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MOISTURE SORPTION CHARACTERISTICS OF GARRI PRODUCED USING A MECHANICAL DRYER

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ABSTRACT

Sorption characteristics of *garri* produced from a Conductive Rotary Dryer (CRD) at four different temperatures (40, 45, 50, and 55°C) and water activities ranging from 4.94 to 96.41% was determined using the static gravimetric method. The sorption data obtained were fitted to four models (GAB, Modified BET, Modified Henderson and Modified Oswin) and some parameters (monolayer moisture content, enthalpy and entropy) related to drying and storage was also estimated from the data. Adsorption equilibrium moisture content of *garri* increased with decreasing temperature at constant water activity and the sorption isotherms had a sigmoid shape (Type II). Based on the highest regression coefficient, R^2, lowest Standard Estimated Error and the Mean Squared Error values, the GAB model best fitted the sorption isotherms of *garri* samples. At temperature ranges of 40 to 55 ^{o}C, monolayer moisture content values ranged from 4.18 to 4.95% for the product. The differential enthalpy decreased with increase in moisture content while differential entropy had negative values and increased with increase in moisture content.

Keywords: Moisture content, Conductive Rotary Dryer, temperature, water activities, models.

INTRODUCTION

Cassava *(Manihot esculentacrantz)* is a major food crop in Nigeria, supplying about70 % of the daily calorie of over 50 million people (Oluwole *et al.*, 2004).Cassava is a perishable commodity with a shelf life of less than 3 days after harvest. *Garri* is by far the most popular form in which cassava is consumed in West Africa (Agbetoye and Oyedele, 2007; Irtwange and Achimba, 2009). *Garri* is creamy white or yellow in colour, usually granular flour with a slightly fermented flavour, slightly sour in taste given to it as a result of fermentation and gelatinization in its processing. It can be prepared in a variety of ways for consumption.

Traditional production of cassava to *garri* is labour intensive and the productivity level is quite low compared to the investment of labour, time and money put into production. A wide range of indigenous techniques for the production of *garri* exist but only few of the techniques are fully mechanized to reduce the drudgery involved. In order to minimise the challenges associated with traditional method of roasting, a conductive rotary dryer (CRD) was developed in the Department of Agricultural and Environmental Engineering, Faculty of Technology, Obafemi Awolowo University, Ile-Ife (Sanni *et al*., 2008) for drying or roasting of pulverized and sifted cassava mash for cassava flour and *garri* production. Quality of *garri* produced from the CDR using different operating conditions have been assessed and it has been concluded that using the appropriate operating conditions, the CDR could produce high quality *garri* that is acceptable not only in local markets but also at regional and international markets (Olaosebikan *et al*., 2016). However, this, notwithstanding the storage stability of *garri* from this machine has not been looked into; hence the need for this study.

LITERATURE REVIEW

The quality of most preserved foods depends to a great extent upon their physical, chemical and microbiological stability (Onabolu *et al.*, 2002). This stability is mainly a consequence of the relationship between the sorption characteristics i.e. equilibrium moisture content (EMC) of the food material and its corresponding water activity (aw), at a given temperature which gives rise to water sorption isotherms. These water sorption isotherms are unique for individual food materials and can be used directly to solve food processing design problems, calculation of moisture changes which may occur during storage, selection of appropriate packaging materials, predict energy requirement and to determine proper storage conditions (Fellow, 2003).

Numerous mathematical models have been reported in the literature for describing water sorption isotherms of food materials. Each of the proposed models, which could be empirical, semi-empirical, or theoretical, has some success in reproducing EMC data of a given type of food and in a given range of water activity (relative humidity).

Further analysis of sorption isotherm data by application of thermodynamic principles can provide important information regarding energy requirements of the dehydration process, food microstructure and physical phenomena on the food surfaces, water properties and sorption kinetic parameters (Rizvi, 1995). The isosteric heat of sorption (Δh_d) or differential enthalpy of sorption, gives a measure of the water-solid binding strength. A rapid computational procedure, commonly used for its determination, is the application of the Clausius-Clapeyron equation to the sorption isotherms, at constant moisture content (Gorman *et al*., 2007, Jamali *et al*., 2006, Lahsasni 2003, and Mulet *et al*., 2002). The differential entropy (ΔS_d) of a material is proportional to the number of its available sorption sites at a specific energy level (Simal *et al*., 2007).

The objective of this research is to obtain experimental sorption data of *garri* produced from the CRD, fit the data to four models and estimate parameters such as monolayer-moisture content, and the differential enthalpy and entropy from the data.

METHODOLOGY

Sample Preparation

Cassava tubers used in this study was obtained from Obafemi Awolowo University, Ile-Ife Teaching and Research farm. The tubers were manually peeled, washed and grated using a conventional cassava grater and the grated mash was collected in perforated propylene bags and allowed to ferment for two days (Sanni *et al*., 2008). The bags were tied and placed under a horizontal screw press for dewatering and the pressed cassava cake was then pulverized and sifted using the conventional raffia sieve (of 2.5 mm aperture) to produce wet cassava mash which was introduced into the Conductive Rotary Dryer for roasting to produce *garri* samples.

Adsorption Equilibrium Moisture Content Determination

The adsorption equilibrium moisture content of the *garri* samples was determined by the static gravimetric method using saturated salts to maintain different relative humidity levels (Table 1).

Table 1: Values of relative humidity (%) of saturated salt solutions used at different temperatures

Salts	Temperatures (^{o} *C)*			
	40	45	50	55
NaoH	6.26	5.60	4.94	4.27
Licl	11.21	11.16	11.10	11.03
KF	22.68	21.46	20.80	20.60
Mgcl	31.60	31.10	30.54	29.93
K_2CO_3	43.38	42.34	41.22	40.65
NaBr	53.17	51.95	50.93	50.15
$NaNo_3$	71.00	69.99	69.04	68.15
Kcl	82.32	81.74	81.20	80.70
K_2SO_4	96.41	96.12	95.82	95.53

Garri samples were placed in stainless steel wire mesh baskets and then put in desiccators containing prepared saturated salt solutions which gave different relative humidity levels (Bell and Labuza, 2000). Salt solutions were prepared in such a way that excess undissolved salt remained at the bottom of desiccators. Desiccators (with *garri* samples and salt solutions) were then put in ovens set at the required temperature levels (40, 45, 50 and 55ºC). All the experiments were conducted in triplicates. The weight of the samples was monitored every 24 hours until the weight constant was attained for three consecutive readings. After equilibrium had been reached, *garri* samples were removed from the oven and the moisture content was determined using the oven drying at 105°C for 6 hours (AOAC 2002).

Fitting of Data to Models

EMC data obtained were fitted to four commonly used moisture sorption isotherm models, namely the GAB, Modified BET, Modified Henderson and Modified Oswin models (Table 2). Nonlinear regression analysis, using the computer programs Sigma Plot 11.0 was used to estimate the model coefficients (coefficient of regression, R^2 Standard Estimated Error and Mean Squared Error)to determine the model that best fit the experimental data.

Table 2: Models for fitting equilibrium moisture content data

S/No	Model name	Equation	Reference
1	GAB	$M = \frac{C_1 K M_o aw}{(1-Kaw)(1-Kaw+C_1 Kaw)}$	Falade *et al*. (2003)
2	Modified BET	$M = \frac{(A+BT)\ C(aw)}{(1-aw)\ (1-aw)+(Caw)}$	Jamali *et al*.(2006)
3	Modified Henderson	$Aw = 1 - exp[-A(T+B)M^C]$	Jamali *et al*.(2006)
4	Modified Oswin	$Aw = \frac{1}{\left[{(A+BT)}/{M}\right]^C + 1}$	Jamali *et al*.(2006)

where A, B, C,C_1, K are equation coefficients; M = equilibrium moisture content, % ; M_o = monolayer moisture content; Aw = water activity (decimal) and T= temperature (Kelvin)

Determination of Monolayer Moisture Content

For the GAB equation, the monolayer moisture content value was obtained directly from nonlinear regression of the equation, which is expressed as

$$m= \frac{C_1 K m_o a_w}{(1-Ka_w)(1-Ka_w+C_1 Ka_w)} \qquad (1)$$

where C_1 and K are constants, m_o is the monolayer moisture content and a_w the water activity. The BET isotherm was re-arranged in the form of equation (2) and graph a_w plotted against $\frac{aw}{(1-aw)}$ to obtain its monolayer moisture content (Bell and Labuza, 2000):

$$\frac{a_w}{(1-a_w)m} = I + S(a_w) \qquad (2)$$

Where a_w is the water activity, m is the monolayer moisture content, I is the intercept and S, the slope of the graph

Determination of Differential Enthalpy and Entropy

The net isosteric heat of sorption was determined using Clausius-Clapeyron equation (Chen, 2006):

$$\left[\frac{\partial ln(a_w)}{\partial \frac{1}{T}}\right] = \frac{-q_{st}}{R} \qquad (3)$$

Where $a_w$is water activity, T is the absolute temperature in Kelvin, $-q_{st}$ is the net isosteric heat of sorption (kJ/mol), R the universal gas constant (8.314 kJ/kmol K).

The change (differential) in enthalpy of sorption (ΔH) and entropy (ΔS) were then calculated by plotting ln $a_w$against $\frac{1}{T}$ for specific moisture contents of the *garri* and then determining from the slope,$\Delta H/R$and intercept, $\Delta S/R$ respectively, using equation (4)

$$\ln a_w = \frac{\Delta H}{RT} + \frac{\Delta S}{R} \qquad (4)$$

where (ΔH) is the differential enthalpy,(ΔS)is differential entropy,$a_w$is water activity, T is the absolute temperature in Kelvin, R the universal gas constant (Tirawanichakual *et al*., 2011, Taitano and Singh, 2012).

RESULTS AND DISCUSSION

Adsorption Characteristics of *Garri* Samples

The initial moisture content of *garri* used for the study was about 7%, dry basis. Adsorption equilibration of moisture of *garri* samples was reached in about three weeks (21 days).It was observed that when samples were kept for two weeks in the dessicator at the lowest temperature (40^{o}C) and at water activities above 80 %, moulds were growing on the product; this being a disadvantage associated with the use of the gravimetric method for sorption determination. Hence, samples for this experiment had to be discarded. The sorption data at each water activity was used in plotting the adsorption isotherms of *garri* at various temperatures as shown in Figure 1.

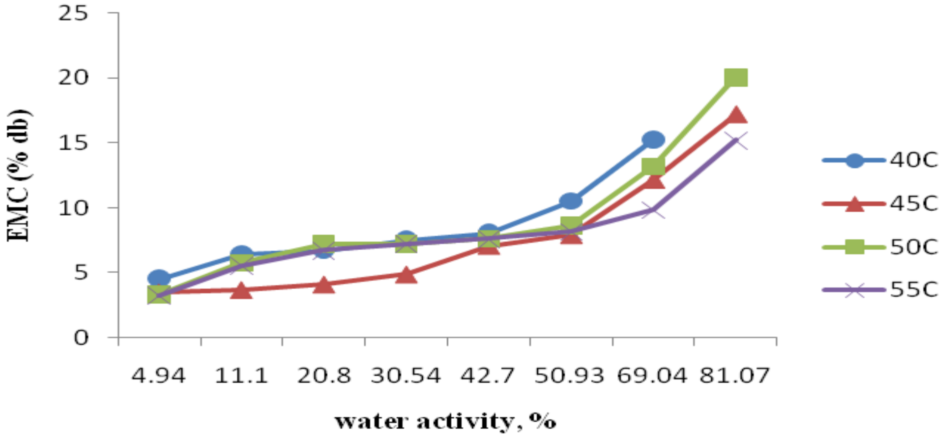

Fig. 1: Equilibrium moisture content of *gari* at different temperature and water activity ranges

Sorption isotherms of *garri* samples increased with decreasing temperature at constant water activity. This is in agreement with other researchers and typical of most agricultural food products (ASAE, 2000). The sorption isotherms were sigmoid shaped (Type II) which is common for many hygroscopic products and food materials especially those rich in carbohydrates (Lahsasni, 2003; Mohamed, 2004, Kouhila *et al*., 2002). Samuel and Ugwanyi (2014) who studied sorption behavior of *garri* sold in South Eastern, Nigeria at temperatures of 20 and 30 ^{o}C, respectively, reported that *garri* samples displayed Type II isotherms.

Fitting Sorption Data to Models

The results of nonlinear regression analysis of fitting the sorption equations to the experimental data are presented on Tables 3.

Table 3: Estimated parameters of different models for the sorption isotherms of *gari*

S/N	Model Name	Temp (^{o} C)	Coefficients	R^2	SEE	MSE
1	GAB	40	K= 0.971, C= 61.675, Mo=5.229	0.994	0.031	0.006
		45	K= 0.945, C=53.206 , Mo= 5.172	0.992	0.015	0.003
		50	K= 0.926, C= 74.855, Mo= 4.960	0.983	0.032	0.006
		55	K= 0.790, C= 63.707, Mo= 4.112	0.940	0.025	0.005
				(0.977)	(0.026)	(0.005)
2	Modified Henderson	40	A= 1.341E-4, B=47.784, C= 1.665	0.907	0.050	0.038
		45	A= 2.986E-4, B=41.372, C= 1.553	0.952	0.026	0.028
		50	A= 1.225E-4, B=40.488, C= 1.781	0.909	0.048	0.061
		55	A= 2.937E-4, B=53.354, C= 3.658	0.954	0.045	0.033
				(0.931)	(0.042)	(0.040)
3	Modified Oswin	40	A=6.467, B=0.110, C= 2.482	0.942	0.031	0.010
		45	A=4.180, B=0.089, C= 2.201	0.972	0.015	0.005
		50	A=5.216, B=0.089, C= 2.713	0.941	0.032	0.010
		55	A=3.902, B=0.083, C= 4.249	0.959	0.025	0.009
				(0.954)	(0.026)	(0.009)
4	Modified BET (aw < 0.5)	40	A=24.725, B=-0.505, C=56.280	0.955	0.047	0.012
		45	A=26.392, B=-0.501, C=78.364	0.941	0.033	0.016
		50	A=30.214, B=-0.511, C=95.906	0.808	0.031	0.014
		55	A=32.497, B=-0.500, C= 94.407	0.819	0.027	0.018
				(0.881)	(0.035)	(0.015)

Generally, all the models had high regression coefficients ($R^2 > 0.90$); hence the four models (GAB, modified BET, modified Oswin, modified Henderson,) could be said to be suitable for describing the adsorption isotherms of *garri*. However, based on the highest regression coefficient, R^2, the lowest standard estimated error, SEE and the mean squared error, MSE values, the GAB was the best suitable model for the sorption isotherms of *garri* compared to the other three EMC models used in this study.

Monolayer Moisture Content Values for *Garri* Samples

Monolayer moisture content values for the garri samples at temperatures of 40, 45, 50, 55 ^{o}C were 4.93, 4.26, 4.33, 4.18 (%, dry basis) for BET model and 5.23, 5.17, 4.96 and 4.11 (%, dry basis) for GAB model, respectively. The BET model generally gave slightly higher than those from the GAB model. The values obtained agreed with monolayer moisture content values (within ranged of 4 to 11 %) reported by Alakali and Satimehin, (2009) for foods that are rich in carbohydrate. The results indicate that within the temperature range studied, *garri* samples are best kept safe for storage at a moisture content of about 4-5 % (db).This implies that the working parameters of the CDR should be adjusted to ensure that *garri* samples are dried to moisture contents between 4-5 % for safe storage. Mariz, *et al.* (2005) also reported that although BET and GAB models are similar, values obtained for monolayer moisture content for GAB model are usually higher than those obtained for the BET model.

It was also observed that the monolayer moisture content decreased with increase in temperature and these results are similar to those reported by Jasim Ahmed *et al.*, (2005). Such a decrease with temperature has been attributed to the fact that the binding of water molecules become less stable at increased temperature and break away from water binding sites of the sample (Simal *et al.*, 2007).

Change in Enthalpy and Entropy of *Garri* Samples During Moisture Adsorption

The plot of natural logarithm of water activity as a function of the inverse of four temperatures is shown in Figure 2.

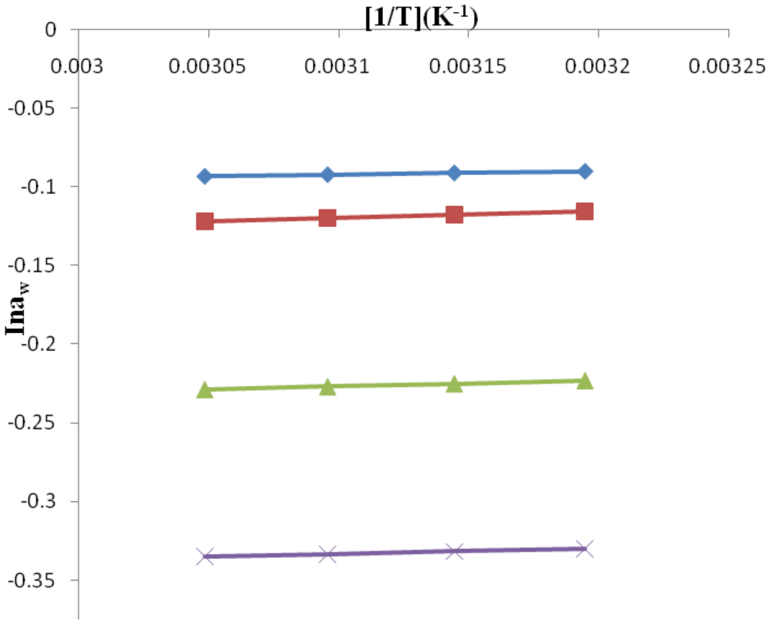

Figure 2: Plots for logarithms of water activity as a function of the inverse of temperatures

From this graph, the values obtained for the differential enthalpy and entropy of *garri* samples produced from the CRD during moisture sorption were 85.85, 43.29, 38.75, 34.69 kJ/mol for enthalpy and 0.13, 0.25, 0.35, 0.44J/mol.K for entropy at moisture contents of 5%, 8%, 10% and 15%, respectively. The elevated net heats of sorption of water at low moisture contents are an indication of strong water-food component interactions. As the moisture content increases, the available sites for sorption of water reduce, resulting in lower values of enthalpy. This trend is identical to those reported in studies on agricultural and food products as well as medical and aromatic plants (Bahloul *et al.*, 2008: Lahsasni, 2003: Phomkong *et al.*, 2006).

The decrease in differential enthalpy with higher amounts of sorbed water can be quantitatively explained by considering that, initially, sorption occurs on the most active available sites giving rise to high interaction energy. As these sites become occupied, sorption occurs on the less active ones, resulting in lower heats of sorption (Lahsasni, 2003). Similar trends like what was obtained in this study were reported on the entropy of some agricultural products by other researchers (Chen, 2006, Arslan and Togrul, 2006, Bahloul *et al.*, 2008).

CONCLUSIONS

The following conclusions can be drawn from the determination of EMC (at temperature range 40 – 55 ^{o}C and water activity range from 5- 96 %) and other related properties of *garri* produced from a CDR:

1. Sorption characteristics of the *garri* produced from the Conductive Rotary Dryer at temperature range studied were of Type II (sigmoid shaped) and GAB model best described the data obtained.
2. The monolayer moisture content was between 4 – 5 % (dry basis) and decreased as temperature increased from 40 to 55°C. Generally, the values obtained for GAB at each temperature were higher than values from BET models.
3. The differential enthalpy decreased with increase in moisture content, while the differential entropy increased slightly with increase in moisture content.

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