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Application of GAB's and Henderson's Model in the study of moisture sorption characteristics of white and yellow gari sold in Abia, Ebonyi and Enugu, South-eastern States of Nigeria

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ABSTRACT: Moisture sorption characteristics of gari sold in Ebonyi, Enugu, and Abia state were studied. The freshly produced gari samples were collected from primary gari producers selling at various markets in the three states mentioned. The gari samples were coded thus: Abia white gari sample (ABW), Abia yellow gari sample (ABY), Ebonyi white gari sample (EBW), Ebonyi yellow gari sample (EBY), Enugu white gari sample (ENW) and Enugu yellow gari sample (ENY), accordingly. The equilibrium moisture content (EMC) was determined using a standard Gravimetric method with tetraoxosulphate (VI) salt and water mixtures providing equilibrium relative humidity (ERH) of 15, 25,35, 45, 55 and 65% respectively to yield a water activity (aw) range of 0.0972 - 0.9811 at 30, 40 and 50°C for adsorption and desorption isotherm arms. The sorption data generated were fitted into GAB and Handerson models. A sigmoidal behaviour (type II) was observed which is a typical attribute of a dry carbohydrate-dense food. There was a general increase in the equilibrium moisture content (%) with increasing water activity. There were significant differences ($p<0.05$) between the sorption behaviour of ABW, EBW and ENW; ABY, EBY and ENY gari samples. The equilibrium moisture content decreased with an increase in temperature at constant water activity. The goodness of fit of the two models was determined using four statistical parameters: coefficient of determination (r^2), root mean square error (RMSE), percentage mean relative deviation modulus (%p) and chi-square (x^2). GAB model appeared as the most suitable model than Henderson model. EBW and EBY gari samples proved to be of good shelf stability through this study of moisture content cum sorption as an index of stability in dry food products.

Keywords: GAB' model, gari, Henderson's model, hysteresis, moisture sorption, water activity.

INTRODUCTION

Cassava (*Manihot esculanta Crantz*) is a key root crop and a major source of carbohydrate for more than 500 million people in underdeveloped countries (Lukuyu *et al*., 2014). It is thought to have originated in Brazil, and the Portuguese introduced it to West Africa. Cassava is thought to have been introduced to Africa about 300 years ago, although it was not widely acknowledged and practiced until the late 1990s. The importance of cassava to the human population has become undeniable. The most popular by-product of cassava is gari (FAO, 2013). Gari is a fermented gelatinized creamy white or yellow (due to the addition of palm oil in the course of its production) granular flour sourced from cassava root (*Manihot esculanta Crantz*) through various food processing unit operations such as; harvesting, peeling, washing, grating and fermentation of the cassava tubers and toasting (Samuel and Ugwuanyi, 2014).

In many countries most especially in the tropics, large populations of humans consume gari because it plays an important role as a significant source of energy. It has a slightly fermented flavour and, a slightly sour taste given to it as a result of fermentation and gelatinization in its processing (FAO, 2013). Understanding the moisture sorption behaviour of dehydrated agricultural products is of great importance in solving food processing and engineering problems such as prediction of shelf life, design and optimization of drying equipment, process development, determination of moisture changes during storage, ingredient mixing, prediction of stability and microbiological safety (Nwanekezi *et al*., 2010; Igbabul *et al*., 2013).

The relationship between water activity and the moisture content of a foodstuff is important in predicting quality stability during drying, process development, storage and selection of appropriate packaging materials for sales purposes (Chikezie and Ojiako, 2013). It has also been used to predict microbial growth and the extent of enzymatic reactions in foods (Prette *et al*., 2013). One of the ancient techniques for the preservation of food employed by man to ensure the stability of foods is through control of moisture content which can be obtained either by removal (drying) or binding of the available moisture in the food product (addition of salt or sugar) to ensure its microbial and chemical shelf-stability (Apati *et al*., 2010).

In the preservation of various dehydrated foods, application of the moisture sorption knowledge has yielded good results over the years (Prette *et al*., 2013). However, moisture sorption isotherm has not been critically studied on gari and other dry staple foods in the tropics which are locations mostly challenged by food security problems. Therefore, Moisture Sorption Isotherm (MSI) is required for the prediction of shelf duration, drying practices and other heat-related processing of foods. Also, it is very essential in the determination of critical values for processing such as equilibrium moisture content, critical moisture content and other moisture management parameters. Since food storage depends on a sound understanding of its moisture sorption characteristics, adequate choice of packaging material and storage environment, information from this study would be needed to achieve enhanced shelf-life of both white and yellow gari since the moisture transfer mechanism is known. The research reported in this paper was designed to obtain adsorption and desorption equilibrium moisture properties for white and yellow gari at 30, 40, and 50°C over a range of water activities of 0.09 – 0.92% and to interpret these data in terms of GAB and Henderson model.

MATERIALS AND METHODS

Sample collection

The gari samples (white and yellow from each state) used in this study were obtained from Ogige market, Nsukka in Enugu state, Orie ndu market, Obim, Isikwuato in Abia state and Nkwor-agu-isu, Afikpo in Ebonyi state, all in the Eastern part of Nigeria (these market sellers freshly produced the gari samples themselves). The gari samples were collected using an airtight plastic container. The airtight plastic containers having 12.8cm diameter, 9cm height and volumetric space of 1158 cm^3 were also procured from “Ogige market”, Nsukka, Enugu state, Nigeria. The various white and yellow gari samples procured from the aforementioned three states were coded as follows; Abia white gari sample (ABW), Abia yellow gari sample (ABY), Ebonyi white gari sample (EBW), Ebonyi yellow gari sample (EBY), Enugu white gari sample (ENW) and Enugu yellow gari sample (ENY), respectively. Also, the saturated salt (H_2SO_4) used is of analytical grade (93%).

Experimental procedure

The moisture sorption isotherms (adsorption and desorption) of the six (6) gari (yellow and white samples each) were obtained using the gravimetric static method (Labuza, 1984). Each gari sample was placed under the required controlled environment (water activity and temperature) at the same time for adsorption and desorption processes and simultaneously measuring the weight loss or gain until constant weight (equilibrium moisture content) was reached. The gari samples for desorption were conditioned to constant weight by sprinkling distilled water on the samples and allowing the samples to stay in the refrigerator for twelve hours, while the samples for adsorption were left in the dried state. The initial moisture content of both samples for adsorption and desorption was determined. An oven (VWR Scientific 1330G) was used as a temperature control chamber.

The equilibrium moisture content (EMC) was calculated using the material balance equation from the initial moisture content using the formula;

$$M/100\,(W_1) + (W_3-W_2) = EMC/100\,(W_1 + (W_3-W_2)$$

Where; M = initial moisture content of the sample, W_1 = Weight of sample used during sorption experiment, W_2 = Initial weight of sample and crown cork, W_3 = Final weight of sample and crown cork at equilibrium, EMC = Equilibrium moisture content

The results of each determination were unified by calculating the mean equilibrium moisture content values which were used for plotting moisture sorption isotherms graphs of the gari samples. The experimental sorption data (values obtained for the equilibrium moisture contents, water activities, and temperatures) were fitted into two moisture sorption isotherm (MSI) models which include Henderson and GAB (Guggenheim-Anderson-de Boer) as shown in Table 1. These models were chosen

Table 1. Selected moisture isotherm models applied to the experimental data obtained.

Model	Equation
Henderson	$MC = \left\{\frac{-In(1-a_W)}{C}\right\}^{\frac{1}{A}}$
GAB	$MC = \frac{M_0 C a_W}{[(1-Ka_W + CKa_W + CKa_W)]}$

because of their suitability for high carbohydrate foods, application over a wide range of water activities, simplicity and ease of evaluation. These chosen models also present the advantage of correctly describing sorption isotherms of agro-food products for water activity values between 0.0-0.95 (Iguedjtal *et al*., 2008). The adequacy of each model used was examined using three statistical parameters; coefficient of determination (R^2), which provides information about the goodness of fit for each model, the Root Mean Square Error (RMSE%) between the experimental and predicted EMCs which determines the accuracy of fit of the models and the reduced Chi-square (x^2) which shows the suitability of the models. These parameters were calculated (Mehta and Singh, 2006). Graph-pad prism version 8.2.1 (441) was used in plotting the sorption curves for accuracy and smoothness purposes.

RESULTS AND DISCUSSION

Moisture Isotherm

The moisture isotherm curve of equilibrium moisture content versus water activity of the moisture adsorption and desorption for the various white and yellow gari samples in accordance with the range of temperatures analyzed are given in Figures 1 and 2 respectively. The equilibrium moisture content of the various gari samples decreased with increasing temperature between 30 and 40°C at constant water activity due to the vapour pressure of water present in samples decreasing with the environment. Meanwhile, at 50°C, EMC was observed to increase with temperature at the adsorption and desorption arm. This is in agreement with other researchers' findings and is typical of most agricultural food products (ASAE, 2000). The sorption isotherms were sigmoid shaped (type II) which is predominant among hygroscopic products and food materials especially those rich in carbohydrates. This is in accordance with the report of Samuel and Ugwuanyi, (2014) who studied the sorption behaviour of white gari sold in Nsukka, Nigeria at temperatures of 20 and 30°C. The type II curves of isotherms are low at water activity less than 0.5 where relatively low moisture was absorbed for a high increase in water activity, while a high amount of water was absorbed for a small rise in water activity above 0.5 water activity. This behaviour is generally ascribed to a reduction in the number of active sites due to chemical and physical changes induced by temperature; the extent of the decrease, therefore, depends on the nature or constitution of the food (Togrul and Arslan, 2006). However, the increase in equilibrium moisture content observed at the adsorption and desorption arms of the gari samples at 50^{O}C is a rare behaviour in sorption studies and could be attributed to the effect of the high temperature on the components of the food product which leads high exposure of more moisture binding sites of the food product through faster dissolution of the food sample. Although the white and yellow gari samples showed the expected type II sigmoidal behaviours, little difference was observed between the sorption behaviour of the yellow and the white gari samples. This slight variation could be attributed to the difference in the unit operations involved in their production (addition of palm oil) because, at every given temperature, the rate of change of moisture content with water activity of white gari was higher than that of the yellow gari samples slightly.

Hysteresis is simply the difference usually observed between the equilibrium moisture content of the adsorption and desorption arms of the sorption isotherm at a particular water activity and temperature. It is mostly seen in most hygroscopic products (products that bind water when the vapour pressure is lowered). The hysteresis curve for the adsorption and desorption isotherm of the various white and yellow gari samples at selected temperatures (30, 40 and 50°C) are shown in Figures 1 and 2, orderly.

A marked intersection of the isotherms was observed for the various white gari samples at 40 and 50°C, while the reverse was observed at 30°C. The yellow gari samples showed a marked intersection at 30, 40 and 50°C. The expected non-crossing over of the white gari sample at 30°C could be ascribed to the fact that gari is a highly starchy food with wide hysteresis values but, there is a very high tendency for 'crossing-over' at higher water activities. According to Yan *et al*., (2008), hysteresis has been attributed to the nature of the components of the food, showing their tendency for structural rearrangement. Hence, the hysteresis effect of the gari samples at 30, 40 and 50°C showed that the adsorption curve of both the white and yellow gari samples is greater than the desorption curve, which is an interpretation of the equilibrium moisture content of the various gari samples, respectively.

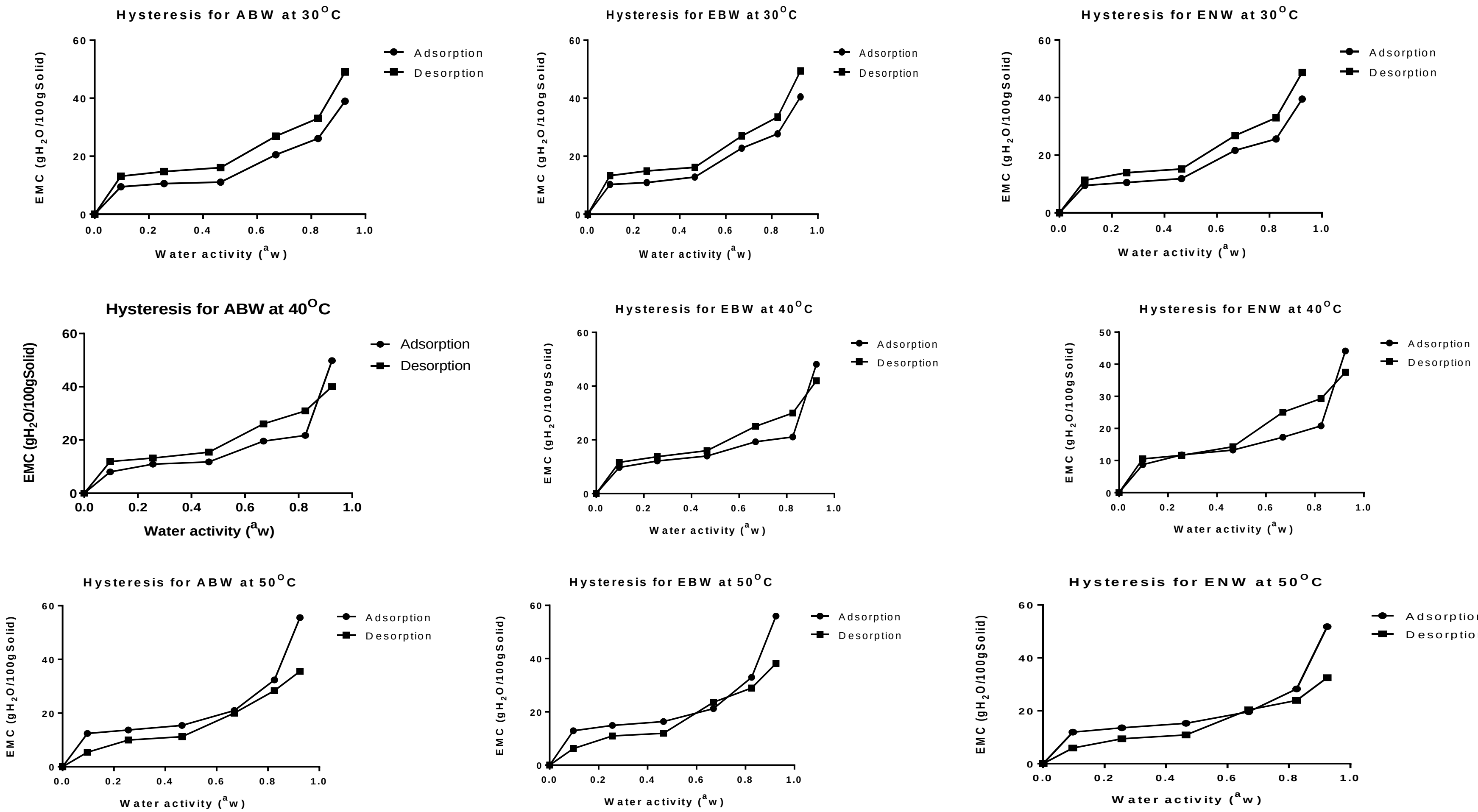

Figure 1. Moisture sorption isotherm of the various white gari samples showing Hysteresis behavior showing adsorption and desorption arms of the various white gari samples at different water activities and temperatures selected. **Key:** EMC= Equilibrium moisture content, ABW= Abia white gari, EBW= Ebonyi white gari, and ENW = Enugu white gari.

Thus, the EMC (equilibrium moisture content) of the adsorption curve for the white gari samples is higher than the yellow gari, although, at 40°C, the EMC of the adsorption arm of the white and yellow gari samples are slightly close at a water activity of 0.4 and below.

Generally, the desorption EMC of the white gari samples is greater than that of yellow gari samples at the temperatures studied. This behaviour could be attributed to the fact that the hysteresis curve of a food product is principally influenced by the components of the food product, the structure of the material, the temperature and the equilibration method applied (Yan *et al.*, 2008). The lower adsorption curve at low water activity could be

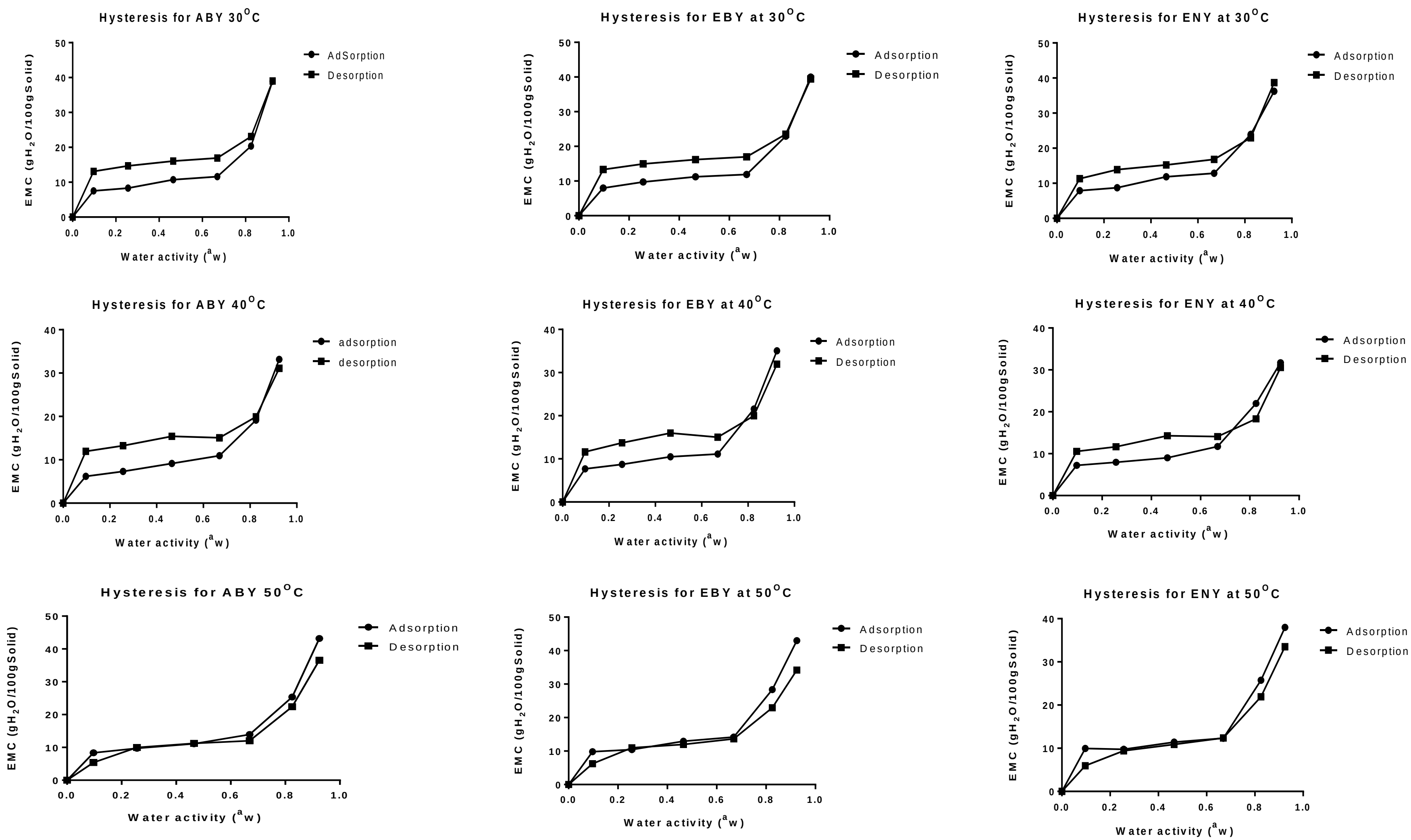

Figure 2. Moisture sorption isotherm of the various yellow gari samples showing HYSTERESIS behavior showing adsorption and desorption arms of the various yellow gari samples at different water activities and temperatures selected. **Key:** EMC= Equilibrium moisture content, ABY= Abia yellow gari, EBY= Ebonyi yellow gari and ENY = Enugu yellow gari.

attributed to the fact that water is absorbed only to the surface –OH sites of crystalline proteins, sugar and polysaccharides while at 50, low hysteresis was observed than 40 and 30°C which may be due to the increase in the elasticity of the capillary walls and higher capacity to yield hydrogen bonds between the constituent of the food such as water, protein and carbohydrate in the structure of the food material (gari) (Labuza *et al*., 1985).

Table 2. GAB' parameters and its derivatives for the moisture sorption and of the white gari samples at 30, 40 and 50°C

Temperature (°C)	Regression parameters	Adsorption			Desorption		
		ABW	ENW	EBW	ABW	ENW	EBW
30	M_o	10.8412	11.3779	13.2011	14.4007	10.6065	9.0937
	K	0.6499	0.6323	0.6106	0.44574	0.5273	0.5858
	C	17.6469	19.0791	22.6431	32.2234	21.2315	16.4153
	r^2	0.91	0.909	0.9248	0.9462	0.924	0.9498
40	M_o	11.5634	9.3508	10.7104	13.71764	19.94963	19.6361
	K	0.6092	0.6549	0.6398	0.447839	0.3740	0.3936
	C	19.9366	15.3270	17.9124	32.1540	51.9289	47.7029
	r^2	0.8375	0.8548	0.819	0.9293	0.8994	0.9627
50	M_o	41.4642	31.6530	24.0618	20.0005	19.7624	37.7576
	K	0.3905	0.4316	0.5174	0.4613	0.4618	0.3363
	C	91.4598	69.2243	47.1754	42.2299	41.7024	95.0239
	r^2	0.9826	0.9519	0.9758	0.79	0.7876	0.7073

Key: ABW= Abia white gari, EBW= Ebonyi white gari and ENW = Enugu white gari. ABY= Abia yellow gari, EBY= Ebonyi yellow gari and ENY = Enugu yellow gari. M_o = monolayer moisture content (g/H_2O/100g solid), K and C = GAB' constant. r^2 = coefficient of determination.

Table 3. GAB' parameters and its derivatives for the moisture sorption of the various yellow gari samples at 30, 40 and 50°C.

Temperature (°C)	Regression parameters	Adsorption			Desorption		
		ABY	ENY	EBY	ABY	ENY	EBY
30	M_o	10.4509	12.5085	9.8749	9.7237	11.8558	8.7426
	K	0.6087	0.5478	0.6334	0.6004	0.3876	0.5673
	C	17.7145	23.5617	16.5762	12.7879	17.7647	14.3656
	r^2	0.8897	0.9019	0.8679	0.9046	0.9105	0.9047
40	M_o	11.3880	13.2431	11.4413	11.6558	12.7843	10.3467
	K	0.4248	0.5115	0.5690	0.5424	0.54860	0.32321
	C	44.0652	27.4367	21.7063	41.3243	25.0432	19.2134
	r^2	0.9342	0.9554	0.872	0.8987	0.8789	0.8726
50	M_o	15.5090	10.9897	19.3890	15.6574	11.7676	19.4659
	K	0.5622	0.6390	0.5197	0.57634	0.6546	0.6051
	C	27.98412	18.47169	36.60915	27.87423	19.9563	35. 120
	r^2	0.9748	0.9318	0.9356	0.8344	0.9103	0.8947

Key: ABW= Abia white gari, EBW= Ebonyi white gari and ENW = Enugu white gari. ABY= Abia yellow gari, EBY= Ebonyi yellow gari and ENY = Enugu yellow gari. M_o = Monolayer moisture content (g/H_2O/100g solid), K and C = GAB' constant. r^2 = coefficient of determination.

Application of the moisture sorption isotherm models and parameters

GAB's Monolayer moisture content values for the gari samples

Monolayer moisture content (Mo) values for the gari samples at temperatures of 30, 40 and 50 ^{O}C were within the range of 9.3508 - 41.4642 g/H_2O/100g solid (adsorption); 9.0937 - 37.7576 (desorption) g/H_2O/100g solid and 9.8749 - 19.3890 g/H_2O/100g solid (adsorption); 8.7426 - 19.4659 g/H_2O/100g solid (desorption) (%, dry basis) for both the adsorption and desorption of white and yellow gari sample as shown in Tables 2 and 3. The GAB model has high monolayer values. According to the results obtained within the temperature range studied, gari samples are best kept safe for storage at a moisture content of about 4 - 5% (db).

Also, it was observed that monolayer moisture content decreased with an increase in temperature from 30 to 40°C and then increased at 50°C for both the yellow and white gari samples. Such a decrease in temperature could be because of binding of water molecules becomes less stable at increased temperature, thus breaking away from the water binding sites of the sample (Simal *et al.,* 2007). While the increase in the monolayer (M_O) values with an increase in temperature could be due to the effect of the temperature rise, which led to the opening of new binding

Table 4. Henderson's parameters and derivatives for moisture sorption of the various white gari samples at 30, 40 and 50°C.

Temperature (°C)	Regression parameters	Adsorption			Desorption		
		ABW	ENW	EBW	ABW	ENW	EBW
	A	4.3513	4.5843	4.6262	5.6267	5.5099	-11.066
30	C	-11.471	-12.073	-12.480	-12.434	-12.289	4.8956
	r^2	0.8272	0.8492	0.8527	0.849	0.8836	0.8449
	A	4.6679	4.4562	4.5364	6.9397	5.9092	5.5468
40	C	-11.962	-11.258	-11.842	-15.447	-13.413	-12.770
	r^2	0.8252	0.8193	0.7908	0.8866	0.8962	0.905
	A	4.9431	5.2175	5.1365	5.1286	5.3440	5.6519
50	C	-14.495	-15.078	-15.239	-13.14	-13.637	-14.855
	r^2	0.8297	0.8169	0.8266	0.9702	0.9656	0.9608

Key: ABW= Abia white gari, EBW= Ebonyi white gari and ENW = Enugu white gari. ABY= Abia yellow gari, EBY= Ebonyi yellow gari and ENY = Enugu yellow gari. A and C = Henderson constant. r^2 = coefficient of determination.

Table 5. Henderson's parameter for the moisture sorption of the various yellow gari samples at 30, 40 and 50°C.

Temperature (°C)	Regression parameters	Adsorption			Desorption		
		ABY	ENY	EBY	ABY	ENY	EBY
30	A	4.337	5.1492	4.5226	5.252	5.269	5.806
	C	-10.559	-12.515	-11.301	-10.395	-12.910	-12.301
	r^2	0.9248	0.9398	0.9001	0.946	0.9801	0.913
40	A	6.644	6.1497	5.6921	6.851	6.174	5.981
	C	-15.991	-14.808	-14.049	-16.153	-15.756	-15.534
	r^2	0.9805	0.9397	0.8059	0.9512	0.927	0.875
50	A	4.5563	4.9701	4.5134	7.6011	6.8746	8.2783
	C	-12.136	-13.123	-12.261	-13.884	-13.646	-12.873
	r^2	0.936	0.8572	0.966	0.903	0.8267	0.9543

Key: ABW= Abia white gari, EBW= Ebonyi white gari and ENW = Enugu white gari. ABY= Abia yellow gari, EBY= Ebonyi yellow gari and ENY = Enugu yellow gari. A and C = Henderson' constant. r^2 = coefficient of determination.

sites, thus allowing more water vapour molecules to bind. According to Sawhney *et al*., (2011) who defined the monolayer moisture content of a food material as the moisture content of that food when its entire surface is covered with one molecular layer of water vapour molecules. This implies that the optimum amount of water strongly adsorbed to specific sites per gram of a dry substance is considered the optimum moisture value at which a food is highly stable (Perez-Alonso *et al*., 2006). At a given temperature, the safest water activity level is the corresponding M_O value or lesser M_O value. M_O values are very important in handling of a food material because below the M_O of a food, water is strongly bound and the rates of deteriorative reactions are lowered.

The GAB's constants; C and K

According to McMinn and Magee (1997), GAB's constant C shows the degree of difference between the chemical potentials of monolayer water molecules and multilayer water molecules. This shows the adsorbent – adsorbate interactions. From this study, Tables 2 and 3 show that C values obtained are greater than 2 and increased with increase in temperature and thus, supported the predictions made earlier that the isotherm curves obtained are sigmoidal. The GAB plots yielded positive intercepts and thus, positive C values were obtained all through. The coefficient of determination (r^2) of the GAB' model for the white gari sample ranged from 0.819 - 0.9826 for adsorption and 0.7073 - 0.9627 for desorption. That of yellow gari samples ranged from 0.8679 - 0.9554 and 0.8344 - 0.9105 for adsorption and desorption, respectively.

Henderson's model, parameters and application on the various gari samples

The parameters of Henderson' model for the adsorption and desorption arm of white and yellow gari samples are presented in Tables 4 and 5, respectively. Also, Henderson' model is mostly applied in the modelling of sorption data of foods. Just like GAB' model, it has a wide water activity range of 0 - 0.9. For this model, the coefficient of determination (r^2) value of the adsorption arm of the white gari sample falls within the range of 0.7908 –

Table 6. Suitability of the selected sorption models for moisture adsorption of ABW, EBW and ENW gari at 30, 40 and 50°C.

Temperature (°C)	Sample	Statistical parameter	Adsorption	
			Henderson	GAB
30	ABW	RMSE	2.3562	1.2098
		X^2	1.8075	4.5346
		%P	0.3884	5.2922
		r^2	0.8272	0.91
	ENW	RMSE	1.9996	1.6797
		X^2	1.4708	3.2456
		%P	0.3043	9.2626
		r^2	0.8492	0.909
	EBW	RMSE	2.0358	1.6218
		X^2	1.4009	2.5113
		%P	0.2880	4.8140
		r^2	0.8527	0.9248
40	ABW	RMSE	1.6139	1.7513
		X^2	0.8629	1.6253
		%P	0.2255	5.9563
		r^2	0.8252	0.8375
	ENW	RMSE	2.1216	1.7955
		X^2	1.4399	2.6828
		%P	0.4043	7.7537
		r^2	0.8193	0.8548
	EBW	RMSE	2.2614	2.1735
		X^2	1.7311	5.3595
		%P	0.4024	4.2149
		r^2	0.7908	0.819
50	ABW	RMSE	1.1292	1.8137
		X^2	0.4164	2.745
		%P	0.9357	9.0749
		r^2	0.8297	0.9826
	ENW	RMSE	0.8698	3.0865
		X^2	0.2701	1.573
		%P	0.8779	7.7396
		r^2	0.8169	0.9519
	EBW	RMSE	1.5619	1.6548
		X^2	0.7413	0.7628
		%P	0.1426	5.7956
		r^2	0.8266	0.9758

Key: ABW= Abia white gari, EBW= Ebonyi white gari and ENW = Enugu white gari. R^2 = Coefficient of determination. RMSE= Root mean square error. x^2 = Reduced chi square. %P = percentage mean relative deviation modulus.

0.8527 while the desorption arm has a coefficient of determination value within the range of 0.7105 - 0.9702. For the yellow sample, the coefficient value ranged from 0.7353 – 0.8261 for adsorption and 0.6911 - 0.9064 for the desorption arm. The derived coefficient of determination values revealed that Henderson's model fits for the experimentation of the data derived from the various gari samples but is not as good as GAB.

Suitability of the selected moisture sorption models on experimental data of ABW, EBW and ENW; ABY, EBY and ENY gari samples

The goodness of fit of a moisture sorption model for the samples ABW, EBW ENW; ABY, EBY and ENY as shown in tables 6, 7, 8 and 9 is derived based on the model with the highest value of r^2, least RMSE, X^2 and % P value. It is

Table 7. Suitability of the selected sorption models for moisture desorption of ABW, EBW and ENW gari at 30, 40 and 50°C.

Temperature (°C)	Sample	Statistical parameter	Desorption	
			Henderson	GAB
30	ABW	RMSE	0.5315	0.6433
		X^2	0.9992	1.1831
		%P	0.5028	5.5896
		r^2	0.849	0.9462
	ENW	RMSE	1.0407	1.3948
		X^2	0.3220	6.6904
		%P	0.1239	11.8010
		r^2	0.8836	0.924
	EBW	RMSE	1.2706	1.6860
		X^2	0.4808	16.1667
		%P	0.1875	7.6928
		r^2	0.8449	0.9498
40	ABW	RMSE	0.6088	2.5145
		X^2	0.1129	1.9252
		%P	0.8925	4.8697
		r^2	0.8866	0.9293
	ENW	RMSE	0.7163	3.6042
		X^2	0.2026	0.7889
		%P	0.8965	8.7440
		r^2	0.8962	0.8994
	EBW	RMSE	0.5945	2.8406
		X^2	0.1412	3.589
		%P	0.7291	8.2706
		r^2	0.905	0.9627
50	ABW	RMSE	0.6923	2.4491
		X^2	0.1867	2.5678
		%P	0.3758	5.8469
		r^2	0.9702	0.79
	ENW	RMSE	0.8540	2.9357
		X^2	0.2188	1.3236
		%P	0.7105	5.7831
		r^2	0.9656	0.7876
	EBW	RMSE	0.4085	2.5493
		X^2	0.6594	1.842
		%P	0.4482	8.8312
		r^2	0.9608	0.7073

Key: ABW= Abia white gari, EBW= Ebonyi white gari and ENW = Enugu white gari. R^2 = Coefficient of determination. RMSE= Root mean square error. x^2 = Reduced chi square. %P = percentage mean relative deviation modulus.

revealed that the GAB model has the best description for the experimental adsorption and desorption data of the gari samples within the water activity range chosen, while Henderson's model showed a poor fit for the data obtained from the gari samples. The statistical parameters selected are very important to ensure that accuracy in selecting

Table 8. Suitability of the selected sorption models for moisture adsorption of ABY, EBY and ENY gari samples at 30, 40 and 50°C.

Temperature (°C)	Sample	Statistical parameter	Adsorption	
			Henderson	GAB
30	ABY	RMSE	1.5489	0.6548
		X^2	0.7037	2.7628
		%P	0.24726	5.9262
		r^2	0.7589	0.8897
	ENY	RMSE	1.2043	4.1688
		X^2	0.4110	1.9655
		%P	0.4105	5.8723
		r^2	0.8156	0.9019
	EBY	RMSE	1.8250	1.2863
		X^2	1.1072	3.2947
		%P	0.3076	10.0997
		r^2	0.7533	0.8679
40	ABY	RMSE	0.4992	2.1041
		X^2	0.8985	4.4539
		%P	0.9534	6.2654
		r^2	0.8176	0.9342
	ENY	RMSE	0.9905	1.5091
		X^2	0.3253	0.5338
		%P	0.1191	9.3339
		r^2	0.7846	0.9554
	EBY	RMSE	1.5265	1.6696
		X^2	0.7450	1.9577
		%P	0.1911	9.9986
		r^2	0.7548	0.872
50	ABY	RMSE	1.5810	1.2694
		X^2	0.8357	3.581
		%P	0.1864	8.9730
		r^2	0.8261	0.9748
	ENY	RMSE	2.3892	1.7626
		X^2	1.6522	1.2943
		%P	0.3476	7.2642
		r^2	0.7353	0.9318
	EBY	RMSE	1.3319	2.2390
		X^2	0.5530	1.1777
		%P	0.9747	4.4505
		r^2	0.8051	0.9356

Key: ABY= Abia yellow gari, EBY= Ebonyi yellow gari and ENY= Enugu yellow gari. r^2 = Coefficient of determination. RMSE= Root mean square error. x^2 = Reduced chi square. %P = percentage mean relative deviation modulus.

the best equation to be applied in the study of moisture sorption characteristics of a dehydrated food product is achieved.

One of the primary principles applied in choosing the adequate model fit for determining the sorption isotherm behaviour of ABW, EBW and ENW; and ABY, EBY and

Table 9. Suitability of the selected sorption models for moisture desorption of ABY, EBY and ENY gari at 30, 40 and 50°C.

Temperature (°C)	Sample	Statistical parameter	Desorption	
			Henderson	GAB
30	ABY	RMSE	1.0642	0.9541
		X^2	0.8201	0.7628
		%P	0.2521	7.9262
		r^2	0.7083	0.9046
	ENY	RMSE	1.2408	1.1670
		X^2	0.4382	0.9682
		%P	0.1402	9.8723
		r^2	0.7844	0.9105
	EBY	RMSE	1.7591	2.1753
		X^2	1.1752	1.2947
		%P	0.3016	7.0997
		r^2	0.7001	0.9047
40	ABY	RMSE	0.9811	2.124
		X^2	0.8476	1.4539
		%P	0.9561	6.2654
		r^2	0.7372	0.8987
	ENY	RMSE	0.9915	1.7805
		X^2	0.7599	0.8841
		%P	0.7191	9.3339
		r^2	0.751	0.8789
	EBY	RMSE	1.7623	1.6696
		X^2	0.7463	1.9537
		%P	0.6911	7.9986
		r^2	0.7422	0.8726
50	ABY	RMSE	1.899	1.1964
		X^2	0.7541	1.6548
		%P	0.1664	9.713
		r^2	0.8853	0.8344
	ENY	RMSE	2.4678	2.6582
		X^2	1.2641	1.4031
		%P	0.3179	8.2219
		r^2	0.904	0.9103
	EBY	RMSE	1.1829	0.1355
		X^2	0.6049	1.1901
		%P	0.9167	4.3906
		r^2	0.9064	0.8947

Key: ABY= Abia yellow gari, EBY= Ebonyi yellow gari and ENY= Enugu yellow gari. r^2 = Coefficient of determination. RMSE= Root mean square error. x^2 = Reduced chi square. %P = percentage mean relative deviation modulus.

ENY gari samples is the statistical principle of coefficient of determination (r^2), followed by reduced Chi-square (x^2), average percentage difference (% P) and root mean square error (RMSE).

Conclusion

The moisture sorption isotherms data of the gari samples (ABW, EBW and ENW; and ABY, EBY and ENY) were analysed properly using two models (GAB and Henderson). Henderson model unlike GAB did not give a good fit. Of all the gari samples, EBW and EBY gari had higher moisture adsorbing capacity and long shelf stability period, followed by ABW, ABY, ENW and ENY gari samples respectively. This could be attributed to prolonged heat treatment process (toasting) that results in a hard, crisp and hygroscopic gari. Generally, the two models had high regression coefficients; hence could be said to be good for the determination of moisture sorption characteristics (adsorption and desorption isotherm) of ABW, EBW and ENW; ABY, EBY and ENY gari samples. Based on the highest regression coefficient (R^2), the root mean square error (RMSE) and the reduced Chi-square (X^2) values, the GAB model is the more suitable model for the sorption isotherms of gari, followed by the Henderson model. For a quality shelf-stable gari to be produced; a very low moisture content (4 – 5%), low water activity (low relative humidity, below 0.5 water activity created within the packaging material), temperature range of 27 – 30°C, good agricultural practices and good manufacturing practices (hygienic handling) from the farm to the point of consumption, and a moisture-proof packaging material (air- tight high-density polyethylene and plastic containers) should be implored.

CONFLICT OF INTEREST

There is no conflict of interest

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