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Modelling the Rehydration Characteristics of White Yam

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Abstract: *Presented in this paper is a proposed model describing the variation in the rehydration ratio with rehydration time for yam slices. The 'new' model describes the relationship between the moisture content of yam slices with time when rehydrated. The changes in mass and moisture content data with rehydration time, during the rehydration process, were recorded. Rehydration was carried out at 27 °C, 40 °C, 60 °C, and 80°C for 3.0 mm thick dehydrated yam slices. Regression analysis established that the variation in rehydration ratio vs rehydration time data, better fitted a two-term exponential equation rather than a quadratic equation. Also, regression analysis done on variation in rehydration ratio vs rehydration time data of cube sweet potatoes found it literature, further validated that the rehydration ratio vs rehydration time data better fitted a two-term exponential equation rather than a quadratic equation. For the recorded moisture content versus rehydration time data, a better fit was obtained for the new model rather than the Weibull, Peleg, and Exponential models. This study is essential for a better understanding of the rehydration characteristics of yam slices during the rehydration process. Information about rehydration characteristics of the yam slices presented in this work will also be valuable to optimise and characterise the soaking conditions, design yam-processing equipment and predict water absorption as a function of time and temperature. The rehydration process clearly indicates that rehydration occurs very rapidly in the first few minutes of the rehydration process, and this process is faster as the rehydration temperature increases.*

Keywords: *Rehydration Ratio Models; Rehydration kinetic models; Yam; Weibull, Peleg, and Exponential models*

1. Introduction

White yams *(Dioscorea rotundata)* are very nutritious and are an excellent source of energy and dietary fiber (USDA, 2017a; USDA, 2017b; Hackett *et al.*, 1986; Subar *et al.*, 1998a; Subar *et al.*, 1998a; Reedy and Krebs-Smith, 2010). Yams are eaten routinely in the tropical region of the world, and they constitute a dominant portion of the standard diet for many people. They are used, worldwide, in many different recipes. For this reason, yam tubers are moved to the many locations where they are consumed. However, they are heavy, constituting of at least 70% water. Dehydrating yams like most foods and agricultural products is becoming an essential method of processing before being shipped to where they are consumed.

Dehydration which is the process of removing moisture from a food product to decrease bulk has been studied extensively. Akinola *et al.* (2017, 2018) and Akinola and Ezeorah (2016, 2018) investigated the use of the Refractance Window^{TM} drying technique to dehydrate carrots, yam, cassava and potato slices in the temperature range of 60 -95°C. The root tubers were sliced to a size range of 1.5 - 6.0 mm; they established that the tuber slices could be dehydrated to a moisture content of 0.01 g-water/g-solid within 45 - 200 minutes depending on the temperature. Lin *et al.* (2007), studied dehydration of yams studied using freeze drying with far-infrared radiation. The study was done using a 3 factor design of temperature, thickness and distance for heater, to find the optimum drying conditions. The yam slices were 1.5-6.0 mm thick. Also, dehydration of yams is performed for preservation purposes.

The dependence of many dehydrated food and agricultural commodities in the present marketplace is increasing as this is a means of extending the length of time that the products may be stored without becoming unfit for future use. Rehydration operations, therefore, are gaining importance as these dried products will need to be rehydrated before use. There is, therefore, need to understand the issues relating to rehydration processes concerning the design and the operations of these processes.

Mathematical modeling has been useful in the study, design, optimisation, and operations of these rehydration processes (Marinos-Kouris *et al.*, 1991; Vagenas and Marinos-Kouris, 1996). This study involves investigating the variations in the rehydration ratio and moisture content of the samples with rehydration time, and estimating other rehydration characteristics of the dehydrated products.

The models that have been used to study the rehydration characteristics of foods are the Peleg model (Gowen *et al.*, 2007), the Weibull distribution model (García-Pascual, *et al.*, 2006; Machado *et al.*, 1999; Marabi *et al.*, 2003), and the exponential model (Gowen *et al.*, 2007; Kashaninejad, 2007). However, for accurate use of these models, the rehydration data and knowledge of some physical parameter(s) of the product studied, is required. For the Peleg, Weibull distribution and Exponential models knowledge of the initial moisture content before rehydration is needed (Misra and Brooker, 1980). For the Exponential model, the equilibrium moisture content also needs to be known; and for the Weibull model, knowledge of scale and shape parameters of the samples are required (Saguy *et al.*, 2007). Presented in this study is a new rehydration model for yam that requires only the moisture content rehydration data. Also, performed is a comparison of all the four (4) rehydration models.

2. Materials and Methods

2.1 Sample Preparation and the Dryer

White yam tubers acquired from the local market were washed, peeled, cut into 3 mm thick slices. As indicated in literature, (Adelaja, *et al*, 2010; Akinola *et al.*, 2017, 2018; Akinola and Ezeorah, 2016, 2018; Lin *et al.*, 2007), tubers are cut into slices 1.5 – 6.0 mm thick before dehydrating. On this basis, yam slices 3.0 mm thick were chosen for the work done in the study. The Refractance Window^{TM} dryer used in this study was fabricated in the laboratory. The equipment is similar to the used by Akinola *et al.* (2018).

The dryer was 2.0 m in length, 1.0 m wide and had a depth of 10 cm and it was covered with a 0.15 mm thick colourless polyethylene terephthalate (PET) Mylar plastic film. The water in the dryer was heated using a 2.5kW electric immersion heater. The temperature of the water was maintained using a BAYITE BTC211 Digital Temperature Controller which was manufactured by Shenzhen Bayite Technology Co., Ltd, Shenzhen City, China, (Shenzhen Bayite Technology Co., Ltd., 2018). The yam slices were dried until the moisture content was about 0.03g-water/g-solid. The dehydrated samples were kept in air-tight polyethylene bags and stored in a refrigerator until further use in the rehydration experiments.

2.2 Rehydration experiments and Rehydration Equipment

The dried samples of yam slices were brought to room temperature before starting the rehydration experiments. Rehydration of the yam slices was done in 250-mL beakers filled with distilled water. The beakers were immersed in a 19.5L Thermo Scientific™ Precision™ General-Purpose Water Bath, Model 184/284, manufactured by Fisher Scientific Suwanee, GA 30024 USA (Fisher Scientific, 2014). Each set of experiments was performed at 27^{o}C, 40^{o}C, 60^{o}C, and 80^{o}C ($\pm$0.5^{o}C). Approximately 3.75 $\pm$ 0.25g of yam slices was immersed in 100 ml of distilled water for periods of 10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 180, 210 and 240 minutes. The temperature of the water inside the beakers was determined with the use of the Digi-Sense® Type K thermocouple thermometer, manufactured by Oakton Instruments, Vernon Hills, IL 60061, USA (Oakton Instruments, 2014). Cups made from perforated plexiglass were used to cover the samples to ensure they were entirely immersed in the water in the beakers during rehydration.

After rehydration, the water was drained from the flask, and excess water on the samples was removed using tissue paper. The samples were then weighed. The moisture content of the samples was determined using an OHAUS MB45 moisture analyser manufactured by OHAUS Corporation, Pine Brook, NJ, USA, (OHAUS Corporation, 2011). The analyser measured moisture content to an accuracy of 0.01% on a wet basis. To eliminate anomalies, in the data recorded, every experiment was done in triplicate.

2.3 Modelling the Rehydration Ratio

The rehydration ratio (RR) was calculated according to equation 1.

$$RR = W_t/W_o \qquad (1)$$

where W_t is the mass of the rehydrated sample at time t, and W_o is the initial mass of the sample to be rehydrated.

The rehydration ratios and rehydration times were correlated first according the quadratic equation of the form given in equation 2.

$$RR = p_5 {*} t^2 + p_6 {*} t + p_7 \qquad (2)$$

where p_5, p_6, and p_7, are constants and t is the rehydration time in minutes.

Singh and Pandey (2011) used equation 2 to correlate the rehydration ratios and rehydration times of cubed potatoes; they claimed to have satisfactory results. However, a quadratic equation model suggests that the rehydration ratio will rise to a maximum value and then fall. However, the laws of mass transfer do not suggest that moisture or water will be lost by a substance when the substance is immersed in water. Rather, the moisture content will rise to a steady value. A two-term exponential equation in the form presented in equation 3, relating the rehydration ratio and rehydration times suggests a peak rehydration ratio value will be attained.

$$RR = p_1 {*} \exp(p_2 {*} t) + p_3 {*} \exp(p_4 {*} t) \qquad (3)$$

where p_1, p_2, p_3, and p_4, are constants and t is the rehydration time in minutes. The constants p_1, p_2, p_3, p_4, p_5, p_6, and p_7 are obtained by regression analysis

2.4 Modelling the Rehydration Data

The experimental moisture content/time variation data was fitted to the equations 4, 5, 6 and 7 to determine the model that best describes the variation data of the yam slices.

$M_t = M_o + (t/(a+bt))$ Peleg model (4)

$M_t = M_o\,[1 - exp(-(t/\alpha)^{\beta})]$ Weibull model (5)

$M_t = (M_o - M_e)\,exp(ct^d) + M_e$ Exponential model (6)

$M_t = g\,exp(h\,t) + j\,exp(q\,t)$ New Model (7)

where M_t is the moisture content at time t, M_o is the initial moisture content, M_e is the equilibrium moisture content, and α, β, a, b, c, d, g ,h, j, and q are constants observed from regression analysis

For quality fit, the coefficient of determination (R^2) should be closest to unity while the sum of square-error (SSE), and the root-mean-square-error (RMSE) should closest to zero. The methods of estimating R^2, SSE and RMSE are discussed extensively in the literature (Ogunnaike, 2011; Johnson, 2017). In this work, the software package from Matrix Laboratory (MATLAB) was used to perform the statistical analysis (MathWorks, 2017).

3. Results and Discussions

3.1 Evaluation of the Rehydration Ratio Models

Four sets of rehydration experiments were performed at rehydration water temperatures of 27°C, 40°C, 60°C, and 80°C. The rehydration ratio at each rehydration time was calculated according to equation 1 using the weight data obtained during the rehydration experiments. Table 1 presents the statistical parameters when the rehydration ratios were correlated with rehydration time according to equations of the form given in equations 2 and 3. Table 1 clearly indicates that the two-term exponential model fits the rehydration ratio versus time data better than the quadratic equation model. For the two-term exponential equation form, the R^2 values were closer to unity and the SSE and RMSE values were closer to zero than the quadratic equation form. Table 2 shows the constants obtained with a 95% confidence bound, by fitting the rehydration ratio data to the exponential equation form presented in equation 2.

Figure 1 shows a plot of the variation in the experimental and the predicted (Exponential) rehydration ratio with drying time at different temperatures for white yam. The initial rehydration ratio is 1.0. The plots of the experimental and predicted rehydration ratios versus time are observed as expected to be a good fit and the results of the regression analysis are shown in Table 1. In the first few minutes of experimentation, the rehydration ratio increases rapidly from a value of 1 and less rapidly thereafter. Besides, the rate of increase of the rehydration ratio increases with increasing rehydration temperature.

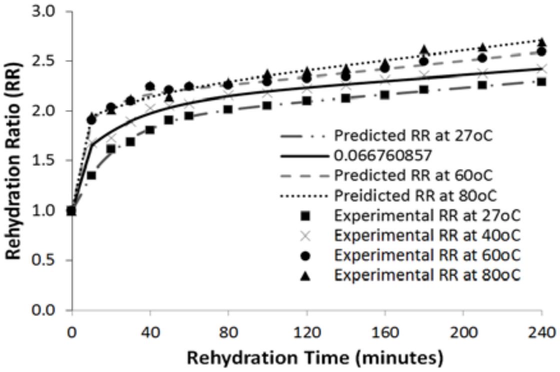

Figure 1. Variation in Rehydration Ratio with Drying Time at Different Temperatures for white yam

Table 1. Statistical Parameters for Yam when correlating Rehydration Ratios with Rehydration Time at different temperature

	Exponential Equation Form			**Quadratic Equation Form**		
Water Temperature	R^2	RMSE	SSE	R^2	RMSE	SSE
27 °C	0.9966	0.0180	0.0032	0.9245	0.0808	0.0719
40 °C	0.9860	0.0311	0.0097	0.9447	0.0591	0.0384
60 °C	0.9030	0.0214	0.0046	0.9420	0.0501	0.0276
80 °C	0.9864	0.0317	0.0100	0.9803	0.0364	0.0146

Table 2. Constants For The Models Obtained By Fitting Rehydration Data The Exponential and Quadratic Models For Yam Slices

Temperature	**Exponential Model Constants**	**Quadratic Model Constants**
27 °C	p_1 = 1.92E+00 ±5.20E-02 p_2 = 7.52E-04 ±1.53E-04 p_3 = -8.88E-01 ±9.01E-02 p_4 = -4.32E-02 ± 8.88E-03	p_5 = -2.04E-05 ± 1.07E-05 p_6 = 8.13E-03± 2.63E-03 p_7 = 1.45E+00 ± 1.26E-01
40 °C	p_1 = 2.08E+00 ±1.14E-01 p_2 = 6.46E-04 ± 2.97E-04 p_3 = -6.22E-02 ±1.34E-01 p_4 = -3.47E-02 ±1.77E-02	p_5 = -1.54E-05 ± 7.80E-06 p_6 = 6.55E-03± 1.92E-03 p_7 = 1.69E00 ± 9.20E-02
60 °C	p_1 = 2.11E+00 ± 4.00E-02 p_2 = 8.50E-04 ± 1.18 E-04 p_3 = -4.871E-01 ± 2.30E-01 p_4 = -7.61 E-02 ± 4.43E-02	p_5 = -5.90E-06 ± 5.90E-06 p_6 = 3.88E-03± 1.63E-03 p_7 = 1.98E+00 ± 7.80E-02
80 °C	p_1 = 2.15E+00 ± 1.40E-01 p_2 = 9.70E-04 ± 3.31E-04 p_3 = -3.08E-01 ± 1.33E-01 p_4 = -2.85E-02 ± 2.85E-02	p_5 = -7.18E-06 ± 4.82E-06 p_6 = 4.87E-03± 1.18E-03 p_7 =1.93E+00 ± 1.99E+00

3.2 Validation of Rehydration Ratio Models

To establish whether the two-term exponential model fits better the rehydration ratio/time data than the quadratic equation model, experimental data in literature was used. Singh and Pandey (2011) studied the rehydration characteristics of sweet potato cubes at 50^{o}C, 60^{o}C, 80^{o}C, and 90^{o}C after dehydration in a cabinet hot air dryer. Singh and Pandey (2011)'s work concluded that rehydration ratio relationship with rehydration time followed a quadratic equation. In this study, the data from Singh and Pandey (2011)'s work was obtained by graphical extrapolation from the graph. The same set of data was applied to the two-term exponential model and the quadratic equation model. Table 3 presents the results of the regression analysis.

3.3 Evaluation of the Rehydration Moisture Content/ Time Variation Models

Yam slices with moisture content of 0.03g-water/g-solid were rehydrated at 27^{o}C, 40^{o}C, 60^{o}C, and 80^{o}C. The moisture content data obtained from the rehydration experiments was fitted to the New Model, the Weibull model, the Peleg model, and the Exponential model presented in equations 4, 5, 6 and 7. Table 4 presents the statistical results of correlating the moisture content rehydration data using the Peleg, Weibull, and Exponential and New models. For quality fit, the model chosen to best fit the rehydration moisture content/time variation data of the yam slices is the one that meets the following three criteria: R^2 is closest to unity, and SSE and RMSE are closest to zero. While most of the models fitted the moisture content experimental data with a coefficient of variance values exceeding 0.9600, the R^2 for the New model was the one closest to unity for all the temperatures. For the experiments performed at 27^{o}C, 40^{o}C, 60^{o}C, and 80^{o}C, R^2 exceeded 0.995 for the model.

Moreover, for the temperatures considered, the SSE, and RMSE, values were the least for the New model. The implications are that the model best fits the rehydration data among the models examined. However, the SSE, and RMSE values are large. This implies that the model would be used in the range of process conditions studied, but it would not be used for predictions outside that range. The coefficients obtained by fitting rehydration moisture content data to the new model for the yam slices are presented in Table 5.

To validate whether the new rehydration model best fits the moisture content rehydration data, a simple linear regression analysis was performed between the experimental and predicted rehydration values. Table 6 depicts the relationship between the experimental and predicted rehydration moisture content values.

Figure 2 shows the variation in moisture content of the yam samples with time rehydrated at different temperatures. The initial moisture content of the yam slices was 0.03 g-solid/g-water. The plots show that for any given time, the moisture content of the yam sample is higher as temperature increases. The plots show that as the rehydration temperature increases the extent of rehydration increases.

Table 3. Statistical Parameters for Sweet Potatoes When Correlating Rehydration Ratios with Rehydration Time at Different Temperature

	Exponential Equation Form			**Quadratic Equation Form**		
Temperature	R^2	SSE	RSME	R^2	SSE	RSME
50 ^{o}C	0.9966	0.0007	0.0132	0.9739	0.0053	0.0325
60 ^{o}C	0.9967	0.0008	0.0139	0.9718	0.0065	0.0362
80 ^{o}C	0.9976	0.0007	0.0130	0.9647	0.0101	0.0450
90 ^{o}C	0.9975	0.0008	0.0141	0.9599	0.0126	0.0503

Table 4. Regression Constants Correlating the Moisture Content Rehydration Data Using Different Models

Temperature	**Models**	$\mathbf{R^2}$	**RMSE**	**SSE**
27 ^{o}C	New	0.997	1.511	15.00
	Peleg	0.995	2.772	92.19
	Weibull	0.977	6.089	444.92
	Exponential	0.976	6.234	466.40
40 ^{o}C	New	0.996	1.842	33.91
	Peleg	0.988	3.050	111.59
	Weibull	0.966	5.174	321.28
	Exponential	0.965	5.224	327.42
60 ^{o}C	New	0.996	1.596	25.46
	Peleg	0.952	4.866	284.15
	Weibull	0.976	3.454	143.19
	Exponential	0.976	3.473	144.73
80 ^{o}C	New	0.993	2.248	50.53
	Peleg	0.881	8.195	805.82
	Weibull	0.982	3.171	120.63
	Exponential	0.982	3.152	119.22

Table 5. Coefficients Obtained by Fitting Rehydration Moisture Content Data to the New Model for Yam Slices

	Temperature			
Constants	27^{o}C	40^{o}C	60^{o}C	80^{o}C
α	99.76000	46.11000	24.63000	17.30000
β	0.50350	0.33500	0.27290	0.30650
a	0.15880	0.06158	0.03210	0.03559
b	0.00513	0.00528	0.00522	0.00490
c	-0.09350	-0.26920	-0.40800	-0.40840
d	0.51180	0.33900	0.27570	0.30960
g	136.10000	154.60000	164.20000	176.10000
h	0.00118	0.00089	0.00080	0.00081
J	-128.40000	-116.80000	-85.58000	-59.72000
q	-0.03772	-0.06141	-0.06353	-0.03705

Table 6. Relationship between the Experimental and Predicted Rehydration Moisture Content

Temperature	**Equation**	**R^2**
27 ^{o}C	*PMC* = 0.9991*EMC*	0.9945
40 ^{o}C	*PMC* = 0.9997*EMC*	0.9962
60 ^{o}C	*PMC* = 1.0018*EMC*	0.9977
80 ^{o}C	*PMC* = 0.9998*EMC*	0.9925

In the first ten minutes, the moisture content of the yam slices for rehydration temperatures of 27^{o}C, 40^{o}C, 60^{o}C and 80^{o}C are 46.69, 91.53, 120.41, and 137.87 g-water/g-solid respectively. There is a 3-fold magnitude in the moisture content of the samples rehydrated with a water temperature of 80^{o}C over the moisture content of sample rehydrated at 27^{o}C. However, after about 240 minutes, the difference in the magnitude of the moisture contents decreases; the moisture content ranged from 179.02 - 212.60 g-water/g-solid for rehydration done in the temperature range of 27-80 ^{o}C.

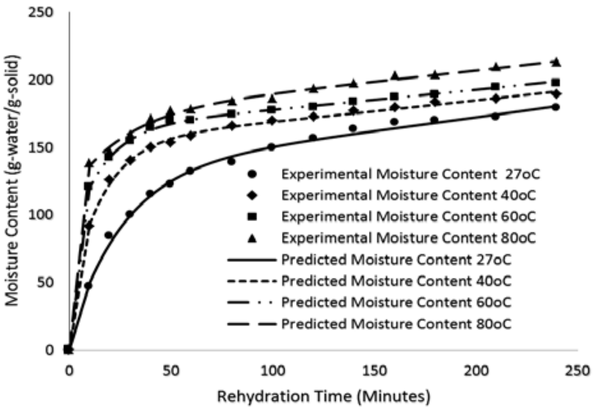

Figure 2. Variation in Moisture contents of yam with rehydration time at 27 ^{o}C, 40 ^{o}C, 60 ^{o}C and 80^{o}C

4. Conclusions

White yam *(Dioscorea rotundata)* slices, 3.0 mm thick, dehydrated to a moisture content of about 0.03g-water/g-solid in a Refractance Window^{TM} dryer were rehydrated at 27^{o}C, 40^{o}C, 60^{o}C and 80^{o}C. The variation in mass and moisture content of the samples with rehydration time was recorded. By fitting the variation in rehydration ratio with time data, to the two-term exponential and the quadratic rehydration ratio models, and by fitting the variation in moisture content with rehydration time data to the Weibull, Peleg, and Exponential models, the following are the conclusions:

1. The two-term exponential equation fits the rehydration ratio variation data better than the quadratic equation proposed by Singh and Pandey, (2011). For the rehydration temperatures considered, the R^2 values for the two-term exponential equation were higher and also closest to unity in all cases. For the samples rehydrated at 27^{o}C, 40^{o}C, 60^{o}C and 80^{o}C, R^2, for the two-term exponential equations were 0.9966, 0.9860, 0.9903, and 0.9864, respectively as opposed to 0.9245, 0.9447, 0.9420 and 0.9803 for the quadratic equation. Also, for the samples rehydrated at 27^{o}C, 40^{o}C, 60^{o}C and 80^{o}C, the root-mean-square-error (RMSE) were 0.0180, 0.0311, 0.0214 and 0.0317 respectively, and the sum-of-squared-error (SSE) were 0.0032, 0.0097, 0.0046 and 0.0100, respectively. All the RMSE and SSE values are close to zero.
2. When applying the models to Singh and Pandey (2011) data for rehydrating cubes of sweet potato, the two-term exponential equation was a better fit than the quadratic equation. The coefficient of variation, R^2, for the two-term exponential equations, was closer to unity than for the quadratic equations at all temperatures (see Table 4).
3. When rehydrating the slices, the mass (see Figure 1) and moisture content (see Figure 2) values reached higher values for the same rehydration time as the temperature increased. The rehydration ratio and moisture content for the slices rehydrated at 80^{o}C were about 50% higher for samples rehydrated at 27^{o}C after ten minutes.
4. For the yam slices, the new model better fits the rehydration moisture content/time variation data than the Peleg, Weibull and Exponential rehydration models for the process temperatures studied. Among the models investigated, the R^2 value for the new models was closest to unity for all the process temperatures studied.

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References:

Adelaja, A.O., Asemota, O.S., and Oshiafi, I.K. (2010), “Experimental determination of the moisture content pattern in yam during drying”, *Journal of Applied Sciences Research*, Vol.6, No.8, pp.1171-1181.

Akinola, A.A., Shittu A.S and Ezeorah, S.N., (2017), “Dehydration and rehydration characterisation of yam (*Dioscorea Rotundata*) tuber slices using a Refractance Window^{TM} Dryer”, *Zimbabwe Journal of Science and Technology*, Vol.12, pp.75-87 (e-ISSN 2409-0360)

Akinola, A.A. and Ezeorah, S.N. (2017), “Study of the drying characteristics of cassava (*Manihot Esculanta*) using a Refractance Window™ Dryer”, J*ournal of the Nigerian Society of Chemical Engineers*, Vol.32, No.1, pp 55-63.

Akinola, A.A., Ayo, D.B. and Ezeorah, S.N., (2018), “Temperature dependence of the effective moisture diffusivity of yam (*Dioscorea rotundata*) slices dried using a Refractance Window^{TM} Dryer”, *The Journal of the Association of Professional Engineers of Trinidad and Tobago* (JAPETT), Vol.46, No.1, pp 30 - 34 (ISSN 1000 7924).

Akinola, A.A. and Ezeorah, S.N., (2016), “Dehydration studies of root tubers using a Refractance Window Dryer”, *Proceedings of the 20th International Drying Symposium*, Nagaragawa Convention Centre, Gifu, Japan, August, Available at: https://s3.amazonaws.com/academia.edu.documents/48293897/P1-1.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1547045996&Signature=oJv7OVyx902m9zjefdGAayv7E%2BA%3D&response-content-disposition=inline%3B%20filename%3DDEHYDRATION_STUDIES_OF_ROOT_TUBERS_USING.pdf (Accessed January 09, 2019).

Fisher Scientific (2014), *Fisher Scientific Catalog*, 3970 John’s Creek Court, Suite 500, Suwanee, GA 30024 USA

García-Pascual, P., Sanjuán, N., Melis, R., and Mulet, A. (2006), “Morchella esculenta (morel) rehydration process modelling”, *Journal of Food Engineering*, Vol.72, No.4, pp.346-353.

Gowen, A., Abu-Ghannam, N., Frias, J., and Oliveira, J. (2007), “Influence of pre-blanching on the water absorption kinetics of soybeans”, *Journal of Food Engineering*, Vol.78, No.3, pp.965-971.

Hackett, A.F., Rugg-Gunn, A.J., Appleton, D.R., and Coombs, A., (1986), “Dietary sources of energy, protein, fat and fibre in 375 English adolescents”, *Applied Nutrition*, Vol.40, No.3, pp.176-184.

Johnson, R.A., (2017), *Miller and Freund’s Probability and Statistics for Engineers*, Pearson Education.

Kashaninejad, M., Maghsoudlou, Y., Rafiee, S., and Khomeiri, M. (2007), “Study of hydration kinetics and density changes of rice (*Tarom Mahali*) during hydrothermal processing”, *Journal of Food Engineering*, Vol.79, No.4, pp.1383-1390.

Lin, Y.P., Lee, T.Y., Tsen, J.H., and King, V.A.E. (2007), “Dehydration of yam slices using FIR-assisted freeze drying”, *Journal of Food Engineering*, Vol.79, No.4, pp.1295-1301.

Machado, M.F., Oliveira, F.A., and Cunha, L.M. (1999), “Effect of milk fat and total solids concentration on the kinetics of moisture uptake by ready-to-eat breakfast cereal”, *International Journal of Food Science and Technology*, Vol.34, No.1, pp.47-57.

Marabi, A., Livings, S., Jacobson, M., and Saguy, I. S. (2003), “Normalised Weibull distribution for modelling rehydration of food particulates”, *European Food Research and Technology*, Vol.217, No.4, pp.311-318.

Marinos-Kouris, D., Maroulis, Z.B., and Kiranoudis, C.T., (1996), “Computer simulation of industrial dryers”, *Drying Technology - An International Journal*, Vol.14, No.5, pp.971-1010, DOI: 10.1080/07373939608917137

MathWorks, (2016), *MATLAB and Statistics Toolbox Release 2016*, The MathWorks, Inc., Natick, Massachusetts, United States.

Misra, M.K., and Brooker, D.B. (1980), “Thin-layer drying and rewetting equations for shelled yellow corn”, *Transactions of the ASAE*, Vol.23, pp.1254-1260.

Oakton Instruments, (2014), *The Digi-Sense® Type K Thermocouple Thermometer*, Oakton Instruments, P.O Box 5136, Vernon Hills, IL 60061, USA.

Ogunnaike, B.A., (2011), *Random Phenomena: Fundamentals of Probability and Statistics for Engineers*, CRC Press.

OHAUS Corporation (2011), *Instruction Manual MB45 Moisture Analyser*, OHAUS Corporation, 7 Campus Drive, Suite 310, Parsippany, NJ 07054 USA.

Reedy, J., and Krebs-Smith, S.M., (2010), “Dietary sources of energy, solid fats, and added sugars among children and adolescents in the United States”, *Journal of the American Dietetic Association*, Vol.110, No.10, pp.1477-1484.

Saguy, I.S., Marabi, A., and Wallach, R. (2005), “New approach to model rehydration of dry food particulates utilising principles of liquid transport in porous media”, *Trends in Food Science and Technology*, Vol.16, No.11, pp.495-506.

Shenzhen Bayite Technology Co., Ltd., (2018), *BAYITE BTC211 Digital Temperature Controller Manual*, Retrieved January 27, 2018 from https://images-na.ssl-images-amazon.com/images/I/91SaoMRr+8L.pdf.

Singh, N.J., and Pandey, R.K., (2011), “Rehydration characteristics and structural changes of sweet potato cubes after dehydration”, *American Journal Food Technology*, Vol.6, No.8, pp.709-716.

Subar, A.F., Krebs-Smith, S.M., Cook, A., and Kahle, L.L. (1998a), “Dietary sources of nutrients among US children, 1989-1991”, *Pediatrics*, Vol.102, No.4, pp.913-923.

Subar, A.F., Krebs-Smith, S.M., Cook, A. and Kahle, L.L. (1998b), “Dietary sources of nutrients among US adults, 1989 to 1991”, *Journal of the American Dietetic Association*, Vol.98, No.5, pp.537-547.

USDA (2017a), *Agricultural Research Service USDA Food Composition Databases*, United States Department of Agriculture, Retrieved August 30, 2017 from https://ndb.nal.usda.gov/ndb/foods/show/3266?man=&lfacet=&count=&max=&qlookup=&offset=&sort=&format=Abridged&reportfmt=other&rptfrm=&ndbno=&nutrient1=&nutrient2=&nutrient3=&subset=&totCount=&measureby=&Qv=1&Q6170=1&Qv=21&Q6170=1

USDA (2017b), *Agricultural Research Service USDA Food Composition Databases*, United States Department of Agriculture, Retrieved August 30, 2017 from https://ndb.nal.usda.gov/ndb/foods/show/3207?fg=&manu=&lfacet=&format=&count=&max=50&offset=&sort=default&order=asc&qlookup=potato%2C+raw&ds=&qt=&qp=&qa=&qn=&q=&ing=

Vagenas, G.K., and Marinos-Kouris, D. (1991), “The design and optimisation of an industrial dryer for sultana raisins”, *Drying Technology*, Vol.9, No.2, pp.439-461.

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