Effects of processing parameters on moisture sorption isotherms of dehydrated catfish (*Clarias gariepinus*)

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Abstract: Effects of processing parameters on moisture sorption isotherms of dehydrated catfish (*Clarias gariepinus*) at 25°C and 30°C and water activity ranged 0.1-0.85 were determined using the static gravimetric method. The interaction of processing variables, regarded as treatment was done using response surface methodology. Three best treatments selected through preliminary sensory evaluation falls within the parameters' range (brine concentrations (6% and 9%), brining time (60 and 90 min) and drying temperatures (90°C and 110°C)) and used in the production of the dehydrated catfish. Two un-brined samples, dried at each temperature were used as the control. The moisture sorption isotherm curves were fitted with Oswin, Smith, GAB and BET models. The constants of the equations used in fitting the curves were determined by non-linear regression analysis while the models were compared using the coefficient of determination, root mean square error and reduced Chi-square; and average grade ranking. Microbial qualities of the samples were determined. Sorption isotherms exhibited type II characteristics of BET classification. The equilibrium moisture content of the dehydrated catfish in all treatments decreased with increasing temperature and increased with increasing water activity at the same temperature. Oswin model ranked first in all the treatments and the set of temperature, indicating the best fit for the curves. However, treatment: 9%, 90 min and 90°C provided the lowest monolayer moisture content (0.298373 g water 100 g^{-1} dry matter) of GAB at 30°C which could aid the product stability. Total viable counts of the product samples ranged from 1.0×10^3-1.6×10^4 cfu g^{-1} and fungi from 1.0×10^3-2.0×10^3 cfu g^{-1} TVC. No pathogenic organism detected; indicating safety for consumption. Information and data useful in designing equipment for commercial processing of catfish with simple dehydration technique and the optimum conditions are provided which could boost the economic importance of catfish.

Keywords: catfish, dehydration, sorption isotherm, processing parameters, modelling, microbial quality

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1 Introduction

In Nigeria, fish farming has become a lucrative business which is mainly boosted by the continuous rise in the demand for catfish. Despite the popularity of catfish farming in Nigeria, catfish market can be described to still be in its infancy in comparison with the large market experienced with other species of fish. Catfish is highly perishable item and the fluctuation in the market could be traced to lack of proper method of preservation and distribution (Eyo, 2001). Processing and preservation aid the inhibition of the metabolic changes that lead to fish spoilage and minimized post-harvest losses. Considering the high demand, food and economic values of catfish (*Clarias gariepinus*) in Nigeria (Adeparusi et al., 2010), dehydration is considered one of the simplest and inexpensive ways of processing fish in comparison with such methods as freezing, freeze-drying and canning. This could encourage more production and export of the dehydrated catfish (Balachandra, 2011). However, inefficient dehydration process could make a

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mess of this preservation method for fish due to a high moisture level that supports microbial deterioration of the product. Particularly with dried fish is the problem of mould growth and insect infestation as a direct result of moisture uptake during storage (Aworh et al., 2002). Thus, proper knowledge of optimum dehydration and storage conditions through the determination of moisture sorption isotherm could help in the production of low moisture and stable product.

Moisture sorption isotherm is one of the most notable aspects of the concept of water activity in food systems and it is the relationship of moisture content as a function of relative humidity at the same temperature. Bell and Labuza (2000) described this relationship to be different from one food material to another as it describes the quantity of water adsorbed or desorbed at equilibrium by a material at known water activity (a_w) and constant temperature. An understanding of the sorption characteristics of agricultural commodities is therefore essential to know the stability and acceptability of stored food products, design of drying equipments and optimization of drying operations and selection of suitable packaging materials (Samapundo et al., 2006; Osundahunsi et al., 2014). Moisture sorption behaviour has been extensively reported for agricultural materials of plant origin (*akara* Ogbomoso), dehydrated tomato slices, *Chilean papaya*, African arrowroot lily (*Taca involucrate*) tuber-mash products, acetylate and native starches by Falade et al. (2003), Akanbi et al. (2006), Vega-Galvez et al. (2008), Igbabul et al. (2013), Osundahunsi et al. (2014), respectively. Although, Sobukola et al. (2012) reported the effect of salting methods (brined and dry-salting) on the sorption isotherms of African catfish (ACF); little or no information exists on the sorption characteristics of dehydrated catfish as influenced by combination of three processing parameters as a treatment. This study was designed to predict the optimum parameters for catfish dehydration and investigate the effects on moisture sorption isotherms and to determine the microbial load of the dehydrated catfish.

2 Materials and methods

2.1 Materials

Six months old Catfish (*Clarias gariepinus*) each of an average weight and length 500±20 g and 43±2 cm, respectively were used in the study. Common table salt (NaCl- Mr Chef Brand) used for the brine solution was purchased from a local market in Akure while other chemicals used for the analyses were of analytical grade. The drying was achieved in an experimental convective fish dryer with electric heating elements (radiating-convective heat transfer system), 2012 model, Korea obtained from Dickem Aquatech Nigeria Ltd., Odan-Isashi, Lagos, Nigeria. *C. gariepinus* was obtained from the Fishery Teaching and Research Farm of the Federal University of Technology, Akure (FUTA).

2.2 Methods

2.2.1 Experimental design for the processing of dehydrated catfish

The design of experiment for the processing of dehydrated catfish was done using response surface methodology (RSM). The independent variables (factors) of the design were brine concentration (3%, 6% and 9%), brining time (30, 60 and 90 min) and drying temperature (90°C, 110°C and 130°C) chosen based on literature reports (Chukwu and Shaba, 2009; Sobukola and Olatunde, 2011) and preliminary experiments. The variables were interacted using a face-centred, full factorial central composite design (CCD) to evaluate the combined effect of the variables. Seventeen of the twenty generated experimental runs were used for the production of dehydrated catfish as shown in Table 1. Preliminary sensory evaluation of the dehydrated catfish samples was done by 18-man untrained panelists on general appearance, aroma, texture, taste and overall acceptability. The panelists were used based on the familiarity with and likeness of the product. Three best runs were selected based on the result of the evaluation with two additional un-brined and dried samples, making five samples used in the moisture sorption isotherms study as presented in Table 2.

2.2.2 Pre-processing and brining operation

The fish were slaughtered, degutted and washed thoroughly with tap water to remove all adhesive materials and blood. Brine solutions of appropriate concentrations (6% and 9%) were prepared by dissolving the salt in water (60 and 90 g per litre, respectively). Beheaded fish of an average weight of 254 g were randomly selected and immersed in plastic bowls containing appropriate brine solutions and left for each appropriate time. The effect of moisture diffusion from fish muscle into the brine solution was minimized by multiple ratio of the volume of brine solution to the brining fish. Brined fish, singly arranged on mesh trays were left for 1 h for brine equilibration and drain off of excess solution.

Table 1 Response surface design runs (CCD) for catfish processing

RSM run	A	B	C
1	6	60	110
2	6	90	110
3	3	60	110
4	3	30	90
5	6	30	110
6	9	90	130
7	9	60	110
8	6	60	110
9	9	90	90
10	6	60	130
11	3	90	130
12	6	60	110
13	6	60	90
14	3	90	90
15	3	30	130
16	9	30	130
17	9	30	90

Note: CCD = Central composite design; A = Brine concentration; (%); B = Brining time (min); C = Drying temperature (^{o}C).

Table 2 Selected treatments for catfish dehydration based on single factor ANOVA for sensory overall acceptability of the dehydrated catfish

Treatment	A (%)	B (min)	C (^{o}C)	Average/ranking	Variance
Tr1	9	90	90	4.225^{2}	0.18681
Tr2	6	60	90	4.100^{3}	0.30833
Tr3	0	0	90	-	-
Tr4	6	90	110	4.325^{1}	0.11181
Tr5	0	0	110	-	-

Note: A = Brine concentration; B = Brining time; C = Drying temperature; Tr = Treatment; NB: Superscripts 1, 2 and 3 indicated rankings of the average overall acceptability scores.

2.2.3 Drying operation

The convective dryer used, consists of heating chamber at the middle with eight electrical heating elements (1500 W) each enclosed in a glass tube and equidistantly fixed round the chamber, radiating heat to the drying materials. The dryer was preheated to the desired temperature (90^{o}C or 110^{o}C) and a dry bulb thermometer inserted to monitor the temperature. The fish were singly arranged on three-level mesh trays inside the dryer and monitored to ensure that no case hardening occurred (Otolowo, 2017). Two un-brined samples dried at each temperature factors of the selected treatments were used as the control. The initial time for drying was taken as the time the temperature stabilizes at the set temperature. Drying of catfish at 90^{o}C and 110^{o}C was achieved at 27 h and 24 h 40 min, respectively. The fish were cooled to room temperature (25±2^{o}C) and packaged in polyethylene bag prior to the analyses. The processing of catfish is presented in Figure 1.

Live-catfish
↓
Slaughtering (beheaded)
↓
Washing
↓
Degutting
↓
Washing
↓
Brining
↓
Draining (to remove excess solution)
↓
Drying
↓
Cooling (at room temperature: 25±2^{o}C)
↓
Dehydrated catfish

Figure 1 Processing of dehydrated catfish (Eyo, 2001)

2.2.4 Determination of sorption isotherms of dehydrated catfish

The selected treatments earlier presented in Table 2 were used in the sorption isotherm determination. The water activity used ranged from 0.1 to 0.85 and isotherm temperatures of 25^{o}C and 30^{o}C. A static gravimetric method was used as described by Osundahunsi and Aworh (2000). The saturated solutions used for the experiment to maintain a constant relative humidity environment in the desiccators were extracted from those presented by Buxton and Mellenby (1934) and Rockland (1960) as presented in Table 3. Three gramme each, of the ground muscle part of the dehydrated catfish samples, were weighed into different Petri dishes and carefully arranged in the desiccators containing the saturated solutions. The dishes were stacked with wire gauze in-between. A thin film of grease was rubbed on the edge of the lids to ensure air-tight desiccators. The desiccators were kept under the stated temperatures. Moisture gains were monitored by weighing the samples at three days interval until moisture equilibrium was attained. The equilibrium moisture content (EMC) was determined gravimetrically using moisture analyser (KERN DBS 60–3, Germany). The equilibrium moisture content on a dry weight basis was plotted against the equilibrium relative humidity (a_w) to obtain the moisture sorption isotherms.

Table 3 Saturated solutions used to maintain constant relative humidity

Relative humidity (%)	Appx. solute in hot water (g 100 mL^{-1})	Saturated solution
10	110.0	KOH
20	87.5	KOH
50	52.0	KOH
75	40.0	NaCl
85	50.0	KCl

Note: Sources: Buxton and Mellenby, 1934; Rockland, 1960 (modified).

2.2.5 Modelling of sorption isotherms of dehydrated catfish

The data obtained from the moisture sorption isotherm were fitted to four sorption isotherm mathematical models presented in Table 4 using Excel Solver (2013) software. Statistical analyses of the experimental data were performed using the same software. The coefficient of determination (R^2) was used as the criterion in selecting the best model; root mean square error (RMSE) and mean bias error (MBE) were used to determine the goodness of fit (Sun and Woods, 1994c; Rehman, 1998, Seid and Hensel, 2012). The average ranking was determined to verify the selection while the rating parameters were calculated as described in (Equations (1) to (3)) below.

$$R^2 = \frac{\sum_{i=1}^{N}(M_i - M_{pre,i}) \times (M_i - M_{exp,i})}{\sqrt{\sum_{i=1}^{N}(M_i - M_{pre,i})^2} \times \sqrt{\{\sum_{i=1}^{N}(M_i - M_{pre,i})^2\}}} \quad (1)$$

where, R^2 is the coefficient of determination; M_i is the initial moisture content (gH_2O/100 g solid); $M_{exp,i}$ is the equilibrium moisture content found in any measurement; $M_{pre,i}$ is the predicted equilibrium moisture content for this measurement and N is the total number of observations.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(M_{exp,i} - M_{cal,i})^2}{n}} \quad (2)$$

where, $RMSE$ is the root mean square error which signifies the noise in the data; n is the number of constants.

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(M_{pre,i} - M_{exp,i}) \quad (3)$$

where, MBE is the means bias error which represents the systemic error.

Table 4 Mathematical models fitted for sorption isotherm curves

Model	Equation
Oswin	$M = C\left[\left(\frac{a_w}{(1-a_w)}\right)^n\right]$
Smith	$M = C_1 + C_2 \ln(1-a_w)$
GAB	$X = \frac{X_m CKa_w}{(1-Ka_w)(1-Ka_w+CKa_w)}$
BET	$X = \frac{X_m Ca_w}{(1-a_w)(1+(C-1)a_w)}$

Note: Source: Rizvi (2005); Andrade et al. (2011). Key: M or X = Equilibrium moisture content (EMC); C, K = Model constants; X_m = Monolayer moisture content.

2.2.6 Determination of the microbial load of the dehydrated catfish

The microbial load of dehydrated catfish was determined using the pour plating method as described by Harrigan and McCance (1976). The following selective media: Nutrient Agar (Sigma-Aldrich-70148), McConkey Agar (Sigma-M7408), Desoxycholate Agar (Sigma–Aldrich - D7809), Eosin Methylene Blue (Sigma-Aldrich - 70186) Agar and Potato Dextrose Agar (Sigma-Aldrich- 70139) were used for total viable count (TVC), *Coliforms, Salmonella, Escherichia coli* and fungi growth, respectively. The muscle part of the samples was ground and dilutions were made up to 10^{-3}. Bacteria plates were incubated at 37°C for 24 h and fungi plates at 25°C for 48 to 72 h. After incubation, colony growths were enumerated using a digital colony counter (Gallenkamp, England).

2.2.7 Data analysis

The RSM runs were developed using Design Expert software DX 8.0.3.1, USA, while the Excel solver (2013) software was used for the statistical modelling of the sorption isotherm data. The analysis of variance (ANOVA) was used to establish differences among treatments using Statistical package for social sciences (SPSS version 22).

3 Results and discussion

3.1 Sorption isotherms of dehydrated catfish (C. gariepinus)

3.1.1 Effect of processing parameters on sorption isotherms of dehydrated catfish

Dehydrated catfish, processed treatments earlier presented in Table 2 were used for the sorption isotherms study. The curves of equilibrium moisture content (EMC) against the range of water activities expressed on moisture free basis and corresponding to each relative humidity at 25°C and 30°C for the dehydrated catfish of all treatments (Tr1-Tr5) are represented in Figure 2. The full range of water activities (a_w) and isotherm temperatures had significant effects on EMC irrespective of the treatments. The EMC decreased with increasing temperature from 25°C to 30°C at a constant a_w. The decrease is attributed to a reduction in the number of active polar sites for water binding as a result of physical and chemical changes induced by increased temperature similar to the reports of Falade et al. (2003); Sobukola et al. (2012). The same trend was followed in all the treatments, but at higher relative humidity (a_w), a reverse trend was observed in Tr1, Tr4 and Tr5 that is, the EMC increased with increase temperature. The reverse trend may be due to more dissolution of salt and increased microbial activity that causes more water to be held by the product. This agreed with the report of Sobukola et al. (2012) on sorption isotherms of brined and dry salted African catfish (ACF). It also is a documented fact that effect of temperature on the sorption isotherm is generally of great importance given that foods are exposed to a range of temperatures during processing and storage and water activity changes with temperature for the same moisture content (Osundahunsi and Aworh, 2000). The gradual slope of isotherms of the dehydrated catfish samples at relative humidity below 50% is consistent with the chemical composition of the product. Products with high protein content like dehydrated catfish have been reported to exhibits gradually sloping isotherm at low relative humidity and the shape is typical for most dehydrated foods. Also, the moisture sorption characteristics of foods have been shown to be influenced by food composition and process treatments (Osundahunsi and Aworh, 2000).

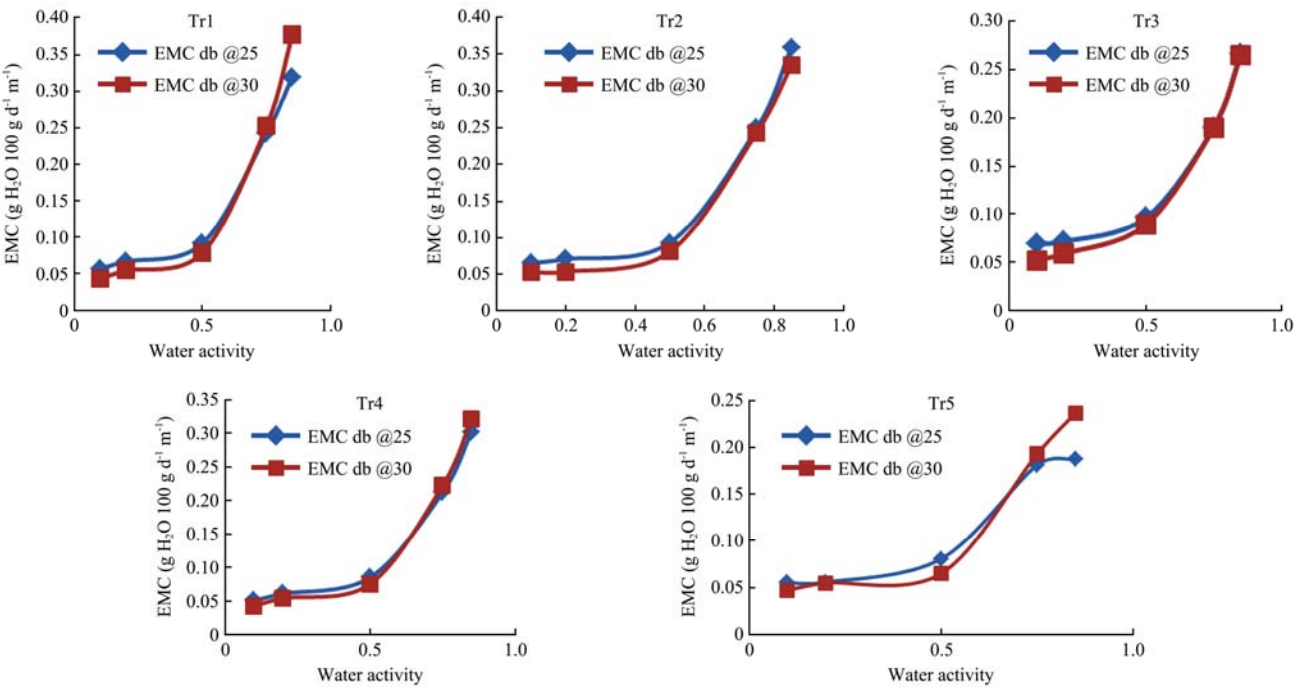

Figure 2 Sorption isotherms for the dehydrated catfish processed with different processing parameters (brine concentration: brining time: drying temperature): 9%: 90 min: 90°C (Tr1); 6%: 60 min: 90°C (Tr2); 0%: 0 min: 90°C (Tr3); 6%: 90 min: 110°C (Tr4); 0%: 0 min: 110°C (Tr5), respectively

Dehydrated catfish products in the present study showed higher equilibrium moisture content at the same temperature as a_w increased and the sorption isotherm curves follow the sigmoid type II shape of Brunauer et al.

(1938) classification similar to the report of previous researchers on moisture adsorption isotherms of food products. The same responses were reported for African arrowroot lily (*Taca involucrate*) tuber-mash products, *akara* Ogbomoso and acetylated and native starches from cultivars of cassava at diffrent ranges of temperature (Igbabul et al. (2013) at 30°C, 50°C, 70°C; Falade et al. (2003) at 20°C, 30°C, 40°C and Osundahunsi et al. (2014) at 18°C, 30°C; respectively). The observed trend in the present work may be attributed to the high protein content of dehydrated catfish. The samples adsorbed minimal amount of water at a region of water activity (a_w) 0.0-0.25 where the moisture is unavailable for reactions (monolayer adsorption). Visible mould growth was observed during the experiment in some of the samples at 85% relative humidity (0.85 a_w) after three weeks at 25°C and after two weeks at 30°C. This concord with the report of Osundahunsi et al. (2014) who reported that some samples of native cassava starch beyond equilibrium relative humidity of 75% (0.75 a_w) were discarded due to mould growth.

3.1.2 Modelling of sorption isotherms of the dehydrated catfish samples

The sorption isotherm data were fitted into four sorption models namely: Oswin, Smith, Guggenheim-Anderson-de Boer (GAB), and Brunauer-Emmett-Teller (BET) represented earlier in Table 4. The models were chosen based on literature report that the models were among the most common equations used for describing sorption isotherm in food products (Andrade et al., 2011). A non-linear regression was used to fit the experimental curves to the models and all calculations were performed using Microsoft Excel Solver (2013) with 200 iterations before a constant is fixed. The statistical results were detailed in Tables 5 and 6 for the sorption isotherms at 25°C and 30°C, respectively.

Table 5 Modelling of sorption isotherms of dehydrated catfish samples at 25°C

Treatment	Model	Model constants						RMSE	MBE	R^2	Ranking
		C	n	C1	C2	M_o	K				
	Oswin	0.6022	0.8224					0.0037	–0.0004	0.9988	1
Tr1 A:B:C 9:90:90	Smith			0.011941	–0.80956			0.0034	0	0.9989	1
	GAB	0.199874				1.081638	0.95105	0.0241	0.0078	0.9487	4
	BET	0.132282				1.643636		0.0242	0.0125	0.9481	3
	Oswin	0.577221	0.797114					0.0053	–0.00064	0.99796	1
Tr2 A:B:C 6:60:90	Smith			0.015203	–0.78495			0.005	0	0.9982	1
	GAB	0.150585				1.397892	1.019439	0.0269	0.0094	0.9475	3
	BET	0.182456				1.140991		0.027	0.0097	0.9474	4
	Oswin	0.6674	0.8687					0.0011	0.0173	0.9996	1
Tr3 A:B:C 0:0:90	Smith			0.010879	–0.83248			0.0022	0	0.9992	1
	GAB	0.587194				1.518867	0.267626	0.030622	0.0091	0.8456	3
	BET	0.035347				5.691743		0.0245	0.0179	0.824	4
	Oswin	0.612	0.8305					0.0036	–0.0005	0.9987	1
Tr4 A:B:C 6:90:110	Smith			0.010463	–0.82116			0.0034	0	0.9988	1
	GAB	0.199886				1.08163	0.95102	0.0241	0.0044	0.9487	4
	BET	0.164638				1.11866		0.0201	0.0094	0.9587	3
	Oswin	0.6846	0.8822					0.0031	0.0013	0.9974	1
Tr5 A:B:C 0:0:10	Smith			0.006295	–0.8741			0.0031	0.0014	0.9973	2
	GAB	0.427461	0.462803	0.86887		0.462803	0.86887	0.0249	0.0109	0.9452	3
	BET	0.010616				20.1147		0.0215	0.017	0.873	4

Note: Tr = Treatment; A = Brine concentration (%); B = Brining time (min); C = Drying temperature (°C); C, n, C1, C2 and K = Model constants or parameters.

Table 6 Modelling of sorption isotherms of dehydrated catfish samples at 30°C

Treatment	Model	Model Constants						RMSE	MBE	R^2	Ranking
		C	n	C_1	C_2	M_o	K				
Tr1 A:B:C 9:90:90	Oswin	0.57	0.7943					0.0067	–0.0012	0.9974	1
	Smith			0.012813	–0.78369			0.006425	–5.40E-08	0.997636	1
	GAB	0.507223				0.298373	0.948732	0.020255	0.006442	0.976559	3
	BET	0.304549				0.541633		0.020667	0.005478	0.97558	4
Tr2 A:B:C 6:60:90	Oswin	0.595464	0.818764					0.004604	–0.00063	0.998393	1
	Smith			0.011304	–0.80568			0.004223	3.79E-07	0.998648	1
	GAB	0.410424				0.428117	0.918445	0.022878	0.007295	0.960491	3
	BET	0.201825				0.92455		0.023411	0.006166	0.958581	4
Tr3 A: B: C 0:0:90	Oswin	0.6744	0.8758					0.0013	0.0173	0.9995	1
	Smith			0.009022	–0.83986			0.002483	3.57E-08	0.999115	2
	GAB	0.050457				3.774785	1.07424	0.018343	–0.02235	0.952043	3
	BET	0.060865				2.988293		0.017548	0.012347	0.923537	3
Tr4 A:B:C 6:90:110	Oswin	0.6035	0.8257					0.0044	–0.0007	0.9984	1
	Smith			0.009976	–0.81548			0.004156	5.86E-08	0.998571	1
	GAB	0.41007				0.428536	0.918544	0.022878	–0.00632	0.960491	3
	BET	0.233859				0.700866		0.019335	0.009001	0.988974	3
Tr5 A:B:C 0:0:110	Oswin	0.661398	0.871014					0.001595	–0.00013	0.999598	1
	Smith			0.0066	–0.8582			0.001415	1.60E-07	0.99991	1
	GAB	0.41007				0.428536	0.918544	0.022878	0.007293	0.960491	3
	BET	0.114409				1.513704		0.022869	0.010867	0.917908	4

Note: Tr = Treatment; A = Brine concentration (%); B = Brining time (min); C = Drying temperature (°C); C, n, C1, C2 and K = Model constants or parameters.

The statistical parameter estimated showed that the R^2 values in all the samples at 25°C ranged from 0.8240 of BET to 0.9997 of Smith and at 30°C, from 0.9179 of BET to 0.99991 of Smith. Of all the fitted models, Oswin and Smith models had the best ranking value (1) and were at par in almost all the treatments. More than one model has been reported to describe sorption characteristics of foods (Kaymak-Ertekin and Sultanoglu, 2001). Akanbi et al. (2006) reported Oswin and GAB as the best models that described the sorption isotherms of dehydrated tomato slices at 20°C, 30°C and 40°C while Vega-Galvez et al. (2008) reported Smith and Henderson models as best among the eight models tried for modelling the adsorption isotherms of *Chilean papaya* at 5°C. However, Oswin model's best ranking cut across all the treatments at both temperatures and was chosen as the one that presented the best fit for the sorption isotherm curves in this work (Smith model ranked second in Tr5 at 25°C and Tr3 at 30°C; both are treatments without brining). Oswin model values of R^2 ranged (0.9974 to 0.9996) at both 25°C and 30°C; RMSE (0.0011 to 0.0053) at 25°C; and (0.0013 to 0.0067) at 30°C and MBE (–0.0003 to 0.0173) at 25° C and (–0.00013 to 0.0173) at 30°C. The fitting of the experimental curves with predicted of Oswin model for all the samples at 25 and 30°C were shown in Figure 3. It could be observed from Figure 3 that the theoretically predicted isotherms by Oswin model curves for each un-brined sample (Tr3 and Tr5) at 25°C presented almost a perfect fit with the experimental curves. This shows strong agreement between the predicted and the experimental data; thus, the reliability of the experimental data.

GAB model also fitted adequately. The least ranked and least fitted model was BET (average ranking value is generally 4) in comparison with other models investigated at both 25°C and 30°C. This, probably due to higher water activities (above 0.5) involved in the experiment as it has been indicated in previous research reports that BET model fits only for sorption isotherms data with water activities equal to or below 0.45 (Andrade et al., 2011).

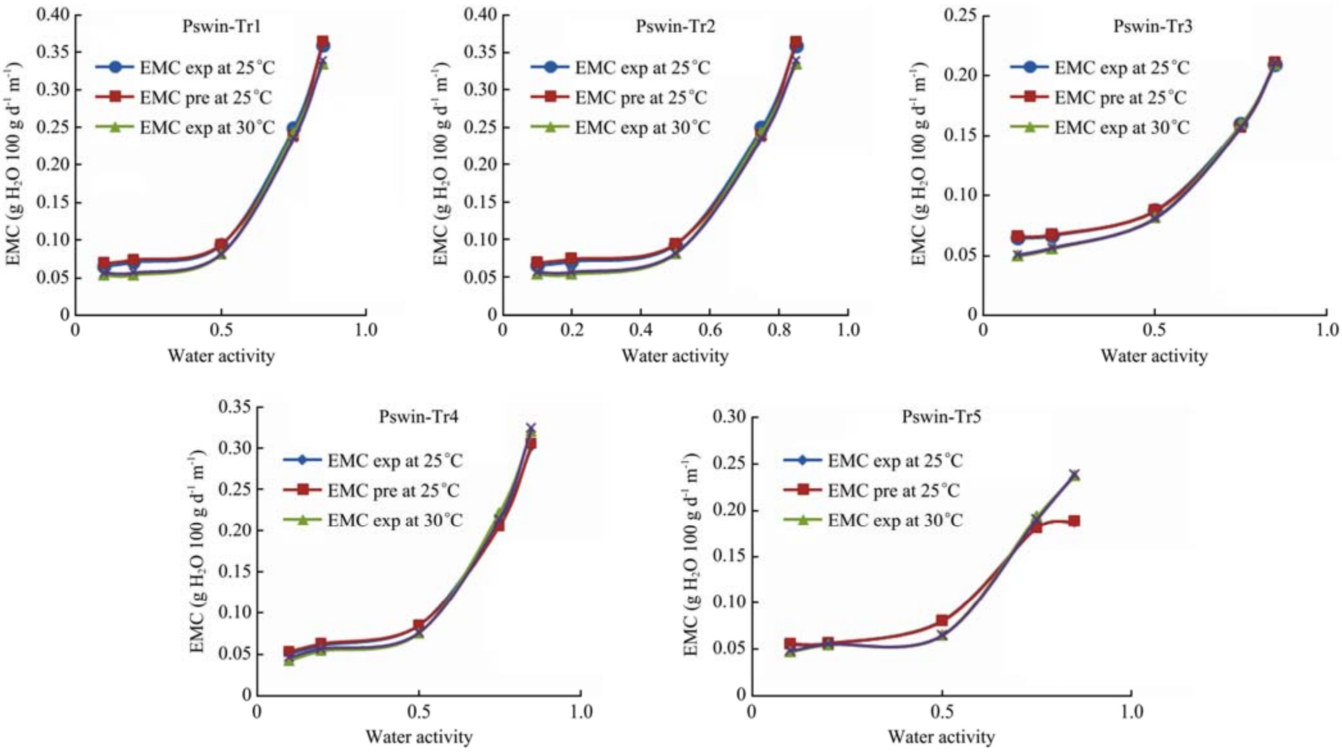

Figure 3 Predicted and experimental sorption isotherms curves at 25°C and 30°C, of dehydrated catfish processed with 9%, 90 min, 90°C (Tr1); 6%, 60 min, 90°C (Tr2); 0%, 0 min, 90°C (Tr3);6%, 90 min, 110°C (Tr4); 0%, 0 min, 110°C (Tr5), respectively (Note: °C is the unit for temperature and is equivalent to °C)

3.1.3 Effects of process parameters on monolayer moisture content (M_o) of dehydrated catfish

Though Oswin presented the best fit for the sorption curves, the predicted monolayer moisture content (M_o) of GAB and BET model (Table 5 and 6) were of particular importance because M_o indicates the amount of water that is strongly adsorbed in specific sites and is considered to be the value at which a food is most stable, that is, the optimal moisture content that minimizes spoilage reactions especially during storage (Falade et al., 2003; Andrade et al., 2011; Choudhurya et al., 2011). The M_o (g water 100 g^{-1} dry mater) of GAB ranged from 0.4628 to 1.5189 at 25°C and 0.2984 to 3.7748at 30°C while that of BET ranged from 1.1149 to 20.1147 at 25°C and 0.5416 to 2.9883 at 30°C. Generally, M_o values of GAB and BET were lower at 30°C than at 25°C in all the samples which implies, M_o decreased with increasing temperature (exception Tr3 of GAB). This confirmed the theory of physical adsorption that food loses hygroscopicity at higher temperature (Falade et al., 2003). The same trend was reported by Osundahunsi and Aworh (2000), Falade et al. (2003), Sobukola et al (2011), Seid and Hensel (2012). The GAB M_o values were generally lower than that of BET in all cases except in Tr2. The lower the M_o values, the better the product stability (Swami et al., 2005, Osundahunsi et al., 2014). GAB was reported to be more applicable at higher water activity levels than BET (Akanbi et al., 2006). Differences in calculated M_o values of GAB and BET models have been reported by previous researchers (Labuza et al., 1985; Igbabul et al., 2013). However, the differences in M_o in the present work took a reverse order in comparison with that reported by Igbabul et al. (2013). This could be as a result of the differences in the materials used. Tr1 (9%, 90 min, 90°C) gave dried catfish of lowest predicted M_o value (0.298373 g water 100 g^{-1} dry mater) by GAB at 30°C isotherm temperature. This implies that Tr1 parameters produced positive influence on M_o value of GAB at 30°C in the present work. Therefore, the greater influence of the combination of process parameters of Tr1 would enhance the shelf-life and storage stability of the dehydrated catfish (*C. gariepinus*).

Whereas, the un-brined sample dried at 110°C provided relatively low M_o value (0.428536) of GAB as the other brined samples that may also be adequate for good shelf-life (probably due to drying at higher temperature); the highest M_o value (3.77479) was obtained in the un-brined sample dried at 90°C which may not be able to provide as much stability to the dehydrated catfish especially during storage. This suggests that the drying of body-mass catfish of average weight of 254 g that would not be brined prior drying should be done above 90°C for dehydrated catfish of good shelf-life.

3.1.4 Effect of processing parameters on model constants

Model constants (Tables 5 and 6) were the model coefficients, and for most selected models, the constants were reported to be only numbers without theoretical backgrounds except in the case of GAB model (Seid and Hensel, 2012). In GAB equation, constant C is the Guggenheim constant related to the energy of sorption of the adsorbed monolayer water molecules while constant 'K' is a factor corresponding to properties of the multilayer molecules with respect to the bulk liquid (Seid and Hensel, 2012). In the present work, the constant 'C' did not show a particular trend within treatments of lower drying temperature (90°C) and does not fall within the range ($5.67 \leq C \leq \infty$) predicted by other researchers. However, equal values for 'C' were obtained in treatments of higher drying temperature (110°C). The cause for this observation was not presently known. The values of 'K' generally ranged from 0.26763 to 0.95105 and were within the recommended range of values ($0.24 < K < 1$) as predicted by other researchers for the GAB equation in all the treatments and at the two temperatures (25°C and 30°C) used (except in Tr2 at 25°C and Tr3 at 30°C). This guarantees a relatively good description of the sigmoidal isotherms (Seid and Hensel, 2012). The observations were in agreement with the reports of other researchers (Simal et al., 2007; Vega-Galvez et al., 2008; Dosumu and Okoro, 2012; Seid and Hensel, 2012).

3.2 Microbial quality of freshly processed dehydrated catfish used in the moisture sorption isotherm study

The microbial qualities of freshly processed dehydrated catfish (*C. gariepinus*) of the selected treatments are presented in Table 7. The total viable counts (TVC) ranged from 2.0×10^3 to 1.6×10^4 cfu g^{-1}. The highest count (1.6×10^4 cfu g^{-1} TVC) was found in Tr3 sample; this could be as a result of lack of brining and the low drying temperature (90°C) involved in Tr3. However, the recorded values were within the recommended safe value of TVC for quality dried fish which is 5.0×10^5 cfu g^{-1} (ICMSF, 2002). The considered pathogenic bacteria (*Coliforms Salmonella, and Escherichial coli*) were not detected in samples of all the treatments indicating the safety of the product. Olayemi et al. (2011) recorded the same occurrence in freshly processed smoked dried catfish. Salt / brine as well as the thermal processing employed for food products were reported could prevent the growth of both spoilage and pathogenic bacteria (da Silva et al., 2008). Fungi counts (1.0×10^3 and 2.0×10^3 cfu g^{-1}) were recorded in the samples processed with Tr4 and Tr5, respectively; the values still falls within the limit of the acceptable number of mould growth on dried fish (1.0×10^6 cfu g^{-1}) according to CFS (2007). The drying of samples of Tr4 and Tr5 were done at the same time and temperature; therefore, brining effect might have been the contributing factor to the lower fungi counts recorded in Tr4 than in Tr5 implies that ordinary drying of body-mass catfish without prior brining may not provide enough stability for dehydrated catfish; although, Tr5 showed a better performance than Tr3. This is in accordance with the report of Leroi et al. (2000). The combined effect of combinations of three processing parameters used as treatments (Tr1, Tr2, and Tr4) in the present work could be viewed as been effective for the microbial safety of the dehydrated catfish.

Table 7 Microbial quality of the freshly processed dehydrated catfish used for the moisture sorption isotherm study (cfu g^{-1})

Treatment	Process parameters			Total viable count	*Coliform*	*Salmonella*	*E. coli*	Fungi (mould/yeast)
	A	B	C					
Tr1	9	90	90	2.0×10^3	ND	ND	ND	ND
Tr2	6	60	90	ND	ND	ND	ND	ND
Tr3	0	0	90	1.6×10^4	ND	ND	ND	ND
Tr4	6	90	110	ND	ND	ND	ND	1.0×10^3
Tr5	0	0	110	3.0×10^3	ND	ND	ND	2.0×10^3

Note: Key: Tr = Treatment; A = Brine concentration (%); B = Brining time (min); C = Drying temperature (°C); ND = Not detected.

4 Conclusion

The experimental sorption isotherms of all the treatments determined at 25°C and 30°C exhibited the type II sigmoid curve with decreased EMC as temperature increased from 25°C to 30°C. Of the five tried models, Oswin model presented the best fit in describing the adsorption isotherms of the dehydrated catfish. The corresponding combination of processing parameters of Tr1 (9%, 90 min, 90°C) that gave the lowest monolayer moisture content (M_o) of GAB model at 30°C (0.29837g water 100 g^{-1} dry matter) could be recommended for storage stability of the product. Tr1 could also be considered as optimum conditions for dehydration of body-mass catfish (*C. gariepinus*). The result also showed that 30°C at relative humidity below 75% could be optimum storage conditions for dehydrated catfish. These conditions are similar to the prevailing environmental conditions of the tropical climate thus; processing, packaging, transportation and storage at ambient conditions in this region may not pose any challenge to the stability of the dehydrated catfish. The treatments employed in this work enhanced the shelf-stability and microbial safety of the dehydrated catfish especially the brining prior drying. However, ordinary drying of body-mass catfish (254 g) without brining may not provide as much stability that may be required during storage of the dehydrated catfish. The findings in this research could serve as a basis for designing appropriate equipment for the simple dehydration technique described in this experiment.

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