FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 4 No. 2, June, 2020, pp 620 – 626
DOI: https://doi.org/10.33003/fjs-2020-0402-247

MOISTURE SORPTION ISOTHERM CHARACTERISTICS OF *AWARA* FOOD

[*1]Maigalura, K. A. and [2]Suleiman, J.

[1]Department of Food Process Engineering, Sam Higginbotton University of Agriculture Science and Technology Allahabad, India
[2]Department of Crop Production and Protection, Faculty of Agriculture and Agricultural Technology, Federal University Dutsin-Ma, Nigeria

[*]Corresponding Author's Email: kamilumaigalura@gmail.com

ABSTRACT
Moisture sorption and storage stability of Awara were evaluated using gravimetric method. Guggenhein-Anderson-de boer (GAB) and Brunauer Emmett and Teller (BET) were used in evaluating sorption and desorption isotherm at temperature range of 30, 40 and 50oc in the range of water activity (0.1-0.9).Sigmoid moisture isotherm shapes were obtained at various temperatures. Lowest level EMC was obtained at highest temperature (500c).A non-linear regression analysis was used to fit both BET and GAB. GAB was found to generate higher coefficient of determination R2 (0.9986, 0.9959 and 0.9933) and lowest mean of relative percentage p% (0.231, 0.0061 and 0.0017) at temperature range (30, 40 and 500c) respectively. Safe % water and storage stability were all predicted from adsorption isotherm curve. 3.14, 3.19 and 3.10 were found to be the safe % water which corresponds to the 3.8aw for GAB adsorption graphs at 30, 40 and 500c temperatures respectively. This safe % water will be useful in packaging and determination of shelf- life of Awara.

Keywords: Awara, sorption isotherm, BET and GAB models, water activity

INTRODUCTION

Awara food is commonly consumed in a daily basis in northern part of Nigeria. It is processed soybean (Glycine max species) available in fresh, sun dry and in fried form. It is a popular food called tofu in Asian countries like China and India, Awara (tofu) was invented in China (Fen and Jin, 2013). It is a curd made by coagulating soy protein by mineral salts or acid. In Awara making, a coagulant (calcium, magnesium salt, or glucono delta-lactone) is used to precipitate the soy protein from soymilk to form a jelly-like curd. Depending on the downstream process, this curd can be converted into different types of products. The jelly-like curd can be further pressed to make Awarawith various hardness and moisture levels, flavours can be added to create different form and varieties (Fen and Jin, 2013).

Historically, tofu is a major source of protein in the Chinese diet in which meat supply was not in abundance until recent year, Calcium-coagulated tofu also serves as an important source of calcium, an essential macro mineral, which is deficient in typical Chinese diet (Fen and Jin, 2013).

Several mathematical models have been developed to describe sorption isotherm of foods (Alkali, J.S and satimehin, 2009; Palou et al, 1997). The models were tested and the constant evaluated for sorption data of many agricultural crops (Ajibola, et al, 2004). More than 23 commonly use models equation for fitting the sorption of different food materials have been review and discussed (Ajibola, et al, 2004).In more recent years, among the sorption models, the Guggenheim-Anderson-deBoer (GAB) equation has been applied most successfully to various foods (Timmermannet al., 2001). Brunauer-Emmett-Teller (BET) sorption isotherm was the model with the greatest application to water sorption isotherms of foods and foodstuffs (Labuza, 1968; Iglesias and Chirife, 1976), although it was known to hold only for a limited range of water activity. Despite the theoretical limitations of the BET adsorption analysis, the BET monolayer concept was found to be a reasonable guide with respect to various aspects of interest in dried foods (Karel, 1973; Iglesias and Chirife, 1981). The monolayer moisture content (Mo) is the moisture content at which the rate of quality loss is negligible (Labuza, 1984).

The study was aimed to investigate the water material interaction phenomenon (desorption and adsorption moisture content) of Awara food and determine the best moisture sorption (MIS) model that would predict desorption and adsorption isotherm. This would help in determining the shelf- life of the Awara food, and also in designing and selecting materials for packaging.

MATERIALS AND METHOD

Moisture sorption isotherm determination was carried out in Lab one Food process Engineering Department Sam Higginbottom University of Agriculture Science and Technology Allahabad, India at three different temperatures in (30-50^{o}C) over the range of water activity 0.1- 0.9 using the static gravimetric method.

For the moisture adsorption studies, the moisture contents of the 5.0g of samples were reduced to very low levels by oven drying step wisely from 40oc to 105°C. The samples were allowed to cool in separate desiccators, and thereafter, packaged in polyethylene bags and store in desiccators, from where they were removed and used for experiments.

For the desorption studies, the samples were rewetted to very high moisture levels (40 and 60% db) and then packaged in sealed polyethylene bag and stored in a refrigerator for 24 hours to attained uniform moisture distribution. Prior to investigation, the required sample were removed from the refrigerator and allowed to equilibrate with the ambient condition for 2 hours.

Material Procurement and Preparation

Bulk sample of fresh sample of Awarasealed in polyethylene bag and stored at ambient temperature, in order to take care of moisture migration within the material. Glass bottles oven and salt solution were used.

Experimental Procedure

Seven sealed glass bottle were used in this research (Gazor, 2010). Each bottle was provided with the sample holder. The holder kept the sample above the saturated salt solution in order to avoid contact with the solution. In each bottle three replication were used with 5.0g each sample. At each temperature (i.e. 30, 40 and 500c) fourteen glass bottles were used for both adsorption and desorption. All the bottles were put in the oven and set at the required temperature. The weight loss of each sample in the bottle was measured daily and the salt solution was maintained at the saturated state. The experiment was completed when three consecutive readings were obtained.

The equilibrium moisture content of the samples were determined after each sorption experiment using a precision air-oven method at a temperature of 135˚C for 2 hours until constant weight was achieved, according to the standard method of AOAC (2000). The mean values of three replications were obtained for each experiment. To establish the moisture sorption isotherms, the equilibrium moisture contents were plotted against water activity at constant temperature.

Fitting isotherm models to the experimental data

Base on the nonlinear analysis result obtained as given in table 6. GAP and BET parameters were calculated. The coefficient of determination (R2) and mean relative percentage deviation modulus (P %) were computed for desorption and adsorption at various temperatures (30, 40 and 50oC). The models were compared on the basis of R2 and P (%). GAP was found to have R2 closed to one for both temperatures and with lest P (%) approximately zero. This is in accordance with rule of P (%) < 10%, indicated good fitness (Bernnan, 1991; lomauro et al, 1985).

Adsorption and Desorption Equilibrium Moisture Contents (EMC) Determination

The adsorption and desorption equilibrium moisture contents (EMC) were determined for the samples using saturated salt solution method at 30, 40, 50oc over the range of relative humidity from 0.1 to 0.90. BET and GAB models were used in predicting the best fit model. The monolayer moisture content (mm) values at different temperatures were calculated using BET and GAB equations.

Moisture Adsorption Isotherm Determination

To determine moisture adsorption isotherm, 5.0g of the samples at very low dry basis moisture content in triplicate were weighed into sample cans and placed inside glass bottle to maintain different constant relative humidity in the glass bottle (Gazor, 2010). Excess salt was maintained in each solution to ensure saturation. The bottle containing the salt solutions and the samples were marked and placed inside temperature controlled oven set at a specified temperature. The oven temperature was monitored.

The samples were weighed daily using an electronic balance with an accuracy of 0.001 g. Equilibrium was considered to have been attained when three consecutive readings were obtained. Three replications were used for each experiment. The dry matter content of sample was determined by oven drying step wisely from 40oc to 120oc until constant weight was obtained. The EMC was calculated in dry basis from weight change and dry matter weight. The average EMC obtained at each relative humidity (water activity when expressed in decimal) at a given temperature were recorded.

Moisture Desorption Isotherm Determination

The procedures followed in determining the adsorption EMC were repeated so as to obtain desorption EMC.The average EMC obtained at each relative humidity (water activity when expressed in decimal) at a given temperature were recorded.

Isotherm Plots

The data obtained on the adsorption and desorption EMC of the sample were used to carry out the following plots:

Moisture sorption isotherms of the sample in adsorption at different temperatures over the water activity range employed.

Moisture sorption isotherms of the samples in desorption at different temperatures over the water activity range employed.

The adsorption and desorption isotherms of the sample constructed at each temperature to investigate the occurrence of moisture sorption hysteresis.

Moisture Sorption Isotherm modelling equation

Several different isotherm models have been proposed and compared in the literature. These models were chosen because they are most widely used to fit experimental sorption data of various food materials and are used to evaluate thermodynamic functions of water in foods. The parameter of the sorption models were estimated from the experimental result using the nonlinear regression analysis (SPSS 9.0 for window 1998) which minimise the residual some of squares. Best fitting equations were evaluated with the mean relative percentage deviation (P) value. Defined as

$$P(\%) = \frac{100}{N}\sum_{i=1}^{N}\frac{[M_{ei}-M_{ci}]}{M_{ei}} \quad (1)$$

Where M_{ei} and M_{ci} are experimental and predicted moisture content values respectively, and N is the number of the experimental data. A models is considered acceptable if the P value is below 10% (Boquet, Chirife and Iglesias, 1978; Lomauro et al., 1985).

The experimental equilibrium moisture content (EMC) data were processed using Microsoft Excel (2007) software and analysed using the linear trend method on transformedlinearised equations for the BET parameters; whereas the polynomial regression method was used on the transformed binomial equation for the GAB parameters.

Brunauer Emmett-Teller (BET) Equation

The Brunauer Emmett-Teller (BET) Equation is

$$\frac{m}{m_o} = \frac{ca_w}{(1-a_w)(1-a_w+ca_w)} \quad (2)$$

Where m is the moisture content (kg/kg dry solid), m_o is the monolayer moisture content (kg/kg dry solid), a_w is water activity and c is a constant related to the net heat of sorption.

The two-parameter BET model can be expressed as follows (Brunauer, Emmett and Teller, 1938):

$$m = \frac{m_o ca_w}{(1-a_w)[1+(c-1)a_w]} \quad (3)$$

where: m = equilibrium moisture content, %, d.b., m_o= BET monolayer moisture content, %, d.b., a_w= water activity, decimal c = BET constant related to the net heat of sorption

To obtain the two characteristic constants, $m_o$and c, the BET equation (1) was linearised as follows (Timmermann, 2003):

$$\frac{a_w}{(1-a_w)m} = \frac{1}{cm_o} + \frac{c-1}{cm_o} a_w \quad (4)$$

Which can easily be transformed to a linear equation with the following form:

$$\frac{a_w}{(1-a_w)m} = Aa_w + b \quad (5)$$

where

$$A = \frac{c-1}{cm_o} \quad (6)$$

$$b = \frac{1}{cm_o} \quad (7)$$

The BET parameters were obtained by plotting aw / (1-aw) M versus aw which would usually give a linear part at low activities up to 0.55 aw. From the slope (A) and the intercept (b), the BET parameters were determined using the following relationships:

$$m_o = \frac{1}{(A+b)} \quad (8)$$

$$c = \frac{A+b}{b} \quad (9)$$

Guggenhein-Andersiosn-de Boer (GAB) Equation

Guggenhein-Andersiosn-de Boer (GAB) Equation

$$m = \frac{m_o cka_w}{(1-ka_w)(1-ka_w+cka_w)} \quad (10)$$

where m = equilibrium moisture content, %, db., m_o= GAB monolayer moisture content, c = constant related to the monolayer heat of sorption, k= factor related to the heat of sorption of the multilayer (Rizvi, 1986)

This equation has a similar form to BET, but has an extra constant k. BET is actually a special case of GAB, where k= 1. The GAB parameters were determined following the method of the transformed form of the GAB isotherm (Timmermannet al., 2001).

The GAB model can be rearranged to a polynomial equation as follows:

$$\frac{a_w}{m} = \frac{k}{m_o(1/c)} a_w{}^2 + \frac{c-2}{m_o c} a_w + \frac{1}{m_o ck} \quad (11)$$

$$\propto = \frac{k}{m_o(1/c)} \quad (12)$$

$$\beta = \frac{c-2}{m_o c} \quad (13)$$

$$\varepsilon = \frac{1}{m_o ck} \quad (14)$$

$$\frac{a_w}{m} = \propto a_w^2 + \beta a_w + \varepsilon \quad (15)$$

A polynomial direct nonlinear regression method of aw/M versus aw was carried out using Microsoft Excel (2007) software in order to determine the values of the coefficient of the quadratic term α, the linear term coefficient β and the constant ε. Then the GAB parameters were calculated as follows:

$$k = \frac{f^{0.5}-\beta}{2\varepsilon} \quad (16)$$

$$m_o = \frac{1}{\beta+2k\varepsilon} \quad (17)$$

$$c = 2 + \frac{\beta}{k\varepsilon} \quad (18)$$

where

$$f = \beta^2 - 4\alpha\varepsilon \quad (19)$$

The temperature dependency of the GAB parameters was given by the following Arrhenius-type equations:

$$c(T) = c_o exp\left(\frac{\Delta H_c}{RT_{abs}}\right) \quad (20)$$

$$k = k_o exp\left(\frac{\Delta H_k}{RT_{abs}}\right) \quad (21)$$

$$m_o = m_o exp\left(\frac{-E_a}{RT_{abs}}\right) \quad (22)$$

where c_o, k_o and m_o are adjustable constants for the temperature effect; ΔHc= difference in enthalpy between monolayer and multilayer sorption (kJ/kmol), ΔHk= difference between the heats of condensation of water and the heat of sorption of the multilayer (kJ/kmol), R = universal gas constant, 8.314J/mol K

Tabs = absolute temperature, K

Ea = activation energy, KJ/mol

For the monolayer moisture content, an Arrhenius–type equation was calculated using a linearised form of Equation (22):

$$L_n(m_o) = L_n(m_o) - \frac{E_a}{RT_{abs}} \quad (23)$$

The coefficient of Equation (23) was easily obtained by plotting on an $L_n(m_o)$ versus 1/Tabs diagram. The Ea and m_o coefficient was subsequently related to the temperature by applying the regression technique.

Ea was calculated by plotting $L_n(m_o)$ versus the reciprocal of the absolute temperature. The slope of the curves found by applying the linear regression yields the coefficient Ea/R, while the intercept is equal to ln (m_o`). The other GAB parameters' coefficients were determined using the same procedure.

RESULTS AND DISCUSSION

Moisture sorption isotherms

Various data were obtained for desorption and adsorption EMC for *Awara*at temperature levels of 30, 40 and 50°C over the range of water activity 0.1-0.9 as given in fig 2, 3 and 4 respectively. The EMC for each desorption and adsorption represent the mean of three replication at a given a_w. The EMC increaseswith increase in a_w.

The isotherms plot showed sigmoid shape when EMC was plotted against a_w, this type of behaviour is commonly obtained for most food items more especially low sugar product (labuza 1984). Although BET is more popular models that give the base fit model for food with high water content. (Labuza, 1968; Iglesias and Chirife, 1976), the reverse is the case in Awara food this may be due to high protein content. Hysteresis was observed between 0.3 to 0.8 water activities for all the temperatures.

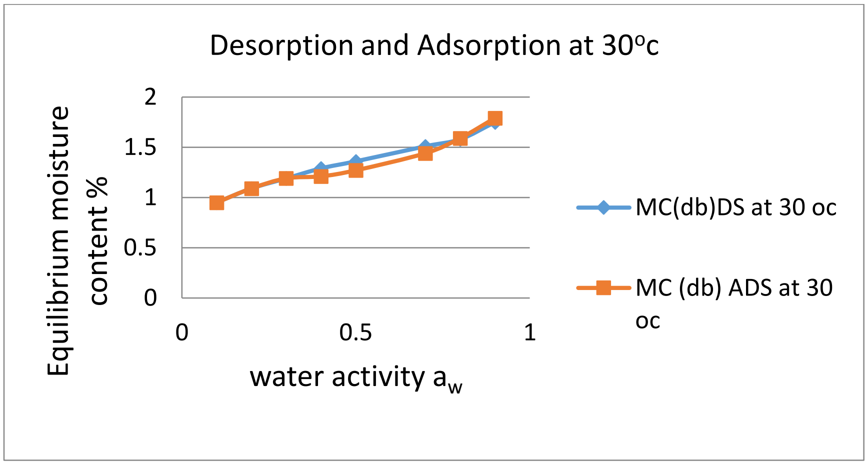

Fig 1: desorption and adsorption isotherm plot at 30°C

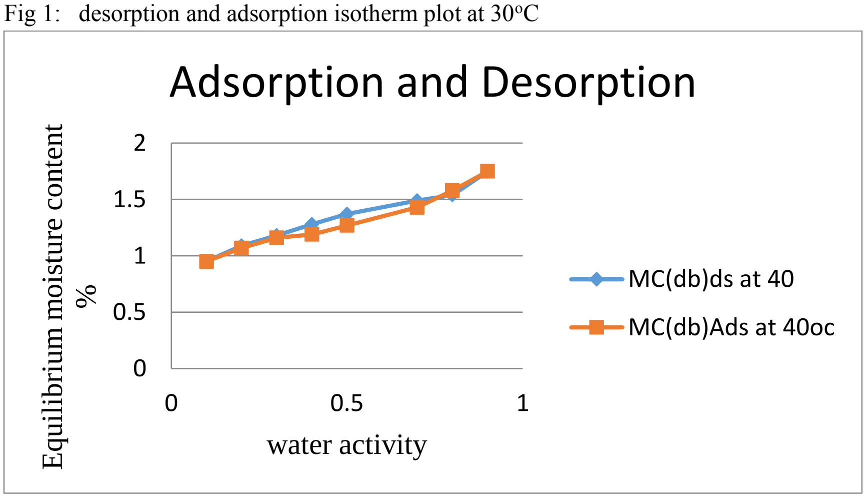

Fig 2: desorption and adsorption isotherm plot at 40°C

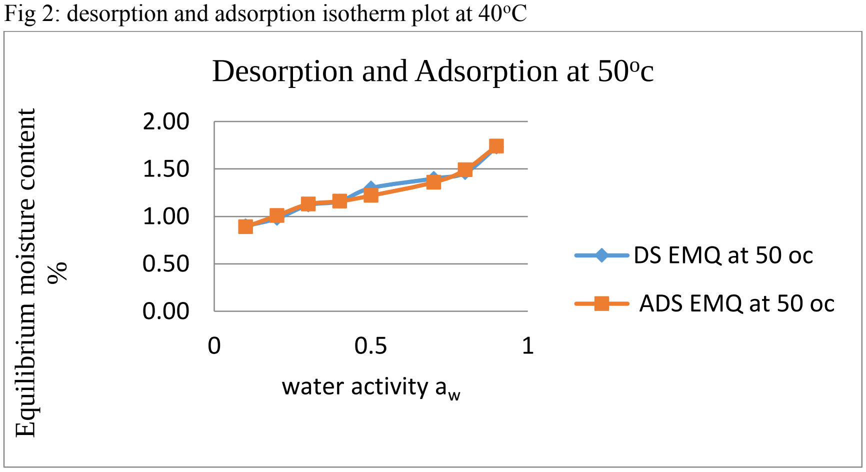

Fig 3: desorption and adsorption isotherm plot at 50°C

Desorption and adsorption

Desorption and adsorption temperature dependency was shown in table 6. The equilibrium moisture content increases with decrease in temperature as indicated in fig 4 and 5. The results were in agreement with this hypothesis as it was widely accepted by many researchers (Figen and Atil, 2003). Both desorption and adsorption isotherms sigmoid curve increase with decrease in temperature. The curves for temperature 30 and 40°C were observed to almost over lap this could be due to the nature of the product of high protein content. An attempt to carry out the experiment above 50°C gave undesirable result this indicated that it might be practically impossible.

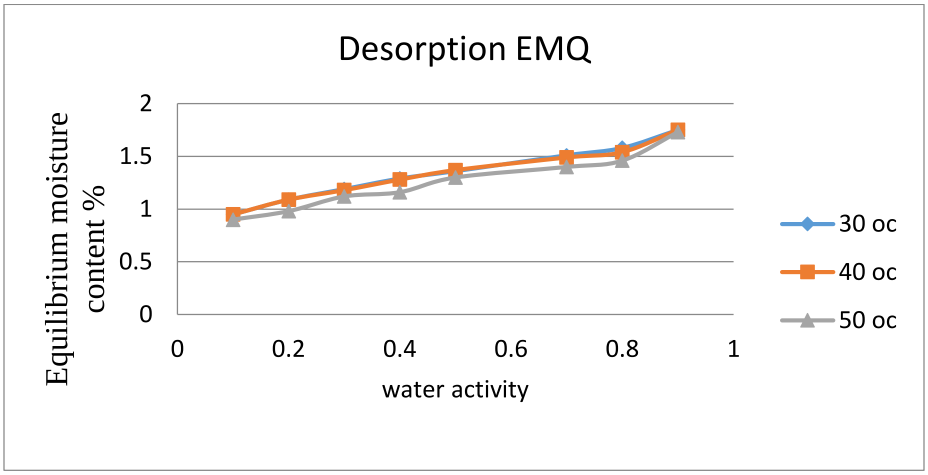

Fig 4: Desorption isotherm plot at 50, 40 and 30°C

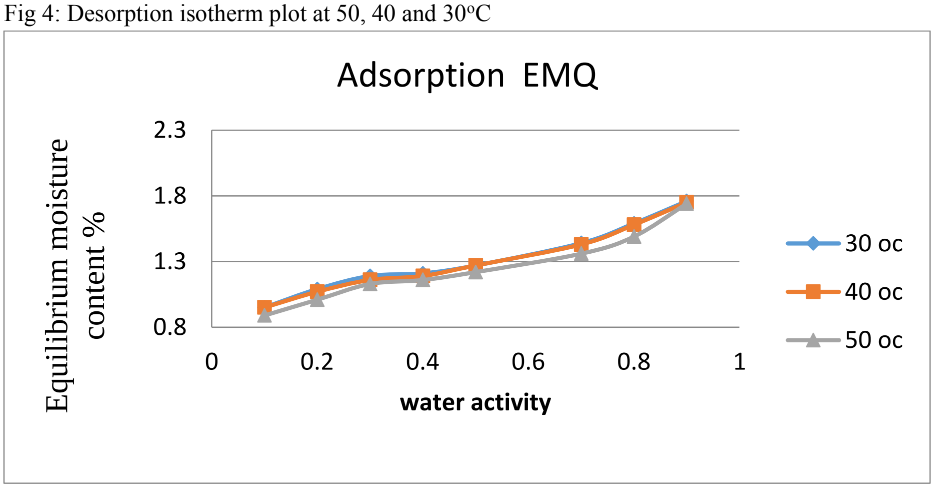

Fig 5: Adsorption isotherm plot at 50, 40 and 30°C

Table 6: Non-linear regression analysis

Model		Desorption			Adsorption		
		30 °C	40 °C	50 °C	30 °C	40 °C	50 °C
BET	C	-3.4322	-3.6371	-3.6949	-3.7311	-3.7168	-3.7561
	M	0.6922	0.2461	0.2357	0.2499	0.2459	0.2390
	R^2	0.7539	0.7603	0.7678	0.7714	0.7653	0.7799
	P (%)	6.8210	7.6469	8.6859	9.3454	9.0671	9.9119
GAB	C	0.8037	124.76	137.38	-431.09	-1753.67	- 802.94
	M	1.1154	1.1038	0.9952	0.9452	0.9484	0.9000
	R^2	0.9986	0.9959	0.9933	0.9966	0.9983	0.9937
	P (%)	0.23	0.0061	0.0017	0.03877	0.0241	0.0320
	K	0.4025	0.4012	0.4433	0.5113	0.5010	0.5125

A non-linear regression analysis was used to fit both BET and GAB. GAB was found to generate higher coefficient of determination R^2 (0.9986, 0.9959 and 0.9933) and lowest mean of relative percentage p% (0.231, 0.0061 and 0.0017) at temperature range (30, 40 and 50^{0}c) respectively. Safe % water and storage stability were all predicted from adsorption isotherm curve. 3.14, 3.19 and 3.10 were found to be the safe % water which corresponds to the 3.8a_w for GAB adsorption graphs at 30, 40 and 50^{0}c temperatures respectively. This safe % water will be useful in packaging and determination of shelf- life of Awara.

CONCLUSION

Desorption and adsorption at all the temperatures were found to be sigmoid curve in shape as it is true with many food products and hysteresis behaviour was also clearly observed for all temperatures. GAP model was found to be the best fit model that could be used to predict the behaviour of the product (*Awara*).

REFERENCES

Ajibola, O.O, Aviara, N.A, and Abodunrim,V.K (2004). Sorption Equilibrium and thermodynamic properties of palm Kernel. *Journal of Food Technology*2(1) 18-27.

Alkali, J.S and Satimehin, A.A, (2009). Moisture Adsorption characteristics of ginger (Zingiberofficinale) Powder.*CIGR Journal* 1286 XI

Aviara, N.A, Ajibola, O.O, Aregbesola, O.A, Adedeji, M.A (2006).”Moisture sorption isotherms of sorghum malt at 40 and 50^o c”. *Journal of stored products research,* 42,290-301.

AOAC. 2000. Official method of analysis. 17th ed. Horwitz, USA.

Brunauer, S., Emmett, P.H. and Teller, E. 1938. Adsorption of gases in multimolecular layer. Journal of American Chemists Society 60: 309-319.

Boquet, R., Chirife, J., and Iglesias, H, A. (1978). ‘Equations for fitting water sorption isotherms of foods’. II. Evaluation of various Two parameter models. *Journal of food Technology,13, 139-327.*

ChrispeelsM.J and savada D.E (1994).”Plants genes and Agriculture” *Jones and Bartlett publishers, Canada P. 143.*

Decagon devices, Inc., (2009). “Moisture sorption heats of sorption for potatoes” *J. Food engineering, isotherm generator*: Pullman, Washington, USA: operator’s manual. Version 3.0.35(3):261-280.

FabraMJ, Talens P, Moraga G, Martínez-Navarrete N. (2009) ‘Sorption isotherm and state diagram of grapefruit as a tool to improve product processing and stability’. *J Food Eng. 2009 Jul*; 93 (1): 52-58.

Fellow, P. (2003).’ Food processing technology, principles and practice.2nd edition wood sponge-cake as related to porous structure evaluation and moisture content’. *Journal of food science* 68, 555-562.

Fen-Jin He, Jin-Qiang Chen (2013). Consumption of soybean, soy foods, soy isoflavones and breast cancer incidence: Differences between Chinese women and women in Western countries and possible mechanisms. *Food science and human wellness.* 2 (2013) 146-161.

Figen, K.E and Atil G. (2003). ‘Sorption Isotherms and isosteric heat sorption for grapes apricots, apples and potatoes’ *Journals of swiss society of food science and technology,* lebensm-wiss.u.-Technol. 37 (2004) 429-438.

Iglelsias, H. A., and chirife, J., (1976). ‘Isosteric heat of water vapour sorption and dehydrated food’. Part II hysteresis and heat of sorption comparison with BET theory. Lebesmittel-wissenschaft und Techology, 9, 123-127.

GazorH.R (2010). ‘Moisture isotherms and heat of desorption of canola’. Agricultural Engineering international the CIGR E *journal, Manuscript* 1440 vol XII. May 2010.

Greenspan, L (1977). ‘Humidity fixed points of binary saturated aqueous solution’. *Journa. Res. Nat’l Bureau of standards-Section A. Physics and chemistry,* 81(1) 89-96.

Labuza,T. P. (1984). ‘Moisture sorption: practical aspect of isotherm measurement and use’. St. Paul, MN: American association of cereal chemists.

LabuzaT.P., A. Kaanane and Y. Chen, (1985). ‘Effect of temperature on moisture sorption isotherm and water activity shift of two dehydrated food’. *Journal of food science, 50, 385-391*

Liu, K. (1997).”Soyabeans”, chemistry, technology and utilization. Springer.Pp. 532.

Lomauro, C. J., BakshiA.S., and Labuza T.P (1985) Evaluation of food moisture sorption isotherm equation. Part I. Fruit vegetable and meat products. *Lebensmittel-wissenschaft and tecnoloie,* 111-117

Mekov, N.D., Durakova,A.G. and Krastera, A. (2005). Moisture Sorption Isotherms of common Beans Flour at several temperature. *Electronic Journalof environment, Agriculture and food chemistry* 4(2), 892-992.

Mujumdar AS (Ed.). (1980) ‘Advances in Drying’, Vol. 1. Washington, USA: Hemisphere Publishing Corporation; 1980. Fortes M, OkosMR. Drying theories: Their bases and limitations as applied to foods and grains; 301 p.

Palou, E. Lopes-malo, A. And Angaiz, A. (1997). Effect of temperature on Moisture Sorption of some Cookies and Snacks. *Journal of food Engineering,*31,85-93.

Raji AO, Ojediran JO. (2011). 'Moisture sorption isotherms of two varieties of millet'. Food Bioprod Process. 2011 Jul; 89 (3): 178-184.

Sahin S, Gülüm S. Physical Properties of Foods. New York, United States: Springer; 2006. 205, 218 p.

Salunkhe , D. K., chavan, J.C., Adsule, R.N. and kadam, S.S. (1992). 'World Oil Seed', Chemistry, Technology and Utilization. Van Nostrand Reinhold, New York.

Timmermann, E. O. 2003. Multilayer sorption parameters: BET or GAB values? Colloids and surfaces A: Physicochemical and Engineering Aspects 220: 235-260.

Timmermann, E. O., Chirife, J. and Iglesias, H.A. 2001. Water sorption isotherms of foods and foodstuffs: BET or GAB parameters? Journal of Food Engineering 48:19-31.