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Original Research Article

Modelling the Effects of Temperature on Moisture Adsorption and Desorption Isotherms for Baobab (Adansonia digitata) Pulp Powder

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Abstract

Moisture sorption isotherms describe the relationship between moisture content and water activity in food. In this study, adsorption and desorption isotherms for baobab fruit pulp powder was investigated. Static gravimetric method for adsorption and desorption over the range of temperature (27-42 ^{o}C) and water activity (a_w) (0.10-0.80) was used. The experimental data were compared with four recommended models in the literature for food sorption isotherms (GAB, modified Oswin (MOE), modified Henderson (MHDE), and modified Chung-Pfost (MCE). Equilibrium moisture contents decreased with increase in temperature at all the water activity levels studied. The differences between the adsorption and desorption curves were significant at $p<0.05$ and the hysteresis loops were affected by temperature. GAB model was found to be suitable for predicting the moisture sorption isotherms for baobab fruit pulp powder. Results obtained from this study showed the relationship between temperature and water activity as it affects the shelf life of baobab fruit pulp powder.

Keywords: Baobab fruit pulp powder, water activity, temperature, mathematical model, adsorption, desorption, isotherm.

INTRODUCTION

The baobab is a deciduous tree and belongs to the plant family called *Bombacacee* which is originally from central Africa and is distributed throughout the savanna region of Africa [1]. The search for lesser known and underutilized crops and legumes, many of which are potentially valuable as human and animal foods has been intensified to maintain a balance between population growth and agricultural productivity, partially in the tropical and subtropical areas of the world [2]. Baobab (*Adansonia digitata*) is an example of a less known and underutilized crop in Nigeria. The pulp can be dissolved in water or milk and the liquid is used as a drink as a sauce for food, as fermenting agents in local brewing or as a substitute for cream of tartar in baking [3]. Sidibe *et al.*, [1] reported that the fruit pulp can be stored for months under dry condition in polyethylene bags which protect it against ambient moisture. Due to the importance of the fruit pulp powder in products development, it is necessary to investigate the stability of the pulp in storage and this could be achieved by the knowledge of moisture sorption isotherm.

The knowledge of the sorption characteristics is essential in regards to stability in storage and acceptability of food products, drying process modelling, design and optimization of drying equipment, aeration, calculation of moisture changes which occur during storage, and for selecting appropriate packaging materials [4-8].

Chowdhury *et al.*, [6] and Aviara *et al.* [9] reported that saturated solutions are commonly used to create the necessary micro-climate for sorption experiments. These according to their reports have necessitated the production of template-like data to prepare the standard solutions referred to by several researchers. Aviara *et al.*, [9] reported the use of gravimetric technique as the preferred method for determining the moisture sorption isotherms of food products. This method was reported to have several advantages such as the ability to determine the exact dry weight of the sample, temperature fluctuation minimization between samples and the source of water vapor, registering the weight change of the sample in equilibrium with the respective water vapor pressures, and achieving hydroscopic and thermal equilibrium between samples and water vapor sources, over the manometric and hydrometric techniques.

Acid solutions can also control the relative humidity of air at different temperature levels [10]. Their report revealed that the usage of acid solutions for conditioning the micro-climate has advantages based on their availability and lack of CO_2 absorption compared with KOH or some other salt solutions. The choice of acids as desiccants can therefore reduce the risk of uncertainty in determinations of water activity during sorption studies.

Therefore, the specific objective of the study is to determine the sorption characteristic of the baobab fruit pulp powder over a range of temperatures and relative humidities experienced in temperate environment.

MATERIALS AND METHODS

Material Preparation

The baobab fruit pulp (*adansonia digitata L.*) powder used in this study was collected from parent trees around Ladoke Akintola University of Technology, Ogbomoso. The capsules were broken to extract the white pulp and sieved into powdery form. The research was conducted at Food Science and Engineering Laboratory, Ladoke Akintola University of Technology, Ogbomoso.

Micro-Climate

H_2SO_4 was prepared using the baseline properties provided by Perry and Green as the micro-climate condition for the experiment [11].

Determination of Adsorption Isotherm

Static gravimetric method was used. Three replicates of each weighed sample of the powder (0.5 g) were weighed into moisture pans in the desiccator at each humidity point and temperature level [12]. The desiccators were maintained at relative humidity (rh) values between 10 and 80% using H_2SO_4 solution. The desiccators were placed in a Genlab (England) incubator (Model M75CPD) to maintain the required temperature level (27, 37 and 42 ^oC) and sample monitored for equilibration by weighing at interval until constant weight were attained. Moisture content of the equilibrated samples was then found by calculation from the original moisture content and the known change in weight in dry basis form [10, 13].

Determination of Desorption Isotherm

Samples used in the adsorption experiments were used to conduct desorption isotherms by transferring the samples in the range 0.20-0.80a_w, step-wisely to the immediate lower humidity level at the same temperature. The desiccators were placed in the incubator for desorption until the equilibrium conditions were reached [10, 12, 14].

Isotherm Equations and Modelling

Four widely recommended isotherm mathematical expressions (GAB, Modified Oswin, Modified Henderson, and Modified Chung-Pfost), as presented in Table-1 were investigated with the experimental data.

Table-1: Sorption Models used to fit the experimental values

Models	$M = f(a_w, T)$
GAB	$M = \frac{abca_w}{(1-ca_w)(1-ca_w+bca_w)}$
MOE	$M = (a+bT)(a_w/1-a_w)^c$
MHDE	$M = \left[\frac{In(1-a_w)}{(-a(T+b))}\right]$
MCE	$M = -\frac{1}{c} In\left[\frac{(T+b)In(a_w)}{-a}\right]$

GAB = Guggenheim, Anderson and de Boer equation, MOE = modified Oswin equation, MHDE = modified Henderson equation, MCE = modified Chung-Pfost equation, M = equilibrium moisture content (%, dry basis); a, b, c = constant parameters; T = temperature, ^oC

Statistical Analysis

All analysis was carried out in three replicates and was subjected to SAS (9.1) to generate a mathematical model for the data. The SAS procedure for non-linear regression was used to fit the experimental equilibrium moisture content and water activity data in modelling the isotherms. The level of significant was tested at ($p<0.05$). The accuracy of the models was evaluated by using three different indicators, namely percentage mean relative deviation (%E), standard error of estimate (SEE), and coefficient of determination (R^2). These indicators of errors are defined in Equations (1) and (2).

$$SEE = \sqrt{\frac{\Sigma(M_{exp}-M_{pred})^2}{n}} \quad \text{.....................} (1)$$

$$\%E = \frac{100}{n}\sum\left|\frac{M_{exp}-M_{pred}}{M_{exp}}\right| \quad \text{.....................} (2)$$

Where,

M_{exp} is the experimental equilibrim moisture content

M_{pred} is the predicted moisture content and n is the number of observations

RESULTS AND DISCUSSION

Adsorption Moisture Isotherms

The equilibrium moisture content at different water activity used in plotting the adsorption isotherms curves is shown in Figure-1. It was observed that the isotherms conformed to the characteristics type II (sigmoid shape) of Brunauer *et al.*, [15], an indication that the adsorption in baobab pulp powder was a multilayer absorption typical of samples with microcapillary structure [16]. The EMC decreased as storage temperature increased for any given water activity. This could be attributed to the fact that at higher temperatures, the activation energy of the water molecules changes to higher energy levels which invariably makes the bonds become less stable, thereby breaking away from water-binding sites of the flour [17]. The trend followed the reports of Sanni *et al.*, [18] and Oyelade *et al.*, [19] on fufu and cassava starches respectively.

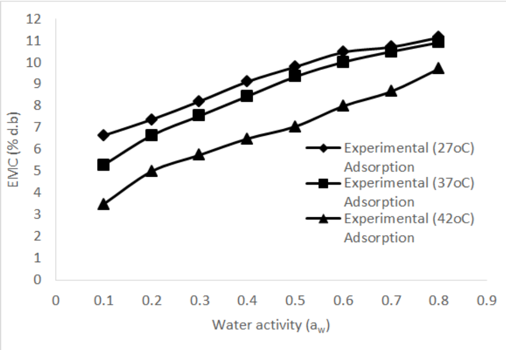

Fig-1: Adsorption isotherm curves for baobab pulp powder at 27°C, 37°C and 42°C

Moisture Sorption Hysteresis Loop

The hysteresis loops displayed a tendency of executing a closed loop between the upper and lower bounds of relative humidity observed as shown in Figure-2. The distribution of hysteresis loop relative to water activity showed a slight change at various temperature. Deshmukh *et al.*, [20] observed a similar trend on moisture sorption hysteresis in kalakand at different temperatures. Table-2 indicates that differences between the adsorption and desorption curves were significant at ($p<0.05$).

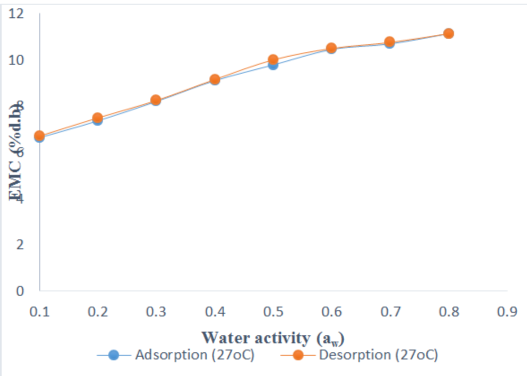

Fig-2: Hysteresis plot for baobab flour at 27°C

Table-2: Comparison of adsorption and desorption data for baobab pulp powder

Temperature (°C)	Mean difference	Standard deviation	P-value
27	-0.0725	0.0960	0.035
37	-0.2413	0.1779	0.003
42	-0.2525	0.2371	0.010

*Significant level is ($p<0.05$)

Isotherm Models Prediction

Four widely recommended models as presented in Table-1 were considered for baobab pulp powder. Tables 3 and 4 shows the parameters that were estimated for each of the models and the indices for estimating the errors associated with the models, which represents the coefficient of fit (R^2), % mean relative deviation (E) and SEE for the temperatures observed for the adsorption and desorption isotherms, respectively. The four tested models were suitable for predicting the adsorption isotherms for baobab powder, with R^2 values ranging from 0.9669 to 0.9966. These values falls within the range reported by Oyelade *et al.*, [19]. The R^2 for GAB and MHDE, models at 37 °C displayed no distinction in the value as presented in Table-3. Oyelade *et al.*, [10] reported the value of the residual plot as an index of assessing the closeness of fit because R^2 could be viewed as a measure of systematic departure from linearity. It was also reported that using the mode of closeness of fit indicator and the closeness of fit parameters were generally lower for the prediction of adsorption in comparison with the desorption isotherms [10].

GAB appeared to be the most suitable model for predicting the isotherms with the least % mean relative deviation, SEE and a high R^2 value and also met the convergence criterion using the proc NLIN SAS. Figures 3-6 shows the comparison of the experimental value and the GAB predictive for adsorption and desorption, respectively.

Table-3: Comparison of Different Models of Baobab Adsorption at Various Temperatures

Model	A	B	C	% E	SEE	R^2
			27 °C			
MHDE	2.974E-07	0.5730	5.0138	1.58	0.1735	0.9884
GAB	8.3561	80.955	0.3552	2.49	0.1921	0.9800
MOE	- 463	17.5000	0.1463	2.64	0.2802	0.9948
MCE	1311.2	- 9.1700	0.4966	3.07	0.3299	0.9936
			37 °C			
MHDE	4.062E-06	- 1.0250	3.8506	2.75	0.2252	0.9669
GAB	8.4400	39.4027	0.3495	1.89	0.1669	0.9669
MOE	-638.7	17.8000	0.1879	4.06	0.3879	0.9940
MCE	727.2	- 9.1700	0.4132	4.48	0.4222	0.9935
			42 °C			
MHDE	0.000062	- 1.0250	2.8547	2.42	0.1673	0.9966
GAB	5.8025	25.0743	0.5325	1.72	0.1405	0.9933
MOE	-728.1	17.5000	0.2525	3.99	0.2562	0.9906
MCE	355.4	- 9.1700	0.3950	3.89	0.2417	0.9935

Table-4: Comparison of Different Models of Baobab Desorption at Various Temperature

Model	A	B	C	% E	SEE	R^2
27 °C						
MHDE	2.087E-07	0.5830	5.1541	1.49	0.2013	0.9880
GAB	8.4841	84.3707	0.3431	1.90	0.2118	0.9777
MOE	- 463	17.5000	0.1423	2.67	0.3008	0.9949
MCE	1488.7	-9.1700	0.5065	3.09	0.3506	0.9935
37 °C						
MHDE	1.946E-06	0.5830	4.1172	2.51	0.2455	0.9916
GAB	8.7163	45.4385	0.3282	2.27	0.1950	0.9624
MOE	-638.4	17.5000	0.1759	4.20	0.4023	0.9944
MCE	926.7	-9.1700	0.4294	4.42	0.4436	0.9935
42 °C						
MHDE	0.000036	0.5830	3.0529	1.63	0.1140	0.9959
GAB	6.3329	26.4316	0.4770	1.62	0.0101	0.9884
MOE	-727.8	17.5000	0.2358	3.71	0.2736	0.9917
MCE	422.8	-9.1700	0.4056	3.45	0.2632	0.9935

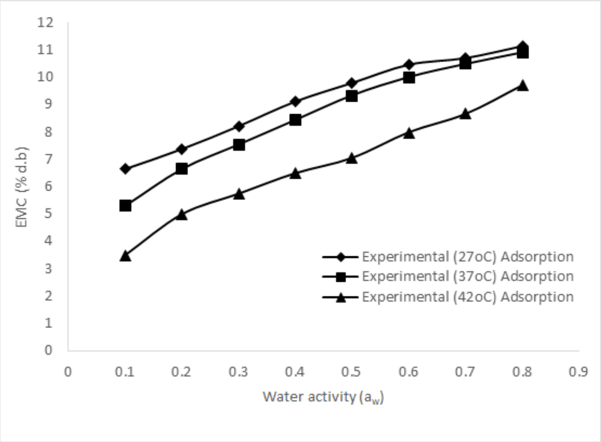

Fig-3: Comparison of experimental and GAB predictive adsorption isotherm

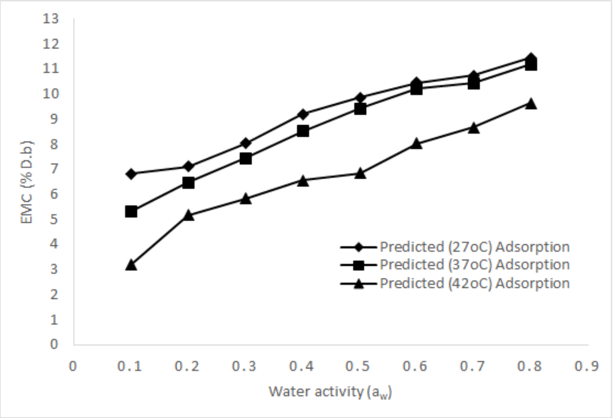

Fig-4: Comparison of experimental and GAB predictive adsorption isotherm

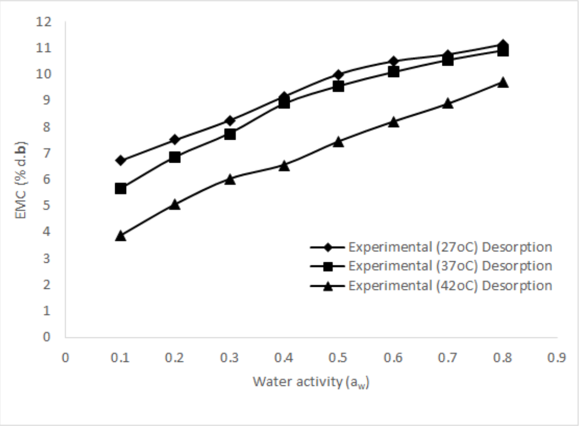

Fig-5: Comparison of experimental and GAB predictive desorption isotherm

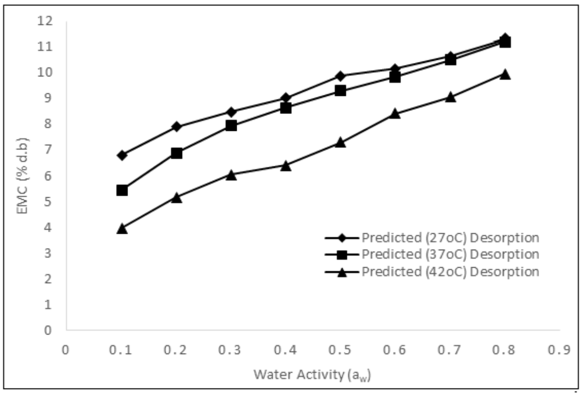

Fig-6: Comparison of experimental and GAB predictive desorption isotherm

CONCLUSION

This study has shown that temperature dictate to a very large extent the orientation of the moisture sorption isotherm of baobab fruit pulp powder. The sorption capacity of baobab fruit pulp powder decreased with an increase in temperature at constant relative humility. Analysis of sorption data in line with the prediction of models for the sorption isotherms showed clearly that GAB model fits the moisture isotherm at all the temperatures.

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