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MODELS FOR PREDICTING SORPTION BEHAVIOR OF *GUNA* *(Citrullus lanatus)* SEEDS

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Abstract
The moisture sorption behavior (adsorption and desorption) of guna seeds (shelled and unshelled) was observed under water activity range of 0.147 to 0.981 and temperatures of 10°C, 30°C and 50°C, respectively. The sorption data were subjected to spreadsheet computer plots (Microsoft excel) of equilibrium moisture content versus water activity. Best fit curves were observed to be polynomials of the third order with correlation coefficients (for unshelled seeds) ranging from 0.9854 to 0.9434 for adsorption and 0.9778 to 0.9749 for desorption and percentage root mean square of error (%RMS) ranged from 0.63 to 1.35 and 0.58 to 0.65 for adsorption and desorption, respectively. The curves for the shelled seeds showed correlation coefficients that ranged from 0.9812 to 0.8986 for adsorption and 0.9706 to 0.9065 for desorption, with corresponding %RMS of 0.66 to 2.15 (adsorption) and 0.76 to 1.41 (desorption). In all cases, the correlation coefficient decreased with increasing temperature while %RMS increased with temperature.

Keywords: Moisture sorption, equilibrium moisture content, guna seeds, adsorption and desorption, models

1. Introduction

Guna *(Citrulus lanatus)* is an oilseed observed to have high economic and food potentials, based primarily on its high protein (up to 26%) and oil (up to 56%) contents. It is widely cultivated in the North-Eastern States of Borno and Yobe, and some parts of Jigawa State of Nigeria. These States are characterized by high sunshine and low humidity during most of the year and particularly during the harvesting periods of May/June and October/November. When the seeds are extracted from pods and dried, they normally contain very low moistures (4% to 6% wet basis). This makes them very prone to moisture uptake (Mujumdar and Devahasting, 2001) particularly during transportation to other more humid parts of the country. This normally results to clumping of the seeds, mold growth and heat promoted deteriorative changes (Fortes and Okos, 1980). In order to effectively address this phenomenon (through appropriate packaging or storage structures), the sorption behavior of the seeds under varying environmental conditions need to be studied and the basic parametric data needed for design purposes obtained.

The water sorption characteristics of some oilseeds and plants foods have been reported (Villota *et al.*, 1980; Paredes *et al.*, 1986; Pollio *et al., 1987;* Ezeike, 1988; Kanade and Pai, 1988; Sopade *et al.*, 1994, 1995 and 1996) with results that vary both in terms of the exact dependency relationship of moisture sorption with physical parameters such as temperature and water activity, and between moisture uptake and proximate composition of foods. It may be said that the sorption behavior of plant foods generally, and oilseeds in particular, appears to be affected by the types and initial concentration of proteins and lipids. This imply that for any meaningful development relating to moisture sorption phenomenon of plant foods, and in particular the oilseeds, to be carried out, specific investigations involving the material will produce better results than those based on adopting models developed for other materials.

Various theoretical models have been proposed to describe the sorption phenomenon (Boquet *et al.*, 1980; Van-den-Berg and Bruin, 1981; Bizot, 1983). These are mainly two or three parametric models, which are either empirical or semi-empirical (or theoretical) and which are based on physical chemistry of the surfaces, but none of these equations (Van-den-Berg and Bruin, 1981), is applicable to all foods, while only a few of the models are suitable over the entire water activity range.
This study was aimed at obtaining suitable models that best describe the moisture adsorption and desorption behavior for guna seeds (shelled and unshelled) at temperatures of 10^oC, 30^oC, and 50^oC over a water activity range of 0.147 to 0.981, using spreadsheet computer plots method.

2. Materials and methods

2.1 Materials and equipment

Guna samples for the study were obtained from Nguru (the commercial center of guna), Yobe State, Nigeria, as dried unshelled samples. The sample stock (20kg) was maintained in air-tight plastic buckets and kept under ambient conditions (30 ± 2^oC; 18±5% R.H.), from where experimental samples were taken throughout the study period.
Experimental sorption units were locally fabricated using plastic containers. Other equipment were the Metler Toledo weighing balance, Rotronic hygroskop GT-L water activity meter; Gallenkamp incubator, T-200 thermo-cool refrigerator and assorted quality glasswares obtained from the food analysis laboratory of the Department of Food Science and Technology, University of Maiduguri, Maiduguri, Nigeria.

2.2 Sample preparation

Guna samples for the experiments were manually winnowed to remove contaminants and fluffy immature seeds. Other forms of contaminants were thereafter removed by hand picking. Samples to be dehusked were shelled manually by hand to prevent breakage of the guna seeds. All samples for sorption studies were treated with sodium azide powder (antimould) at a level of 0.25% of sample weight (Gevaundan *et al.*,1989; Sopade and Ajisegiri, 1994), to prevent molds growth at high humidity during conditioning, and during actual experimentation. There are no reports of significant adverse effects on sorption isotherms as a result of antimould treatments (Polio *et al.*, 1987; Gevaundan *et al.*, 1989.)
Proximate analysis of the samples (both unshelled and shelled) for moisture, crude protein, lipids, ash and carbohydrates contents were determined using the AOAC (1984) methods.

2.3 Experimental procedure

Water activity levels in the respective sorption units were attained using varying concentrations of sulfuric acid (Ruegg, 1980; Rizvi, 1986) to cover the selected a_w range of 0.147 to 0.981, at temperatures of 10^oC, 30^oC and 50^oC. Sorption was carried out using the integral gravimetric method (Neuber, 1981). Temperature limits were obtained using a refrigerator (10^oC), an electric oven (50^oC) and the ambient condition (30 ± 2^oC). Samples for adsorption experiments were first conditioned to constant weight over calcium chloride pellets (drying) and those for desorption experiments were treated with 0.5% sodium chloride solution (wetting).

For each sorption unit and temperature, triplicate samples (5g each) were taken. These were weighed at regular daily interval using the sensitive weighing balance (0.001g accuracy) until fairly constant weights were obtained for three successive weighing. The moisture contents at this point (referred to as equilibrium moisture content) for each sample was then calculated using material balance method (Mujumdar and Devahastin, 2001). Results of each triplicate determination were unified by computing the arithmetic mean, and the mean equilibrium moisture contents (M) values were used for plotting sorption isotherms from which the best fit equations and correlation coefficients (r^2) were obtained, using the spreadsheet analysis procedure outlined by Ayaode and Sanni (2002). The percentage root mean square of error (%RMS) between observed equilibrium moisture contents (M_{obs}) and that predicted from the models (M_{est}) was computed as described by Mok and Hettiaracy (1990) and Wang and Brennan (1991).

3. Results and discussion

3.1 Proximate composition

The results for proximate analysis of guna seeds is as shown (Table 1) below:

Table 1. Proximate composition of guna seeds

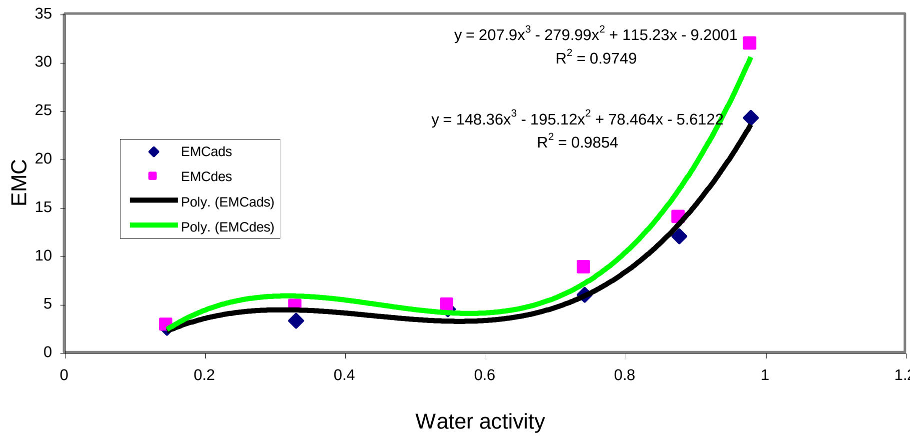
Nutrient (g/100gsolids)	Unshelled seeds	Shelled seeds
Moisture content (%, w.b)	3.51	3.79
Crude protein	5.18	5.23
Crude fats	11.74	11.38
Carbohydrates	3.45	3.73
Crude fiber	1.38	0.50

Generally, the moisture content was observed to be low for unshelled (3.51%) and shelled (3.79%). This value is within the range of 3.5% to 4.5% reported by Gwandzang (1994). The low moisture content is advantageous in preservation of the seeds, but highly susceptible to moisture uptake in humid environments due to high moisture gradient (Fortes and Okos, 1980; Rizvi, 1986).

The protein content was observed to be about.5.23g/100g solids (for shelled seeds).This is slightly lower than the 27% (5.85g/100g solid) reported by Norton (1993) and the 28% (6.07) reported by NEAZDP (1994). On the other hand, the crude fat content of 54% (i.e. 11.50g/100g solid) fall within the range of 49.6% to 60% (i.e about 10g/100g solid to 12g/100g solid) reported by Norton (1993) and NEAZDP (1994). The crude fiber was observed to be higher in the unshelled than in the shelled samples, apparently, because fiber constitute a major component of structural carbohydrates which are mostly found in plant seed coats or husks and barks of plant tissues (Brennan *et al.*,1990; Kyzlink 1990). The mean crude fiber value 2.3% (or 0.50g/100g solid) and 6.4% (or 1.38g/100 solid for unshelled and shelled seeds respectively, agreed with the 5.5% (YADP,1994) for unshelled, and 2.6% (Norton, 1993)for unshelled guna seeds respectively.

3.2 Moisture sorption isotherms

Results of sorption studies are presented in Figures 1 and 2 below as plots of equilibrium moisture contents versus water activity, on which the best fit polynomial curves are shown. The resulting model equations for these curves, their correlation coefficients and percentage root mean square of errors (%RMS) are summarized in Table 2:



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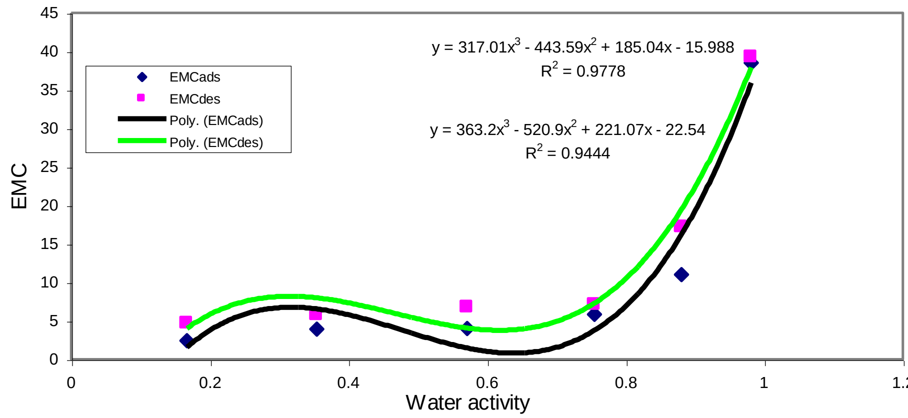

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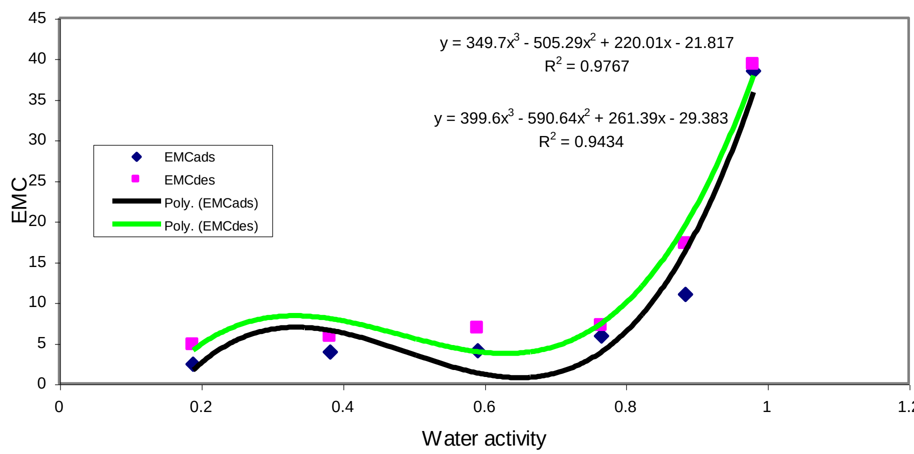

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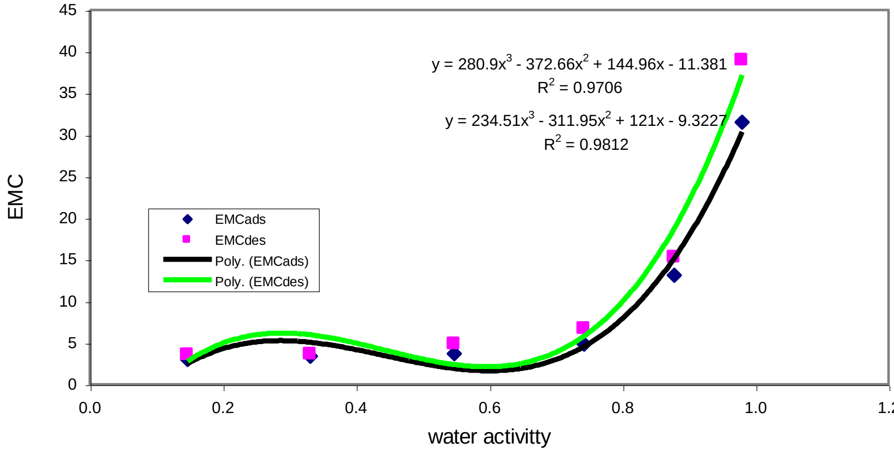
Figure 1: Moisture adsorption and desorption isotherms of raw unshelled guna at (a) 10^{o}C; (b) 30^{o}C and (c) 50^{o}C



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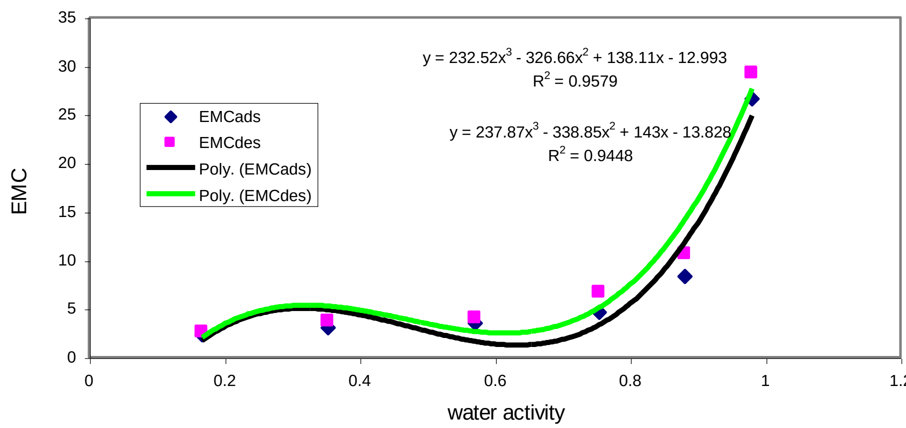

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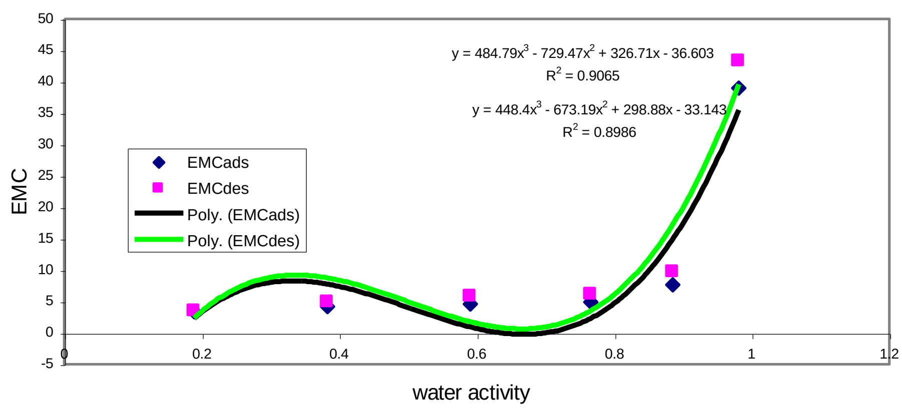

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Figure 2: Moisture adsorption and desorption isotherms of raw shelled guna at (a) 10^{o}C; (b) 30^{o}C and (c) 50^{o}C

Table 2: Model equations for moisture sorption isotherms of guna seeds

Sample	Temp (°C)	Equation	r^2	%RMS
Unshelled (Adsorption)				
	10	$M = 207.9(a_w)^3 – 279.9(a_w)^2 +115.2a_w - 9.2$	0.9749	0.63
	30	$M = 317.0(a_w)^3 – 443.6(a_w)^2 +185.0a_w -16.0$	0.9778	1.21
	50	$M = 349.7(a_w)^3 – 505.3(a_w)^2 + 220.0a_w -21.8$	0.9767	1.35
Unshelled (Desorption)				
	10	$M = 148.4(a_w)^3 – 195.1(a_w)^2 + 78.5a_w -5.6$	0.9854	0.58
	30	$M = 363.2(a_w)^3 – 520.9(a_w)^2 + 221.1a_w -22.5$	0.9444	0.61
	50	$M = 399.6(a_w)^3 – 590.6(a_w)^2 + 261.4a_w -29.4$	0.9434	0.65
Shelled (Adsorption)				
	10	$M = 280.9(a_w)^3 – 372.7(a_w)^2 + 145.0a_w -11.4$	0.9706	0.66
	30	$M = 232.5(a_w)^3 – 326.7(a_w)^2 + 138.11a_w -13.0$	0.9579	1.11
	50	$M = 484.8(a_w)^3 – 729.5(a_w)^2 + 326.7a_w -36.6$	0.9065	2.15
Shelled (Desorption)				
	10	$M = 234.5(a_w)^3 – 312.0(a_w)^2 + 121.0a_w -9.3$	0.9812	0.76
	30	$M = 237.9(a_w)^3 – 338.9(a_w)^2 + 143.0a_w -13.8$	0.9448	0.89
	50	$M = 448.4(a_w)^3 – 673.2(a_w)^2 + 298.9a_w -33.1$	0.8986	1.41

It was observed that the best fitting model equations for guna seeds were polynomials of the third order. The correlation coefficients were observed to be quite high (above 0.9 in most cases) and the %RMS of the error was found to be impressively low (0.61 to 2.15). The high correlation coefficient and corresponding low %RMS is indicative of the suitability of these model equations in describing sorption data for guna seeds. For practical purposes, correlation coefficients of up to and above 0.9, and %RMS of 10 and below are accepted for sorption data analysis (Iglesias and Chirife, 1976). It was also observed that (in all cases), the correlation coefficients decreased with increasing temperature, while the %RMS decreased with increasing temperature for all the model equations. Although the decrease in r^2 and the corresponding increase in %RMS were within acceptable limit, this observation may imply the influence of increased temperature on sorption data. Temperature treatments have been observed (Hill and Rizvi, 1982; Labuza *et al.*,1985; Rizvi,1986) to affect both the monolayer moisture content and the equilibrium moisture contents (both of which are critical parameters for sorption isotherm characterization) of dehydrate foods.

The use of spreadsheet analysis for moisture sorption evaluation has been shown (Ayaode and Sanni, 2002) to provide good fit for various experimental data similar to those obtained with other statistical software. Several moisture sorption equations of cubic polynomials have been proposed (Alam and Shove, 1973; Bakker-Arkema *et al.,* 1978) for the evaluation of moisture sorption in food systems.

4. Conclusions

The moisture sorption isotherms of guna seeds have been shown to be suitably described by polynomial equations of the third order. Although the suitability equations for describing the sorption data of guna seeds was observed to decrease with increasing temperature, this decrease remained within the acceptable limit of goodness. It could therefore be inferred that within the temperature range of 10oC to 50oC, the models adequately described the sorption behavior of guna seeds. It is possible that, based on similarities in proximate composition and physical structures [between guna and

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