Measurement and Modeling of the Thin Layer Drying Properties of Selected Varieties of Yam Assisted by Hot-Water Blanching

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Abstract
The design and construction of industrial yam dryers will rely on appropriate yam drying property data; hence this work is aimed at measuring the thin layer drying properties of two varieties of yam samples: white yam (Dioscorea Rotunda) and water yam (Dioscorea Alata) on dry basis using experimental and empirical techniques. To achieve this aim, yam samples were prepared into thin rectangular slices of average thickness, 8 mm, and were blanched by plunging into hot-water medium operating at 70 and 80 ^oC at varied cooking time of 5, 10 and 15 mins using method of cook and shock. The yam samples were dried in a hot air oven dryer (with cabinets) operating at constant air velocity of 4 m/s and at two oven drying temperatures: 30 and 50 ^oC each for 6-hour drying period. The results obtained showed that the drying curves of the sliced yam samples followed the falling rate regime, and that the moisture ratio, moisture absorption capacity and effective diffusivity of the blanched sliced yam samples were highly enhanced relative to the not-blanched. Optimum blanching condition for the sliced yam samples was recommended for 70 ^oC at 5 mins. The Wang and Singh model and the Logarithmic model were also recommended as more accurate drying models for fitting the drying properties of blanched sliced yam samples dried at 30 and 50 ^oC respectively.

Keywords: *Sliced yam sample, Blanching condition, Drying property, Thin layer drying model and Drying temperature.*

1.0 Introduction

Yam belongs to the family of Dioscoreacea for which the genus is called Dioscorea. About six species exists for the yam crop: White yam (Dioscorea Rotundata), Yellow yam (Dioscorea Cayenensis), Water yam (Dioscorea Alata), Trifoliate or Three-leaved yam (Dioscorea Dumentorum), Arial yam (Dioscorea Bulbifer) and Chinese yam (Dioscorea Esculenta) (Ayanwuji et al, 2011). The most often cultivated yam species in Nigeria are the white yam, yellow yam (or guinea yam) and water yam (Amusa et al, 2003).

Yam is often challenged by post-harvest losses recorded at more than 30 % annually. These losses are partly caused by external agents such as insects, rodents and moulds (Osunde, 2008). Other major causes of yam losses after harvest are deterioration and degradation conditions caused by poor storage and preservation methods (Dje et al, 2010). To overcome this challenge, preliminary treatments such as peeling, washing, drying of its slice, and crushing into powdery (or flour) form can be carried out. Other identified storage and preservation methods for yam tubers include shelving and hanging system, silos, refrigeration of sliced tubers and contact with preservation chemicals (Osunde, 2008).

Drying is the most popular and universal method for preserving yam. It requires the use of heat to expel moisture from its content to such a level that will allow a balance with ambient air without compromising the physical and chemical properties of the yam (Torres et al, 2012). In addition, drying will ensure that the yam moisture content is reduced to such a level that will prevent (or inhibit) growth of microorganisms as well as reduce its bulk weight for ease of transportation and storage (Ajadi and Sanusi, 2013).

The native drying method for yam tuber is carried out by sun-drying. Although it is cheaper to operate, but it is often tedious, requires long drying time, the drying conditions are uncontrolled while its overall performance is subject to weather conditions (Ajala et al, 2012). Modern drying methods use industrial dryers with high capacity for drying. Common sources of energy for the dryers are drawn from gas or biomass firing, electric heating, hot air contacting and solar collector plates (Akintunde et al, 2011). Typical examples of industrial dryers include batch dryer, tray dryer, vacuum dryer, solar dryer, steam dryer etc.

Yam drying can be assisted by pretreatments. Microwave heating and blanching are the two most recognized methods. The former uses electromagnetic wave (at frequency of 3 – 3000 MHz) to cause the preheating of yam samples which in turn help ensure its speedy drying process, increase mass transfer, and ensures good quality drying for the yam product (Zhang et al, 2006). Blanching is on the other hand a pretreatment process which requires yam tubers to be cooked in hot-water (or wet steam) at short time interval after which it is removed and shocked by plunging into cold running water in order to truncate the cooking process (Egbuonu and Nzewi, 2014).

The application of hot-water blanching to bitter yam slices (Dioscorea dumetorum) at different cooking times (prior to drying) had been reported. Peak effects were reported at blanching temperature and time of 100^oC for 18 mins wherein the trends of the properties of blanched bitter yam samples relative to the not-blanched showed: decreases in bulk density, moisture absorption capacity, oil absorption capacity, swelling index and foam capacity of the yam samples, while the pH was increased (Egbuonu and Nzewi, 2014). Also, Abano and Amoah (2015) had studied the effects of microwave heating and hot-water blanching on the drying kinetics of white yam. The results showed enhanced effective diffusivities for yam slices pretreated with microwave oven than those treated with hot-water blanching.

In another report, Leng et al (2011) investigated the impact of blanching and drying behavior of Dioscorea schimperiana on the cellular exchange and on basic nutrients contained in the yam (such as calcium, ascorbic acid and β-carotene). The controlled parameters for the study were blanched temperature and time, yam slice thickness and dryer configuration. The results showed strong variations in cellular exchange in yam slices and increased losses of nutrients (e.g. calcium, ascorbic acid and β-carotene) even as the blanching condition increases with the decreasing slice thickness. The effective diffusivity of the yam slice was also observed to have decreased largely as the blanching temperature and time increases. Similar results have also been reported in other works on assisted drying of yams such as in Lu et al (1998), Lin et al (2007), Falade et al. (2007) and Xiao et al (2012).

Kinetic models for describing thin layer drying properties of yam slices are already established in the literature. Notable ones are Lewis, Page, Henderson and Pabis, Logarithmic models etc. These models can be used to fit measured experimental drying data for yam slices in terms of moisture ratio (MR) and drying time (t), while the model constants can be estimated. Also, the goodness-of-fit (or accuracy test) of these models can be ascertained based on test parameters: correlation coefficient (R^2), root mean square error (RMSE), percentage deviation (P) and chi-square (χ^2) (Karaaslan and Tuncer, 2008).

The focus of this present paper is on the measurement and modelling of the drying properties of two different varieties of yam samples pre-treated by hot-water blanching. Specifically, white and water yam samples were selected and prepared into slices, and plunged into hot-waters operating at different temperature conditions for varied cooking time and shocked thereafter. The moisture contents of the yam slices were measured at intervals of time in a hot air oven dryer operating at controlled air temperature and velocity. The resulting drying data from this process were then fitted using thin layer drying models. The model coefficients and its goodness-of-fit were also determined.

2.0 Materials and Method

2.1 Materials

The main materials used for this work were samples of white yam (Dioscorea Rotundata) and water yam (Dioscorea Alata). Additional materials includes hot air oven dryer (model: BHG 9140A, with cabinets), temperature controlled water bath (model: WBH 14/F2, England), desiccators, weighing balance, vernier caliper, thermometer and stopwatch.

2.2 Methodology

The following methods were adopted: sample preparation, blanching process, oven drying, drying parameters measurement and curve fitting.

2.2.1 Sample Preparation

Samples of white and water yams species were obtained from a local market in Rivers State, Nigeria. Thereafter, they were subjected to preliminary treatments: peeling, washing and slicing. The sliced tubers were cut into rectangular shapes (8 cm x 4 cm) with each having thickness of 8 mm. The sliced yam samples were also weighed accordingly.

2.2.2 Blanching Process

The sliced yams were blanched in hot-water contained in a temperature controlled water bath. The method of cook and shock was used. In it, sliced yam samples were separately plunged into hot-waters operating at 70 and 80 ^oC for 5 minutes, after which the sliced yam samples were fished and immediately shocked in a basin of cold-water at 25 ^oC to truncate the cooking process. This procedure was repeated for other sliced yam samples while being subjected to other cooking time of 10 and 15 minutes respectively. The blanched yam slices were drained, weighed again, labelled according to it cooking temperature and time, and stored in desiccators.

2.2.3 Oven Drying

A hot air oven dryer was used for the drying process. The dryer was equipped with centrifugal air fan, electric heater and measurement sensors. Its operating parameters are fan speed = 9.1 rps, air velocity = 4 m/s, air pressure = near 1 atm. The dryer is normally switched on for 30 minutes prior to actual drying in order to attain steady dryer condition. Operating temperatures for drying the sliced yam samples were chosen as 30 and 50 ^oC. At these conditions the physicochemical and nutritional properties of the yam samples cannot be compromised (Akintunde et. al, 2011).

After the dryer had stabilized, sliced yam samples were loaded into the dryer cabinet in single layer with the aid of a tray of size 70 cm x 60 cm. The sliced yam samples were graded according to specified blanching condition: not-blanched, blanched (at 70 ^oC for 5, 10, 15 mins) and blanched (at 80 ^oC for 5, 10, 15 mins). For each drying run, samples were removed from the dryer and re-weighed at every 1 h interval. The drying process was terminated when the weight of dried sliced yam samples became stabilized (or assumed constant), in which case a dynamic equilibrium was attained. Bone-dry (or oven-dry) weight of the yam samples were obtained and recorded after 8 h of drying in the oven. Thus, a total of 28 drying runs were carried out in this work. This is because each drying test run was repeated twice for each sample and the average value was recorded.

2.3 Drying Parameter Measurement

2.3.1 Moisture Content

The following moisture contents were determined on dry basis by computing from the raw drying data obtained from experiment.

- **Initial Moisture Content (M_0):** Ratio of overall weight of moisture contained in the sliced yam sample to its bone-dry (or oven-dry) weight. This can be determined from experimental data using Eq. 1.

  $$M_0 = \frac{W_0 - W_d}{W_d} \quad \text{[g moisture/g dry-solid]} \qquad (1)$$

  Where, W_0 = initial weight of sliced yam sample, g; W_d = bone-dry (or oven-dry) weight of sliced yam sample, g.

- **Instantaneous Moisture Content (M_i):** Ratio of weight of moisture contained in the sliced yam sample (undergoing drying) at any given time to its bone-dry (or oven-dry) weight. It can be estimated from experimental data using Eq. 2.

  $$M_i = \frac{W_i - W_d}{W_d} \quad \text{[g moisture/g dry-solid]} \qquad (2)$$

  Where, W_i = instantaneous (or time-dependent) weight of sliced yam sample undergoing drying.

- **Equilibrium Moisture Content (M_e):** Measure of balanced moisture content of sliced yam sample undergoing drying. In other word, it is the ratio of constant weight moisture (at any given time) contained in the sliced yam sample undergoing drying to its bone-dry (or oven-dry) weight. It can be estimated from experimental data using Eq. 3.

  $$M_e = \frac{W - W_d}{W_d} \quad \text{[g moisture/g dry-solid]} \qquad (3)$$

  Where, W = time-independent (or constant) weight of sliced yam sample undergoing drying.

2.3.2. Moisture Ratio

The moisture ratio (MR) is dimensionless moisture calculated for sliced yam sample being dried, and can be assumed to be equal to the Fickian diffusion model (Abano and Amoah, 2015 and Leng et al, 2011) as shown in Eq. 4.

$$MR = \frac{M_i - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\exp\left[-\frac{\pi^2 D_{eff} t}{4L^2}\right] = A\exp(-kt) \qquad (4)$$

Assuming oven air humidity varies continuously throughout the drying exercise, then the equilibrium moisture (M_e) of the sliced yam sample will become negligible because $W = W_d$

(i.e, $M_e = 0$). Thus, Eq. 4 reduces to Eq. 5.

$$MR = \frac{M_i}{M_0} = \frac{8}{\pi^2}\exp\left[-\frac{\pi^2 D_{eff} t}{4L^2}\right] = A\exp(-kt) \quad (5)$$

Where, D_{eff} = effective diffusivity of yam slice, m^2/s; L = half the thickness of yam slice, m, t = drying time, h and A, k = constants. Specifically, the constant k can be define in terms of yam slice effective diffusivity and thickness as shown in Eq. 6,

$$k = \frac{\pi^2 D_{eff}}{4L^2} \quad (6)$$

2.3.3 Moisture absorption capacity

The percentage moisture absorption capacity (MAC) of the sliced yam sample is estimated using Eq. 7.

$$MAC = \frac{W_{0AB} - W_{0BB}}{W_{0BB}} x \frac{100}{1} \quad (7)$$

Where W_{0BB} = weight of sliced yam sample before blanching, g; W_{0AB} = weight of sliced yam sample after blanching, g.

2.3.4 Drying data prediction for dried sliced yam sample and goodness-of-fit

Five existing models for describing thin layer drying properties were tested in this study: Lewis, Page, Henderson and Pabis, Logarithmic, Wang and Singh models. Using experimental data, the empirical constants associated with these models were measured by curve fitting method which requires the linearization and simulation of the given model using LINEST function in MS-EXCEL environment. The value of the model constants were returned along with other parameters: correlation coefficient, R^2 and root-mean-square-error, RMSE. The goodness-of-fit for the models were assessed using R^2 and RMSE.

(a). Lewis Model: $MR = \exp(-kt)$ (8)

(b). Page Model: $MR = \exp(-kt^n)$ (9)

(c). Henderson and Pabis Model: $MR = a\exp(-kt)$ (10)

(d). Logarithmic Model: $MR = a\exp(-kt) + c$ (11)

(e). Wang and Singh Model: $MR = 1 + at + bt^2$ (12)

Where, k, n = drying constant and index specific for each model; while a, b, c = model constants.

3.0 Discussion of Results

The results obtained from this work are discussed under the following sub-headings: General trends of the sliced yam sample drying data, Effect of blanching condition on sliced yam sample drying property and thin layer drying model analysis.

3.1 General trends of the sliced yam sample drying data

The drying data are presented in Tables 1 → 4 and Figures 1→ 4. The Figures are 2-D graph plots of moisture ratio versus drying time. Irrespective of the blanching condition the drying data were observed to have generally showed similar trends for both sliced white and water yam samples. From the same Figures, it was deduced that the drying curves for all samples and drying conditions followed a falling rate regime for which the drying curves slopes downward from left to right within the 6 h duration of drying. Actually, the moisture content and moisture ratio reduces as the drying time increases.

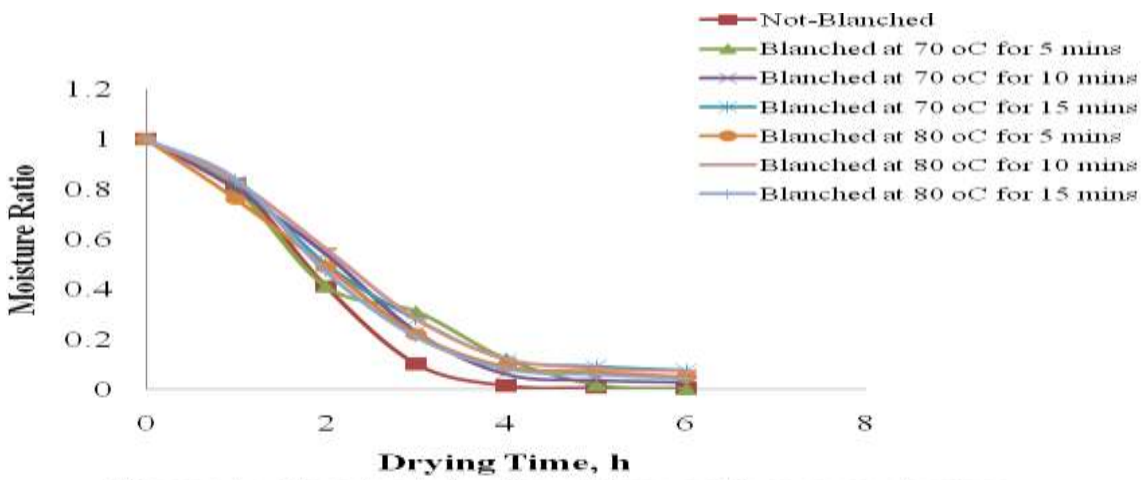

Figure 1: Graph plots of moisture ratio versus drying time for sliced white yam samples dried at 30 °C under different blanching condition

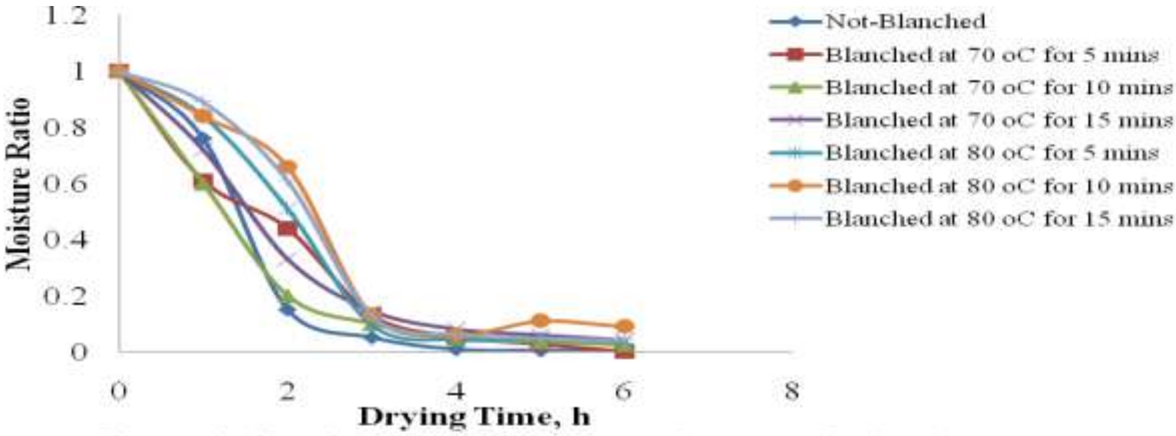

Figure 2: Graph plots of moisture ratio versus drying time for sliced water yam samples dried at 30 °C under different blanching condition

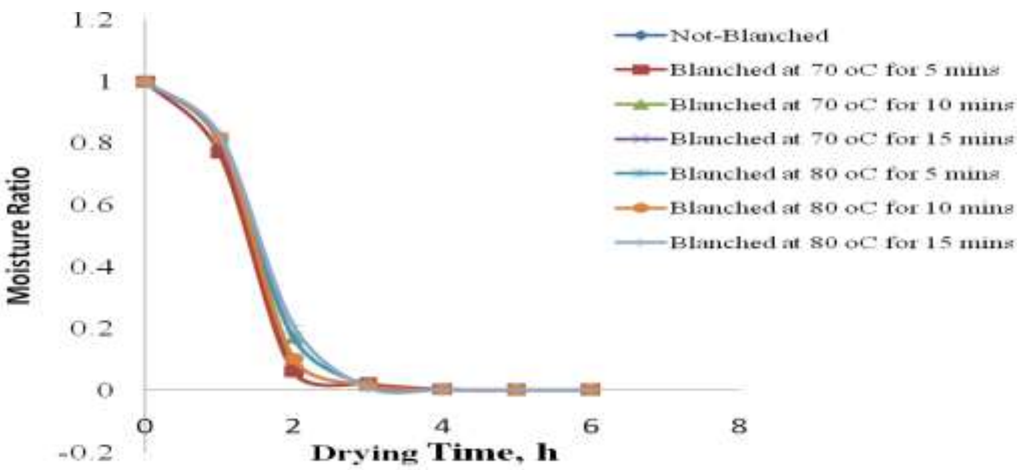

Figure 3: Graph plots of moisture ratio versus drying time for sliced white yam samples dried at 50 °C under different blanching condition

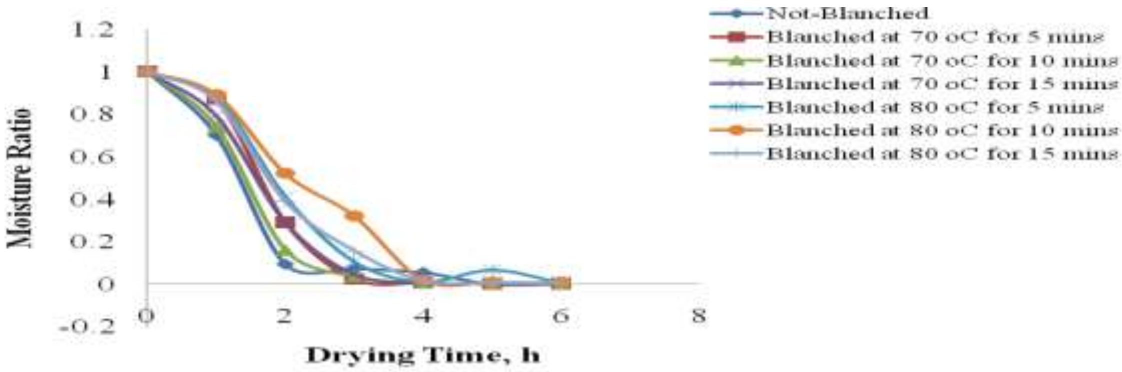

Figure 4: Graph plots of moisture ratio versus drying time for sliced water yam samples dried at 50 °C under different blanching condition

For instance, within a 6 h duration of drying at 30 °C for sliced white yam, the moisture content of the not-blanched sample decreased from 2.71 to 0.007 g water/g dry-solid, while that which was blanched at 70 °C for 5 mins, had its moisture content decreased from 3.86 to 0.0021 g water/g dry-solid at drying temperature of 30 °C. At similar drying condition as the white yam, the sliced water yam sample which was not-blanched had its moisture content decreased from 4.98 to 0.017 g water/g dry-solid at drying temperature of 30 °C, while at blanched condition 70 °C for 5 mins, moisture content of the water yam decreased from 5.37 to 0.004 g water/g dry-solid. Similar trends were also observed for the yam samples dried at other blanched conditions with the moisture ratio inclusive.

Table 1: Drying data for sliced white yam samples dried at 30°C

Blanching Condition	Drying Time (h)	Moisture Content (g moisture/g dry-solid)	Moisture Ratio, MR	Effective Diffusivity, D_{eff} (m^2/h)
Not-blanched	0	2.71	1	-
	1	2.23	0.82	-3.2E-07
	2	1.11	0.41	8.82E-06
	3	0.28	0.1	1.81E-05
	4	0.034	0.013	2.68E-05
	5	0.012	0.0045	2.69E-05
	6	0.007	0.0025	2.5E-05
Blanched at 70 °C for 5 mins	0	3.86	1	-
	1	3.08	0.8	3.19E-07
	2	1.57	0.41	8.82E-06
	3	1.18	0.31	8.29E-06
	4	0.46	0.12	1.24E-05
	5	0.066	0.017	2E-05
	6	0.0021	0.0005	3.19E-05
Blanched at 70 °C for 10 mins	0	3.86	1	-
	1	3.08	0.8	3.19E-07
	2	2.08	0.54	5.25E-06
	3	0.89	0.23	1.09E-05
	4	0.23	0.06	1.69E-05
	5	0.14	0.036	1.61E-05

	6	0.11	0.028	1.45E-05
Blanched at 70 °C for 15 mins	0	4.32	1	-
	1	3.6	0.83	-6.3E-07
	2	2.15	0.5	6.25E-06
	3	1.23	0.28	9.17E-06
	4	0.53	0.12	1.24E-05
	5	0.4	0.092	1.13E-05
	6	0.33	0.076	1.02E-05
Blanched at 80 °C for 5 mins	0	4.32	1	-
	1	3.29	0.76	1.65E-06
	2	2.1	0.49	6.51E-06
	3	0.96	0.22	1.13E-05
	4	0.4	0.09	1.42E-05
	5	0.3	0.069	1.28E-05
	6	0.21	0.049	1.21E-05
Blanched at 80 °C for 10 mins	0	4.28	1	-
	1	3.59	0.84	-9.4E-07
	2	2.03	0.47	7.05E-06
	3	0.88	0.21	1.17E-05
	4	0.35	0.082	1.48E-05
	5	0.25	0.058	1.37E-05
	6	0.19	0.044	1.26E-05
Blanched at 80 °C for 15 mins	0	4.25	1	-
	1	3.54	0.83	-6.3E-07
	2	2.37	0.56	4.78E-06
	3	1.18	0.28	9.17E-06
	4	0.51	0.12	1.24E-05
	5	0.35	0.082	1.19E-05
	6	0.3	0.0705	1.05E-05

Table 2: Drying data for sliced water yam samples dried at 30 °C

Blanching Condition	Drying Time (h)	Moisture Content (g moisture/g dry-solid)	Moisture Ratio, MR	Effective Diffusivity, D_{eff} (m^2/h)
Not-blanched	0	4.98	1	-
	1	3.81	0.76	1.65E-06
	2	0.77	0.15	2.18E-05
	3	0.24	0.05	2.4E-05
	4	0.038	0.008	2.99E-05
	5	0.022	0.004	2.75E-05
	6	0.017	0.003	2.42E-05
Blanched at 70 °C for 5	0	5.37	1	-
	1	3.26	0.61	7.34E-06
	2	2.35	0.44	7.9E-06
	3	0.71	0.13	1.58E-05
	4	0.29	0.054	1.75E-05

mins	5	0.14	0.026	1.78E-05
	6	0.004	0.00074	3.02E-05
Blanched at 70 ^oC for 10 mins	0	6.33	1	-
	1	3.82	0.6	7.77E-06
	2	1.25	0.2	1.81E-05
	3	0.65	0.1	1.81E-05
	4	0.29	0.046	1.86E-05
	5	0.22	0.035	1.63E-05
	6	0.15	0.024	1.52E-05
Blanched at 70 ^oC for 15 mins	0	4.95	1	-
	1	3.55	0.72	3.05E-06
	2	1.63	0.33	1.16E-05
	3	0.72	0.145	1.49E-05
	4	0.41	0.08	1.5E-05
	5	0.29	0.059	1.36E-05
	6	0.2	0.0404	1.29E-05
Blanched at 80 ^oC for 5 mins	0	4.05	1	-
	1	3.43	0.84	-9.4E-07
	2	2.06	0.51	5.99E-06
	3	0.39	0.096	1.84E-05
	4	0.17	0.043	1.9E-05
	5	0.2	0.049	1.45E-05
	6	0.15	0.037	1.33E-05
Blanched at 80 ^oC for 10 mins	0	3.79	1	-
	1	3.18	0.84	-9.4E-07
	2	2.52	0.66	2.65E-06
	3	0.48	0.13	1.58E-05
	4	0.23	0.06	1.69E-05
	5	0.42	0.11	1.03E-05
	6	0.34	0.09	9.48E-06
Blanched at 80 ^oC for 15 mins	0	4.9	1	-
	1	4.37	0.89	-2.4E-06
	2	2.98	0.61	3.67E-06
	3	0.63	0.13	1.58E-05
	4	0.31	0.063	1.65E-05
	5	0.25	0.05	1.44E-05
	6	0.2	0.041	1.29E-05

Table 3: Drying data for sliced white yam samples dried at 50 ^{0}C

Blanching Condition	Drying Time (h)	Moisture Content (g moisture/g dry-solid)	Moisture Ratio, MR	Effective Diffusivity, D_{eff}, (m^2/h)
Not-blanched	0	3.89	1	-
	1	3.13	0.81	-2.6E-09
	2	0.24	0.063	3.31E-05
	3	0.083	0.021	3.15E-05
	4	0.014	0.0044	3.38E-05
	5	0.0006	0.0001	4.66E-05
	6	0.0033	0.0008	2.99E-05
Blanched at 70 ^{o}C for 5 mins	0	6.48	1	-
	1	5.02	0.77	1.31E-06
	2	0.39	0.06	3.37E-05
	3	0.14	0.022	3.11E-05
	4	0.014	0.002	3.89E-05
	5	0.0002	0.00003	5.29E-05
	6	0.000019	0.0000029	5.41E-05
Blanched at 70 ^{o}C for 10 mins	0	7.24	1	-
	1	6.38	0.88	-2.1E-06
	2	1.12	0.15	2.18E-05
	3	0.2	0.03	2.85E-05
	4	0.024	0.003	3.62E-05
	5	0.046	0.0064	2.51E-05
	6	0.05	0.0069	2.06E-05
Blanched at 70 ^{o}C for 15 mins	0	6.78	1	-
	1	5.81	0.86	-1.6E-06
	2	1.31	0.19	1.88E-05
	3	0.13	0.02	3.2E-05
	4	0.011	0.0015	4.07E-05
	5	0.018	0.0011	3.42E-05
	6	0.016	0.0024	2.51E-05
Blanched at 80 ^{o}C for 5 mins	0	6.11	1	-
	1	5.03	0.82	-3.2E-07
	2	1.03	0.17	2.02E-05
	3	0.104	0.017	3.34E-05
	4	0.026	0.004	3.44E-05
	5	0.009	0.0014	3.29E-05
	6	0.006	0.00098	2.9E-05
Blanched at 80 ^{o}C for 10 mins	0	6.31	1	-
	1	5.2	0.82	-3.2E-07
	2	0.64	0.102	2.68E-05
	3	0.11	0.017	3.34E-05
	4	0.015	0.0024	3.77E-05
	5	0.004	0.00063	3.71E-05
	6	0.004	0.0006	3.11E-05
	0	6.41	1	-

Blanched at 80 °C for 15 mins	1	5.33	0.83	-6.3E-07
	2	1.33	0.21	1.75E-05
	3	0.06	0.009	3.88E-05
	4	0.008	0.0012	4.22E-05
	5	0.006	0.001	3.47E-05
	6	0.004	0.00062	3.1E-05

Table 4: Drying data for sliced water yam samples dried at 50 °C

Blanching Condition	Drying Time (h)	Moisture Content (g moisture/g dry-solid)	Moisture Ratio, MR	Effective Diffusivity, $D_{eff,}$ (m^2/h)
Not-blanched	0	8.2	1	-
	1	5.75	0.7	3.78E-06
	2	0.77	0.094	2.79E-05
	3	0.605	0.074	2.07E-05
	4	0.45	0.055	1.74E-05
	5	0.005	0.0006	3.73E-05
	6	0.007	0.0008	2.99E-05
Blanched at 70 °C for 5 mins	0	3.6	1	-
	1	3.14	0.87	-1.9E-06
	2	1.051	0.29	1.33E-05
	3	0.085	0.024	3.04E-05
	4	0.02	0.0056	3.22E-05
	5	0.0048	0.00133	3.32E-05
	6	0.001	0.00028	3.44E-05
Blanched at 70 °C for 10 mins	0	5.53	1	-
	1	4.09	0.74	2.34E-06
	2	0.88	0.16	2.1E-05
	3	0.19	0.035	2.71E-05
	4	0.035	0.006	3.18E-05
	5	0.009	0.002	3.11E-05
	6	0.004	0.0006	3.11E-05
Blanched at 70 °C for 15 mins	0	5.11	1	-
	1	4.01	0.79	6.45E-07
	2	1.51	0.29	1.33E-05
	3	0.23	0.045	2.5E-05
	4	0.025	0.005	3.29E-05
	5	0.013	0.0025	2.99E-05
	6	0.025	0.005	2.2E-05
Blanched at 80 °C for 5 mins	0	4.18	1	-
	1	3.69	0.88	-2.1E-06
	2	1.73	0.41	8.82E-06
	3	0.44	0.105	1.76E-05
	4	0.05	0.011	2.78E-05
	5	0.28	0.066	1.3E-05
	6	0.025	0.006	2.12E-05
	0	4.84	1	-

Blanched at 80 °C for 10 mins	1	4.32	0.89	-2.4E-06
	2	2.52	0.52	5.74E-06
	3	1.57	0.32	8.02E-06
	4	0.09	0.018	2.46E-05
	5	0.04	0.0083	2.37E-05
	6	0.03	0.006	2.12E-05
Blanched at 80 °C for 15 mins	0	4.96	1	-
	1	4.28	0.86	-1.6E-06
	2	1.94	0.39	9.46E-06
	3	0.78	0.156	1.42E-05
	4	0.07	0.0145	2.6E-05
	5	0.029	0.0058	2.56E-05
	6	0.038	0.007	2.05E-05

3.2 Effect of blanching condition on sliced yam sample drying property

Hot-water blanching can affect the drying properties of sliced yam samples. Consequently, the effects of blanching on moisture ratio, moisture absorption capacity and effective diffusivity were investigated in this study. As evident from the drying data, enhanced drying was observed in the blanched sliced yam samples than in the not-blanch after 6 h of drying duration. Specifically, the terminal moisture ratios of the sliced white and water yam samples blanched at 70 °C for 5 mins and that of the not-blanch for all drying conditions showed: 0.0005, 0.0025; 0.00074, 0.003; 0.0000029, 0.0008 and 0.00028, 0.0008 (Table 1 → 4). The reduction in moisture ratios of the blanched samples relative to the not-blanch is an indication of an improved drying.

The moisture absorption capacities of the blanched yam samples were also seen to have decreased even at increased blanching temperature and time. Thus, at blanching condition 70 °C for 5 mins, the sliced white yam sample absorbs 56.4 % moisture; which subsequently decreased to 53 and 50.8 % for peak blanching conditions of 70 and 80 °C each for 15 mins. Similar trends were also evident in the sliced water yam samples (Table 5). These results corroborates the findings of Egbuonu and Nzewi (2014) wherein the moisture absorption capacity of blanched bitter yam sample were observed to have decreased relative to the not-blanched sample even as blanching condition increases.

For this study, 70 °C for 5 mins is recommended as optimum condition for hot-water blanching of sliced white and water yam. Beyond this condition, the effectiveness of the pretreatment during actual drying begins to decline while compactness and gradual closure of pores of the yam seeds microstructure may begin to set-in, resulting in heat and mass transfer rate reduction within the yam sample and can reduce the rate of moisture loss. This finding is similar to that of Hong-Wei et al (2009) wherein an electron-microscope scan analysis of over-blanched sweet potato bars showed no pores with evident decrease in moisture diffusivity.

Table 5: Moisture absorption capacity of sliced yam samples at different blanching conditions

Sample type	Average weight of sample, g	Moisture absorption capacity, %
Sliced white yam		
Before blanching	6.56	
After blanching:		
At 70 °C for 5 mins	10.26	56.4
At 70 °C for 10 mins	10.22	55.8
At 70 °C for 15 mins	10.04	53.0
At 80 °C for 5 mins	10.16	54.9
At 80 °C for 10 mins	10.06	53.3
At 80 °C for 15 mins	9.89	50.8
Sliced water yam		
Before blanching	8.15	
After blanching:		
At 70 °C for 5 mins	12.26	50.4
At 70 °C for 10 mins	10.76	32.0
At 70 °C for 15 mins	11.21	37.5
At 80 °C for 5 mins	10.23	25.5
At 80 °C for 10 mins	10.73	31.6
At 80 °C for 15 mins	10.56	29.6

Effective diffusivity (D_{eff}) is a measure of rate of drying. It can help determine the extent of internal moisture movement within the sliced yam and even up to the surface before the moisture is detached by evaporation. This parameter can also be affected by the blanching condition. Thus, effective diffusivity of the sliced yam samples (within the 6 h drying duration) did not show clearly defined trend in most of the drying runs, except for those blanched at 70 °C for 5 mins in which the effective diffusivity increased from 3.19 x 10^{-7} to 3.19 x 10^{-5} $m^{2/}$h (for white yam dried at 30 °C) and from 7.34 x 10^{-6} to 3.02 x 10^{-5} m^2/h (for water yam dried at 30 °C).

The peak conditions (70, 80 °C for 15 mins) showed irregular trends or relative decrease in the effective diffusivity for both white and water yam samples especially after 4 h of drying. In other word, at peak conditions the blanching become excessive and can negatively affect the effective diffusivity of the sliced yam samples which can in turn reduce the rate of moisture loss during actual drying as shown in Tables 1 → 4. These observations corroborates the findings of Leng et al (2011), Lu et al (1998), Lin et al (2007) and Falade et al. (2007) wherein yam samples blanched at peak conditions showed decreased effective diffusivity during drying.

3.3 Thin layer drying model analysis

The following thin layer drying models: Lewis, Page, Henderson and Pabis, logarithmic, and Wang and Singh were used to fit experimental drying data obtained for hot-water blanched sliced yam samples while empirical constants for the models were estimated. The summary of the models results and its assessment for sliced white and water yam samples are shown in Tables 6 → 9. From the results obtained, all models tested appeared to have adequately fits the experimental drying data relative to R^2 and RMSE values.

The Wang and Singh model fitted the drying data more accurately for blanched sliced white and water yam samples at drying temperature of 30 °C having R^2 ranged between 0.9 to 1.0 and RMSE, 0.0002 to 0.22 (Tables 6 and 7). On the other hand, the Logarithmic model fitted the drying data more accurately for blanched sliced white and water yam samples obtained at drying temperature of 50 °C with R^2 of 0.94 to 1.0 and RMSE of 0.16 to 0.41 (Tables 8 and 9).

Table 6: Drying model parameters for hot-water blanched sliced white yam sample at a drying temperature of 30 °C.

Tested Model	Blanching Condition	Model Constant	Goodness-of-fit	
			R^2	RMSE
Lewis Model: $MR = \exp(-kt)$	Not-blanched	k = 1.27	**0.97**	**0.14**
	70 °C for 5 mins	k = 1.01	**0.93**	**0.11**
	70 °C for 10 mins	k= 1.09	**0.97**	**0.17**
	70 °C for 15 mins	k = 0.90	**0.94**	**0.14**
	80 °C for 5 mins	k = 0.87	**0.91**	**0.12**
	80 °C for 10 mins	k = 0.97	**0.95**	**0.13**
	80 °C for 15 mins	k = 0.89	**0.90**	**0.16**
Page Model: $MR = \exp(-kt^n)$	Not-blanched	k = 0.22; n = 1.99	**0.98**	**0.003**
	70 °C for 5 mins	k = 0.23; n = 1.71	**0.98**	**0.03**
	70 °C for 10 mins	k = 0.20; n = 1.85	**0.99**	**0.02**
	70 °C for 15 mins	k = 0.186; n = 1.78	**1.00**	**0.01**
	80 °C for 5 mins	k = 0.26; n = 1.56	**0.99**	**0.01**
	80 °C for 10 mins	k = 0.19; n = 1.84	**0.99**	**0.01**
	80 °C for 15 mins	k = 0.18; n = 1.79	**0.99**	**0.006**
Henderson and Pabis Model: $MR = a\exp(-kt)$	Not-blanched	a = 1.99; k = 0.11	**0.98**	**0.49**
	70 °C for 5 mins	a = 1.71; k = 0.13	**0.98**	**0.37**
	70 °C for 10 mins	a = 1.85; k = 0.11	**0.99**	**0.39**
	70 °C for 15 mins	a = 1.78; k = 0.104	**1.00**	**0.39**
	80 °C for 5 mins	a = 1.56; k = 0.167	**0.99**	**0.26**
	80 °C for 10 mins	a = 1.84; k = 0.104	**0.99**	**0.42**
	80 °C for 15 mins	a = 1.79; k = 0.099	**0.99**	**0.37**
Logarithmic Model: $MR = a\exp(-kt) + c$	Not-blanched	a = 0.84; k = 0.22; c = -0.87	**0.98**	**0.30**
	70 °C for 5 mins	a = 0.79; k = 0.06; c = -0.56	**0.99**	**0.11**
	70 °C for 10 mins	a = 0.72; k = 0.10; c = -0.44	**0.97**	**0.16**
	70 °C for 15 mins	a = 0.84; k = 0.047; c = -0.56197	**0.99**	**0.12**
	80 °C for 5 mins	a = 0.78; k = 0.055; c = -0.54	**0.98**	**0.13**
	80 °C for 10 mins	a = 0.85; k = 0.12; c = -0.69	**0.99**	**0.20**
	80 °C for 15 mins	a = 0.85; k = 0.019; c = -0.52	**0.99**	**0.10**
Wang and Singh Model:	Not-blanched	a = -0.56; b = 0.0582	**0.99**	**0.12**
	70 °C for 5 mins	a = -0.39; b = 0.034	**0.98**	**0.02**

$MR = 1 + at + bt^2$	70 °C for 10 mins	a = -0.45; b = 0.041	0.99	0.11
	70 °C for 15 mins	a = -0.42 b = 0.036	1.00	0.08
	80 °C for 5 mins	a = -0.40; b = 0.036	1.00	0.08
	80 °C for 10 mins	a = -0.48; b = 0.045	0.99	0.10
	80 °C for 15 mins	a = -0.41; b = 0.035	0.99	0.098

Table 7: Drying model parameters for hot-water blanched sliced water yam sample at a drying temperature of 30 °C.

Tested Model	Blanching Condition	Model Constant	Goodness-of-fit	
			R^2	RMSE
Lewis Model: $MR = \exp(-kt)$	Not-blanched	k = 1.25	0.90	0.03
	70 °C for 5 mins	k = 0.76	0.96	0.09
	70 °C for 10 mins	k = 0.85	0.95	0.006
	70 °C for 15 mins	k = 0.78	0.95	0.05
	80 °C for 5 mins	k = 0.92	0.93	0.14
	80 °C for 10 mins	k = 0.89	0.84	0.20
	80 °C for 15 mins	k = 0.87	0.96	0.18
Page Model: $MR = \exp(-kt^n)$	Not-blanched	k = 0.44; n = 1.304	0.93	0.07
	70 °C for 5 mins	k = 0.454, n = 1.246	0.96	0.04
	70 °C for 10 mins	k = 0.57; n = 1.21	0.97	0.03
	70 °C for 15 mins	k = 0.37; n = 1.38	0.98	0.02
	80 °C for 5 mins	k = 0.193; n = 1.89	0.96	0.008
	80 °C for 10 mins	k = 0.166; n = 1.873	0.92	0.05
	80 °C for 15 mins	k = 0.13; n = 2.08	0.96	0.013
Henderson and Pabis Model: $MR = a\exp(-kt)$	Not-blanched	a = 1.75; k = 0.214	0.93	0.405
	70 °C for 5 mins	a = 1.24; k = 0.36	0.96	0.067
	70 °C for 10 mins	a = 0.406; k = 1.41	0.97	0.071
	70 °C for 15 mins	a = 1.38; k = 0.27	0.98	0.195
	80 °C for 5 mins	a = 1.89; k = 0.102	0.96	0.426
	80 °C for 10 mins	a = 1.87; k = 0.09	0.92	0.37
	80 °C for 15 mins	a = 2.08; k = 0.063	0.96	0.50
Logarithmic Model: $MR = a\exp(-kt) + c$	Not-blanched	a = 0.75; k = 0.36; c = -1.06	0.98	0.056
	70 °C for 5 mins	a = 0.63; k = 0.049; c = -0.45	0.94	0.129
	70 °C for 10 mins	a = 0.59; k = 0.201; c = -0.68	0.99	0.2
	70 °C for 15 mins	a = 0.72; k = 0.17; c = -0.69	1.0	0.21
	80 °C for 5 mins	a = 0.87; k = 0.18; c = -0.81	0.95	0.29
	80 °C for 10 mins	a = 0.88; k = 0.070; c = -0.63	0.89	0.216

	80 °C for 15 mins	a = 0.93; k = 0.13; c = -0.76	**0.94**	**0.27**
Wang and Singh Model: $MR = 1 + at + bt^2$	Not-blanched	a = -0.55; b = 0.062	**0.90**	**0.008**
	70 °C for 5 mins	a = -0.35; b = 0.033	**0.97**	**0.005**
	70 °C for 10 mins	a = -0.38; b = 0.039	**0.93**	**0.084**
	70 °C for 15 mins	a = -0.4; b = 0.042	**0.97**	**0.0002**
	80 °C for 5 mins	a = -0.55; b = 0.056	**0.97**	**0.156**
	80 °C for 10 mins	a = -0.50; b = 0.048	**0.92**	**0.22**
	80 °C for 15 mins	a = -0.56; b = 0.055	**0.96**	**0.21**

Table 8: Drying model parameters for hot-water blanched sliced white yam sample at a drying temperature of 50 °C.

Tested Model	**Blanching Condition**	**Model Constant**	**Goodness-of-fit**	
			R^2	**RMSE**
Lewis Model: $MR = \exp(-kt)$	Not-blanched	k = 1.585	**0.86**	**0.009**
	70°C for 5 mins	k = 1.68	**0.78**	**0.01**
	70°C for 10 mins	k = 1.99	**0.997**	**0.056**
	70°C for 15 mins	k = 1.87	**0.941**	**0.07**
	80°C for 5 mins	k = 1.64	**0.99**	**0.05**
	80°C for 10 mins	k = 1.88	**0.77**	**0.032**
	80°C for 15 mins	k = 1.80	**0.96**	**0.07**
Page Model: $MR = \exp(-kt^n)$	Not-blanched	k = 0.37; n = 1.94	**0.89**	**0.074**
	70°C for 5 mins	k = 0.41; n = 1.895	**0.89**	**0.064**
	70°C for 10 mins	k = 0.20; n = 2.36	**0.94**	**0.08**
	70°C for 15 mins	k = 0.41; n = 1.09	**0.95**	**0.09**
	80°C for 5 mins	k = 0.43; n = 1.37	**0.94**	**0.066**
	80°C for 10 mins	k = 0.308; n = 2.11	**0.91**	**0.066**
	80°C for 15 mins	k = 0.27; n = 2.17	**0.94**	**0.038**
Henderson and Pabis Model: $MR = a\exp(-kt)$	Not-blanched	a = 1.936; k = 0.19	**0.89**	**0.52**
	70°C for 5 mins	a = 1.895; k = 0.217	**0.89**	**0.48**
	70°C for 10 mins	a = 2.36; k = 0.086	**0.94**	**0.75**
	70°C for 15 mins	a = 2.30; k = 0.099	**0.95**	**0.69**
	80°C for 5 mins	a = 2.05; k = 0.142	**0.94**	**0.56**
	80°C for 10 mins	a = 2.11; k = 0.146	**0.91**	**0.60**
	80°C for 15 mins	a = 2.17; k = 0.199	**0.94**	**0.51**
Logarithmic Model: $MR = a\exp(-kt) + c$	Not-blanched	a = 0.78; k = 0.46, c = -1.23	**0.97**	**0.40**
	70°C for 5 mins	a = 0.75; k = 0.44; c = -1.19	**0.97**	**0.38**
	70°C for 10 mins	a = 0.87; k = 0.45; c = -1.27	**0.99**	**0.44**
	70°C for 15 mins	a = 0.85; k = 0.41; c = -1.21	**0.997**	**0.42**

	80°C for 5 mins	a = 0.813; k = 0.41; c = -1.176	**0.995**	**0.40**
	80°C for 10 mins	a = 0.806; k = 0.452; c = -1.24	**0.984**	**0.41**
	80°C for 15 mins	a = 0.83; k = 0.399; c = -1.16	**0.997**	**0.41**
Wang and Singh Model: $MR = 1 + at + bt^2$	Not-blanched	a = -0.60; b = 0.069	**0.83**	**0.003**
	70°C for 5 mins	a = -0.58; b = 0.066	**0.83**	**0.018**
	70°C for 10 mins	a = -0.66, b = 0.073	**0.89**	**0.07**
	70°C for 15 mins	a = -0.64; b = 0.071	**0.916**	**0.077**
	80°C for 5 mins	a = -0.614; b = 0.069	**0.90**	**0.05**
	80°C for 10 mins	a = -0.62; b = 0.070	**0.86**	**0.024**
	80°C for 15 mins	a = -0.625; b = 0.07	**0.924**	**0.072**

Table 9: Drying model parameters for Hot-water blanched sliced water yam sample at a drying temperature of 50 °C.

Tested Model	Blanching Condition	Model Constant	Goodness-of-fit	
			R^2	RMSE
Lewis Model: $MR = \exp(-kt)$	Not-blanched	k = 1.41	**0.86**	**0.014**
	70°C for 5 mins	k = 0.91	**0.7**	**0.053**
	70°C for 10 mins	k = 1.46	**0.605**	**0.043**
	70°C for 15 mins	k = 0.69	**0.81**	**0.017**
	80°C for 5 mins	k = 0.94	**0.80**	**0.106**
	80°C for 10 mins	k = 1.355	**0.80**	**0.185**
	80°Cfor 15 mins	k = 1.13	**0.91**	**0.117**
Page Model: $MR = \exp(-kt^n)$	Not-blanched	k = 0.77; n = 0.36	**0.91**	**0.114**
	70°C for 5 mins	k = 0.226; n = 1.41	**0.84**	**0.105**
	70°C for 10 mins	k = 0.396; n = 1.77	**0.96**	**0.040**
	70°C for 15 mins	k = 0.36; n = 1.427	**0.94**	**0.0345**
	80°C for 5 mins	k = 0.173; n = 2.01	**0.92**	**0.034**
	80°C for 10 mins	k = 0.119; n = 2.32	**0.96**	**0.013**
	80°C for 15 mins	k = 0.18; n = 2.06	**0.96**	**0.031**
Henderson and Pabis Model: $MR = a\exp(-kt)$	Not-blanched	a = 1.59; k = 0.29	**0.91**	**0.325**
	70°C for 5 mins	a = 1.911; k = 0.118	**0.845**	**0.497**
	70°C for 10 mins	a = 1.773; k = 0.223	**0.96**	**0.398**
	70°C for 15 mins	a = 1.845; k = 0.166	**0.944**	**0.42**
	80°C for 5 mins	a = 2.014; k = 0.086	**0.92**	**0.52**
	80°C for 10 mins	a = 2.32; k = 0.051	**0.96**	**0.64**
	80°C for15 mins	a = 2.06; k = 0.089	**0.964**	**0.544**
Logarithmic Model: $MR = a\exp(-kt) + c$	Not-blanched	a = 0.69; k = 0.36; c = -1.02	**0.975**	**0.317**
	70°C for 5 mins	a = 0.875; k = 0.379; c = -1.145	**0.98**	**0.419**

	70°C for 10 mins	a=0.732; k = 0.353; c = -1.03	**0.995**	**0.338**
	70°C for 15 mins	a = 0.79; k = 0.298; c = -0.998	**0.995**	**0.342**
	80°C for 5 mins	a = 0.898; k = 0.265; c = -0.97	**0.98**	**0.350**
	80°C for 10 mins	a = 0.907; k = 0.066; c = -0.655	**0.97**	**0.155**
	80°C for 15 mins	a=0.87; k = 0.226; c = -0.901	**0.994**	**0.301**
Wang and Singh Model: $MR = 1 + at + bt^2$	Not-blanched	a = -0.53; b = 0.06	**0.88**	**0.035**
	70°C for 5 mins	a = -0.625; b = 0.069	**0.92**	**0.108**
	70°C for 10 mins	a = -0.542; b = 0.06	**0.91**	**0.0013**
	70°C for 15 mins	a = -0.57; b = 0.062	**0.97**	**0.077**
	80°C for 5 mins	a = -0.595; b = 0.0625	**0.971**	**0.144**
	80°C for 10 mins	a = -0.505; b = 0.0462	**0.99**	**0.141**
	80°C for 15 mins	a = -0.57; b = 0.059	**0.99**	**0.121**

Conclusion

This study has reaffirmed that hot-water blanching is a pre-dry treatment required prior to yam drying because it has helped to improve the yam drying properties. Hence, the drying kinetic parameters (e.g. moisture ratio, moisture absorption capacity and effective diffusivity) of the blanched sliced yam samples were highly enhanced relative to the not-blanched samples. Based on data obtained from the drying experiment, optimum condition for hot-water blanching for sliced yam samples prior to actual drying was recommended to be at 70 °C for 5 mins. At this condition, moisture absorption capacity and effective diffusivity of the sliced yam samples were increased beyond that of the not-blanched sample while still retaining the natural yam nutrients. The drying properties of the sliced yam samples were also observed to generally follow a falling rate period under the operating conditions employed. All thin layer drying models tested for this study were observed to have adequately fitted the experimental drying data at the prescribed conditions. But the Wang and Singh model fitted the drying data more accurately for all blanched conditions for both sliced white and water yam samples at drying temperature of 30 °C, while the Logarithmic model fitted the drying data more accurately at drying temperature of 50 °C.

Abbreviation

mins = minutes
h = hour
MAC = moisture absorption capacity, %
MR = moisture ratio
M_o = initial moisture content, g moisture/g dry-solid
M_i = instantaneous (or time dependent) moisture content, g moisture/g dry-solid
M_e = equilibrium moisture content, g moisture/g dry-solid
D_{eff} = effective diffusivity, m^2/h

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