International Food Research Journal 25(6): 2531-2538 (December 2018)

Journal homepage: *http://www.ifrj.upm.edu.my*

Adsorption isotherms of three composites flours of plantain *(Musa* spp var. *Horn 1* (AAB), *FHIA 21* (AAAB) and *PITA 3* (AAAB)) and cassava (*Manihot esculenta* var. *Bonoua 2*)

[1]Brou, K. S., [1]Yué Bi, Y. C., [2]Yao, N. B., [1]Kouamé, A. F., [3]Kouamé, F. D. V. and [1,*]Tano, K.

[1]UFR of Food Science and Technology, University Nangui Abrogoua, Abidjan, Côte d'Ivoire
[2]UFR of Agroforestery, University Jean Lorougnon Guede of Daloa, Côte d'Ivoire
3Institut of Ivorian Tropical Technology (I2T), Abidjan, Côte d'Ivoire

Article history

Received: 27 September 2017
Received in revised form:
6 February 2018
Accepted: 9 February 2018

Keywords

Pplantain
Composite flour
Adsorption isotherm
GAB model
Water activity
Storage.

Abstract

Adsorption isotherms constitute a source of significant information to establish the stability of the foodstuffs and their storage conditions. The storage of flours requires the knowledge of their hygroscopicity. Adsorption isotherms of composite flours of plantain of the local variety *Horn 1* (FC) (*Musa* AAB) and the two plantains hybids varities *FHIA 21* (FF) (*Musa* AAAB) and *PITA 3* (FP) (*Musa* AAAB) and cassava (var. *Bonoua 2*), were determined using the standard static gravimetric method. The adsorption isotherms were determined at the temperatures of 28 ± 1°C under 0.11 to 0.90 water activity (a_w) range. The adsorption isotherms of three composites flours were found to be type II (S-shaped), characteristic of high sugar products. The model of GAB adjusts well the data expériementeles for the isotherm of adsorption of three studied composite flours. A higher water content was observed in *Horn 1* composite flour (FC (74.16 ± 0.04g H_2O / 100g)) compared to *PITA 3* composite flour (FP (68.38 ± 0.01g H_2O / 100g)) and *FHIA 21* composite flour (FF (66.37 ± 0.12g H_2O / 100g)) of dry matter. The GAB monolayer moisture content (X_0) (g H_2O /100g dry matter) range from 6.086 g H_2O / 100 g for *FHIA 21* flour to 7.375g H_2O /100 g for *Horn 1* composite flour. That of *PITA 3* composite flour was 6.443g H_2O / 100g. These values were optimal in order to ensure safe storage condition.

Introduction

The banana (plantain) represents one of the most significant cultures in the world (Odah *et al*., 2013). Plantain constitutes a basic starch food in the population diet of the areas low altitude of wet tropical Africa (Ngalani and Crouzet, 1995). Plantain represents also a substantial source of incomes for many rural and urban populations. The annual production of plantain in Côte.d'ivoire is estimated at 1.5 million tons, which classifies it in the 3rd place of the food products behind the yam and rice (Ducroquet, 2002; FAO, 2009). The storage of fresh plantain in the tropical countries is difficult because of their very perishable character (Talla, 2012). However, storage of plantain in a fresh state causes problems limiting its availability and utilisation period. Thus, for the storage of food product over a long period, its transformation into flour proves to be necessary to reduce the post-harvest losses. In order to preserve these fruits, and make it available to consumers during the whole year, it undergoes specific technological treatments, such as drying. Drying may be an interesting method in order to prevent fresh fruit deterioration (Elamin and Dieter, 2013). The consumption of plantain contributes to food security in developing countries such as Côte d'Ivoire. The important post-harvest losses of fruit such as plantain in developing countries are mainly due a lack of appropriate handling (Tano, 1997). Reducing the post-harvest losses may be partly due to their processing into flour, allowing their preservation for a long period.

The level of moisture affects the physical and rheological characteristics of food and their stability (Lewicki, 2004). It is well known that the microbial stability of food is strongly dependent on its water activity (a_w). This water activity which is defined as the ratio of the vapor pressure of water in the food to the vapor pressure of pure water at the same temperature, is used to express the amount of water available in a food system for microbial growth and biochemical reactions (Brou *et al.*, 2014). Water activity (a_w) has long been considered as one of the most important quality factors, especially for long-term storage. All chemical and microbial deteriorations are directly affected by changing

*Corresponding author.
Email: *pasqual_kab@hotmail.com*

water activity. Therefore, the determination of the relationship between water activity and moisture content is significant. Moisture adsorption isotherms describe the relationship between the equilibrium moisture content (EMC) and the water activity at constant temperature and pressure. For food material, these isotherms give information about the sorption mechanism and the interaction of food biopolymers with water. The moisture adsorption isotherms are extremely important in modelling the drying process, in the design and optimisation of drying equipment, in predicting shelf-life stability, in calculating moisture change which may occur during storage and in selecting appropriate packaging material (Gal, 1987). Several preservation processes have been developed in order to prolong the shelf-life of food products by lowering the availability of water to micro-organisms and inhibiting some chemical reactions (Siripatrawan and Jantawat, 2006). Several researchers have determined water sorption isotherms for various products and temperatures and at selected ranges of water activity (Labuza, 1984; Maroulis *et al*., 1988; McLaughlin and Magee, 1998; Gabas *et al*., 1999). The water sorption isotherm of foods is therefore of great importance.

Empirical and semi-empirical equations have been proposed to correlate the equilibrium moisture content (EMC) with the water activity of food products. These models or equations were chosen because of their suitability for high carbohydrate foods, application over a wide range of water activities, simplicity, and ease of evaluation (Ajisegiri *et al*., 2007; Oluwamukomi, 2008). GAB (Guggenheim-Anderson-De Boer) model has been applied most successfully to describe food isotherms up to aw of 0.9 (Iglesias and Chirife, 1976; Van de Berg and Bruin, 1981; Labuza *et al.,* 1985) and this has also been recommended by the European Project Group COST 90 on the Physical Properties of Foods as the fundamental equation for the characterization of water sorption of food materials (Wolf *et al*., 1985).

Therefore the objectives of this study were: (1) to investigate the moisture adsorption isotherms of three composite flours and (2) to evaluate the applicability of the GAB assorption model for predicting the equilibrium moisture content (EMC) of the three composites flours.

Material and Methods

Material

Material used in this study is consisted of plantain formulated flours FC, FF and FP of varieties *Horn 1, FHIA 21* and *PITA 3* respectively, used for the preparation of foutou. The bunches of the variety *Horn 1* were harvested in Tiassalé of latitude 5°53′54″North and longitude 4°49′42″West (Côte d'ivoire). The bunches of the varieties *FHIA 21* and *PITA 3* were harvested in Azaguié of latitude 5°37'40"North and longitude 4°5'12"West (Côte d'ivoire). The two towns are located in Agnéby-Tiassa area. Cassava (variety *Bonoua 2*) was purchased from the Port-bouet market (Abidjan, Côte d'Ivoire). These three formulated flours are made up each one of a mixture 60% of ripe plantain and 40% of cassava. The three composite flours were produced at the laboratory of the Institut of Ivorian Tropical Technology (I2T) Abidjan, Côte d'ivoire.

Adsorption isotherm of the formulated flours of FC, FF and FP

The adsorption isotherms of the three plantain flours were determined by the standard static gravimetric method standardised in the European COST project (Wolf *et al*., 1985) at temperatures of 28±1°C. The method is based on the use of saturated salt solutions to maintain a fixed relative humidity which corresponds with the tissue's water activity. A gravimetric method was used in this work. The method was based on the use of saturated salt solutions to maintain a fixed relative humidity. This relative humidity of salts solution and temperature were monitored using a thermohygrometer (Haar-Synth. Hygro, Germany). Eight salts were selected to give different water activities in the range of 0.11-0.90. The corresponding values of water activities were: Lithium chloride (LiCl) (a_w = 0.11), Magnesium chloride ($MgCl_2$) (a_w = 0.32), Potassium carbonate (K_2CO_3) (a_w = 0.43), Calcium nitrate (Ca $(NO_{3)2}$) (a_w = 0.56), Serenium chloride (SrCl) (a_w = 0,69), Sodium chloride(NaCl) (a_w = 0.75), Potassium chloride (KCl) (a_w = 0.85), and Baryum chloride ($BaCl_2$) (a_w = 0.90) (Greenspan, 1977). In addition to these salts, the desiccant (silica gel) was used for aw of 0. The water activities of the respective saturated solutions (a_w = 0.11- 0.90) were based on the values given by Greenspan (1977) and Bell and Labuza (2000). Duplicate samples, 1±0.0023 g each previously dried in an vacuum oven at 45°C for 24 hours, for adsorption were weighed into glass bottles with an analytical sensitive balance (Sartorius, Goettingen, Germany) of 0.0001g accuracy and placed in 2 little anaerobic jar containing saturated salt solutions prepared as recommended by Labuza (1984) and the COST 90 project (Wolf *et al*., 1985). Two replications of the same experiment were carried out. The samples were weighed within interval of 48 hours and allowed to equilibrate until there was no discernible weight change, as evidence by constant weight values (±0.002 g). The total time required for removal, weighing and replacing samples anaerobic jar was 15-25 second.

The dry mass was determined gravimetrically. The EMC of the samples was determined after each adsorption experiment using an electronic humidimeter (METTLER TELEDO, France), at 150°C for 5 to 12 mins until constant weight was reached. The mean values of two replicates were obtained for each experiment. To establish the moisture sorption isotherms, the EMCs were plotted against water activity at constant temperature.

Modeling equations

Guggenheim-Anderson-De Boer (GAB) model is considered to be the most versatile and the best one for fitting the sorption data for the majority of food products in a water activity range of 0.0-0.90 (Mayor *et al*., 2005). This model is one of the best for the characterization of the curves of food adsorption (Ferradji *et al.*, 2008a).

The equilibrium moisture content (EMC =X) data were processed using Microsoft Excel (2007) software and analysed using the polynomial regression method on transformed binomial equations for the GAB parameters. The GAB equation can be expressed as follows (Van de Berg, 1984 ; Labuza *et al*., 1985):

$$X = \frac{X_0 \times C \times K \times a_w}{(1 - K \times a_w)(1 - K \times a_w + C \times K \times a_w)} \quad (1)$$

Where: X = equilibrium moisture content, %, d.b.
X_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

The three parameters of GAB values of c, k and Xo were derived from the second order polynomial form (equation 1) which was solved by multi-linear regression analysis to obtain, R and MRE (Jouppila and Roos, 1997; Abramovič and Klofutar, 2002):

$$\frac{a_w}{X} = \alpha a_w^2 + \beta a_w + \gamma \quad (2)$$

Where; $\alpha = K/X_o(1/C - 1)$
$\beta = 1/X_o(1 - 2/c)$
$\gamma = 1/X_oKC$

The values of parameters α, β, and γ were obtained at the temperature through the following relations:

$K = f^{½} - \beta / 2\gamma$ where $f = \beta^2 - 4\alpha\gamma$
$X_0 = 1 / (\beta + 2K\gamma)$
$C = 2 + (\beta / K\gamma)$

To evaluate the goodness-of-fit for the models (GAB), the coefficient of correlation (R) and Mean Relative Error (MRE) were used. The coefficient of correlation was calculated using the following equation:

$$R = \frac{\sum_{i=1}^{N} (X_{exp} - \overline{X_{exp}})(X_{theo} - \overline{X_{theo}})}{\sqrt{\sum_{i=1}^{N} (X_{exp} - \overline{X_{exp}})^2 (X_{theo} - \overline{X_{theo}})^2}} \quad (3)$$

Where : X_{exp} = experimental EMC value
$\overline{X_{exp}}$ = experimental EMC mean value
X_{theo} = predicted EMC value
$\overline{X_{theo}}$ = predicted EMC mean value
N = number of experimental observations

The suitability of model fit was determined in terms of mean relative percentage deviation (MRE (%)) value (Boquet *et al*., 1978; Lomauro *et al*., 1985). A model is considered to be suitable if MRE < 10% (Lomarou *et al*., 1985; Wang and Brennan, 1991). The mean relative error percentage deviation was calculated using the following equation:

$$MRE = \frac{100}{N} \sum_{i=1}^{N} \left| \frac{X_{exp} - X_{theo}}{X_{exp}} \right| \quad (4)$$

X_{exp} = experimental EMC value
X_{theo} = predicted EMC value
N = number of experimental observations

Results and Discussion

Sorption characteristics of three composites flours

The adsorption isotherms obtained from three formulated flours containing plantain and cassava at 28±1°C are given in Figure 1. All adsorption isotherms demonstrated an increase in the equilibrium water content along with an increase in aw (Figure 1). The adsorption isotherms of formulated flours of the three varieties plantain follow the characteristic shape of high-sugar foods according to the BET classification [namely, type II (S-shaped)] with the EMC increasing sharply at the high water activities (Moraga *et al*., 2004). These findings are in agreement with Pott *et al.* (2005) for the adsorption characteristics of dried Kent variety mango slices at 20°C, Telis–

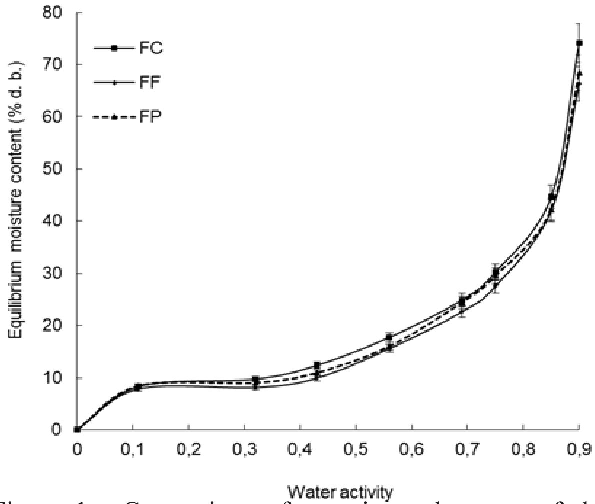

Figure 1. Comparison of experimental curves of the adsorption isotherms of the three composites flours of plantain (var *Horn1, FHIA 21* and *PITA 3*) and cassava (var. *Bonoua 2*)

Romero *et al.* (2005) for the adsorption isotherms of Haden variety mango pulp at different temperatures (30-70°C), and Falade and Aworh (2004) for the adsorption isotherms of osmo-oven dried African mango. The isotherm are typically divided into three regions:

- the "monolayer region" (a_w = 0 - 0.32) represents strongly bound water, and the enthalpy of vaporization is considerably higher than the one of pure water. The bound water includes structural water (H-bonded water) and monolayer water, which is sorbed by the hydrophilic and polar groups of food components (polysaccharides, proteins, etc.). Bound water is unfreezable and it is not available for chemical reactions or as a plasticizer. The relatively slow increase in water content for aw values ≤ 0.32 is due to the weak attraction between water and constituents of these flours. According to Ferradji *et al.* (2008a), the low water adsorption is explained by the fact that water vapor is adsorbed by the hydroxyl groups of crystalline carbohydrates.

- the "multilayer region" (a_w = 0.32 - 0.75), water molecules bind less firmly than in the first zone, they usually present in small capillaries. The vaporization enthalpy is slightly higher than the one of pure water. This class of constituent water can be looked upon as the continuous transition from to free water. A faster increase for average values of $a_w \geq 0.32$ which is due to the high capillarity; typical for most food products (Yué and Tano, 2008).

- the "condensed water region" (a_w = 0.75 to 1), the properties of water in this region are similar to those of the free water that is held in voids, large capillaries, crevices and the water in this region loosely binds to food materials (Tano *et al*., 2008). A rapid increase for aw ≥ 0.75 can be explained partly by the dissolution of carbohydrates and secondly by the passage of carbohydrates from the crystalline form to amorphous form. Anything that increases the water content because this phase transition carbohydrates increases the adsorption sites number (Saravacos *et al.*, 1986; Ferradji *et al.*, 2008a).

Table 1. Estimated GAB model coefficients, R and MRE fitted to the adsorption isotherms of three composites flours of plantain (var. *Horn 1, FHIA 21* and *PITA 3*) and cassava (var. *Bonoua 2*)

Model		FC	FF	FP
GAB	X_0	7,375	6,086	6,443
	C	90,335	402,463	1490,212
	K	1,000	1,020	1,011
	E (%)	0,227	0,208	0,662
	R	0,997	0,994	0,995

The experimental adsorption isotherms of three fomulated flours containing plantain (FC, FF and FP) were classified in hygroscopicity order descending following: *Horn 1* flour (FC), *PITA 3* flour (FP) and *FHIA 21* flour (FF) (Figure 1). The sorption isotherms had a sigmoid sharp (type II) which is common for many hygroscopic products (Kane *et al*., 2008). These results are similar to those of Johnson and Brennan (2000) and Medeiros *et al.* (2006) who worked respectively on the moisture sorption isotherm characteristics of plantain (Musa, AAB) and the sorption isotherm of cocoa powder and chocolate. This sigmoid shape is characteristic of food products containing sugar which absorbs small water content for low water activities and high water content for high water activity (Yué and Tano, 2008; Brou *et al.,* 2014). These results also corroborate those of Goula *et al*. (2008) who have worked on the sorption isotherm of tomato powder.

The characteristic shape of moisture isotherms depends upon the variety and total amount of hygroscopic materials present in the particular heterogeneous mixture of hydrophilic substances (Falade *et al*., 2003). At low water activities, water can be adsorbed only onto the surface-OH sites of crystalline sugars. Wiesser (1985) reported that at low water activities there was a local dissolution of sugar, a swelling of the biopolymers and the appearance of new active sites. At high water activities, dissolution of sugar occurs and crystalline sugar is converted into amorphous sugar. The amount of water to be absorbed

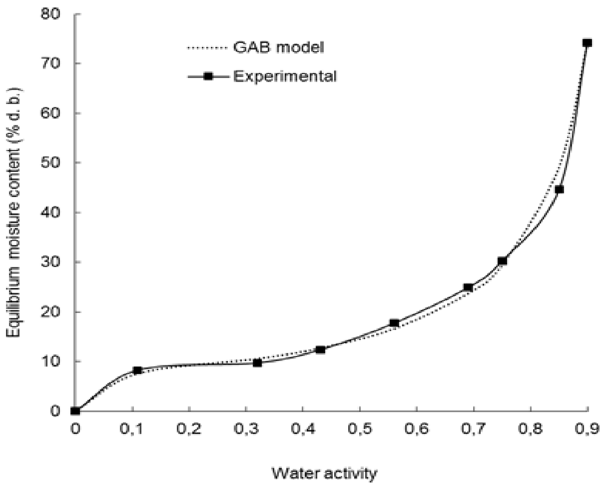

Figure 2. Comparisons of experimental and predicted adsorption isotherms of the composite flour of plantain of the variety *Horn 1* and cassava variety *Bonoua 2* using GAB model

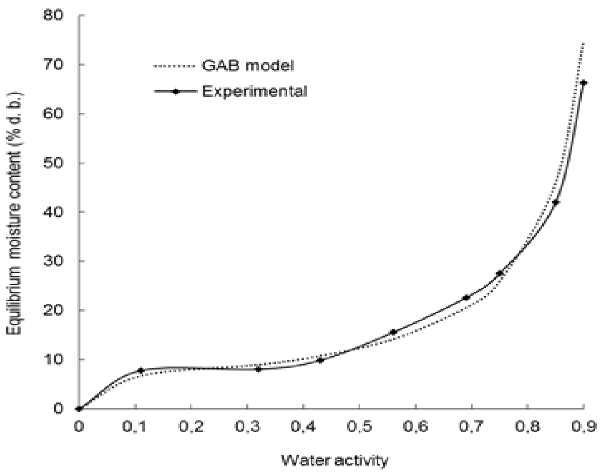

Figure 3. Comparisons of experimental and predicted adsorption isotherms of the composite flour of plantain of the variety *FHIA 21* and cassava variety *Bonoua 2* using GAB model

increases greatly after this transition because of the increase in the number of adsorption sites arising upon the breakage of the sugars' crystalline structure (Ayranci *et al.*, 1990).

Fitting of the GAB model to the adsorption isotherms data of three formulated flours of Horn 1 (FC), FHIA 21 (FF) and PITA 3 (FP)

The GAB's model was used to predict the value of the equilibrium moisture content and monolayer moisture content. The sorption relationships detailed in Table 1 were fitted to the experimental data for all samples. The moisture content models were compared according to their coefficient of correlation (R) and mean relative error (MRE).

Using these coefficients, the adsorption isotherms of fomulated flours FC, FF and FP were predicted by GAB. The representation of these results is shown in figure 2 to 4 from which it can be noted that the predicted curve by GAB's model and the experimental data had practically the same rate. The predicted curves (Figures 2, 3 and 4) have a sigmoid shape (type II) for all three fomulated flours containing planatin. The mathematical models tested to estimate equilibrium moisture content (EMC) of *Horn 1* flour; *FHIA 21* flour and *PITA 3* flour presented values of determination correlation (R) above 85% (Table 1). The GAB model is applicable to all three flours. This agrees with the work of Akanbi *et al.* (2006) who states that the GAB's model is applicable if $R \geq 0.85$. It should be noted that only the high value of R, is not enough to appreciate the goodness of fit of the model.

There must also be low MRE values. Low MRE (%) (0.227, 0.208 and 0.662) in ascending order for FP, FC and FF respectively shows good fitting experimental curves (Arévalo - Pinedo *et al.*, 2004; Talla, 2012). The GAB model was applicable to all three flours (FC, FF and FP). The GAB model fitted well over the whole range of water activity, giving a low MRE (%) which varied between 0.208 and 0.662. This result is <10% and so it is an indication of good fit according to both Wang and Brennan (1991) and Lomauro *et al*. (1985). This assertion is justified by the works of Ferradji *et al.* (2008b) adsorption isotherm of dattes and dried potatoes. It is also consistent with the work of Farahnaky *et al.* (2009) modeling of adsorption figs and potatoes. These results are similar to the work of Ferradji *et al.* (2008a) on the adsorption isotherm of dattes and those of Oluwamukomi (2009) and Brou *et al*. (2014) on the modeling of sorption isotherm of garis and plantain, okra and pepper flour respectively of GAB model. But more applicable to the plantain composite flour (MRE of *PITA 3* composite flour were higher than those two composite flours (*Horn 1* and *FHIA 21*).

The three formulated flours had not the same monolayer moisture content (X_0). *Horn 1* composite flour (X_0 = 7.375g H_2O^*100 g^{-1}) was higher than *FHIA 21* composite flour (X_0 = 6.086g H_2O^*100 g-1) and *PITA 3* composite flour (X_0 = 6.443g H_2O^*100g-1) (Table 1), confirming the hygroscopicity of three flours. Fitting of this model to results is of particular value given the physical significance of the parameters. The monolayer moisture content is the water content to which any available hydrophilic sites are linked to the first monolayer to the adsorbent water surface (Ferradji *et al.*, 2008b). It represents the maximum water content below which is not available for chemical and biochemical reactions.

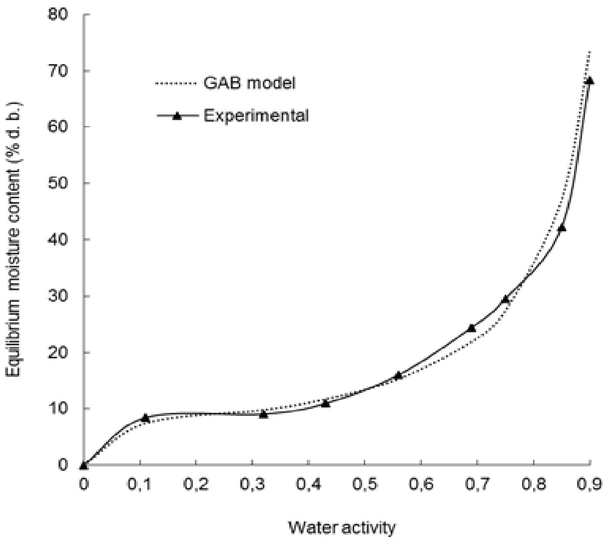

Figure 4. Comparisons of experimental and predicted adsorption isotherms of the composite flour of plantain of the variety *PITA 3* and cassava variety *Bonoua 2* using GAB model

This parameter is important for the control of product stability during storage (Ferradji and Malek, 2005). The monolayer moisture content X_0 is recognized as the moisture content according the longest time period with minimum quality loss at given temperature.

The constants C and K, which relate to the interaction energies between th e the highest values of C (90.335, 402.463 and 1490.212 for FC, FF and FP respectively), but the e water and food, also vary according to the method of regression used. The polynomial regression gav values of K were smaller (1.000, 1.020, 1.011 for FC, FF and FP respectively). The constants C shows also the characteristics of the isotherm. If C < 10, the isotherm is of type III. But, if C > 10, the isotherm is type II according Medeiros *et al*. (2006).

Conclusion

The moisture adsorption isotherms of the three plantain formulated flours (FC, FF and FP) at temperature 28±1°C under 0.11 to 0.90 water activity (a_w) range were determined with standard gravimetric methods using various saturated salt solutions. The adsorption isotherms provide valuable informations about the equilibrium moisture content of FC, FF and FP flour. They present a clear idea on the stability of these flour after drying, as well as information on the different kind of water in the product. So, these curves are valuable for storage of *Horn 1*, *FHIA 21* and *PITA 3* flour. The adsorption isotherms of *Horn 1*, *FHIA 21* and *PITA 3* flour had been determined by experiment and then described by GAB. The experimental results show that the adsorption isotherms of these three flours taked a form of the sigmoid type (II) and that GAB's model gave a better fit for the three adsorption isotherms of *Horn 1, FHIA 21* and *PITA 3* flour. GAB's model was also used to determine the monolayer moisture content of *Horn 1, FHIA 21* and *PITA 3* flour and the values of the constants C and K.

Acknowledgements

This work is integrated within the framework of the project "Seeks the best methods of conservation of plantain (Musa AAB) in a green state" initiated by West Africa Agricultural Productivity Programme (WAAPP), carried out by the Institute of Ivorian Tropical Technology (I2T) under the supervision and the coordination of the Agricultural Council and Research of Interprofessional Funds (FIRCA) and financed by the World Bank. We are deeply grateful to them.

References

Abramovič, H. and Klofutar, C. 2002. Water adsorption isotherms of some maltodextrin samples. Acta Chimica Slovenica 49: 835-844.

Ajisegiri, E. S., Chukwu, O. and Sopade, P. A. 2007. Moisture sorption study of locally-parboiled rice. Australian Journal of Technology 11(2): 86-90.

Akanbi, C. T., Adeyemi, R. S. and Ojo, A. 2006. Drying characteristics and sorption isotherm of Tomato slices. Journal of Food Engineering 73: 157-163.

ANADER (National Agency for Rural Development support). 2013. Study of the organization of plantain sector in Côte d'Ivoire, p. 66. Africa.

Arévalo-Pinedo, A., Giraldo-Zuñiga, A. D., Santos, F. L., Arévalo, Z. D. S. and Arévalo, R. P. 2004. Application of mathematical models of two and three parameters in the prediction of sorption isotherms for Ingá (Ingá edulis) pulp In Drying 2004 – Proceedings of the 14th International Drying Symposium (IDS 2004), vol. A, p. 628-633. São Paulo, Brazil.

Ayranci, E., Ayranci, G. and Dogantan, Z. 1990. Moisture sorption isotherms of dried apricot, fig and raisin at 20°C and 36°C. Journal of Food Science 55: 1591-1593.

Bell, L. N. and Labuza, T. P. 2000. Moisture sorption: Practical aspects of isotherms measurement and use. 2nd ed. St. Paul: American Association of Cereal Chemists.

Boquet, R., Chirife, J. and Igelias, H. A. 1978. Equation for fitting water sorption isotherms of foods. II. Evaluation of various two-parameter models. Journal of Food Technology 13: 319-327.

Brou, K. S., Yué Bi, Y. C., Konan, K. H. and Tano, K. 2014. Comparison and modeling of adsorption isotherms of tropical vegetables: plantain (*Musa paradisiaca* AAB var. Corne 1), okra *(Abelmoschus esculentus* var. Tomi) and bell pepper (Capsicum annuum var. Pm17/04a). International Journal of Development Research 4(9): 1868-1874.

Ducroquet, H. 2002. Ivorian Agriculture with the magnifying glass (1). The agricultural professional 3: 10-12.

Elamin, O. M. A. and Dieter, von H. 2013. Moisture sorption isotherms of mango slices. International Journal of Agricultural and Food Science 3(4): 164-170.

Falade, K. O. and Aworh, O. C. 2004. Adsorption isotherms of osmo-oven dried African star apple *(Chrysophyllum albidum)* and African mango *(Irvingia gabonensis)* slices. European Food Research and Technology 218: 278-283.

Falade, K. O., Adetunji, A. I. and Aworth, O. C. 2003. Adsorption isotherm and heat of sorption of fresh and osmo-oven dried plantain slices. European Food Research and Technology 217: 230-234.

FAO. 2009. Food and Agriculture Organization of the United Nations, Rome. Productions 2008. FAOSTAT, FAO Statiscal Databases. Downloaded from *http:// faostat.fao.org on 18/7/2013.*

Farahnaky, A., Ansari, S. and Majzoobi, M. 2009. Effect of glycerol on the moisture sorption isotherms of figs. Journal of Food Engineering 93: 468–473.

Ferradji, A., Matallah, M. A. A. and Malek, A. 2008a. Storage of the dates "Deglet Nour"- Adsorption isotherms at 25, 30 and 50°C. Reviews of Renewable Energies SMSTS'08 Alger: 207-219.

Ferradji, A., Acheheb, H., Malek, A. and Hadjad, N. 2008b. Adsorption isotherm at 25 and 45°C of apples charged with aqueous solutions and dried. Reviews of Renewable Energies 11(4): 165-177.

Ferradji, A. and Malek, A. 2005. Adsorption isotherm of dry apricots at 25 and 45°C. Reviews of Renewable Energies 8(1): 39-48.

Gabas, A. L., Telis-Romero, J. and Menegalli, F. C. 1999. Thermodynamic models for water sorption by grape skin and pulp. Drying Technology 17(4&5): 961-974.

Gal, S. 1987. The need for, and practical applications of sorption data. Physical Properties of Foods, 2, 1325. London: Elsevier Applied Science.

Goula, A. M., Karapantsios, T. D., Achilias, D. S. and Adamopoulos, K. G. 2008. Water sorption isotherms and glass transition temperature of spray dried tomato pulp. Journal of Food Engineering 85: 73-83.

Greenspan, L. 1977. Humidity fixed points of binary saturated aqueous solutions. Journal of Research of National Bureau of Standards (A): Physics and Chemistry 81A (1): 89-96.

Iglesias, H. A. and Chirife, J. 1976. Prediction of the effect of temperature on water sorption isotherms of food materials. Journal of Food Technology 11: 109-116.

Johnson, P-N. T. and Brennan, J. G. 2000. Moisture sorption isotherm characteristics of plantain (Musa, AAB). Journal of Food Engineering 44: 79-84.

Jouppila, K. and Roos, Y. H. 1997. Water sorption isotherm of freeze dried milk products: applicabilityof linear and non-linear regression analysis in modelling. International Journal of Food Science and Technology 32: 459-471.

Kane, E. C. S., Kouhila, M., Lamharrar, A., Idlimam, A. and Mimet, A. 2008. Moisture sorption isotherms and thermodynamic properties of two mints: Mentha pulegium and Mentha rotundifolia. Reviews of Renewable Energies 11(2): 181-195.

Labuza, T. P., Kaanane, A. and Chen, J. Y. 1985. Effect of temperature on the moisture sorption isotherms and the water activity shift of two dehydrated foods. Journal of Food Science 50: 385-391.

Labuza, T. P. 1984. Moisture sorption: practical aspects of isotherm measurement and use. 150. St. Paul: American Association of Cereal Chemists.

Lewicki, P. P. 2004. Water as the determinant of food engineering properties. A review. Journal of Food Engineering 61: 483-495.

Lomauro, C. F., Bakshi, A. S. and Labuza, T. P. 1985. Evaluation of food moisture sorption isotherm equations. Part 1. Fruit, vegetable and meat products. Lebensmittel-Wissenschaft und Technologie 18: 111-117.

Maroulis, Z. B., Tsami, E., Marinos-Kouris, D. and Saravacos, G. D. 1988. Application of the GAB model to the moisture sorption isotherms for dried fruits. Journal of Food Engineering 7: 63-70.

Mayor, L., Moreira, R., Chenlo, F. and Sereno, A. M. 2005. Water sorption isotherms of fresh and partially osmotic dehydrated pumpkin parenchyma and seeds at several temperatures. European Food Research and Technology 220: 163–167.

McLaughlin, C. P. and Magee, T. R. A. 1998. The determination of sorption isotherm and the isosteric heats of sorption for potatoes. Journal of Food Engineering 35: 267-280.

Medeiros, M. L., Ayrosa, A. M. B., Pitombo, R. N. M. and Lannes, S. C. S. 2006. Sorption isotherms of cocoa and capuassu products. Journal of Food Engineering 73: 402-406.

Moraga, G., Martinez-Navarrete, N. and Chiralt, A. 2004. Water sorption isotherms and glass transition in strawberries: influence of pretreatment. Journal of Food Engineering 62: 315-321.

Ngalani, J. A. and Crouzet, J. 1995. Plantain flour use in the transformation of breads, biscuits and instantaneous flours. Agriculture Books 4: 61-64.

Odah, K., Aziadekey, M., Tozo, K., Akpavi, S., Koukouma, R., Guelly, A., Kokou, K., Assignon, K., Akogo, Y., Aidam, A., Akpagana, K., Kenny, L., Ait-Oubahou, A., Zinsou, C. and Gbeassor, M. 2013. The genetic diversity of plantains cultivated in the Western zone of the Area of the Plates in Togo. International Journal of Biological and Chemical Sciences 7 (5): 1910-1918.

Oluwamukomi, M. 2009. Adsorption isotherm of soy-melon-enriched and un-enriched gari using GAB equation. African Journal of Food Science 3 (5): 117-124.

Oluwamukomi, M. O. 2008. Formulation and associated storage stability study of soy-melon “gari”: a protein-enriched cassava product. Akure, Nigeria: Federal University of Technology, PhD thesis.

Pott, I., Neidhart, S., Mühlbauer, W. and Carle, R. 2005. Quality improvement of non-sulphited mango slices by drying at high temperatures. Innovative Food Science and Emerging Technologies 6: 412-419.

Saravacos, G. D., Tsiuorvas, D. A. and Tsami, E. 1986. Effect of temprature on the water adsorption isotherms of sultana raisins. Journal of Food Science 51(2): 381-394.

Siripatrawan, U. and Jantawat, P. 2006. Determination of moisture sorption isotherms of jasmine rice crakers using BET and GAB models. Food Science and Technology International 12: 459-465.

Talla, A. 2012. Experimental determination and modelling of the sorption isotherms of Kilishi. British Journal Applied Science and Tecnology 2 (4): 379-389.

Tano, K., Yué Bi, Y. C., Kouamé, A. F. and Oulé, K. M. 2008. Determination and Modelling of Moisture Sorption Isotherms of Chitosan and Chitin. Acta Chimica Slovenica 55: 677–682.

Tano, K. 1997. Fruit and vegetables modified atmosphere packaging: impact of the temperature fluctuations during transportation and storage, p. 221. Québec, Canada: University of Laval, PhD thesis.

Telis-Romero, J., Kohayakawa, M. N., Junior, V. S., Pedro, M. A. M. and Gabas, A. L. (2005). Enthalpy-entropy compensation based on isotherms of mango. Sociedade Brasileira de Ciência e Tecnologia de Alimentos 25 (2): 297-303.

Van den Berg, C. 1984. Description of water activity of foods for engineering purposes by means of the GAB model of sorption. In McKemenne B.M. (Ed). Engineering and Food, p. 1,311- 1,321. London: Elsevier Applied Science.

Van den Berg, C. and Bruin, S. 1981. Water activity and its estimation in foods systems: theoretical aspects. In Water Activity Influence on Food Quality, p. 1-61. New York: Academic Press.

Wang, N. and Brennan, J. G. 1991. Moisture sorption isotherm characteristics of potatoes at four temperatures. Journal of Food Engineering 14: 269-282.

Weisser, H. 1985. Influence of temperature on sorption equilibra. In Simatos D. and Multon J. L. (Eds). Properties of Water in Foods, p. 95-118. Dordrecht, Boston and Lancaster: Martinus Nijhoff Publishers.

Wolf, W., Spiess, W. E. L. and Jung, G. 1985. Standardisation of isotherm measurements (COST-project 90 and 90BIS). In Simatos D. and Multon J. L. (Eds). Properties of Water in Foods, p. 661-679. Dordrecht, Boston and Lancaster: Martinus Nijhoff Publishers.

Yué Bi, Y. C. and Tano, K. 2008. Experimental Determination of the Sorption Isotherms of “Beta” Lactose, New Water Absorbent and Sodium Bicarbonate. Journal of Food Technology 6(4): 152-157.