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Dehydration and Rehydration Characterization of Yam (*Dioscorea Rotundata*) Tuber Slices Dehydrated Using a Refractance Window[tm] Dryer

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ABSTRACT

The effect of slice thickness on the dehydration and rehydration characteristics of yam was studied in a Refractance Window ™ (RW) type dryer constructed from a laboratory water bath. Yam slices 1.5, 3.0 and 4.5 mm thick were dried in a laboratory scale RW dryer where the water in the bath was maintained at temperature of 80 °C. The initial moisture content of the yam samples was 69% on a wet basis (wb). The drying process was carried out until the final moisture content of the product was below 10% (wb). The experimental data indicate that the drying time decreases rapidly as the yam slices decrease; the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices, dried to below 10% within 40 minutes, 80 minutes and 120 minutes respectively. The experimental data indicated that the drying kinetics for the yam slices fitted the Haghi and Ghanadzadeh thin-layer drying model with a regression coefficient exceeding 99.9 % for the 1.5, 3.0 and 4.5 mm thick slices. The rehydration ratio increased to a steady value of about 1.91 when soaked in water for about 180 minutes.

Key words: Dehydrating Yams, Refractance Window™ Drying, Drying Curves, Rehydration Ratio, Thin-layer Dying Models.

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1. INTRODUCTION

Yams are starchy staples in the form of large tubers grown bi-annually in Africa, the Americas, the Caribbean, South Pacific and Asia. Various wild and domesticated *Dioscorea* species exist. However, white guinea yam, *Dioscorea rotundata*, is the most important species especially in the dominant yam production zones in West and Central Africa. White yams are indigenous to West Africa, as is the yellow yam, *Dioscorea cayenensis* (IITA, 2009).
Yam tubers, processed into powdered form, are used to prepare many cuisines in West Africa and around the world. In Nigerian, yam based cuisines include, *Iyan*, *Amala* and *Asaro* (Hudgens and Trillo, 2003). Iyan called pounded yam in English is completely smooth with no yam chunks left (Hudgens and Trillo, 2003). *Amala* (or *aririguzofranca*) is a thick paste made from yam, which has been peeled, cleaned, dried and then blended. It is similar to *Iyan* but darker in color. *Asaro*, also known as yam porridge, is a popular Nigerian dish. Ghanaian cuisines include *Ampesie* – boiled yam and yam-fufu. Yam peels have also been used as a source of feed for some animals. Yam tubers and its products are excellent sources of dietary energy (Ayankunbi *et al*., 1991). The roots contain about 32% starch, 65% moisture and 0.8–1% protein on a wet basis (Cock, 1985). Over 200 million people worldwide rely on yam products as a major source of dietary calories. The yam flour preparation process involves peeling, slicing, cleaning and drying the tuber. The dried tuber is then pulverized into a fine powder to make “Elubo”. The preparation process is laborious and time-consuming (Lancester *et al*., 1982) and the quality of the yam flour produced is determined mainly in the drying stage. Natural sun drying is the most common method used to dry yam tubers in regions where they are grown (Mlingi, 1985). However, this process is slow as it depends on the ambient

temperature in those regions. Also, natural sun drying can only be done properly in the dry season. When drying times exceed three days, the quality of the product may degrade (Agoreyo *et al.,* 2011). If the drying process is fast enough and the final product is dry enough, this degradation can be prevented (Maskan, 2000). There is, therefore, a need to find an alternative drying method to reduce significantly, the time taken to dry yam tubers. The Refractance Window™ drying technique developed by MCD Technologies Inc., Tacoma, WA, USA, is finding much favour in dehydrating food. Drying studies by Nindo and Tang, (2007) using the Refractance Window™ drying technique demonstrated that purees or juices prepared from fruits, vegetables, or herbs could be dehydrated within a short period of time. Studies by Akinola *et al.* (2014) on dehydration of onions demonstrated that the Refractance Window™ drying could dehydrate onions to 10% moisture content within 150 minutes. With a Refractance Window™ dryer, Akinola *et al.* (2016), dehydrated 3 mm carrot slices to below 10% moisture content in about 200 minutes; Akinola and Ezeorah (2016), also dehydrated 3 mm root tubers dry to moisture content of less than 10% within 150 minutes. However, Akinola *et al.* (2016) , did not investigate the effect of the yam slice size. This work examines the effect of slice size on the dehydration and rehydration characteristics of yam using the Refractance Window™ drying technique.

2. METHODS AND MATERIAL

2.1 The Refractance Window™ Dryer

The Refractance Window™ type dryer used in this study was constructed by modifying an electrically heated thermostatic water bath; replacing the bath cover with a transparent 0.15 mm thick Polyethylene terephthalate (PET) plastic film (Fig. 1). The plastic film was held in place with metal brackets.

2.2 Sample Preparation of the Yam Tuber Slicer

The yam tubers used in this study were purchased from the local market in Akoka, lLagos, Nigeria, located at Latitude 6.52N and Longitude 3.38E. Sand, grit and dirt on the yam tubers were washed away from the tubers. The yam tubers were peeled, re-washed and sliced into 1.5 mm, 3 mm and 4.5 mm slices with a Mandolin type slicer. The thickness of the yam slices was verified with a digital Vernier caliper. Unbound water on the yam slices was removed by wiping them on an absorbent material. This was to ensure that the rewashing process did not increase the moisture content of the fresh yam slices. The slices were later placed on the Refractance Window™ dryer to dehydrate.

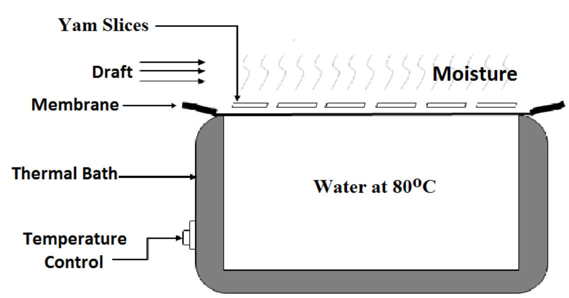

Figure 1. Schematic Diagram of Dryer

2.3 Experimental Procedure

The water in the bath was maintained at a temperature of 80°C throughout the experiment. The yam slices were placed on transparent Polyethylene terephthalate (PET) plastic film to dry. At time intervals of 10 minutes, as the experiment progressed, some yam slices were removed and their moisture content determined, using a moisture analyzer. The drying process was stopped when the moisture content of the dehydrated sample was below 10%. The drying experiments were performed in triplicates for each drying period and the average moisture content values for each time period were taken. An air current with a velocity of 1.7 m/s was maintained across the transparent Polyethylene terephthalate (PET) plastic film with the use of a fan; this was to ensure that the evaporating vapour above the drying sample did not inhibit the drying process.

2.4 Determination of the moisture content and the Moisture Ratio

The moisture content was determined using an MB45 OHAUS moisture analyzer (OHAUS Corporation, 2011). The moisture analyser measured both the weight and moisture content of the yam slices. The mass and moisture contents readings were determined to an accuracy of 0.01g and 0.01% respectively.
The Moisture Ratio (MR) also called Dimensionless Moisture Content is determined from the experimentally observed data according to equation 1.

$$MR = MC_t - MC_e / MC_i - MC_e \qquad [1]$$

Where MC_t is the moisture content of sample after drying for time t; MC_e is the equilibrium moisture content of sample and MC_i is the initial moisture content of fresh sample all in the unit of grams of water removed/grams of solids.
However, equation 1 can be simplified to equation 2 because for long drying times, the values of MC_e are small when compared with the values of MC_t and MC_i (Doymaz, 2007a, 2007b; Goyal *et al*., 2007 Menges and Ertekin, 2006).

$$MR = MC_t / MC_i \qquad [2]$$

2.5 Rehydration Ratio (RR) Assessment

The rehydration capacity was used as a quality characteristic of the dried product (Velić *et al,* 2004). The rehydration ratio was determined as recommended by Baron Spices and Seasonings (2015). Samples of the dehydrated yam slices were soaked in water with a weight ratio greater than 1 to 6. After rehydration, the samples were removed from the water and the unbound water on the yam slices were removed by wiping them on an absorbent. The samples were then weighed. The experiments were repeated by increasing the soaking time. In each instance the mass of the rehydrated solid was measured and the rehydration ratio determined using equation 3.

$$RR = M_r / M_d \qquad [3]$$

Where, M_r is the mass of the rehydrated solid and M_d is the mass of the dry sample.

2.6 Processing the Kinetic Data

The Drying curve, the Drying rate curve, and the Krischer curve were plotted from the experimental data obtained as suggested by Kemp *et al*. (2001). Regression analysis was used to determine the best of 17 thin-layer drying models that model the drying data.

2.7 The Drying curve

Using the experimental data, the Drying curve was plotted. The Drying curve is a plot of moisture content *vs.* drying time.

2.8 The Drying rate curve

The Drying rate curve is a plot of the drying rate D_r of yam slices *vs.* drying time. The drying rate is calculated using equation 4

$$D_r = \frac{M_{t+dt} - M_t}{dt} \qquad [4]$$

Where D_r is the drying-time (min), M_t and M_{t+dt} are the moisture content of the yam slices at time t and $t+dt$ respectively.

2.9 Krischer Curves

The Krischer curve is a drying rate *vs.* moisture content plot. Again, the drying rate is calculated using equation 4.

2.10 Obtaining the best drying model

The experimental data obtained in this study were fitted to the 17 thin-layer drying models presented in Table 1.

Table 1 Thin-Layer Drying Models

S/N	Model
1	MR = exp (-k.t) Newton Model (Ayensu, 1997)
2	MR =exp (−k.t^n) Page Model (Page, 1949)
3	MR = exp (−$(k.t)^n$) Modified Page Model (Ozdemir and Devres,1999)
4	MR =a.exp (-k.t) Henderson and Pabis Model (Henderson and Pabis, 1961)
5	MR =a.exp (-k.t)+ b.exp (-g.t)+c.exp (-h.t) Modified Henderson and Pabis Model (Karathanos,1999)
6	MR =a.exp (-k.t) + c Logarithmic Model (Togrul and Pehlivan, 2003)
7	MR =a.exp (−k_0.t) + b exp (−k_1.t) Two term Model (Madamba, 1996)
8	MR =a.exp (-k.t) + (1-a) exp (-k.a.t) Two term exponential Model (Sharaf-Elden *et al*.,1980)
9	MR = 1+ a.t + b.t^2 Wang and Singh Model (Wang and Singh, 1978)
10	MR = a.exp (-k.t) + (1-a).exp (-k.b.t) Diffusion Approach Model (Demir *et al*., 2007)
11	MR = a.exp (-k.t) + (1-a).exp (-g.t) Verma *et al*. Model(Verma *et al*., 1985)
12	MR = exp (-k_1.t/1+k_2.t) Aghbashlo *et al.* Model (Aghbashlo *et al*., 2009)
13	MR = a.exp (−k.t^n) + b.t Midilli *et al.* Model (Midilli *et al*., 2002)
14	MR = a.exp (-b.t^c) + d.t^2 + e.t + f Haghi and Ghanadzadeh Model (Haghi and Ghanadzadeh, 2005)
15	MR = a.exp[-ct/L^2] Simplified Fick's diffusion (SFFD) equation (Diamante and Munro, 1991)
16	MR = exp[-k$(t/L^2)^n$] Modified Page equation –II (Diamante and Munro, 1993)
17	MR = exp(-$(t/a)^b$) Weibull (Corzo *et al*., 2008)

The drying models were evaluated by performing regression analysis using the drying data and the models listed in Table 1. The model chosen to be the best fit was that for which the value of the coefficient of determination (R^2) was closest to unity and the Chi-square (χ2) value was minimum (Akpinar, 2010; Tunde-Akintunde and Afon, 2010; Gikuru and El-Mesery, 2014; John *et al,* 2014). The value of the correlation coefficient (R^2) is determined using equation 5 (Ogunnaike, 2011; Barrett, 1974).

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{avg}\right)^2} \qquad [5]$$

Where $MR_{avg} = \sum_{i=1}^{N} MR_{pre,i} \Big/ N$

N is the total number of observations, MR denotes the moisture ratio; $MR_{pre,i}$ and $MR_{\exp,i}$ is the predicted experimental moisture ratio at *i*th and observation respectively.

The Root Mean Square Error (RMSE) is determined using equation 6 (Ogunnaike, 2011).

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

Chi-square (χ2) is determined using equation 7 (Ogunnaike, 2011).

$$\chi 2 = \frac{\sum_{i=1}^{N}(MR_{\exp,i} - MR_{pre,i})^2}{N-n} \quad [7]$$

Where

n is the number of models parameters.

Mean Bias Error (MBE) is determined using equation 8 (Ogunnaike, 2011).

$$MBE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{\exp,i})\right] \quad [8]$$

The 17 thin-layer drying models to which the drying data were fitted are presented in Table 1. The parametric coefficients of each model were determined using the Datafit 9.1 data regression software developed by Oakdale Engineering, Oakdale, PA. USA (2014). The software uses the Levenberg-Marquardt Method for Nonlinear Least Square Problems in determining its solution (Gavin, 2012). Table 2 presents the parametric constants, the Mean Bias Error (MBE), the coefficient of determination (R^2), the Root Mean Square Error (RMSE), and the Chi-square (χ2) values for each model.

3. RESULTS AND DISCUSSIONS

3.1 Processing the Kinetic Data

Yam slices 1.5 mm, 3.0 mm and 4.5 mm thick, with an initial moisture content of about 69% wet basis were dried using a Refractance Window™ dryer until their moisture content were less than 10%. The moisture content at specified drying times was determined and the moisture ratio calculated. The moisture ratio for each drying time was calculated assuming that the equilibrium moisture content was negligible. Drying was carried out with a draft of air at a velocity of 1.7 m/s across the dryer. The humidity of the air during drying varied between 48 and 59%, while the air temperature varied between 26 and 29°C.

For the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices, the experimental data of the drying process were fitted to 17 thin-layer mathematical drying models frequently used in food drying (Table 1). The regression results presented in Tables 2, 3, and 4 show that the Haghi and Ghanadzadeh (2005) thin-layer drying model gave the lowest value of Mean Bias Error (MBE), Chi-square (χ2), Root Mean Square Error (RMSE) values compared to the other 16 models; it also had the highest value of the coefficient of determination (R^2). The R^2 values were 0.9997, 0.9999 and 0.9999 for the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices respectively.

The good fit to the Haghi and Ghanadzadeh (2005) thin-layer drying model was further validated by plotting the experimental moisture content values against the predicted moisture content values as presented in Figures 2, 3 and 4. In all cases, the experimental and predicted moisture content values vary around a straight line which has a slope of approximately one and intercept of almost zero.

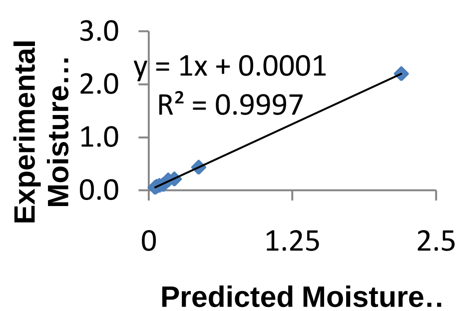

Figure .2 Experimental vs. Predicted Moisture Content for 1.5 mm thick Yam slices

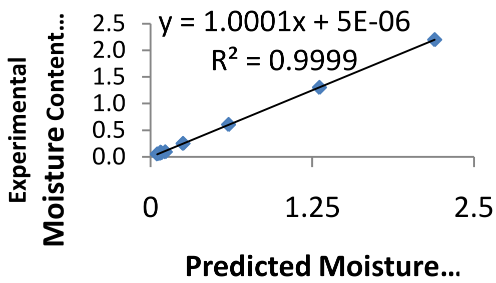

Figure 3. Experimental *vs*. Predicted Moisture Content for 3.0 mm thick Yam slices

Table 2: Constants and Coefficients Obtained by Fitting Data to the Various Thin-layer Models to 1.5mm Thick Yam Slices at 80 °C

No.	Model Name	Constants		R^2	MBE	χ2	RMSE
1	Newton (Ayensu, 1997)	k = 0.291323		0.9814	-0.02846073	0.00204093	0.04225885
2	Page (Page, 1949)	k = 0.8402249	n = 0.4164559	0.9994	-0.00018878	7.49E-05	0.00749325
3	Modified Page (Ozdemir and Devres,1999)	k = 0.6583515	n = 0.4164557	0.9994	-0.00018876	7.49E-05	0.00749325
4	Henderson and Pabis (Henderson and Pabis, 1961)	a = 0.9951653	k = 0.2902518	0.9814	-0.02898367	0.00237723	0.04222463
5	Modified Henderson and Pabis (Karathanos,1999)	a = 0.2868627 g = 0.073255 b = 0.2349916	c = 0.477091 h = 0.3992997 k = 41.82807	0.9977	0.004093945	0.00086793	0.01473031
6	Logarithmic (Togrul and Pehlivan, 2003)	a = 0.9503001 c = 0.0487723	k = 0.3575145	0.9965	-2.81E-08	0.00053489	0.01828409
7	Two term (Madamba, 1996)	a = 0.8294536 b = 0.170577	k_0 = 0.501765 k_1 = 0.055294	0.9996	3.55E-05	7.18E-05	0.0059905
8	Two term exponential Model(Sharaf-Elden *et al*.,1980)	a = 0.3614222	k = 0.5951218	0.9861	-0.02269998	0.00177787	0.03651583
9	Wang and Singh (Wang and Singh, 1978)	a = -0.0943858	b = 0.0020155	0.6974	0.038592778	0.03877577	0.17053394
10	Diffusion Approach (Demir *et al*., 2007)	a = 0.8294239 b = 0.1102002	k = 0.501757	0.9996	3.17E-05	5.74E-05	0.00599051
11	Verma et al. Model(Verma *et al.,* 1985)	a = 0.1705763 k = 0.0552938	g = 0.5017573	0.9996	3.17E-05	5.74E-05	0.00599051
12	Aghbashlo et al. (Aghbashlo *et al.,* 2009)	k_1 =0.5259845	k_2 =0.1276107	0.9992	0.000353181	0.00010171	0.00873379
13	Midilli *et al.* (Midilli *et al.,* 2002)	k = 0.8162379 n = 0.4338483	a = 1.000027 b = 0.0001427	0.9994	-4.11E-05	0.0001097	0.00740604
14	Haghi and Ghanadzadeh (Haghi and Ghanadzadeh, 2005)	a = 0.8363472 c = 1.93249 e = -0.0071468	b = 0.1122265 d = 9.11E-05 f = 0.163654	0.9997	1.98E-06	0.00011061	0.00525847
15	SFFD (Diamante and Munro, 1991)	a = 0.9951652	c = 2.612264	0.9814	-0.02898362	0.00237723	0.04222463
16	Modified Page equation –II (Diamante and Munro, 1993)	k = 2.097951	n = 0.4164562	0.9994	-0.00018875	7.49E-05	0.00749325
17	Weibull (Corzo *et al*., 2008)	a = 0.0008271	b = 0.096417	0.9825	-0.00118375	0.0022492	0.04107187

Table 3: Constants and Coefficients Obtained by Fitting Data to the Various Thin-layer Models to 3.0 mm Thick Yam Slices at 80 °C

No	Model Name	Constants		R^2	MBE	χ2	RMSE
1	Newton (Ayensu, 1997)	k = 0.0416277		0.9908	-0.00733215	0.000921728	0.02895
2	Page (Page, 1949)	k = 0.0192378	n = 1.23004	0.99456	-0.01413992	0.000599338	0.02214
3	Modified Page (Ozdemir and Devres,1999)	k = 0.0402713	n = 1.231638	0.99456	-0.01417715	0.00059932	0.02214
4	Henderson and Pabis (Henderson and Pabis, 1961)	a = 1.017514	k = 0.04225	0.9911	-0.00599665	0.000986717	0.02841
5	Modified Henderson and Pabis (Karathanos,1999)	a = 0.2111376	c = 0.6039398	0.9912	-0.0059965	0.001776091	0.02841
		g = 0.0422501	h = 0.04225				
		b = 0.202437	k = 0.0422498				
6	Logarithmic (Togrul and Pehlivan, 2003)	a = 1.006922	k = 0.0439854	0.9920	-1.52E-07	0.000997477	0.02693
		c = 0.0135007					
7	Two term (Madamba, 1996)	a = 0.2676148	k_0 = 0.04225	0.9911	-0.00599633	0.001268636	0.02841
		b = 0.7498996	k_1 = 0.0422499				
8	Two term exponential Model(Sharaf-Elden et al.,1980)	a = 0.0090191	k = 4.576484	0.9904	-0.00709793	0.001063664	0.0295
9	Wang and Singh (Wang and Singh, 1978)	a = -0.0214221	b = 0.0001056	0.8800	0.022068705	0.013299799	0.10432
10	Diffusion Approach (Demir *et al*., 2007)	a = 0.9993239	k = 0.0421325	0.9927	-3.57E-05	0.000913555	0.02578
		b = -0.6133384					
11	Verma et al. Model(Verma *et al.,* 1985)	a = 0.9993239	g = -0.0258417	0.9927	-3.55E-05	0.000913555	0.02578
		k = 0.0421325					
12	Aghbashlo et al. (Aghbashlo *et al*., 2009)	k_1 =0.0339139	k_2 = -0.005842	0.9930	-0.01686437	0.000774475	0.02517
13	Midilli et al. (Midilli *et al*., 2002)	k = 0.0147865	a = 0.999996	0.9994	-0.00062709	8.23E-05	0.00724
		n = 1.32087	b = 0.0002549				
14	Haghi and Ghanadzadeh (Haghi and Ghanadzadeh, 2005)	a = 1.141478	b = 0.0150982	0.9999	2.05E-05	2.60E-05	0.00343
		c = 1.2917	d = -1.29E-05				
		e = 0.0030382	f = -0.14174				
15	SFFD (Diamante and Munro, 1991)	a = 1.017514	c = 0.3802496	0.9911	-0.0059965	0.000986717	0.02841
16	Modified Page equation –II (Diamante and Munro, 1993)	k = 0.2865674	n = 1.231461	0.9950	-0.01417315	0.00059932	0.02214
17	Weibull (Corzo *et al.,* 2008)	a = 24.83153	b = 1.231637	0.9946	-0.01417739	0.00059932	0.02214

Table 4: Constants and Coefficients Obtained by Fitting Data to the Various Thin-layer Models to 4.5 mm Thick Yam Slices at 80 °C

No	Model Name	Constants		R^2	MBE	χ2	RMSE
1	Newton (Ayensu, 1997)	k = 0.0286055		0.9925	0.001885	0.00094729	0.0284949
2	Page (Page, 1949)	k = 0.0103597	n = 1.270369	0.9966	-0.00553235	0.00052327	0.01933299
3	Modified Page (Ozdemir and Devres,1999)	k = 0.0273952	n = 1.272043	0.9966	-0.00557486	0.00052325	0.01933267
4	Henderson and Pabis (Henderson and Pabis, 1961)	a = 1.010503	k = 0.0288453	0.9927	0.00326724	0.00111373	0.02820495
5	Modified Henderson and Pabis (Karathanos,1999)	a = 0.2452321	c = 0.0000123	0.9271	-0.02361738	0.05533315	0.08890858
		g = 0.0345479	h = 0.991145				
		b = 0.901456	k = 0.678412				
6	Logarithmic (Togrul and Pehlivan, 2003)	a = 1.023216	k = 0.0278001	0.9931	2.25E-07	0.00131008	0.02736091
		c = -0.0145787					
7	Two term (Madamba, 1996)	a = -1.775922	k_0 = 0.0192262	0.9937	-0.00093358	0.00158998	0.02610405
		b = 2.783624	k_1 = 0.0221643				
8	Two term exponential Model(Sharaf-Elden et al.,1980)	a = 1.986173	k = 0.0431373	0.9974	-0.00602666	0.00040167	0.01693829
9	Wang and Singh (Wang and Singh, 1978)	a = -0.0187892	b = 8.41E-05	0.9694	0.00874387	0.00465062	0.05763567
10	Diffusion Approach (Demir *et al.*, 2007)	a = -0.5301269	k = 0.3314659	0.9981	-0.00482732	0.00029535	0.01452458
		b = 0.1184332					
11	Verma et al. Model(Verma *et al.*, 1985)	a = 2.337212	g = 0.0286062	0.9925	0.00188501	0.00142093	0.0284949
		k = 0.0286059					
12	Aghbashlo et al. (Aghbashlo *et al.*, 2009)	k_1 = 0.0244226	k_2 = -0.003138	0.9949	-0.00532409	0.00077467	0.02352303
13	Midilli et al. (Midilli *et al.*, 2002)	k = 0.0070755	a = 1.001456	0.9977	-0.00064852	0.00057531	0.01570223
		n = 1.381757	b = 0.0001704				
14	Haghi and Ghanadzadeh (Haghi and Ghanadzadeh, 2005)	a = 0.6558495	b = 0.0004203	0.9999	2.45E-05	6.77E-05	0.00310948
		c = 2.268268	d = 1.47E-05				
		e = -0.0044032	f = 0.3447511				
15	SFFD (Diamante and Munro, 1991)	a = 1.010503	c = 0.2596077	0.9927	0.00326724	0.00111373	0.02820495
16	Modified Page equation –II (Diamante and Munro, 1993)	k = 0.1685089	n = 1.271844	0.9966	-0.00556998	0.00052325	0.01933267
17	Weibull (Corzo *et al.*, 2008)	a = 36.50269	b = 1.272042	0.9966	-0.00557515	0.00052325	0.01933267

Clearly, this demonstrates that the Haghi and Ghanadzadeh (2005) model could be used to explain the thin-layer drying behaviour of the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices. The coefficient of variance, (R^2), in all cases is better than 0.999.

The conclusion is that the Haghi and Ghanadzadeh thin-layer model best fits the experimental data. This is in agreement with other results reported by Akinola and Ezeorah (2016) for drying yam slices at 60 ^oC..

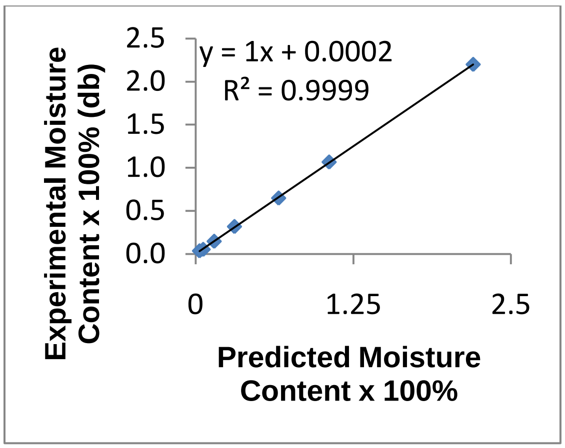

Figure 4. Experimental *vs*. Predicted Moisture Content for 4.5 mm thick Yam slices

3.2 The Drying Curves

The drying curves, i.e. moisture content *vs*. time plots, for the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices are shown in Fig. 5. The plots display the data points obtained experimentally for the 1.5 mm, 3.0 mm and 4.5 mm thick slices of yam; the line plot obtained from the model is also presented.

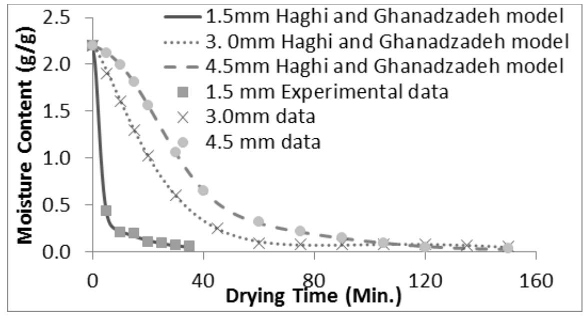

Figure 5 The Drying Curve

The 1.5 mm, 3.0 mm and 4.5 mm thick yam slices were observed to dry to a moisture content below 10% within 40 minutes, 80 minutes and 120 minutes respectively. Clearly the smaller the yam slices the faster the dehydration process; this is because it take less time for the moisture within the structure of the yam to travel the dimension of the slice.

3.3 Drying rate curves

The drying rate curves, i.e. drying rate *vs.* time plots for the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices are shown in Fig. 6. The plots are theoretical line plots of the drying rate which is based on the model equation. The theoretical plots of the drying rates are used because of the limited number of data points. As indicated in Fig. 6, the drying rate increases with time to a maximum value and then decreases. The increasing rate drying period for the yam slices is shorter than the falling rate drying period. The falling rate drying period takes place in two stages. The first stage is the unsaturated drying period where the surface is drying out and the second stage is the saturated drying period where moisture has to move through the aggregate before being released; this saturated drying period is slower. For the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices, the maximum drying rate which occurs in the constant rate period is very short, just a couple of minutes.

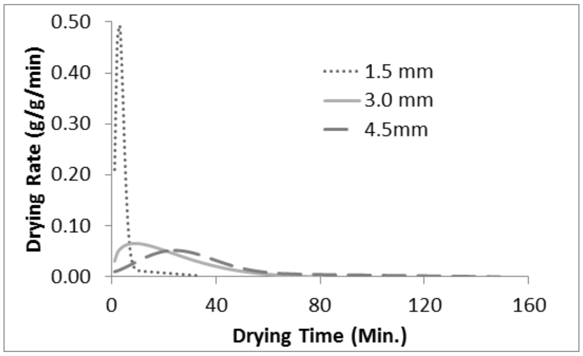

Figure 6 The Drying Rate Curve

3.4 Krischer Curves

The Krischer curves, i.e. drying rate *vs* moisture content plots for the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices are shown in Fig. 7. Each plot is a combination of the Drying curve and the Drying rate curve. The plots, (Fig. 7), show that the drying rate (right to left) increases from its initial value when the tuber slice is fresh (warming up), it reaches its' peak value (constant rate period) and then drops (falling rate period). The drying rate increases most rapidly for the 1.5 mm thick yam slices.

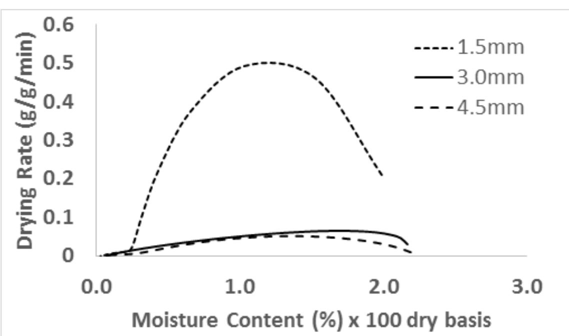

Figure 7 The Krischer Curve

3.5 Rehydration Ratio

The Rehydration ratio *vs.* Rehydration time plots for the yam is shown in Fig. 8. Rehydration was performed using 1.5 mm thick yam slices. Being the smallest thickness of the yam slices, it is expected that yam samples of this size will rehydrate fastest. Observations indicate that the

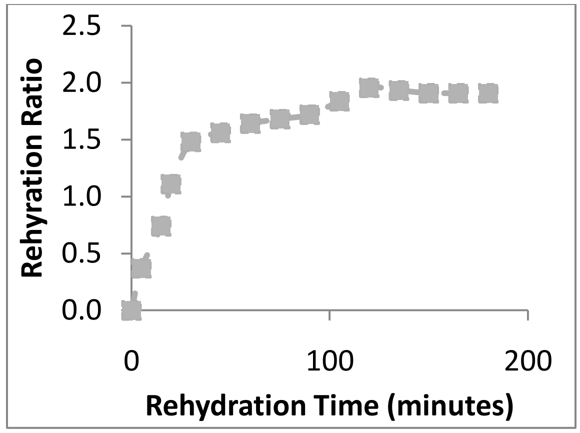

Figure. 8 Rehydration Ratio *vs.* Rehydration time plot for yam

rehydration ratio for the yam slices increased rapidly in the first hour and attained a steady value thereafter. For the yam slices, the rehydration ratio increased rapidly to about 1.64 in the first 60 minutes and increased slowly to about 1.91 in the next 60 minutes after which it maintained a steady value.

4. CONCLUSION.

1.5 mm. 3.0 mm and 4.5 mm thick yam slices, with initial moisture content of about of 69% (wet basis) were dried until the moisture contents were less than 10% using a Refractance Window^{TM} type dryer. The following conclusions are made:

1. The smallest 1.5 mm thick yam slices dehydrated faster than the larger 3.0 and 4.5 mm thick slices; because it take less time for the moisture within the yam slice structure to travel the dimension of the slice.
2. Of the 17 thin-layer drying models tested, the Haghi and Ghanadzadeh thin drying model was observed to best fit the drying kinetics of the 1.5 mm, 3.0 mm and 4.5 mm thick yam slices with the experimental data fitting the model with a coefficient of determination (R^2) value exceeding 99.9%.
3. The 1.5 mm, 3.0 mm and 4.5 mm thick yam slices dried to a moisture content of

less than 10% within 40 minutes, 80 minutes and 120 minutes respectively.

4. The rehydration ratio of the 1.5 mm thick yam slices, increased to a steady value of about 1.91 in about 180 minutes.

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