Moisture sorption isotherm characteristics of moringa seed at two different temperatures

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Abstract

The moisture sorption isotherm experiments of moringa seed were conducted in a climate test chamber (CTS), the relative humidity of which is regulated by an atomizing humidifier, at temperatures of 25 and 60°C and a relative humidity range of 25 to 95%. The sorption isotherms were sigmoidal in shape (Type II). The experimental sorption data was applied to various isotherm equations (BET, Oswin, Modified Oswin, GAB, MGAB, Fraction Linear (FL), Modified Chung-Pfost and Modified Henderson) and were evaluated for their ability to fit the experimental data using non-linear regression techniques. Comparisons were made on the basis of coefficient of fit (R^2), mean relative error (MRE) value, standard error of moisture (SEM) and residual plots. The comparison showed that the Fraction Linear (FL) equation was the most appropriate equation followed by the Modified Oswin equation for modeling the EMC/ERH (water activity) adsorption isotherms of moringa seed. The adsorption EMC data obtained in this work agree with previous published data and therefore will be helpful for future work on drying and for predicting the quality change during the storage of moringa seed.

Keywords: adsorption, modeling, moringa, water activity, equilibrium moisture content

INTRODUCTION

Different cultures utilized plant species available in their domains for the treatment of several ailments. Parts of plants such as seeds, roots, barks, leaves, pods and flowers are used for this purpose (Rajanandh et al., 2012). The tradition of these uses was transferred through generations by oral means (Popoola and Obembe, 2013). This continued until the 19th century when the ground breaking scientific research instigated the extraction and amendment of the active ingredients from plants. The major aims of the chemists were the reproducibility, dosing and consistent availability of drugs. This gave way to mass production of synthetic drugs and the decline in the use of herbal medicine (Chumark et al., 2008). However, the safety of the continuous use of synthetic drugs coupled with the high cost of the prescription has led to a gradual return of interest in natural medicine. The WHO recently reported that 80% of the total world population trusts herbal remedies (also called alternative medicines) for their primary health care needs (Rajanandh et al., 2012). Among the important sources of herbal medicines whose therapeutic potentials have been severally reported is *Moringa oleifera*.

Moringa oleifera is the most widely known and utilized species in the family of *Moringaceae* and is reported to have originated from Northwest India (Abdulkarim et al., 2005). Different parts of the plant have been reported to possess nutritional, therapeutic and prophylactic potentials for an array of illnesses and diseases (Popoola and Obembe, 2013; Nkukwana et al., 2014). Constituents of *Moringa* confer this special value on it. Nearly all the parts of the plant contain natural antioxidants like phenolic compounds, carotenoids, sesquinterpenoids, α and γ-tocopherol among others (Chumark et al., 2008). Its seed was reported by Abdulkarim et al. (2005) to contain a significant amount of oleic acid, mono unsaturated fatty acids which lowers the risk of coronary heart disease in man. Several

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studies have been carried out to proffer scientific approach to the traditional uses of *M. oleifera* (Rajanandh et al., 2012).

The abundance of *M. oleifera*, biosafety of its active ingredients and ease of extraction have made it to be regarded as a safe and cheap source for the prevention and treatment of several diseases (Rajanandh et al., 2012). The health benefits of *M. oleifera* parts are being assessed by eaten fresh, cooked or as ground dried powder taken singly or in composite with complementary ingredients. Ground dried *M. oleifera* parts are already being promoted and marketed as health and nutritional supplements for humans in South Africa (Nkukwana et al., 2014) and Nigeria. However, we are not aware of any published information on the storage stability of dried *M. oleifera* seed.

Managing storage temperature and storage duration of moringa seed has potential to improve the seed quality and germination percentage (Mubvuma et al., 2013). Moringa seed quality improves with prolonged storage period up until three months, thereafter the quality of seed deteriorates (Mubvuma et al., 2013). The resulting seed quality deterioration after three months may be due to biochemical redox imbalance, membrane disintegration, and decline in enzyme activity (Singh and Dadlani, 2003).

The storage life is a function of the equilibrium moisture content and is affected by the temperature and relative humidity. Considering the global importance of *M. oleifera* seed to humanity, it is essential to establish the moisture sorption isotherm of its seed to accurately predict its storage stability. Information generated will serve as insight on the best storage condition to ensure its bio-viability and consistent availability. Therefore, the aims of this study were to determine the sorption isotherm of *M. oleifera* seed at 25 and 60°C, and establish the best fit mathematical model to predict the adsorption isotherm within the studied temperature range.

MATERIALS AND METHODS

Sample preparation

Moringa seed was produced at Ukulinga Research Farm of the University of KwaZulu-Natal, South Africa. The unhusked seed was harvested and cleaned to remove foreign materials and impurities. The unhusked seed was stored at 4°C during the experiment. The initial moisture content of the seed was determined by drying whole husked 3 g samples in a hot air ventilated oven which was set at 105°C (±1°C) for 24 h (ASAE, 1995) and was found to be 22.5% dry basis (d.b).

Equilibrium moisture content determination

The sorption experiments were conducted using temperature and relative humidity combinations of 25 and 60°C and 25 to 95% at 20% interval, respectively. About 3 g of moringa seed samples were used for the moisture content determination. These conditions were controlled in a Climate Test Chamber (CTS) (Model C-40/100) with a temperature range of -40°C to +180°C and a humidity range of 10 to 98%, with an accuracy of temperature and relative humidity of ±0.1°C and ±0.1%, respectively. Samples were weighed at time interval of 2 d using a digital electronic balance with ±0.1 mg resolution. The drying of the samples was stopped when the samples weight remained constant during three consecutive measurements (Singh et al., 2001; Ghodake et al., 2007). It took 7 to 10 d to reach the equilibrium condition which depended on the air temperature and relative humidity used in the experiment. Finally, the equilibrium moisture content was estimated by drying the moringa seed samples in a convective hot air oven adjusted at the temperature of 105°C (±1°C) for 24 h. Each test was triplicated to determine mean values.

Modelling equations

The experimental sorption data of all samples at two different temperatures was fitted to eight sorption equations shown below:

$$\text{BET: } M = (ACa_w)/[1-a_w)+(C-1)(1-a_w)a_w] \quad (1)$$

$$\text{Oswin: } M = A(a_w/1-a_w)^c \tag{2}$$

$$\text{Modified Oswin: } M = (A+Bt)\ )[a_w/(1-a_w)]^c \tag{3}$$

$$\text{GAB: } M = ABCa_w/(1-Ba_w)(1-Ba_w + BCa_w) \tag{4}$$

$$\text{MGAB: } M = AB(C/t)a_w/(1-Ba_w)(1-Ba_w+B(C/t)a_w) \tag{5}$$

$$\text{Fraction Linear (FL): } M = (\mathrm{A+BT})/(1-Ca_w) + Da_w \tag{6}$$

$$\text{Modified Chung-Pfost: } M = (-1/C)In[(t+B)In(a_w)/-A] \tag{7}$$

$$\text{Modified Henderson: } M = [In(1-a_w)/-A(t+B)]^{1/C} \tag{8}$$

where M is the equilibrium moisture content; a_w is the water activity; t is the temperature (°C); T is the absolute temperature (K); A, B, C and D are the model constants.

The models were chosen because they are most widely used to fit experimental sorption data of various food materials. The parameters of the sorption models were estimated from the experimental results using the nonlinear regression analysis (SPSS 16.0 for Windows) which minimizes the residual sum of squares. The best fitting equations were evaluated with the coefficient of fit (R^2), mean relative error (MRE) value and standard error of moisture (SEM):

$$MRE = \frac{100}{N}\sum\left|\frac{M_{exp}-M_{pred}}{M_{exp}}\right| \tag{9}$$

$$SEM = \sqrt{\frac{\sum(M_{exp}-M_{pred})^2}{df}} \tag{10}$$

$$Residual, e_i = M_{exp} - M_{pred} \tag{11}$$

where M_{exp} and M_{pred} are experimental and predicted moisture content values, respectively, and N is the number of experimental data and df is the degree of freedom (number of data points minus number of coefficients in the model).

The residuals obtained for each model with its respective coefficients were plotted against measured EMC and assessed visually as random or patterned. A model is considered acceptable if the MRE values are below 10% (Kaymak-Ertekin and Gedik, 2004).

RESULTS AND DISCUSSION

Adsorption moisture isotherms

The equilibrium moisture content at different a_w were used in plotting the adsorption isotherms shown in Figure 1. The sorption isotherms followed the characteristic typical sigmoid shaped curve, an indication that the adsorption in moringa seed was multilayer typical of cereal samples with micro-capillary structure (Ertugay and Certel, 2000; Oyelade et al., 2008).

Our findings confirmed the widely accepted fact that an increase in temperature results in a decreased equilibrium moisture content. Similar results were also observed for fruits with high sugar contents (Abdelhaq and Labuza, 1987; Tsami et al., 1990). There was also no intersection point with an increase in temperature for the adsorption of the moringa seed studied.

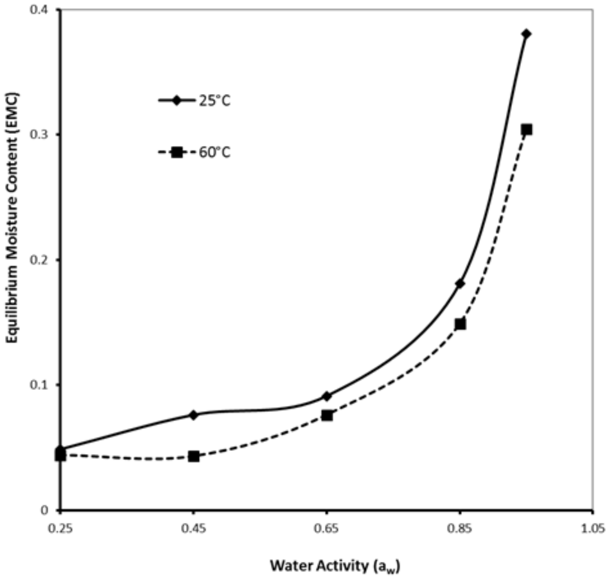

Figure 1. Adsorption isotherm curves of moringa seeds at 25 and 60°C.

Fitting of sorption models to experimental sorption data

The results of nonlinear regression analysis of fitting the sorption equations to the experimental data including estimated sorption model constants, R^2, MRE and SEM values are shown in Table 1. All the tested models gave good fit to the experimental data as evidenced by their high R^2 values ranging from 0.875 (BET) to 0.990 (FL). They are therefore suitable for predicting the adsorption isotherms for moringa seed since they gave high degree of reliability. However, FL was the best model to predict the adsorption isotherm of moringa seeds.

Table 1. Estimated sorption model constants, R^2, MRE and SEM values for moringa seed.

Model	Model constants				R^2	MRE		SEM	
	A	B	C	D		25°C	60°C	25°C	60°C
BET	0.018		9.16E+07		0.875	38.805	27.367	0.033	0.025
Oswin	0.066		0.558		0.953	16.570	20.850	0.019	0.016
Modified Oswin	0.084	0.000	0.556		0.987	14.070	12.326	0.012	0.006
GAB	0.033	0.951	3.26E+07		0.956	14.569	15.045	0.019	0.015
MGAB	0.037	0.940	278.57		0.958	14.860	17.756	0.019	0.015
Fraction Linear (FL)	0.087	0.000	0.964	0.026	0.990	9.687	8.929	0.011	0.004
Modified Chung-Pfost	139.547	44.117	11.341		0.903	26.725	34.930	0.029	0.022
Modified Henderson	-0.249	111.183	-0.252		0.944	24.619	24.678	0.022	0.016

The residual plots (Figure 2) displayed systematic patterns for the FL and MOS models which shows the value of the residual plot as an index of assessing the closeness of fit. This is because the R^2 could be viewed as a measure of systematic departure from linearity and it explores the amount of variability in the response variable explained by the predictors.

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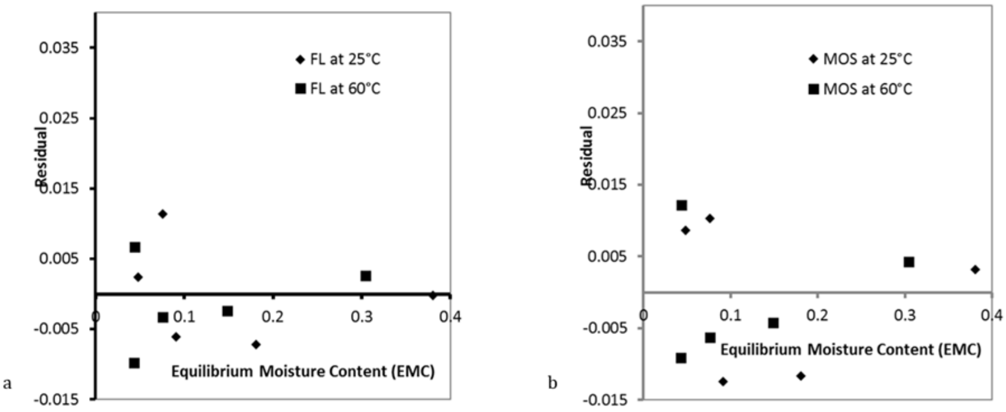

Figure 2. Plot of residuals fit of FL (a) and MOS (b) models to adsoption data of moringa seeds at 25 and 60°C.

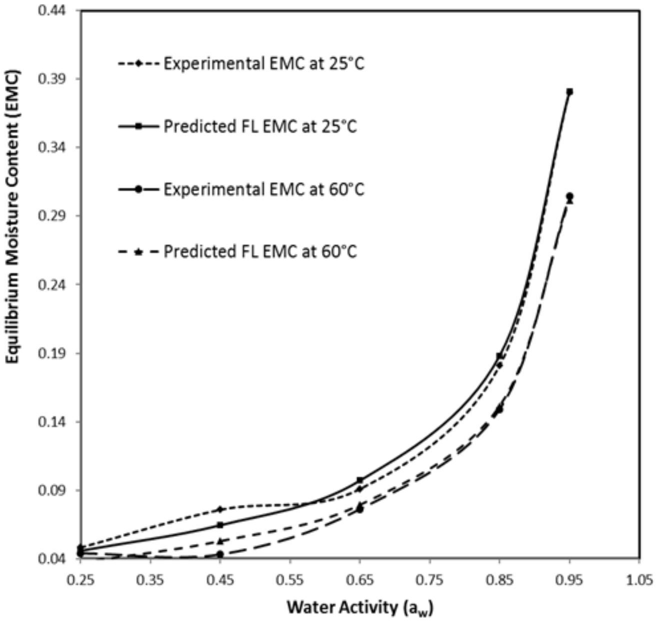

Figure 3. Comparison of experimental and predicted adsorption isotherms for FL model at 25 and 60°C.

CONCLUSIONS

The following conclusions are drawn from the study into the moisture sorption isotherms of moringa seed at 25 and 60°C, respectively:

- The adsorption isotherms are sigmoidal in shape and are influenced by temperature.
- FL model appeared the most suitable out of the eight commonly recommended models that are acceptable for describing and predicting the adsorption isotherms with the least MRE, SEM and highest R^2 followed by MOS model.

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