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Predictive equilibrium moisture content equations for yam (*Dioscorea rotundata*, Poir) flour and hysteresis phenomena under practical storage conditions

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Abstract

Fitting equilibrium moisture content data of food products into empirical equations is a first vital step in identifying acceptable mathematical expressions that could be subsequently applied in several food processing related operations. Adsorption and desorption (sorption) moisture isotherms were constructed for yam flour at the temperature of 27, 32, 37 and 40 °C, in the water activity (a_w) range of 0.10–0.80. Effects of temperature were significant on the isotherms which appeared sigmoidal. Five widely recommended three parameters sorption models were fitted to the generated data from the gravimetric method. Desorption isotherms appears well fitted than adsorption isotherms. Over all, the modified Oswin (MOE) model describes the sorption characteristics of yam flour better than other models. Constructed moisture sorption plots showed a tendency of executing a closed loop (hysteresis loop) of which size appears to decrease as temperature increases.

Keywords: Yam flour; Equilibrium moisture content; Sorption isotherms; Predictive equations; Hysteresis

1. Introduction

Yam (*Dioscorea* spp.) is a tuber crop of over 600 species and is highly perishable when fresh, primarily because of its high moisture content (50–80% wet basis) (Degras, 1993; Falade et al., 2006). However, when dried and milled (flour), yam becomes a durable commodity that can be stored for several months. The flour can be consumed as food ingredient in various forms such as *amala* and instant pounded yam (Degras, 1993; Akanbi et al., 1996).

Therefore, due to the importance of the flour, it is necessary to investigate the stability of yam flour in storage, and this requires the knowledge of moisture sorption isotherms (Aviara et al., 2006). This study has been undertaken to determine experimentally, the adsorption and desorption isotherms of yam flour within the temperature range of 27–40 °C and water activity range of 0.10–0.80, and fit five widely recommended models that have been reported by Jowitt et al. (1983) into these data.

2. Materials and methods

2.1. Material preparation

Matured white yam (*Dioscorea rotundata*) used in this study was purchased at a local market in Ogbomoso, Nigeria. It was processed into flour in accordance with the traditional procedure in Nigeria (Fig. 1). Peeled yam was

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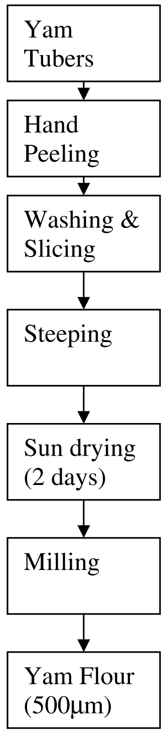

Fig. 1. Traditional yam flour production.

prepared into about 15 mm thickness each and subsequently steeped overnight in warm water for about 15 h. The initial temperature of the warm water was 60 °C because the starting water temperature from five (5) randomly selected local processors of yam flour in Ogbomoso was 59.60 ± 3.2 °C. A Cyclotec 1093 Sample Mill (Tecator AB, Hoganas Sweden) was used to mill the yam slices into flour after sun-drying.

Initial moisture content of the flour was determined as 12.49 ± 0.01% (wet basis) using the AACC (2000) procedures by placing 1 g of sample in an oven set at 130 °C for 1 h. Thin layer drying of the flour (50 g) was carried out in the oven that was set at 105 °C before being used for the sorption experiment. Weight loss was monitored until the weight of the yam flour was 47.92 g after 8 h, and the moisture content determined to be 4.16%, wet basis.

2.2. Determination of adsorption isotherms

The various micro-climates for the sorption study at 27, 32, 37 and 40 °C, respectively, were simulated through the application of the baseline properties of H_2SO_4 which was provided by Perry and Green (1984) based on previous experience (Oyelade et al., 2001). The sulphuric acid solution (BDH Laboratory Supplies, Poole, England) was of analytical grade. At each water activity, three samples of the yam flour (between 1.00 and 1.03 g) for placement over H_2SO_4 solution in dessicator were measured.

Static gravimetric method was used as previously described (Bell and Labuza, 2000; Oyelade et al., 2001). The desiccators were placed in Genlab Incubator M75CPD (Genlab Ltd., Cheshire, England) which maintained the micro-climate temperature within ±0.1 °C value of each chosen temperature level. Samples in desiccators were placed in the incubator and monitored for equilibration by weighing at 24 h intervals for duration of ten (10) days before all samples equilibrated. Equilibration was attained when at least three consecutive readings gave same values. Weights were determined with an electronic balance HF-300 G (A&D Instruments Ltd., Oxon, United Kingdom) having a resolution of 0.001g. Moisture contents of the equilibrated samples were calculated from the original moisture content and the known change in weight (Bell and Labuza, 2000; Oyelade et al., 2001).

2.3. Determination of desorption isotherms

The equilibrated yam flour samples in the adsorption experiments increased in moisture contents at each micro-climate as the level of a_w increased at all the temperatures. A step-wise transfer of these samples at each higher a_w to the immediate lower a_w point was made. This involved the cyclic transfer of equilibrated samples after the adsorption process, within the range of a_w points of 0.80–0.15, to the range of a_w points of 0.75 through 0.10. The desiccators containing the samples were placed in the incubator for duration of 7 days before equilibrium conditions were reached for all the samples when three (3) consecutive measurements which were determined at 24 h intervals gave same readings (Ajibola, 1986). Through this, new equilibrated samples were dried off to new moisture levels. This seeks to investigate the desorption phenomena that occur in the yam flour under practical tropical storage condition.

2.4. Isotherm equations and modelling

The five isotherm equations (GAB, modified GAB (MGAB), modified Oswin (MOE), modified Henderson (MHDE) and modified Chung-Pfost (MCE)) that were fitted with the experimented emc – a_w data are shown in Table 1. SAS procedure for non-linear regression (Proc

Table 1
Sorption isotherm models for yam flour moisture sorption isotherms

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

GAB = Guggenheim, Anderson and de Boer equation, MGAB = modified 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 = unknown values to be estimated.
T = temperature, °C.