

Modeling the equilibrium moisture content of desorption and adsorption of yam (*Dente*)

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Abstract: The experimental equilibrium moisture content of yam (*Dioscorea rotundata*; cultivar: *Dente*) at temperatures of 25°C and 50°C were determined at relative humidity from 0% to 95% employing the dynamic vapor sorption analyzer. Wet yam samples with about 68% initial moisture content were used, first for desorption and subsequently for sorption. Water activity decreased with increased temperature at constant equilibrium moisture content. The desorption and adsorption isotherms were fitted by the Guggenheim-Anderson-de Boer (GAB), Henderson, Halsey, Oswin, Smith, Brunauer-Emmett-Teller (BET) and Peleg models. On the basis of the fit the Peleg, GAB and Oswin models were most suitable for describing the observed data. When the focus is on drying, the GAB (3 parameters) and empirical Peleg model (4 parameters) performed best. Of these, GAB is preferable because it has fewer parameters, which, moreover, have a physical meaning.

Keywords: sorption isotherm, yam, equilibrium moisture content, GAB

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1 Introduction

Yam is an important food crop for many people in the yam zone of West Africa. It forms about 10% of the total roots and tubers produced in the world. It has been estimated that the world yam production would increase by 27% between the years 2003-2020. In past decades, yam production in Ghana increased by 10% per year (Kenyon et al., 2006). It is second to cassava as the most important tropical root crop but is nutritionally better than cassava on account of their vitamin C (40-120 mg g⁻¹ edible portion) and crude protein (40-140 g kg⁻¹ dry matter) content (Opara, 2003). Yam has a moisture content of about 70% when harvested (Fioreze and Morini, 2000), making it highly perishable. Therefore it is essential to develop effective methods that prolong the shelf life of yam without compromising on its nutritional and healthy components. With this purpose in mind, it is

imperative to obtain more information on some properties of yam that can help to reduce post-harvest losses.

Sorption isotherms give an indication of the equilibrium conditions of a food product under varying conditions of relative humidity and temperature. Information about the sorption isotherms is necessary for the optimization and design of drying equipment, predictions of quality parameters, shelf-life study, milling, mixing, packaging and storage investigations. Sorption data helps to predict the water activity which is indicative of the susceptibility of food product to spoilage microorganisms. One of the ways by which yam can be preserved to extend its shelf life is by drying, but not much is known about the parameters related to drying characteristics of yam, especially regarding desorption and sorption isotherms. Sorption isotherms of food materials have been reported by amongst others Gálvez et al. (2006), Montes (2009) and Saad et al. (2014). The majority of the work pertains to constant temperatures in the range of 15-60°C on samples from a variety of crops such as potato, carrots, green pepper, onions and dates (Samaniego-Esquerria et al., 1991; Kiranoudis et al., 1993;

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Myhara et al., 1998a, b). However, not much attention has been given to yam. A recent work on the desorption isotherms of two varieties of *D. rotundata* was studied by Montes et al. (2009). It was shown that, according to the general accepted view, the equilibrium moisture content (EMC) increases with water activity of the air (a_w) and decreases with temperature. A similar result was found by Igathinathane et al. (2005). There is also some recent work on water yam flour, which, however, is a derived product (Owo et al., 2017). Empirical and semi-empirical equations have been proposed to fit the EMC to relative humidity (RH) of food samples. Models that have been used to describe the sorption isotherms of foods include: Guggenheim-Anderson-de Boer (GAB), Henderson, Halsey, Oswin, Smith, Brunauer-Emmett-Teller (BET), Peleg. These models do not all apply over the full moisture content range. The GAB equation has been applied successfully to various foods up to 0.9 water activity (Maroulis et al., 1988; Samaniego-Esquerria et al., 1991; Andrade et al., 2011) but is not suitable beyond 0.93 water activity (Andrade et al., 2011). That of Halsey is effective between 0.1-0.8 (Rizvi, 1995). While others have reported a decrease in EMC for increased temperature at the same water activity, Montes et al. (2009) showed no temperature effect on the desorption isotherms of yam (*Dioscorea rotundata*) at temperatures 45°C and 55°C. Moreover, some works were restricted to desorption or adsorption alone as reported in the work of Andrade et al. (2011), Montes et al. (2009) and Saad et al. (2014). The reported investigations also differ in the method of assessing the parameters, whereas limited attention has been given to the uncertainty in the parameters (a noteworthy exception is e.g. Quirijns (2005)). In addition, there is generally no methodological attention to the choice of the most appropriate model. The object of this research is to obtain experimental equilibrium moisture isotherms for yam at 25°C and 50°C, both for sorption and desorption, to estimate the parameters and their uncertainty range for each of the models (GAB, Henderson, Halsey, Oswin, Smith, BET and Peleg), and then to use objective criteria to select the model that best describes the experimental desorption and adsorption isotherms over the relevant range of moisture contents.

2 Materials and methods

2.1 Source and preparation of material

The yam tubers of the variety, *D. rotundata* and cultivar (*Dente*) were purchased from a commercial farmer at Ejura, in the Sekyere Odumasi district of the Ashanti region of Ghana. The yam tubers were sent to Wageningen, the Netherlands for the sorption measurements. For each experiment, a tuber of the yam was washed and cut into two halves. An amount of 13.36 and 31.39 mg of fresh samples at initial moisture contents 69.87% and 65.25% w.b. for 25°C and 50°C constant temperature experiments, respectively, was scooped from the middle part of one surface of the cut yam. The sample was carefully placed in the sample pan.

2.2 Procedure and measuring equipment

The experimental technique of the dynamic method was used to determine the desorption isotherms of the fresh yam. The dynamic vapor sorption (DVS) analyzer (Surface Measurement System DVS Advantage (ET), UK) was used for the measurement. The DVS analyzer uses a microbalance to measure the weight changes of samples. Two air mass flow controllers (wet and dry) mix air in such a way that the RH of the air flow is set and controlled in the range of 95% to 0% (desorption) with an optical vapor concentration RH detector. At equilibrium between sample and air RH/100 corresponds to the water activity a_w . RH and temperature in the DVS are computer controlled and followed by a chosen procedure. The RH starts at 95% and goes down by steps of 10% to 15% and then to 0% RH. At each step the sample mass was measured every minute and equilibrium was reached when the standard deviation between three successive measurements was less than 3×10^{-4} g (i.e. in terms of EMC 1.5×10^{-5} g water g⁻¹ dry weight). The adsorption behavior was measured by the reverse procedure by stepping up from 0% through 15% to 95% RH. This process was repeated for temperatures 25°C and 50°C.

2.3 Observed curves

The observed data were determined for *D. rotundata* varieties (cultivar *Dente*) at 25°C and 50°C at relative humidity from 95% to 0% for desorption and 0%-95% for adsorption. During the RH ramp the micro balance (0.0001g accuracy) continuously measures the mass of

the sample at intervals of 1 minute. Based on the mass of the sample as function of the RH, the EMC was calculated in dry basis (kg water kg⁻¹ dry weight). The equilibrium moisture content was then plotted against the water activity (RH/100) of the air, to obtain equilibrium moisture curves.

2.4 Models

The most common equations for describing sorption isotherms of food products are the BET model, Oswin model, Smith model, Halsey model, Henderson model, GAB model, and Peleg model (Sahin and Sumnu, 2006). In order to make sure that parameters are dimensionally consistent across models, the models of Halsey, Henderson, Smith and Peleg were reformulated, such that the parameter C₁ in all models has the same units as X_e, and all other parameters are dimensionless (Table 1).

Table 1 Sorption model equations as a function of water activity

Name	Model
Two parameter models	
Henderson (reformulated)	$X_e = C_1[-\ln(1 - a_w)]^{\frac{1}{n}}$ (1)
Halsey (reformulated)	$X_e = C_1 \left[\frac{-1}{\ln(a_w)} \right]^{\frac{1}{n}}$ (2)
Oswin	$X_e = C_1 \left[\frac{a_w}{1 - a_w} \right]^n$ (3)
Smith (reformulated)	$X_e = C_1 - [C_2 \ln(1 - a_w)]$ (4)
BET	$X_e = C_1 \frac{C_2 a_w}{(1 - a_w)(1 + (C_2 - 1)a_w)}$ (5)
Three parameter models	
GAB	$X_e = C_1 \frac{C_2 C_3 a_w}{[(1 - C_3 a_w)(1 - C_3 a_w + C_2 C_3 a_w)]}$ (6)
Four parameters models	
Peleg (reformulated)	$X_e = C_1(a_w^{C_3} - C_2 a_w^{C_4})$ (7)

Note: X_e is the equilibrium moisture content (EMC), a_w is the water activity, C₁, C₂, C₃ and n are constants to be fitted for each equation.

The Henderson model is often used in describing food sorption isotherms. It was originally formulated as

$$\left[\frac{-\ln(1 - a_w)}{C_1^\#} \right]^{1/n}$$

redefining $C_1 = \left[\frac{1}{C_1^\#} \right]^{\frac{1}{n}}$, which has the same units as X_e,

and avoids a parameter with fractional units. The Halsey model is suitable for describing the sorption behavior of starchy foods. It expresses the condensation of

multilayers at large distance from the surface of the drying product with the assumption that energy potential of a molecule varies as the inverse of the nth power of the distance from the surface. It describes well the sorption isotherm of types I, II and III (Levine and Slade, 1991). The form in the table arises from the original form

$$X_e = \left[\frac{-C_1^\#}{\ln a_w} \right]^{1/n}, \text{ by redefining } C_1 = [C_1^\#]^{\frac{1}{n}}.$$

The Oswin equation is an empirical model that satisfies sigmoidal shaped curves (Labuza et al., 1972). The Smith model, originally formulated as X_e = C₁ + C₂[#]ln(1 - a_w) is an empirical model that describes the final curved portion of water sorption isotherm of high molecular weight biopolymers. The model is based on two fractions of water that are adsorbed onto a dry surface. The first fraction represents the quantity of water in the first sorbed fraction, while the second specifies the quantity of water in the multilayer moisture fraction. In the reformulated equation in Table 1, C₂ is a dimensionless parameter defined by C₂[#]/C₁. The model is suitable for various foods products of water activity within the range 0.5 to 0.95 water activity (Andrade et al., 2011). The BET model is rather qualitative, and it is linear within a limited range of water activity from 0.05 to 0.45 (Andrade et al., 2011). This limits its use to a large extent since most sorption isotherm cases of foods have wider range of water activity. The first constant is the monolayer moisture content (the moisture content at which the water attached to each polar and ionic groups starts to behave as a liquid-like phase). The second constant relates to the net heat of sorption (difference between the molecules that sorb energy of the first layer and the other remaining layers). The GAB model has successfully been applied to many foods and has been recommended by the European Project COST 90 (Oliveira et al., 2006) on physical properties of foods. It has a theoretical basis since it is an improvement of the BET model by the addition of a third parameter, so that the heat of sorption parameter is split over the first layer heat of sorption constant and the multilayer heat of sorption constant (Andrade et al., 2011; Myhara et al., 1998a). Note that the BET model is a special case of the GAB model when C₃=1. It has been found that C₂>1 and C₃<1 as reported for adsorption of

corn flour at 22°C (Gálvez et al., 2006), dried tomato pulp at 30°C (Goula et al., 2008) and Walnut kernels at 25°C (Toğrul and Arslan, 2007) while the opposite was reported by Montes et al. (2009) for the desorption of yam at 70°C rendering the improvement of the BET to GAB irrelevant. Peleg is a four-parameter model, originally given by $X_e = C_1 a_w^{C_3} - C_2 a_w^{C_4}$, which is a purely empirical equation without a theoretical background. Andrade et al. (2011) mentioned that generally $C_3 < 1$ while $C_4 > 1$, but Montes et al. (2009) suggest the opposite which makes these parameter values inconsistent. Note that the two-parameter models deteriorate at $a_w = 1$, as $\lim_{a_w \rightarrow 1} X_e = \infty$. Hence, there is an upper limit for a_w beyond which these models must lose their validity. It is expected in all models that $\lim_{a_w \rightarrow 0} X_e = 0$.

2.5 Statistical analysis of data

The nonlinear regression method in Matlab was used for the parameter estimation of the models, by minimizing the sum of squared differences between experimental and model results of desorption and adsorption. The goodness of fit was determined with three statistical tools, that is:

the standard error (*SE*)

$$SE = \sqrt{\frac{\sum_{i=1}^{N_e} (Residuals)^2}{N_e - N_p}} \quad (8)$$

the percent average relative deviation (*PRD*)

$$PRD(\%) = \frac{100}{N_e} \sum_{i=1}^{N_e} \left(\frac{|Residuals|}{EMC_e} \right) \quad (9)$$

and the coefficient of performance (R^2)

$$R^2 = 1 - \frac{\sum_{i=1}^{N_e} (Residuals)^2}{\sum_{i=1}^{N_e} (EMC_e - EMC_m)^2} \quad (10)$$

where, EMC_m is the modeled value of equilibrium moisture content; EMC_e is the experimental equilibrium moisture content value; N_p is the number of parameters of a particular model; N_e is the number of experimental data points; $\overline{EMC_e}$ is the arithmetic mean of the experimental equilibrium moisture contents, and the residuals are defined by $EMC_e - EMC_m$. All data were processed and evaluated using the Matlab software.

In general, more parameters lead to a better fit, but the

predictive power may be worse, unless the improvement is worthwhile. Akaike's Information Criterion (AIC) is especially suitable for comparing models with a different number of parameters (Ljung, 1987). The criterion is reformulated here as:

$$AIC = 2N_p + N_e \ln(V(\hat{\boldsymbol{p}})) \quad (11)$$

The model with the lowest AIC is preferred. Here $V(\hat{\boldsymbol{p}})$ is the sum of squared errors for the estimated parameter vector $\hat{\boldsymbol{p}}$ i.e. $V(\hat{\boldsymbol{p}}) = \sum_{k=1}^N (MC_m(k, \hat{\boldsymbol{p}}) - MC_e(k))^2$. Since the number of data points is small, it is better to use the small sample corrected variant (Hu, 2007), which is:

$$AIC_c = AIC + \frac{2N_p(N_p + 1)}{N_e - N_p - 1} \quad (12)$$

2.6 Approximate confidence bound

The least squares method with the water activity a_w independent variable does not suffer from the so-called errors-in-variables problem which would occur if both the dependent and independent variable would have errors. Hence, the uncertainty of the parameter estimates can be evaluated by calculating the 2σ confidence interval based on the Jacobian matrix. The Jacobian matrix specifies the sensitivity of each point to each of the parameters. The relationships in Table 1 are linear in the parameter C_1 , meaning that the 2σ bound corresponds to the 95% confidence interval, i.e. there is 5% chance that the true value is outside this range. For the other parameters, the 95% bound is only approximate. For convenience, in the tables below, the uncertainty is reported as the 1σ coefficient of variation, i.e. as $100\sigma p^{-1}$, where p is the parameter estimate.

3 Results and discussion

3.1 Desorption and adsorption isotherms measurements

The experimental values of water activity (a_w) and its corresponding EMC of both desorption and adsorption isotherms of yam (*Dente*) for 25°C and 50°C are shown in Figure 1. Comparing both graphs, it can be seen that the data for water adsorption has lower EMC than the data for water desorption at both 25°C and 50°C. The data for adsorption and desorption crossed each other at

about 0.9 a_w due to high mobility of solute and dissolved sugars at higher water activity during wetting. EMC for adsorption and desorption decreased with increased temperature between water activities of 0-0.83 (Figure 2). At higher water activity a reversal is obtained where water activity levels are lower at a constant EMC, as temperatures increase. This leads to desorption isotherms crossing at $a_w=0.65$ and $a_w=0.83$ for adsorption (Figure 2), collaborating with the work of Myhara et al. (1998a), Siripatrawan and Jantawat (2006), and Montes et al. (2009). The point of crossing depends on the amount of sugar content of the food material. Myhara et al. (1998a) reported adsorption curves of two varieties of dates crossing between $a_w=0.4-0.5$ and attributing it to high sugar content. Tsami et al. (1990) and Myhara et al. (1998a) have reported that the higher the sugar content the lower the a_w of crossing. Temperature on the other hand did not show any significant effect on EMC at constant a_w for the desorption isotherms (Myhara et al., 1998b). This might be due to higher proportion of strongly bonded linear chain amylose molecules which are crystalline in nature. The curves show sigmoidal shape of type II and it can be observed that EMC increases with a_w at constant temperature. This trend is in line with the work of Andrade et al. (2011) and the findings of Montes et al. (2009) who had sigmoidal type II-curves. Others such as Siripatrawan and Jatawat (2006) reported similar trend. Hysteresis is observed for both temperatures where generally the EMC of desorption are higher than that of the adsorption at constant water activity.

One reason for differences in EMC between the desorption and adsorption at constant temperature and water activity is that, during desorption, solutes may supersaturate below their crystallization water activity and therefore can hold more water, especially for products with high sugar content (Aguilera and Stanley, 1999). The other common explanation is that when dried biological material is subjected to a wetting environment, the moisture first adheres to the surface of the cells, primarily in a unimolecular layer. After a high amount of molecules adhered to the surface, the diffusional forces exceed the binding forces and allow moisture to move inside the cell. When, subsequently, the vapor pressure of the environment of the cell surface is reduced again,

absorbed moisture from the cell moves out of the cells due to diffusional forces caused by concentration gradient leading to the hysteresis (Young and Nelson, 1967).

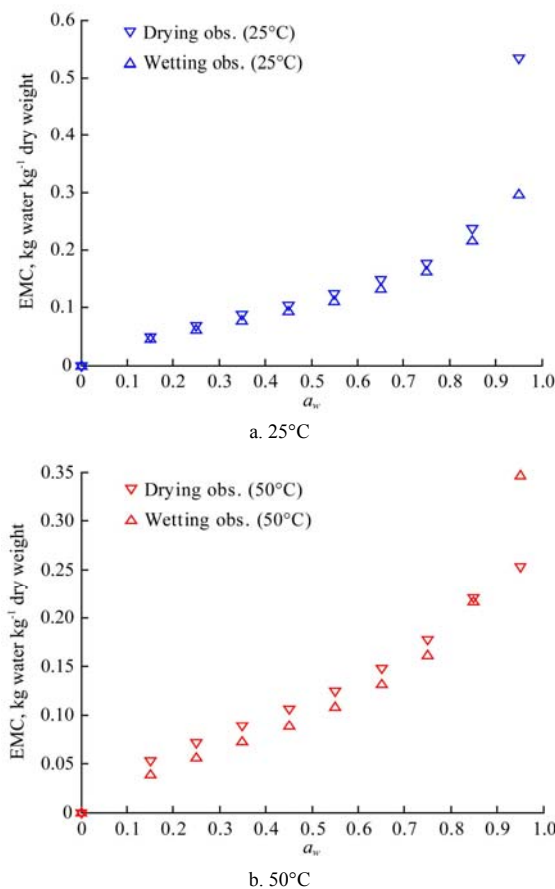


Figure 1 Experimental data of equilibrium moisture content (EMC) against water activity (a_w) at 25°C and 50°C for water desorption and adsorption

3.2 Modeling the isotherms

In fitting the models the data point at water activity 0.95 was ignored since according to the literature beyond a_w 0.9, most models are not able to explain well the experimental data (Samaniego-Esquerria et al., 1991). One reason could be that, according to the differences between wetting and drying behavior at high water activity, it is hard to obtain a reliable measurement point since reaching the equilibrium may require a long equilibration time. Tables 2 and 3 show the outcome of the nonlinear regression analysis of desorption and adsorption isotherms respectively, of yam (*Dente*) for $0 \leq a_w \leq 0.85$ at 25°C and 50°C. The parameters of the seven models, that is, GAB, Henderson, Halsey, Oswin, Smith, BET and Peleg, fitted to the desorption and adsorption data along with SE, PRD, AIC and R^2 , for the temperatures 25°C and 50°C. Peleg is purely empirical (it has the best combination of scores for SE, PRD, AIC of all), but the

GAB and BET have a physiological background. This makes them stronger candidates. It turns out that the SE, PRD, AIC of GAB were equally low, and with fewer parameters than Peleg. On the other hand, with respect to the confidence interval of the parameters using the $2-\sigma$ bound, and in particular on the first parameter, C_1 which has the same unit as that of X_e , the GAB and Oswin recorded the least percentage coefficient of variation ($1-\sigma$, %CV) for all the phenomena at different temperatures

(Tables 4 and 5). The GAB model is subsequently considered for describing the desorption and adsorption data at temperatures 25°C and 50°C. Montes et al. (2009) mentioned that the Peleg model was best for describing the desorption isotherm of two varieties of yam (*D. rotundata*), while Peleg and Oswin models were found suitable by Saad et al. (2014). For graphical presentation, the GAB and Peleg modelled graphs are shown in Figures 2 and 3.

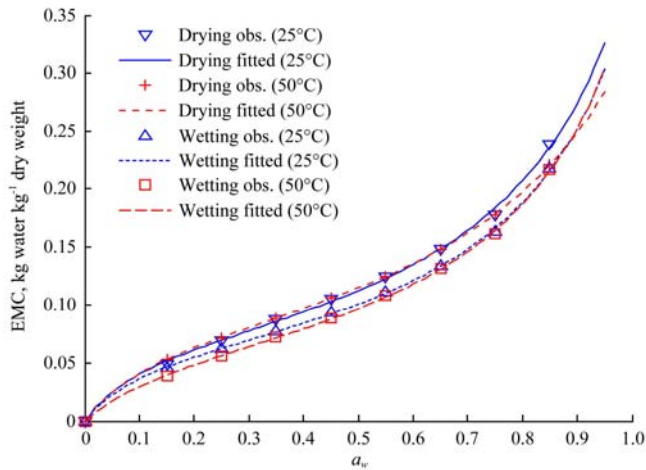


Figure 2 Experimental and modeled curves of equilibrium moisture content (EMC) against water activity (a_w) for desorption (drying) and adsorption (wetting) at temperatures 25°C and 50°C using the GAB model

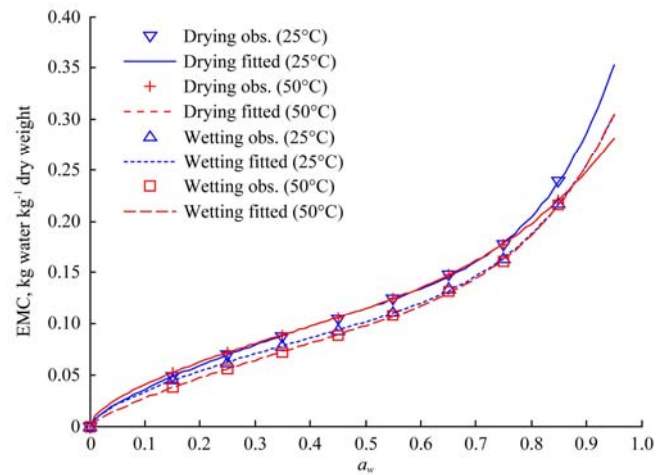


Figure 3 Experimental and modelled curves of equilibrium moisture content (EMC) against water activity (a_w) for desorption (drying) and adsorption (wetting) at temperatures 25°C and 50°C using the Peleg model

Table 2 Results for desorption isotherms fitting for yam (*Dente*) for $0 \leq a_w \leq 0.85$

	Temp	Parameters				SE	PRD	AIC	R^2
		C_1	C_2	C_3	C_4				
GAB	25	0.07551	10.657	0.8152	-	0.0031	1.6376	-77.0689	0.9986
	50	0.08274	10.126	0.7578	-	0.0005	0.2587	-108.975	0.9999
Henderson	25	0.1491 $C1^\#$: 0.0588	1.4890	-	-	0.0061	4.0756	-68.2985	0.9936
	50	0.1468 $C1^\#$: 0.0426	1.6445	-	-	0.0031	2.3238	-80.5615	0.9981
Halsey	25	0.0888 $C1^\#$: 0.0127	1.8044	-	-	0.0068	5.6070	-66.4545	0.9922
	50	0.0913 $C1^\#$: 0.0089	1.9762	-	-	0.0079	6.1604	-63.6301	0.9878
Oswin	25	0.1124	0.4327	-	-	0.0023	1.8441	-85.6891	0.9991
	50	0.1134	0.3938	-	-	0.0030	2.2489	-81.0684	0.9983
Smith	25	0.0275	-4.1366 $C2^\#$: -0.1138	-	-	0.0130	5.8967	-54.6993	0.9711
	50	0.0322	-3.2855 $C2^\#$: -0.1059	-	-	0.0151	6.2719	-51.9945	0.9556
BET	25	0.2718	0.7789	-	-	0.0129	10.092	-54.7542	0.9713
	50	0.2447	0.9898	-	-	0.0107	8.5361	-58.1235	0.9776
Peleg	25	0.2581	0.7235 $C2^\#$: 0.1867	7.8501	0.7142	0.0015	0.7434	-85.1070	0.9997
	50	0.1516	1.1149 $C2^\#$: 0.1690	4.9423	0.6195	0.0005	0.2615	-104.889	0.9999

Table 3 Results for adsorption isotherms fitting for yam (*Dente*) for $0 \leq a_w \leq 0.85$

	Temp	Parameters				SE	PRD	AIC	R ²
		C ₁	C ₂	C ₃	C ₄				
GAB	25	0.0666	10.913	0.8272	-	0.0015	0.9347	-89.6111	0.9996
	50	0.0676	7.3021	0.8272	-	0.0015	0.9214	-90.4369	0.9996
Henderson	25	0.1346 C1#: 0.0541	1.4545	-	-	0.0055	4.5866	-69.9337	0.9936
	50	0.1306 C1#: 0.0646	1.346	-	-	0.0043	3.7491	-74.663	0.9963
Halsey	25	0.0795 C1#: 0.0113	1.7711	-	-	0.0055	4.9815	-70.1532	0.9938
	50	0.0746 C1#: 0.0133	1.6653	-	-	0.007	7.0769	-65.9287	0.9903
Oswin	25	0.101	0.4415	-	-	0.0009	0.8544	-102.288	0.9998
	50	0.0961	0.4722	-	-	0.0022	2.1256	-86.9377	0.9991
Smith	25	0.0238	-4.3745 C2#: -0.1041	-	-	0.0109	5.6366	-57.7567	0.9753
	50	0.0188	-5.6389 C2#: -0.1061	-	-	0.0088	4.808	-61.7074	0.9845
BET	25	0.2522	0.7286	-	-	0.0117	10.472	-56.5193	0.9717
	50	0.2641	0.6116	-	-	0.0096	9.4046	-60.0401	0.9814
Peleg	25	0.2087	0.7524 C2#: 0.1570	6.2198	0.66734	0.001	0.6751	-91.685	0.9998
	50	0.206	0.7947 C2#: 0.1637	6.4882	0.77746	0.0011	0.7935	-89.7608	0.9998

Table 4 The 2σ bounds and 1σ coefficient of variation (CV) for desorption parameters (0 ≤ a_w ≤ 0.85)

	Temp	C ₁			C ₂			C ₃			C ₄		
		-2σ	+2σ	1σ (%CV)	-2σ	+2σ	1σ (%CV)	-2σ	+2σ	1σ (%CV)	-2σ	+2σ	1σ (%CV)
GAB	25	0.0669	0.0841	5.7	5.7718	15.543	22.9	0.7761	0.8543	2.4	-	-	-
	50	0.0809	0.0846	1.1	9.3779	10.875	3.7	0.7491	0.7663	0.6	-	-	-
Henderson	25	0.1434	0.1548	1.9	1.3365	1.6416	5.1	-	-	-	-	-	-
	50	0.1439	0.1497	1	1.5522	1.7368	2.8	-	-	-	-	-	-
Halsey	25	0.0821	0.0955	3.8	1.618	1.9909	5.2	-	-	-	-	-	-
	50	0.0834	0.0992	4.3	1.714	2.2384	6.6	-	-	-	-	-	-
Oswin	25	0.1102	0.1147	1	0.4168	0.4486	1.8	-	-	-	-	-	-
	50	0.1106	0.1163	1.3	0.3734	0.4143	2.6	-	-	-	-	-	-
Smith	25	0.0111	0.0439	29.9	-7.1362	-1.1371	36.3	-	-	-	-	-	-
	50	0.0131	0.0513	29.7	-0.1262	-0.0855	37.7	-	-	-	-	-	-
BET	25	0.2221	0.3215	9.1	0.4223	1.1354	22.9	-	-	-	-	-	-
	50	0.2093	0.28	7.2	0.6036	1.376	19.5	-	-	-	-	-	-
Peleg	25	0.1991	0.317	11.4	0.5804	0.8667	9.9	5.9596	9.7406	12	0.6525	0.776	4.3
	50	0.1449	0.1583	2.2	1.0502	1.1796	2.9	4.4409	5.4437	5.1	0.5905	0.6485	2.3

Table 5 The 2σ bounds and 1σ coefficient of variation for adsorption parameters (0 ≤ a_w ≤ 0.85)

	Temp	C ₁			C ₂			C ₃			C ₄		
		-2σ	+2σ	1σ (%CV)	-2σ	+2σ	1σ (%CV)	-2σ	+2σ	1σ (%CV)	-2σ	+2σ	1σ (%CV)
GAB	25	0.0625	0.0706	3	8.0991	13.727	12.9	0.8068	0.8476	1.2	-	-	-
	50	0.0629	0.0722	3.4	5.6763	8.9279	11.1	0.8055	0.8489	1.3	-	-	-
Henderson	25	0.1294	0.1399	1.9	1.306	1.6029	5.1	-	-	-	-	-	-
	50	0.1265	0.1346	1.6	1.2422	1.4497	3.9	-	-	-	-	-	-
Halsey	25	0.074	0.085	3.4	1.6088	1.9335	4.6	-	-	-	-	-	-
	50	0.0678	0.0815	4.9	1.4762	1.8544	5.7	-	-	-	-	-	-
Oswin	25	0.1001	0.1019	0.4	0.4345	0.4486	0.8	-	-	-	-	-	-
	50	0.094	0.0982	1.1	0.4549	0.4895	1.8	-	-	-	-	-	-
Smith	25	0.0099	0.0377	29.2	-7.438	-4.375	35	-	-	-	-	-	-
	50	0.0077	0.03	29.6	-9.494	-1.784	34.2	-	-	-	-	-	-
BET	25	0.2049	0.2994	9.4	0.3943	1.0628	22.9	-	-	-	-	-	-
	50	0.22	0.3084	8.4	0.3745	0.8487	19.4	-	-	-	-	-	-
Peleg	25	0.186	0.2313	5.4	0.6764	0.8283	5	5.1718	7.2678	8.4	0.611	0.72372	4.2
	50	0.1781	0.2338	6.8	0.6968	0.8926	6.2	5.1563	7.8202	10.3	0.7089	0.846	4.4

4 Conclusion

Important thermodynamic characteristics for predicting the interactions between water and food components are moisture desorption and adsorption isotherms. The moisture desorption and adsorption isotherms for yam (the *Dente* cultivar of *D. Rotundata*) have been determined at 25 °C and 50 °C by the dynamic method using the DVS analyser between 0% to 0.95% water activity. The isotherms showed a sigmoidal shape. The equilibrium moisture contents were found to increase with increasing water activity at constant temperature. While at constant EMC the water activity is higher at higher temperature under adsorption, there is no significant difference in the case of desorption. Crossing of the adsorption isotherms of 25 °C and 50 °C, and of the adsorption and desorption isotherms at 50 °C took place at higher water activity, which is most probable result of the low sugar content in yam compared to other products, as discussed before. Within the range $0 \leq a_w \leq 0.85$ all seven models tested can provide a reasonable fit, although the BET and Smith models are inferior for yam. All models require two different parameter sets to describe the hysteresis between adsorption and desorption, which is a common flaw of these equations. Based on the standard error of prediction, the Peleg, Oswin and GAB models were found as most suitable to describe the experimental equilibrium moisture contents of yam (*Dente*) of both desorption and adsorption. The parameter uncertainty of the Oswin model is low. In general, a low parameter uncertainty means that the parameters can be estimated well from experimental data. At 50 °C the absolute error is larger for the Oswin model than for Peleg and GAB. The Oswin model has the lowest AIC for sorption, which may make it the best model when it is needed to describe wetting of a product. For drying, however, the larger number of parameters in the Peleg and GAB models is justified, as shown by the lowest AIC values at desorption. Of these two, the GAB is preferred since it has a physiological basis, and fewer parameters that can be estimated quite well from experimental data.

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