Croat. J. Food Sci. Technol. (2021) 13 (1) 43-50
"ARTICLES IN PRESS"

Croatian Journal of Food Science and Technology
journal homepage: www.ptfos.unios.hr/cjfst/

Original scientific paper *DOI: 10.17508/CJFST.2021.13.1.06*

Modeling of thin layer drying characteristics of blanch-assisted water yam (*Dioscorea alata*) slices

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ARTICLE INFO

Article history:
Received: March 16, 2020
Accepted: August 3, 2020

Keywords:
water yam slices
drying kinetics
drying models
process design
acceptability

ABSTRACT

The thin layer drying characteristics of blanch-assisted water yam slices were investigated with respect to its un-blanched water yam slices in a convective hot air oven. The yam slices (diameter 4 cm; thickness 0.8 cm) were dried at temperatures 50, 60 and 70 °C, respectively with a constant air velocity of 0.13 m/s. The drying data obtained were fitted into six existing drying models: Page, Newton, Midilli, Henderson and Pabis, Logarithmic and Diffusion model. Non-linear regression analysis was used to determine the model parameters; the coefficient of determination (R^2) and standard error of estimates (SEE) in order to determine the model best fit. The study showed that the drying process occurred in the falling rate drying period. The blanch-assisted slices had a faster drying rate than the un-blanched yam slices. Among the models, the diffusion model gave the overall best fit for the drying data obtained. The effective moisture diffusivity ranged from 3.18×10^{-8} to 4.47×10^{-8} m^2/s for the blanch-assisted slices and from 4.73×10^{-8} to 7.33×10^{-8} m^2/s for the un-blanched slices. The activation energies of the blanch-assisted and un-blanched yam slices were 15.5 kJ/mol and 20.1 kJ/mol, respectively. These processing conditions obtained for water yam flour would be suitable for its process design and control thereby enhancing its utilization and overall acceptability.

Introduction

In many tropical and subtropical countries, yams have served as a staple food and cash crop for millions of people especially along the coast of West Africa (Akanbi *et al*., 1996; Olabode *et al*., 2016). Yam tubers are edible starchy crop, which has been of cultural, economic, and nutritional importance in most countries (Olabode *et al*., 2016). There are more than 600 yam species grown across the globe. The most economically important species in West Africa has been the White yam (*Dioscorea rotundata*), Yellow yam (*Dioscorea cayenensis*) and Water yam (*Dioscorea alata*) (Falade *et al*., 2007).

Water yam (*D. alata*) is a seasonal crop which was first cultivated in Southeast Asia (Oko and Famurewa, 2015). It is less cultivated when compared to other African yams, but it is highly economical and widely distributed worldwide (Udensi *et al*., 2010). According to Opara (1999), water yam has a moisture content of 65-76% per 100g edible tuber portion. Its high moisture content makes it highly perishable with losses in post-harvest increasing due to poor processing and storage conditions.

Drying operation in food processing is an important unit operation that is old and widely practised to enhance food preservation (Koyuncu *et al*., 2007). It helps to reduce the water activity in food products to a level that inhibits or control microbial growth and deteriorative biochemical reaction in order to extend its shelf life (Mujumdar and Law, 2010). The knowledge of the drying kinetics of food products is important in the optimization of the drying process; design of drying equipment and in understanding the appropriate mechanism of drying in order to enhance energy efficiency and the product quality (Ju *et al*., 2015). The drying kinetics of several fruits and vegetables like apple slices, banana slices, carrot slices, tomato slices, mint leaves, jackfruits, and kiwi fruits have been reported using appropriate drying

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models (Onwude *et al.*, 2016). Researches have focused more on drying kinetics of white yam slices, but less research have been conducted on the drying kinetics of water yam slices under different processing conditions. Therefore, the objective of this research was to determine the drying kinetics of water yam slices using appropriate models.

Materials and methods

Sample preparation

The water yam tubers were obtained from Obafemi Awolowo University Research Farm, Ile-Ife, Nigeria. The tubers were washed, hand-peeled and cut into circular slices of radius 4 cm and thickness of 0.8 cm. The slices (100 g) were blanched to deactivate enzymatic activities and prevent browning reaction using hot water at 90 °C for 2 minutes and then drained (Ju *et al.*, 2015). Another 100 g of the slices were prepared as a un-blanched sample which served as the control.

Drying of yam slices

The yam slices (200 g) were dried using the thin layer drying method at temperatures 50, 60, and 70 °C in a hot air oven (SM9053, Uniscope, England) which was operated at an air velocity of 0.13 m/s. The ambient air humidity ranged between 0.008 and 0.010 kg/kg dry air. The change in weight of the slices during the drying process was monitored at 5 minutes intervals for the first one hour, 15 minutes interval for the next one hour and 30 minutes interval until equilibrium was attained (Akanbi *et al.*, 2006). Drying experiments were done in triplicate.

Drying kinetics

The yam slices were dried continuously at a temperature of 105 °C for 24 hours until the bone-dry weight was obtained. The moisture contents of the yam slices on a wet basis (w.b) and dry basis (d.b) was determined using Equations (1) and (2). The moisture ratio (MR) of the yam samples was determined using Equation (3). Drying curves were generated from the experimental drying data obtained. From these curves, the drying rate data were obtained by the method of the gradient at points on the curves (Equation (4)).
Dry basis moisture content

$$(\text{d.b}) = \frac{W - W_s}{W_s} \quad (1)$$

Wet basis moisture content

$$(\text{w.b}) = \left(\frac{W - W_s}{W}\right) X\ 100 \quad (2)$$

where, W = weight of solid + moisture (g)
W_s = weight of dried solid or dry bone weight (g)

$$\text{MR} = \frac{\text{M} - \text{M}_\text{e}}{\text{M}_\text{i} - \text{M}_\text{e}} \quad (3)$$

where, MR = Moisture ratio (dimensionless);

M = average moisture content (kg moisture/kg dry solid) of the slices at time t;
M_e = equilibrium moisture content (kg moisture/kg dry solid) at the drying temperatures;
M_i = initial moisture content (kg moisture/kg dry solid) of the slices at t = 0.

$$\text{Drying rate} = \frac{change\ in\ moisture\ content}{change\ in\ time} \quad (4)$$

Modelling of the drying kinetics of the yam slices

In order to understand the suitable model for the drying characteristics of the yam samples, the drying experimental data were fitted into five existing models (Table 1) widely used in literature for drying experiments of food materials. The models have been used by several authors (Akpinar, 2006; Akanbi *et al.*, 2006; Diamante and Munro, 1993; Aregbesola *et al.*, 2015) for the drying of food materials.

Table 1. Drying Model Equations

Model	Equation	References
Newton	$MR = exp(-kt)$	El-Beltagy *et al*. 2007
Page	$MR = exp(-kt^n)$	Akoy, 2014
Henderson and Pabis	$MR = a\ exp(-kt)$	Akpinar *et al.*, 2003
Midilli	$MR = aexp(-kt^n) + bt$	Midilli *et al.*, 2002
Diffusion	$MR = aexp\ (-kt) + (1-a)\exp(-kbt)$	Yaldiz and Ertekin, 2007
Logarithmic	$MR = a\ exp(-kt) + c$	(Olurin *et al.*, 2012);

where, MR = Moisture ratio; t = Temperature °C; k, a, b, c, and n = unknown values to be estimated

Statistical analysis

The suitability of the models was determined using Excel solver tool and non-linear regression data analysis by comparing the residual sums of squares (RSS), co-efficient of determination (R^2) and sum of the square error (SEE). The RSS, R^2 and SEE values were obtained using Equations (5) (6) and (7), respectively (Akanbi *et al*., 2006):

$$RSS = \sum_{i=1}^{n}(M_{calculated} - M_{predicted}) \quad (5)$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}(M_{calculated} - M_{predicted})^2}{d.f}} \quad (6)$$

$$R^2 = \left(1 - \frac{RSS}{TSS}\right) \quad (7)$$

where, M calculated = equilibrium moisture content (EMC) by experiment, % dry basis;
M predicted = predicted EMC due to models, % dry basis;
RSS = residual sum of squares;
TSS = total sum of squares;
d.f. = total degree of freedom.

The TSS value was obtained from the ANOVA (Analysis of Variance) table of the non-linear regression model.

Effective moisture diffusivity and activation energy

The effective diffusivities of the blanched and unblanched yam slices were estimated using the simplified Fick's second law of diffusion model (Equation (8)). The Fick's second law is based on the assumption that moisture migration is due to diffusion, negligible shrinkage, constant diffusion coefficients and temperature (Akanbi *et al*., 2006).

$$MR = \frac{M - M_e}{M_i - M_e} = \frac{8}{\pi^2}\sum_{i=1}^{n}\frac{1}{(2n-1)^2}\exp[\frac{-(2n-1)^2\pi^2 D_{eff}t}{4H^2} \quad (8)$$

$$MR = \frac{8}{\pi^2}\exp[\frac{-\pi^2 D_{eff}t}{4H^2}] \quad (9)$$

where, D_{eff} = effective diffusivity (m^2/s) at the drying temperature; H = thickness (m) of the slices; t = drying time (s).
The activation energy was obtained by plotting the natural logarithm of D_{eff} against the reciprocal absolute temperature. Akpinar *et al*. (2003) and Falade *et al*. (2007) described the temperature dependence of effective diffusivity using the Arrhenius type equation (Equation (10)).

$$D_{eff} = D_o \exp(-\frac{E_a}{RT}) \quad (10)$$

where, D_o = diffusion coefficient; E_a = activation energy (kJ/mol); R = universal gas constant (8.314 J/mol. K) and T = absolute air temperature (K).

Results and discussions

Effects of temperature and time on the moisture content and moisture ratio of water yam slices

The moisture content of the water yam slices (blanched and un-blanched samples) decreased with the drying time during the drying process until the equilibrium moisture contents of the slices were attained. The Moisture Ratio (MR) obtained decreased exponentially with the drying time as shown in Figures 1 and 2. The continuous decrease in the moisture ratio indicates that the internal mass transfer of moisture occurred through the mechanism of diffusion during the drying process. This trend correlated with the reports of several authors on the drying of various food materials (Falade and Abbo, 2007; Doymaz, 2005; Ertekin and Yaldiz, 2004; Aregbesola *et al*., 2015; Torres *et al*., 2012).

The slices (blanched and un-blanched) dried at 70 °C had the steepest curve and shortest drying time while the samples dried at 50 °C took longer drying time to achieve the equilibrium moisture content and less shrinkage was observed at this temperature. The moisture ratio of the blanched slices was higher than that of the un-blanched samples as shown in Figure 3. According to Falade *et al*. (2007), blanching may have caused the gelatinization of yam starches, resulting in a decreased rate of moisture migration from within the material to the surface during air-drying. A similar result was reported by Dandamrongrak *et al*. (2003) during the air-drying of blanched banana. Also, from Figure 3, it was observed that the unblanched samples took shorter drying time to attain its equilibrium moisture content than the blanched samples.

Effects of drying temperature and drying time on the drying rates

The drying rate of the yam slices (blanched and un-blanched) at higher temperature was faster than at lower temperature. This was due to the increased hot air effect on the slices. The drying rate also decreased with decreasing moisture ratio during the drying process. The drying rate of the un-blanched samples was faster than that of the blanched samples. The drying of the yam slices at the three temperatures occurred predominantly in the falling rate period with no constant rate period observed. The absence of a constant rate period was due to the internal moisture movement that occurred during the drying process. Similar results were reported for okra (Doymaz, 2005), dika nut (Aregbesola *et al*., 2015), date palm (Falade and Abbo, 2007), white yam (Falade *et al*., 2007) and eggplant (Ertekin and Yaldiz, 2004). According to Akanbi *et al*. (2006) when a food material dries mainly in the falling rate period, then it is assumed that internal diffusion had occurred. This phenomenon has also been observed for most hygroscopic food materials (Akanbi *et al*., 2006).

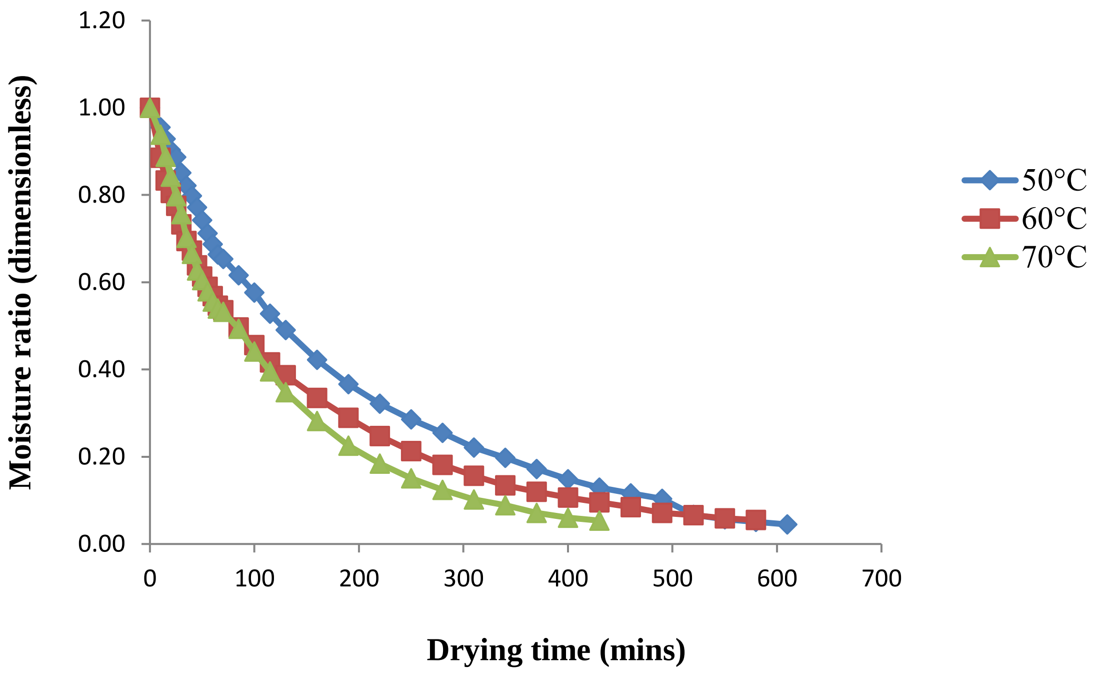

Fig 1. Moisture ratio of the blanched samples dried at different temperatures

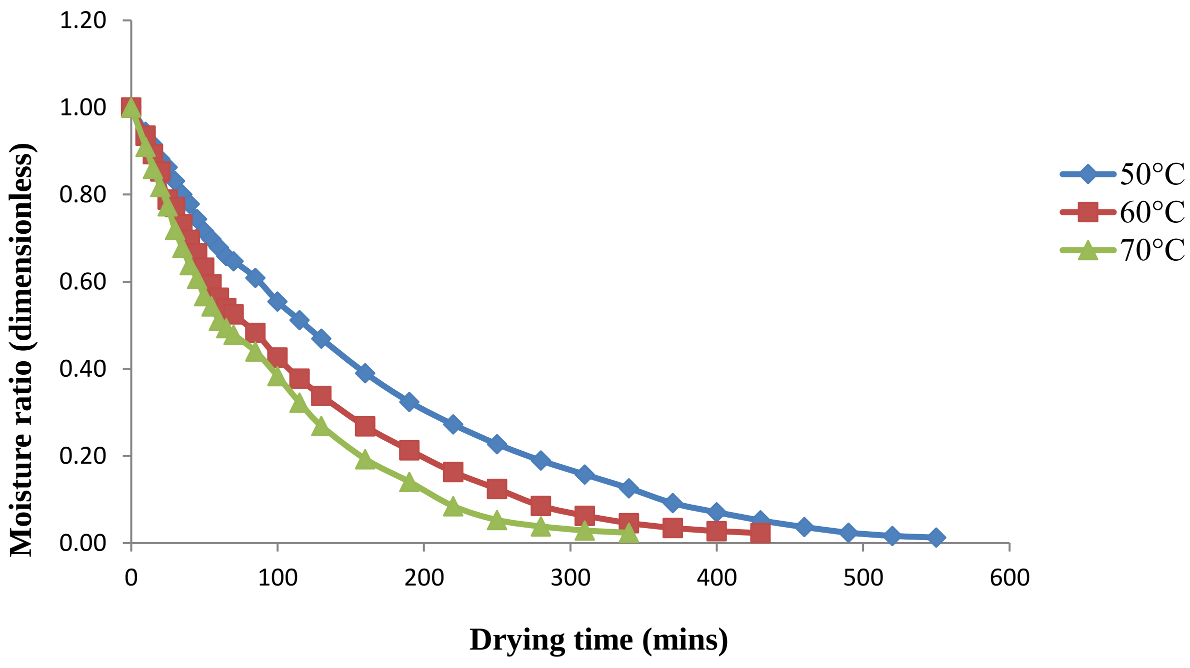

Fig 2. Moisture ratio of the unblanched samples dried at different temperatures

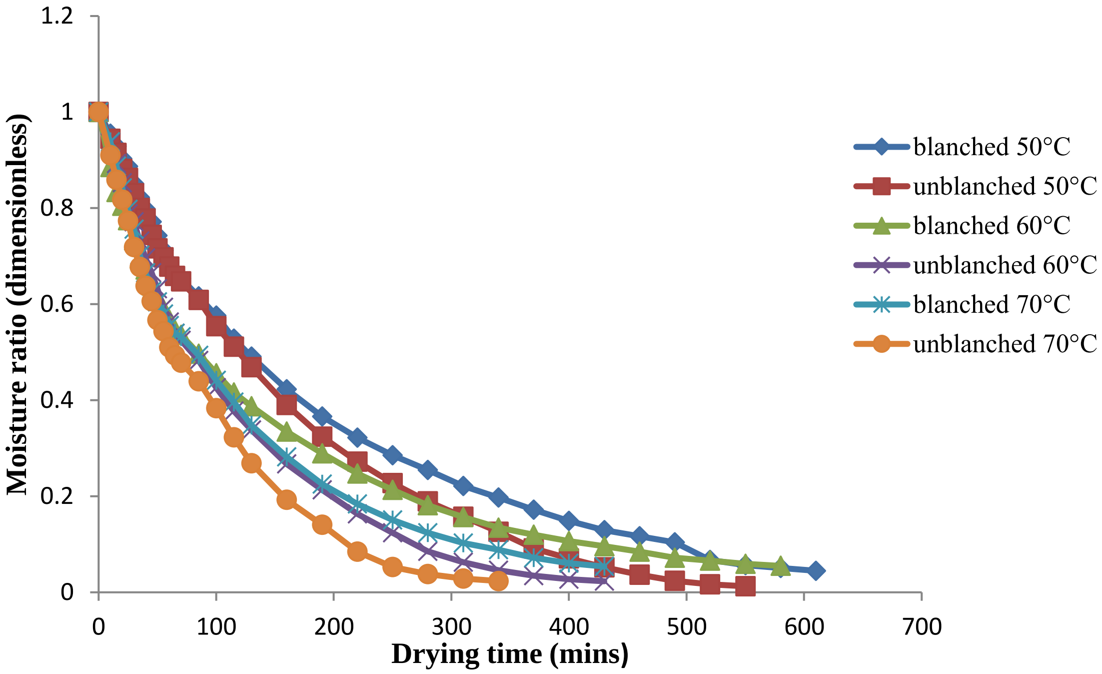

Fig 3. Comparison of the blanched and unblanched samples dried at three different temperatures

Table 2. Model parameters of blanched water yam samples

S/N	Model	Temp. (°C)	Parameters	R^2	SEE
1.	Newton	50	K= 0.0053	0.9975	0.0175
		60	K= 0.0077	0.9935	0.0278
		70	K= 0.0085	0.9953	0.0231
2.	Page	50	K= 0.0080; n= 0.9178	0.9985	0.0134
		60	K= 0.0257; n= 0.7440	0.9989	0.0094
		70	K= 0.0157; n= 0.8661	0.9966	0.0181
3.	Henderson and Pabis	50	K= 0.0051; a= 0.9760	0.9971	0.0183
		60	K= 0.0061; a=0.8867	0.9882	0.0361
		70	K= 0.0079; a= 0.9598	0.9936	0.0260
4.	Midilli	50	K= 0.0155; n= 0.8037; a= 1.0684, b= 0.0000	0.9991	0.0098
		60	K= -5.0111; n= -0.079; a= 0.0138; b= -0.0006	0.9716	0.0495
		70	K=-7.5717; n= -0.0501; a= 0.0012; b= -0.0006	0.9731	0.0487
5.	Diffusion	50	K= 0.0145; a= 0.1796; b= 0.3010	0.9989	0.0112
		60	K= 0.0276; a= 0.3333; b= 0.1622	0.9993	0.0080
		70	K= 0.0180,a= 0.3736,b= 0.3100	0.9974	0.0157
6.	Logarithmic	50	K= 0.0055; a= 0.9612; c= 0.0260	0.9976	0.0163
		60	K= 0.0079; a= 0.8617; c= 0.0627	0.9936	0.0238
		70	K= 0.0092; a= 0.9391; c= 0.0454	0.9960	0.0199

where, k, n, a, b, c, are the model constants, R^2 is the coefficient of determination and SEE is the sum of estimates errors

Modelling of drying kinetic data

The evaluation criteria (R^2 and SEE) for all the models gave a good description of the drying characteristics of yam slices (blanched and unblanched) with R^2 greater than 0.96 as presented in Tables 2 and 3. The three models that best fit the drying data were the Logarithmic, Midilli and Diffusion models. From the R^2 values obtained from these models for all samples and drying conditions, it was observed that the Diffusion model best described the water yam flour samples with a highest R^2 value of 0.9993 and lowest SEE value 0.0080. Satimehin (2017) reported that the Diffusion model satisfactorily described the drying data obtained from white yam dried at 40, 50 and 60 °C.

Effective moisture diffusivity and activation energy

The moisture diffusivity of the blanched and unblanched yam slices obtained from ln (MR) versus drying time increased with increasing temperature as shown in Figure 4. The effective moisture diffusivity of the yam slices (blanched and unblanched) as shown in Table 4 ranged from 3.18×10^{-8} to 7.33×10^{-8} m^2/s. The diffusivity values obtained from the experimental data fall within the range 10^{-11} to 10^{-6} m^2/s reported for most food products (Doymaz, 2007; Tunde-Akintunde, 2009). A similar result was also reported (7.62×10^{-8} to 9.06×10^{-8} m^2/s) by Sobukola *et al*. (2008) for yam slices. From the table, it could be observed that the unblanched slices had higher effective diffusivity values than the blanched slices. A similar observation was reported by Falade *et al*. (2007) in their study on white and water yam slices. From the table, the R^2 obtained were above 0.98. According to Aregbesola *et al*. (2015), this indicates that the best fit for each drying temperature is given by a linear relationship.

The activation energy obtained for the blanched and unblanched slices was 15.5 kJ/mol and 20.1 kJ/mol, respectively as shown in Table 4. These values are within the range of 12.7 to 110 kJ/mol reported for food materials (Zogzas *et al*., 1996; Falade *et al*., 2007; Torres *et al*., 2012; Aregbesola *et al*., 2015). The unblanched slices had higher activation energy than the blanched slices. This implies that the blanching pretreatment reduced the amount of energy required for mass diffusion to be initiated from a food material during the drying process. A similar result was reported by Doymaz (2007) for tomatoes.

Table 3. Model parameters of unblanched water yam samples

S/N	Model	Temp. (°C)	Parameters	R^2	SEE
1.	Newton	50	K=0.0061	0.9986	0.0129
		60	K=0.0087	0.9984	0.0136
		70	K=0.0106	0.9978	0.0154
2.	Page	50	K= 0.0059; n= 1.0097	0.9985	0.0134
		60	K=0.0101; n= 0.9681	0.9984	0.0128
		70	K= 0.0115; n= 0.9808	0.9978	0.0151
3.	Henderson and Pabis	50	K= 0.0061; a= 0.9981	0.9987	0.0127
		60	K= 0.0087; a= 0.9948	0.9984	0.0137
		70	K= 0.0105; a= 0.9948	0.9978	0.0154
4.	Midilli	50	K= -5.0436; n= -0.0638; a= 0.0138; b= -0.0007	0.9633	0.0650
		60	K=0.0155;n= -0.8897; a= 1.0529; b= 0.0000	0.9988	0.0112
		70	K= 0.0134; n= 0.9503; a=1.0181; b= 0.0000	0.9976	0.0154
5.	Diffusion	50	K= 0.0078; a= -2.7238; b= 0.9368	0.9986	0.0130
		60	K= 0.0244; a= 0.0772; b= 0.3317	0.9988	0.0122
		70	K= 0.0449; a= 0.0307; b= 0.2261	0.9979	0.0152
6.	Logarithmic	50	K= 0.0057; a= 1.0125; c= -0.0242	0.9991	0.0105
		60	K=0.0089; a= 0.9910; c= -0.0074	0.9984	0.0136
		70	K= 0.0105; a= 0.9939;c= 0.0016	0.9978	0.0154

where, k, n, a, b, c, are the model constants, R^2 is the coefficient of determination and SEE is the sum of estimates error.

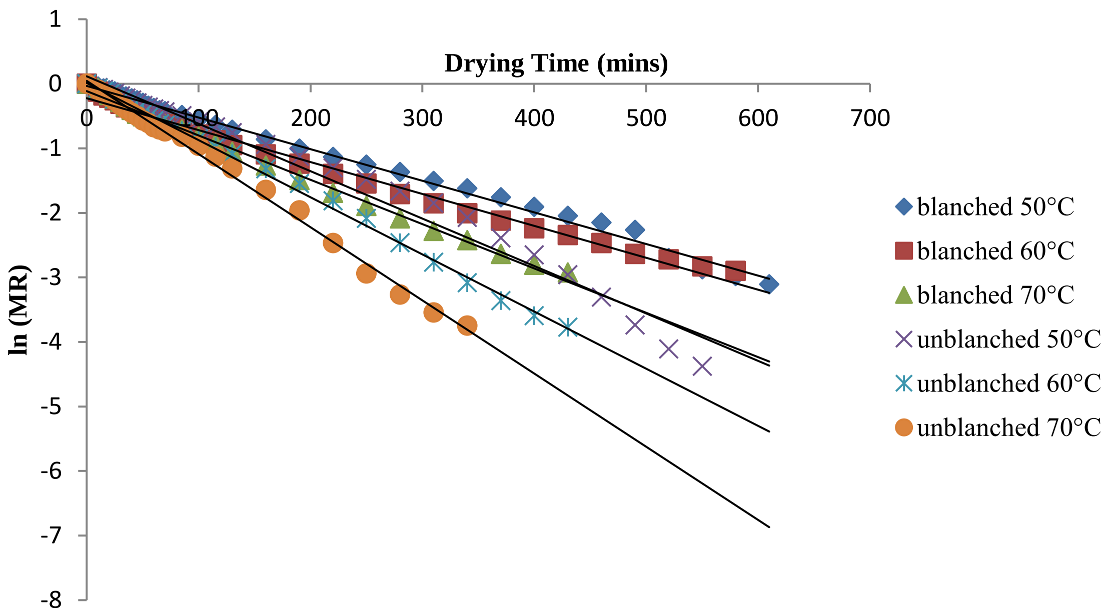

Fig 4. Plot of ln (MR) versus drying time of blanched and un-blanched water yam slices

Table 4. Effective moisture diffusivity and activation energy of water yam slices

	Activation energy, E_a (kJ/mol)	Temperature (°C)	Diffusivity (m^2s^{-1}) x 10^8	Equation of fit	R^2
Blanched	15.5	50	3.18	y = -0.0049x - 0.0333	0.9948
		60	3.18	y = -0.0049x - 0.2237	0.9904
		70	4.47	y = -0.0069x - 0.1138	0.9951
Unblanched	20.1	50	4.73	y = -0.0073x + 0.1159	0.9804
		60	5.77	y = -0.0089x + 0.0127	0.9976
		70	7.33	y = -0.0113x + 0.0453	0.995

Conclusion

The yam slices dried mainly in the falling rate period; hence, the mechanism of diffusion occurred throughout the drying process. The increase in the drying temperature had a strong effect on the rate of drying and the overall drying time of the yam slices. Also, the pretreatment given to the yam slices prior to drying also had a significant effect on the rate of drying and the overall drying time of the yam slices in which the blanched samples had lower drying rate and longer drying time than the un-blanched samples. Among the six mathematical drying models used to describe the moisture ratio of the yam slices with time, the three mathematical models that best describe the drying data were the Logarithmic, Midilli and Diffusion model. The Diffusion model gave a better description of the experimental drying data obtained for the water yam slices. The moisture diffusivity of the yam slices was within the range for food materials with the unblanched samples having higher effective moisture diffusivity value than the blanched samples. The activation energy value for the unblanched samples was higher than that of the blanched samples.

Funding: This research received no external funding.
Conflicts of Interest: The authors declares no conflicts of interest.

References

Akanbi, C. T., Gureje, P. O., and Adeyemi, I. A. (1996): Effect of heat moisture pre-treatmenton physical characteristics of dehydrated yam. *J. Food Eng.* 28, 45–48. DOI 0260-8774(95)00027-5

Akanbi, C.T., Adeyemi, R.S and Ojo, A. (2006): Drying characteristics and sorption isotherm of tomato slices. *J. Food Eng.*, 73, 157-163. https://doi.org/10.1016/j.jfoodeng.2005.01.015

Akoy, E.O. (2014): Experimental characterization and modeling of thin-layer drying of mango slices. *Int. Food Res. J.*, 21 (5), 1911–1917.

Akpinar, E. K., Bicer, Y., and Yildiz, C., (2003): Thin layer drying of red pepper. *J. Food Eng.*, 59 (1), 99–104. https://doi.org/10.1016/s0260-8774(02)00425-9

Aregbesola, O.A., Ogunsina, B.S., Sofolahan, A.E. and Chime N.N. (2015). Mathematical modeling of thin layer drying characteristics of dika (*Irvingia gabonensis*) nuts and kernels. *Nig. Food J*, 33: 83-89 https://doi.org/10.1016/j.nifoj.2015.04.012.

Dandamrongrak, R., Mason, R., and Young, G. (2003). The effect of pretreatments on the drying rate and quality of dried bananas. *Int. J. of Food Sci. and Tech.*, 38: 877–882. https://doi.org/10.1046/j.0950-5423.2003.00753.x

Diamante, L.M. and Munro, P.A. (1993). Mathematical modeling of the thin layer solar drying of sweet potato slices. *Solar Energy*, 51: 271–276. https://doi.org/10.1016/0038-092X(93)90122-5

Doymaz, I. (2005). Drying characteristics and kinetics of okra. *J. Food Eng.*, 69: 275–279. https://doi.org/10.1016/j.jfoodeng.2004.08.019

Doymaz, I. (2007). Air-drying characteristics of tomatoes. *J. Food. Eng.*, 78 (4): 1291–1297. https://doi.org/10.1016/j.jfoodeng.2005.12.047

El-Beltagy, A, Gamea, G.R., Essa, A.H.A. (2007). Solar drying characteristics of strawberry. *J. Food Eng.* 78: 456–464. https://doi.org/10.1016/j.jfoodeng.2005.10.015

Ertekin, C., and Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin Layer drying model. *J. Food Eng.*, 63: 349–359. https://doi.org/10.1016/j.jfoodeng.2003.08.007

Falade, K.O. and Abbo, E.S. (2007) Air-drying and rehydration characteristics of date palm (Phoenix dactylifera L.) fruits. *J. of Food Eng.*, 79: 724–730. doi:10.1016/j.jfoodeng.2006.01.081

Falade, K.O., Ike, E.A., Ogugua, A.C. and Olurin, O.T. (2007). Effect of pretreatment and temperature on air-drying of *Dioscorea alata* and *Dioscorea rotundata* slices. *J. Food Eng.*, 80: 1002-1010. doi:10.1016/j.jfoodeng.2006.06.034

Ju, H.Y., Law, C., Fang, X.M., Xiao, H.W., Liu, Y.H. and Gao, Z.J. (2015) Drying kinetics and evolution of sample's core temperature and moisture distribution of Yam Slices (*Dioscorea alata* L.) during convective hot air drying. *Drying Tech.*, 34 (11): 1299 – 1306. https://doi.org/10.1080/07373937.2015.1105814

Koyuncu, T., Tosun, İ., and Pınar, Y., (2007). Drying characteristics and heat energyrequirement of cornelian cherry fruits (Cornus mas L.). *J. Food Eng.*, 78 (2): 735-739. https://doi.org/10.1016/j.jfoodeng.2005.09.035

Midilli, A., Kucuk, H. and Yapar, Z. (2002). A new model for single-layer drying. *Drying Tech.*, 20 (7): 1503-1513. https://doi.org/10.1081/DRT-120005864

Mujumdar, A. S and Law, C. L (2010) Drying Technology: Trends and Applications in Postharvest Processing. *Food Bio. Tech.* 3: 843–852. https://doi.org/10.1007/s11947-010-0353-1

Oko and Famurewa; Estimation of Nutritional and Starch Characteristics of *Dioscorea alata* (Water Yam) Varieties Commonly Cultivated in the South-Eastern Nigeria. *British J. App. Sci. & Tech.* (BJAST), 6(2): 145-152. DOI: 10.9734/BJAST/2015/14095

Olabode, O.S., Sangodele, A.G. and Akinpelu, F.A. (2016). Effect of atrazine on germination and growth performance of water yam (*Dioscorea alata*). *J. Agric. and Ecology Res. Int.*, 5 (2): 1-6. DOI: 10.9734/JAERI/2016/19781.

Olurin, T.O., Adelekan, A.O., Olosunde, W.A. (2012). Mathematical modeling of drying characteristics of blanched field pumpkin (*Cucurbita pepo L*) slices. *Agric. Eng. Int.: CIGR Journal*, 14(4): 246–254.

Onwude, D. I., Hashim, N., Janius, R. B., Nawi, N. M. and Abdan, K. (2016) Modeling the Thin-Layer Drying of Fruits and Vegetables: A Review. *Comp. Rev. Food Sci. and Food Safety*, 15(3): 599-618. https://doi.org/10.1111/1541-4337.12196

Opara, L.U. (1999). Yam storage. In: Bakker-Arkema *et al.* (eds). CIGR Handbook ofAgricultural Engineering Volume IV Agro Processing. The American Society of Agricultural Engineers, St. Joseph, MI. Vol. IV. Agro processing. pp. 182-214.

Satimehin, A.A. (2017) Kinetics of Gelatinized White Yam (*Dioscorea Rotundata*, Poir) During Convective Drying. FUOYE *J. Eng. and Tech.*, 2(2): 47-52. https://doi.org/10.46792/fuoyejet.v2i2.127

Sobukola, O.P., Dairo, O.U. and Odunewu. V.O. (2008). Convective hot air drying of blanchedyam slices. *Int. J. Food Sci. and Tech.*, 43:1233-1238. https://doi.org/10.1111/j.1365-2621.2007.01597.x

Torres, R., Montes, E. J., Andrade, R. D., Perez, O. A., and Toscano, H. (2012). Drying Kinetics of Two Yam (Dioscorea Alata) Varieties. *Dyna*, 79 (171): 1-9.

Tunde-Akintunde, T. Y., Afon. A. A. 2009. Modelling of Hot-Air Drying of Pre-treated Cassava Chips. *Agric. Eng. Int.: The CIGR E-journal manuscript* 12(2): 1493-1506

Udensi, E.A., Oselebe, H.O. and Onuoha, A.U. (2010): Antinutritional assessment of *D. alata* varieties. *Pak. J. of Nut.* 9 (2): 179-181. https://doi.org/10.3923/pjn.2010.179.181

Yaldiz, O. and Ertekin, C. (2007). Thin-layer solar drying of some vegetables. *Drying Tech.* 19 (3), 583–597. https://doi.org/10.1081/DRT-100103936

Zogzas, N. P., Maroulis, Z. B., and Marinos-Kouris, D. (1996). Moisture diffusivity data compilation in foodstuffs. *Drying Tech.*, 14 (10), 2225–2253. https://doi.org/10.1080/07373939608917205