.
[10] Crank, J.: The mathematics of Diffusion (2nd ed.). Oxford, UK, Clarendon Press, 1975.
[11] Dincer, I. & Hussain, M. M.: Development of a new bi-di correlation for solid drying. International Journal of Heat and Mass Transfer, Vol. 45, No.15, 3065-3069, 2002.
[12] Earle, R. L., Earle, M. D.: Unit operation in food processing. NZIFST (inc), 1966.
[13] Giulbert, E.: Jathropher tanjorensis ("hospital too far"), Ugu-Oyibo, Iyana-Ipaja; an underutilized medicinal plant. Health bubbles, available at http://healthbubbles.com/gb//?p=3534, 2017.
[14] Hosain, D., Abbas R. S., Ali, A., Mohsen A., Gholamhasan N., Jalaj, K.: Study of the drying kinetics of pepper. Journal of the Saudi Society of Agricultural Science. 13, 130-138, 2014.

[15] Jen, Y. L., William, T. S., Steve P. V.: An Inverse Moisture Diffusion Algorithm for the Determination of Diffusion Coefficient. Drying Technology, 19(8), 1555-1568, 2001.
[16] Keey, R. B.: Drying. Thermopedia. Available at www.thermopedia.com/content/711/.2011.
[17] Lamharrar A., Idlimam A., Alouani A., Kouhila M.: Modelling of thin layer solar drying kinetics and effective diffusivity of Urtica dioica leaves. Jounal of Engineering Science and Technology. Vol. 12, no. 8, 2141-2153. 2017.
[18] Lewicki, P. P.: Design of hot air dryer for better foods. Trends in food science and technology, 17, 153-163, 2006.
[19] Kuti, J. O., Torres E. S.: Potential nutritional benefit of tree spinach in: progress in new crops, J. Janick (Ed), Arlington V. A., ASHS Press, 516-520, 1996.
[20] Mursalim, S. and Dewi, Y S.: Drying of cashew nut in shell using solar dryer, science and technology, 3(2), 25-30, 2002.
[21] Mordi, J. C., Akanji M. A.: Phytochemical screening of the dried leaf extract of snidoscolus aconitefolius and associated changes in lower enzymes induced by its administration in winstar rats. Curr. Res. Journ. Biol. Sci. 4(2), 153-158, 2012.
[22] Midilli A.: Determination of Pistachio Drying Behaviour and Condition in a Solar Drying Systems. International Journal of Energy Research, Vol. 25 No8, 715-725, 2001.
[23] Naseer A., Jagmohan S., Harmeet C., Prerna G.,Anisa A., Harleen K.: Different drying methods: Their application and recent advances. International Journal of Food Nutrition and Safety. 4(1), 34-42, 2013.
[24] Omigie, M. I., Agoreyo, F. O., Edobor, E. V.: The effect of jatropher tanjorensis on homoglobin concentration and parcked cell volume of winstar rats. Jos Journal of Medicure. 7,1, 2013.
[25] Olayiwola, G. E. O, Iwalewa E. O., Omobuwajo, A. A., Verspohi, E. J.: The anti-diabetic potential of Jatropher Tanjeronsis leaves. Nigerian Journal of Natural Medicine. 8, 55-58, 2004.
[26] Osuchukwu I. W., Sakpa C. L., Ekezie J., Okeke C. U., Eke C. C., Ezejindu D. N.: Effect of leave extract of Jatropha Tanjeronsis on the testis of wistar rats. Journal of Medical and Dental Science. Volume 15, Issue 4, Ver. IV, 66-71, 2016.
[27] Prabakaran, A. J., Sujalha M.: Jatropher Tanjeronsis Ellis and Saroja, a natural interspecific hybrid occurring in Tamil Nadu, India. Gen. Res. Crop Evol., 46:213-218, 1999.
[28] Ravi K. Why do we extract dried, ground plant material instead of fresh ones? Available at www.researchgate.net, 2015.
[29] Subahana K. R. R., Natarajan A., Melvin M., Muralidharan N. G.: The thin layer drying characteristics of chilly leaf under open sun and in solar dryer. ARPN Journal of Engineering and Applied Sciences. Vol. 9, No. 11, 2158-2167, 2014.
[30] Werner W., Josef B. Solar Drying: Establishment of a production, sales and consulting infrastructure for solar thermal plant in Zimbabwe. Training Course, 2012.
[31] Wang, Z., Sun, J., Chen, F., Liao, X., Hu, X.: Mathematical modelling of thin layer microwave drying of apple pomace with and without hot-air pre drying. Journal of Food Engineering. 80(2), 536-544, 2007.

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