Desorption characteristics of fluted pumpkin seeds (Telfairia occidentalis)

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Abstract: The moisture desorption isotherms of fluted pumpkin seeds（Telfairia occidentalis） were determined at 20°C, 25°C and 30°C respectively, over a relative humidity range of 41%-95% using the static gravimetric technique. Eight saturated salt solutions were used to provide constant relative humidity. The samples were weighed until constant weights were attained and Equilibrium Moisture Contents (EMC) were calculated. The experimental data were fitted to five moisture sorption isotherm models: Guggenheim-Anderson-de Boer (GAB), Modified Oswin, Modified Henderson, Halsey and Chung-Pfost. The models were linearised and a linear regression program was employed to analyse the data. Best models fitting were determined based on the highest coefficient of determination (R2), lowest Standard Error of Estimate (SEE), and lower values of Root Mean Square Error (RMSE). The experimental sorption isotherm of Telfairia occidentalis followed the characteristic shape of type II isotherms. All the five models gave the best fit with R2 (0.95-0.98), SEE (0.03-0.44), and RMSE (0.005-0.095) with the exception of Chung-Pfost at 20oC with R2 (0.089). At a temperature of 30oC, Oswin, GAB, Henderson, Chung Pfost, and Halsey gave good fits.

Keywords: Telfairia occidentalis, desorption, Equilibrium moisture content, water activity

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1 Introduction

Telfairia occidentalis, commonly called fluted pumpkin, is a vegetable which belongs to the family of Cucurbitaceae. It is a crop of commercial importance grown in West Africa (Nigeria, Ghana and Sierra Leone), being the major producers (Nkang, 2003). The main use of *Telfairia occidentalis* is as a leaf and seed vegetable. The seeds are nutritious and rich in oil which can be used for cooking and manufacturing of soap. Chemically, *T. occidentalis* leaves contain 21.3% crude protein, 6.41% crude fibre, 5.50 ether extract, 10.92% ash and 3121ME (kcal/kg) (Nworgu, 2007).

There are many problems associated with and peculiar to *Telfairia* species that can be regarded as threats to the conservation and utilization of these species. These included localized and narrow natural diversity or genetic base and are exacerbated by the systemic neglect of the species in scientific research. The desiccation-sensitive behaviour of *T. occidentalis* seeds poses threats to the conservation and utilization of these species. Seed storage is imperative to provide good quality planting material from season to season as well as inter seasonal food reserves and active collections conserving genetic resources.

Also, lipid oxidation is a major problem for all food products especially in high fat containing foods since the reaction causes an adverse effect on product stability due to a series of organic chemical processes by peroxidation (Angelo, 1991). The amount and degree of unsaturated fatty acid is the most important factor which affects lipid oxidation (Abou-Charbia et al., 2000; Ansorena and Astiasaran, 2004). Lipid oxidation causes major

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chemical and physical changes including flavor, nutritional, textural and overall appearances. The external factors involved in the lipid oxidation are light, temperature, metal ion and microorganism.

Equilibrium moisture content (EMC) and equilibrium relative humidity (ERH) relationship are essential factors in the design of drying, handling, storing, mixing, and packaging systems for agricultural products and in modelling seed longevity. Sorption properties of foods (equilibrium moisture content and monolayer moisture) are essential for the design and optimization of many processes such as drying, packaging and storage (Al-Muhtaseb et al., 2002).

Several investigators have worked on moisture isotherms of different crops. Ajisegiri and Sopade (1990) studied moisture sorption characteristics of millet at 20℃, 25℃ and 40℃ over a range of water activity 0.10-0.98. A static gravimetric method was employed and five sorption models were used in the analysis. At the same water activity, moisture adsorbed or desorbed reduced with temperature. The Chung-Pfost model gave the best fit to the experimental data with or without coupling the temperature effect. The GAB equation was fitted to the experimental data, using the direct nonlinear regression analysis method and the agreement between experimental and calculated values were satisfactory.

Menkov and Dinkov (1999) worked on the equilibrium moisture contents of four varieties of tobacco seeds using gravimetric static method at 15℃, 25℃ and 40℃ over a range of relative humidities from 0.112 to 0.856. The sorption capacity of all the varieties investigated, decreased with an increase in temperature at constant relative humidity. Each variety had a statistically significant effect on the sorption characteristics. Five models were applied for analyzing the experimental data using the following equations: modified Chung–Pfost; modified Halsey; modified Oswin; modified Henderson and GAB (Guggenheim–Anderson–de Boer). The GAB model was found to be the most suitable for describing the relationship among equilibrium moisture content, relative humidity and temperature.

Menkov (2000) determined the equilibrium moisture contents for vetch seeds using the gravimetric static method at 5℃, 20℃, 40℃ and 60℃ over a range of relative humidities from 0.110 to 0.877. The sorption capacity of the seeds decreased with an increase in temperature at constant relative humidity. Five equations were applied for analysing the experimental data: modified Chung–Pfost, modified Halsey, modified Oswin, modified Henderson, and Guggenheim–Anderson–de Boer (GAB) equations.

They have determined the equilibrium moisture contents over a range of relative humidity. Different models were applied for analyzing the experimental data. Also several researchers have undertaken studies in an attempt to compare different Moisture Sorption Isotherms equations for goodness of fit (Chirife and Iglesias, 1978; Iglesias and Chirife, 1976a; Lomauro et. al., 1985; Sun and Woods, 1993). It turned out that at least seventy seven isotherm equations are available in the literature (Van den Berg and Bruin, 1981). Some of these equations have theoretical or half-theoretical backgrounds, others are simply empirical and the fitting abilities of those equations vary with the group of foods, some are suitable for starchy foods, some for vegetables and others for fruits. Despite the availability of the large number of equations, no single equation is found to have ability to describe accurately the EMC/ERH relationships for different grains over a broad range of relative humidity and temperature (Sun and Woods, 1993). Therefore, for a specific crop and processed product, there is a need to search for the most appropriate EMC/ERH equation (Chen and Morey, 1989; Sun and Woods, 1994a, b; Sun and Byrne, 1998). This study is therefore aimed at developing desorption isotherm for *T. occidentalis* seeds and also to fit them into five existing models.

2 Materials and methods

Pumpkins of *Telfaira occidentalis* were purchased from the farmers in Asa dam in Ilorin metropolis of Kwara State. The *Telfairia occidentalis* pumpkin were cut and the seeds were removed as displayed in Figure 1.

Figure 1 Samples of *Telfairia occidentalis* seeds

The initial moisture content of *Telfairia occidentalis* seeds was determined using the oven method recommended by ASABE standards (ASABE, 2003). The moisture dishes were labelled and weighed. The seeds of *Telfairia occidentalis* were chopped with knife and pounded with porcelain mortar and pestle. They were weighed, and put into three moisture dishes. The drying oven (Ldo-201-E) was set at 103^oC for preheating. The samples of *Telfairia occidentalis* were kept in the oven which was set at 100^o C using the low constant temperature oven method for 17 hours using ISTA standard (1985). The low constant temperature was used in order to prevent vapourization of oil and water. The desorption was done using the static gravimetric technique (European Cooperation Project COST 90) (Spiess and Wolf 1983). This method consists of measuring the weight of a sample before and after its dehydration and assigning the difference in weight to moisture content. Data for the preparation of saturated salts solutions were compiled from different sources such as Kate Gold and Fiona Hay (2008). The data depicts solubility, weights of salts, types of salt and their respective relative humidity and temperatures.

Eight different saturated salt solutions were prepared from lithium chloride (LiCl), potassium acetate ($KC_2H_3O_2$), Magnesium chloride ($MgCl_2$.6H2O), potassium carbonate (K_2CO_3), Magnesium Nitrate (Mg (NO_3) $_2$), sodium nitrate ($NaNO_2$), sodium chloride (NaCl) and Potassium chromate (K_2CrO_4). A wide range of relative humidity ranging from 0.4-0.9. The temperature and relative humidity Data logger (EL-USB-2 LCD) sensors were inserted into the containers. All sensors were calibrated by salt solutions. Each of the seeds weighed in petri dishes with analytical weighing balance model AUX 220 Schimadzu. The triplicate samples were put into the respective desiccators having different relative humidity. All the desiccators were put in an incubator. The gain or loss in weights of all the samples in each desiccator was monitored every three days. The Equilibrium Moisture Content were acknowledged when three consecutive weight measurements show a difference of less than 0.001 g. The temperature of the incubator was changed, samples of *T. occidentalis* were prepared and the same experiment was conducted for sorption process at 20^{o}C, 25^{o}C, 30^{o}C.

The equilibrium moisture content and equilibrium relative humidity data for these agricultural products were analyzed using five equations. These models were proposed by Chen and Morey (1989a) to evaluate their utility for agricultural products. They are as follow:

The modified Chung-Pfost, modified Henderson, modified Halsey, modified Oswin and Guggenheim-Anderson-de Boer (GAB) equations, which incorporate the temperature effect. These have been adopted as standard equations by the American Society of Agricultural Engineers (ASAE) for the description of sorption isotherms (ASAE 2005).

1）Modified Henderson equation:

$$M = \frac{1}{AT} ln(1 - a_w)^{\frac{1}{B}} \qquad (1)$$

2）Modified Chung-Pfost equation (1967):

$$RH = exp\left(\frac{-A}{T+C} exp(-B \times M)\right) \qquad (2)$$

3）Modified Halsey equation (1948):

$$M = \left[\frac{A}{ln(^1/_{a_w})}\right]^{\frac{1}{B}} \qquad (3)$$

4） Modified Oswin equation (1946):

$$M = A - \ln(1 - a_w)^B \qquad (4)$$

5）Guggenheim-Anderson-de Boer (GAB) equations (1985):

$$M = \frac{ckm_o a_w}{(1-Ka_w)(1-Ka_w+C_1\,ka_w)} \qquad (5)$$

Where; C = constant;

$$K = k_1\ X\ exp\left[\frac{(H_1-H_n)}{RT}\right] \qquad (6)$$

M = moisture content;

A_w = water activity;

M_o = monolayer value;

H_m = molar sorption enthalpy of the monolayer;

H_n = molar sorption enthalpy of the multilayer on top of the monolayer;

H_1 = molar sorption enthalpy of the bulk liquid;

R = universal gas constant;

T = temperature;

RH = equilibrium relative humidity, decimal;

M= percent moisture content (dry basis);

A, B, C, C_1 and K_1 are constants.

The model constants were estimated using a linear regression analysis. The best suitable model were evaluated by regression coefficient (R^2), standard error of estimate (SEE), and residual sum of squares (RSS) and residual plots which were used by (Ghodake et al; 2007).

3 Results and discussion

3.1 Influence of temperature on the local isotherm transitions and model evaluation of the *Telfairia occidentalis*

The experimental sorption isotherm of *Telfairia occidentalis* followed the characteristic shape of type II isotherms. The equilibrium moisture content (EMC) of the samples increased with the increase in the water activity at constant temperature as presented in Table

Table 1 Desorption equilibrium moisture contents of *Telfairia occidentalis* seed at different water activities and temperatures

Temperature, ℃	Water Activities, a_w	Equilibrium moisture content gH_2O/g solid (db)
20	0.51	0.105
	0.70	0.1187
	0.80	0.2035
	0.90	0.749
	0.925	0.833
	0.95	0.878
	0.98	0.979
25	0.42	0.078
	0.70	0.221
	0.75	. 0.226
	0.80	0.624
	0.95	0.757
30	0.7	0.121
	0.8	0.143
	0.92	0.312
	0.95	0.497

The experimental sorption isotherm of *Telefairia occidentalis* seeds followed the characteristic shape of type II isotherms. The seed lost moisture in the regions I and II because its water potential is greater than that of the environment. This is similar to the observation of (Probert, 2003), 'If the water potential of the seed is greater than the surrounding air, the seed will lose water and become drier'. The EMC of the samples increased with the increase in the water activity at constant temperature. The moisture sorption isotherms of *T. occidentalis* at 20℃, 25℃ and 30℃ are shown in Figures 4.1. The equilibrium moisture content increased at the same water activity (a*w*) as temperature decreased as indicated in Figure 4.1, since samples absorbed more water at low temperatures than at high temperatures, and water molecules at lower temperatures have a lower kinetic energy which is not enough to overcome the corresponding sorption energy (Lagoudaki et al., 1993). This conformed to the generally accepted trend which was observed by Cesar Kepsu *et al.*, (2006) who reported the same observation for shea nuts. At increased temperatures water molecules get activated to higher energy levels, causing them to become less stable and break away from the water binding sites of the material, thus decreasing the EMC (Almuthaseb et al., 2004). Kapsalis (1987) pointed out that temperature affects the mobility of water molecules and the dynamic equilibrium between water vapour and adsorbed phases. It was also observed that the isotherm at temperature 20^{o}C emerged below the isotherm of 25^{o}C and isotherms intercepted between aw 0.4 and 0.8. The different isotherms intersect between the first two transitions mainly due to the rise of product moisture content for these water activity values, which could be due to the rise of sugar solubility of the product. This phenomenon has been demonstrated to occur more frequently in foods rich in sugar such as Chilean papaya (Antonio Vega-gálvez and Marlene Palacios 2008). Furthermore, Nkang *et al.*, (2003) confirmed that seed soluble sugar and lipids increase during maturation and desiccation in *T. occidentalis* seeds.

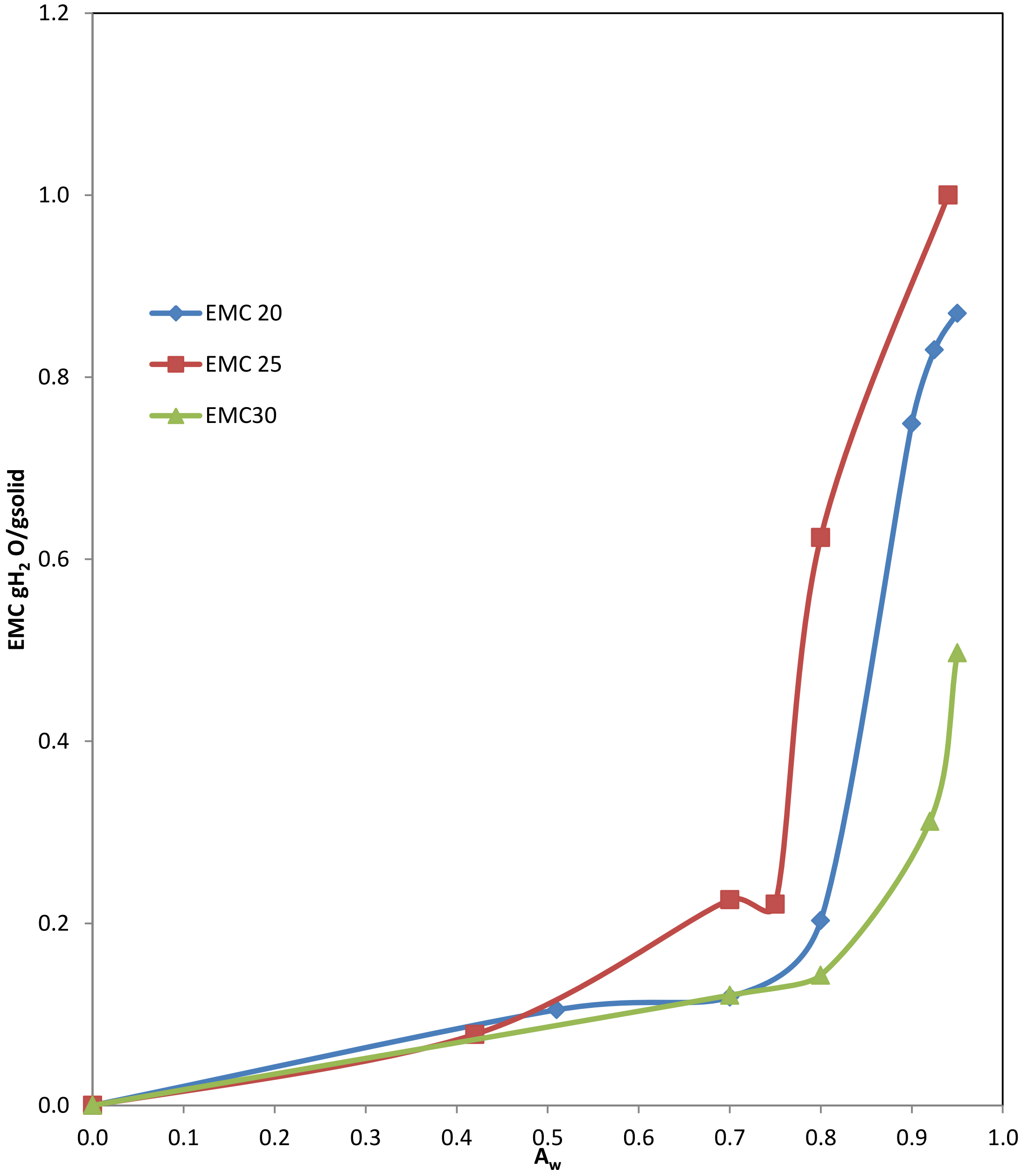

Figure 1 Moisture desorption isotherms of *T. occidentalis* at 20^{o}C, 25^{o} C, and 30^{o}C

The goodness of fit of each of the models was evaluated using an estimate of the residual mean square (RMSE), residual plots, coefficient of determination R^2, and standard error of estimate SEE (%). Several authors have used these parameters to evaluate the fitting ability of EMC-ERH equations. Ajibola (1986a, 1989) and Ajibola et al. (2003) used the standard error of estimate to evaluate different models. Chen and Morey (1989) and Mazza and Jayas (1991) used the standard error of estimate, mean relative percent deviation and residual plots to evaluate the fitting ability of models. The plots of the residuals from a fitted model provide information on the adequacy of different aspects of the model. The RMSE is the square root of the variance of the residuals. It indicates the absolute fit of the model to the data-how close the observed data points are to the model's predicted values. Whereas R-squared is a relative measure of fit, RMSE is an absolute measure of fit. As the square root of a variance, RMSE can be interpreted as the standard deviation of the unexplained variance, and has the useful property of being in the same units as the response variable. Lower values of RMSE indicate better fit. RMSE is a good measure of how accurately the model predicts the response, and is the most important criterion for fit if the main purpose of the model is prediction.

The models; GAB, Modified Oswin, Modified Henderson and Halsey have good fit for the sorption moisture isotherm of *T. occidentalis* at 20°C. Although the Modified Henderson gave the best fit with the coefficient of determination R^2 of 88.9% with Root Mean Square Error (RMSE) and standard error of estimate (SEE %) of 0.134 and 0.366 as depicted in Table 2. They are both less than 0.15% and 0.5% respectively. The GAB model gave the second best fit with R^2 of 0.844, RMSE value of 0.147 and SEE value of 0.022. Also the Oswin model and Halsey model gave the 3rd and 4th best fit respectively with R^2 values range of (0.727 -0.881), RMSE values range of (0.05-0.147) and SEE values of (0.189 -0.223). However, the Chung Pfost model gave the worst fit with lower coefficient of determination of 0.089. This is attributed to the fact that the lowest, or near zero values of SEE and RMSE together with the highest R^2 values (near unity), and %SEE less than 15% identify the best models (Hossain et al., 2001).

Table 2 Suitability of selected sorption models for *T. occidentalis* at 20°C

Parameter	Sorption models				
	Oswin	GAB	Henderson	ChungPfost	Halsey
r^2	0.881	0.844	0.889	0.089	0.727
SEE，%	0.1477	0.43523	0.36651	-	0.22337
Residual	0.022	0.189	0.134		0.050
A	-0.177	-2.780	-2.001	-0.496	0.860
B	-0.939	-0.839	1.620	0.509	1.430
C	-0.939	-0.919	0.943	0.883	0.853

The model constants, R^2, RMSE and SEE values for the different mathematical models at 25°C are summarised in Table 3. At 25°C, Chung Pfost model gave the best fit with R^2 value of 0.901, RMSE of 0.014 and SEE of 0.116. The Modified Oswin, and Henderson gave the second and third best fit with R^2 values of (0.843 and 0.866), RMSE values of (0.013 and 0.038) and SEE values of (0.113 and 0.195) respectively. The GAB model gave a better fit with R^2, RMSE and SEE values of 0.787, 0.095 and 0.308 respectively. The Halsey model gave a good fit with determination of coefficient (R^2) is 0.901 and standard error of estimate (SEE) of 0.898.

Table 3 Suitability of selected sorption models for *T. occidentalis* at 25°C

Parameter	Sorption models				
	Oswin	GAB	Henderson	ChungPfost	Halsey
r^2	0.843	0.787	0.866	0.901	0.901
SEE	0.1133	0.30873	0.19540	0.11646	0.898
Residual	0.013	0.095	0.038	0.014	0.008
A	0.122	-1.669	-1.064	-0.986	0.767
B	-0.918	-0.530	0.841	1.231	0.732
C	-0.939	-0.887	0.956	0.949	0.949

Also, at a temperature of 30°C, Oswin, GAB, Henderson, Chung Pfost, and Halsey gave good fit as depicted in Table 4. They had R^2 coefficient of determination of 0.834, 0.776, 0.963, and 0.983 and 0.983 respectively with SEE% of 0.09, 0.17, 0.06, 0.10, 0.03 and residuals of 0.009, 0.029, 0.005, 0.012, and 0.001, as is shown in Table 4. Henderson, ChungPfost, and Halsey gave better fit because of their higher values of R^2 0.963, 0.983, and lower SEE and residual less than 0.15 and 0.015 respectively.

Table 4 Suitability of selected sorption models for *T. occidentalis* at 30°C

Parameter	Sorption models				
	Oswin	GAB	Henderson	ChungPfost	Halsey
r^2	0.834	0.776	0.963	0.983	0.983
SEE，%	0.09738	0.17089	0.06968	0.10965	0.03113
Residual	0.009	0.029	0.005	0.012	0.001
A	0.479	-0.722	-0.092	-3.631	1.034
B	-0.913	-0.582	0.332	3.492	0.281
C		-0.881	0.981	-0.991	0.991

4 Conclusions

The investigation has shown that the experimental sorption isotherm of *Telfairia occidentalis* followed the characteristic shape of type II isotherms. The EMC of the samples increased with the increase in the water activity at constant temperature. The equilibrium moisture content increased at the same water activity as temperature decreased. The residual plots for the models; modified Chung–Pfost, modified Halsey, modified Oswin, modified Henderson, and Guggenheim–Anderson–de Boer (GAB) equations are randomly dispersed which makes a linear regression suitable for the analysis.

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