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Moisture-Sorption Study of Locally-Parboiled Rice

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Abstract

Moisture sorption characteristics of IR-8 rice variety were investigated at 34^{o}C using the static gravimetric procedure and at 0.10 – 0.98 water activity. Both the adsorption and desorption modes for the grains followed the BET (Brunauer-Emmet-Teller) Type II model. Five moisture sorption models, namely Bradley, Smith, Henderson, BET and GAB (Guggerhein-Anderson-de Boer) were tested for their predictive capability on these grains data. The coefficients of determination varied from 0.8876 – 0.9986 with percent standard errors of estimates between 0 – 52. Both the Henderson and Bradley models gave the closest moisture contents to the experimental data under the adsorptive and desorptive modes. The appropriate constants in the sorption equations were calculated at 34^{o}C. The monolayer moisture contents were calculated using both the GAB and BET models and these are quite useful in assessing the storage stability of the rice grains.

Keywords: *Moisture, sorption, rice, water activity, models, storage stability, monolayer.*

Introduction

In Nigeria, there exists a large volume of agricultural produce at the farm gate and yet a delicate balance exists between food supply and the population depending on it for survival. This unwarranted situation is experienced because a substantial part of the farm produce which includes grains gets spoilt after harvest. This is partly as a result of inadequate storage, packaging and preservation techniques. The post-harvest stability of cereal grains is of paramount importance as grains form a substantial part of energy sources for Nigerians. It therefore becomes pertinent for food engineers to be able to develop effective storage, packaging, preservation and processing strategies to increase the food supply. Rice constitutes a group of important staple foods eaten in different forms in Nigeria.

The post-harvest stability of the grains depends on their moisture contents at harvest; conditions prevailing in their immediate environment during transportation, pre-processing and storage; and also on their moisture-sorption behaviours. Water, as the most important storage factor, plays a significant role in storage stability of agricultural produce depending on the chemical composition and physical structure of the produce and on the form in which it exists in the produce (Ajisegiri and Chukwu 2004; Chukwu and Ajisegiri 2005).

The moisture sorption characteristic of an agricultural material describes its equilibrium moisture content at any relative humidity and the ability for moisture exchange between the agricultural material and its environment (Chukwu and Ajisegiri 2006). When grains, including rice, absorb water they undergo changes in their constitution, dimension, phase transformation, and storage and processing requirements. These changes become relevant in storage studies since environmental factors

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such as relative humidity and temperature are very much different in different locations in Nigeria. These factors are critical for the storage stability or shelf-life of Nigerian agricultural produce including grains since they are transported from production point to other parts of the country where the ambient conditions are different. The knowledge of moisture-sorption phenomena of these grains is a basic requirement for the design of the dehydration and the processing equipment and shelf-life prediction.

A lot of research work has been done in the area of moisture-sorption and many models have been developed to describe the moisture behaviour of grains (Ajisegiri and Sopade 1990). However, no single model is applicable to all foods and not all cover the range of water activity to which they are subjected during processing and storage. This work investigates the sorption behaviours of locally-parboiled rice with the aim of assessing the predictive accuracies of five sorption models.

Materials and Methods

Materials

IR-8 variety of rice (*Oryza sativa*) used for this study was bought from Maiduguri Central Market, Borno State, Nigeria. The parboiled rice grains were brought for milling by rice farmers.

Determination of Equilibrium Moisture Content (EMC)

Duplicate samples of the grains were first treated with 0.25% sodium azide solution to control mould growth. The samples were then conditioned to constant weight over either 96% concentrated sulphuric acid (drying) or 0.5% sodium chloride solution (wetting) in sealed desiccators before the EMC was determined. The static gravimetric method (Spiess and Wolf 1983) of determining the EMC was used. Duplicate samples, 10g each, for the rice grains were placed inside closed desiccators. Each desiccator contained a saturated salt solution selected to provide water activity from 0.10 – 0.98 at 34 ± 0.5°C. This is the prevailing average temperature during harvest and storage period (dry season) in most parts of Nigeria. The experimental set-up was as described in Spiess and Wolf (1983) and Young (1993). The samples were weighed at intervals of 6 hours until equilibrium was reached when four consecutive measurements gave the same readings. The EMC was determined at 95°C to a constant weight without cracking and caking.

Sorption Equations

A number of equations have been published by various workers to describe the water sorption isotherms of foods. Ajisegiri (1987) analyzed their suitability for predicting EMC in agricultural grains. Based on this, five sorption models were selected for estimating the monolayer moisture content of rice grains. These models (Table 1) were chosen because of their suitability for high carbohydrate foods (e.g., cereal grains and their products), application over a wide range of water activities, simplicity, and ease of evaluation. A Programme was written in BASIC language based on the linear regression equations in Mead and Curnow (1983) to fit the models, calculate the parameters and obtain the coefficients of determination and standard error of the estimate. All the models were analyzed using the EMC as the dependent variable. In assessing the models, the computer analysis method used by Ajisegiri and Sopade (1990) was adapted.

Results and Discussion

The water sorption characteristic of rice is depicted in Fig. 1 to emphasize adsorption-desorption phenomena. Figure 1 shows that rice exhibited type II isotherm (Sigmoid or *S*-shaped) according to Ajisegiri (1987) classification. From published data (Ajisegiri and Sopade 1990; Denloye and Ade-John 1985; Gough and King 1980), it appears that for all cereals grains, the BET type II isotherm is the general pattern. Out of the five models, the Bradley model gave the best fit for rice with the adsorption mode while the Henderson model was the best with the desorption mode. The GAB model was better than the BET with the adsorption data and the reverse was the case with the desorption data (Table 2). This is an indication of directional specificity of these sorption models for rice; an observation earlier reported for maize, millet and sorghum (Ajisegiri and Sopade 1990).

Table 1. Sorption Models and Their Linear Forms.

Author	Model	Linear Forms
Bradley (1936)	$\ln a_w = A(B)^M$	$\ln(-\ln a_w) = -\ln A - M \ln B$
BET (1938)	$M = \dfrac{M_O A a_w}{1-a_w} + \dfrac{M_O A}{(A-1)(1-a_w)}$	$\ln M = \ln(M_O A)(1 + a_w(A-1)) - \ln(A-1)(1-a_w)$
Smith (1947)	$M = A - \ln(1-a_w)^B$	$M = A - B\ln(1-a_w)$
Henderson (1952)	$M = -\dfrac{1}{AT}\ln(1-a_w)^{\frac{1}{B}}$	$\ln M = \dfrac{1}{B}\ln(-\ln(1-a_w)) + \dfrac{1}{B}\ln\dfrac{1}{AT}$
GAB (1966)	$M = \dfrac{M_O A B a_w}{(1-Aa_w)(1-Aa_w+ABa_w)}$	$\ln M = \ln M_O A B a_w - \ln((1-Aa_w)(1-Aa_w+ABa_w))$

Note: M = Equilibrium moisture content (decimal, dry basis); M_o = monolayer moisture content (decimal, dry basis); a_w = water activity or relative humidity (decimal); A, B = parameters pertinent to each equation; T = absolute temperature (K); BET is an acronym formed from the surnames of the three authors (Brunauer, Emmet and Teller) that developed the model; GAB is an acronym formed from the surnames of the three authors (Guggenheim, Anderson, and de Boer) that developed the model. The models are therefore referred to as BET or GAB model in literature. The above definitions apply to all tables and figures where they appear.

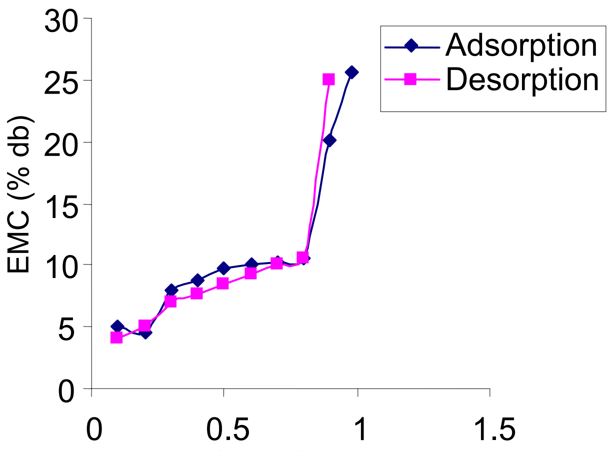

Fig. 1 Moisture-sorption isotherm for Rice at 34°C.

The parameters *A* and *B* were determined by regression analysis. It was observed (Table 2) that the constant *A* of the Bradley model under the adsorption mode was less than *A* under the desorption mode and the reverse was the case for *B*. A similar trend was observed for maize, millet and sorghum (Ajisegiri and Sopade 1990). The monolayer moisture content which was reported (Onayemi and Oluwamukomi 1987; Hui 1996) to define the safest moisture content for storage of agricultural materials was calculated from the GAB and BET models. With the models, the monolayer values were higher for desorption than for adsorption as a result of hysteresis effect (Table 2). It has been reported that the GAB and BET monolayer values are not significantly different (Rizvi 1986; Demertzis *et al*. 1989). Since the GAB model covers the entire water activity range, its monolayer value has been suggested (Ajisegiri and Sopade 1990) to give a better representation of the safe moisture content of agricultural products.

In agreement with some studies (Chukwu and Ajisegiri 2005; Chukwu and Ajisegiri 2006) that some models better describe adsorption than desorption, the observation with the rice is a possible confirmation that the moisture sorption descriptive accuracy of a model is dependent on the sorption characteristics of the agricultural material rather than any inherent property of the model. Possibly, no model is either adsorption-or desorption-specific for every agricultural material. This is however expected since models derived using a typical sorption curve could represent either adsorption or desorption path. Generally, for the variety of rice studied, the equations in Table 3 would be quite suitable to describe its sorption properties at 34°C.

Table 2: Suitability of Selected Sorption Models for Rice at 34°C.

Parameter	Sorption Model				
	Bradley	BET	Smith	Henderson	GAB
Adsorption					
r^2	0.9986	0.9786	0.9776	0.9980	0.9448
s. e. (%)	0	52	1	3	23
A	0.174	14.83	0.0436	0.01452	4.13
B	1.19×10^9	-	0.0574	1.73	3.02
$M_\circ$	-	4.82	-	-	4.02
Desorption					
r^2	0.9590	0.9782	0.9132	0.9878	0.8876
s. e. (%)	2	41	2	7	27
A	0.200	11.14	0.0581	0.01297	3.97
B	5.00×10^8	-	0.0591	1.80	2.72
$M_\circ$	-	5.98	-	-	4.95

r^2 = coefficient of determination; s. e. = standard error of estimate.

Table 3: Predicted Equations for the Rice Grains.

Model	Predicted Equations	
Bradley	$\ln a_w = 1.74x10^{-1}\left(1.19x10^{9}\right)^{M}$	Adsorption
Bradley	$\ln a_w = 3.61x10^{-1}\left(4.46x10^{5}\right)^{M}$	Desorption
Henderson	$M = -\frac{1}{\left(12.97x10^{-2}\right)T}\ln\left(1 - a_w\right)^{\frac{1}{1.8}}$	Desorption

Conclusion

Moisture sorption isotherms of IR–8 rice variety were obtained at 34°C. The Bradley, Smith, Henderson, GAB, and BET equilibrium moisture isotherm equations were used to assess the goodness of fit to experimental data. The Bradley and Henderson models were found to give the best fit. These models could therefore be used to plan and evaluate drying, storage conditions and moisture regime in rice processing and handling. For drying, it is useful for predicting the level to which moisture would be removed during drying and for predicting the desired period for aeration during storage. This information is considered useful for processors and users of rice.

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