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RESEARCH ARTICLE

MATHEMATICAL MODELING OF WATER ADSORPTION ISOTHERM IN CORN (Zea mays L.) DRY GRAIN

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ABSTRACT

The present study aims to experimentally determine the adsorption isotherms of preserved grain corn (single bagging (SB) and triple bagging (TB)) by the static gravimetric method at different temperatures (25 °C, 30 °C, 35 °C). Eight empirical models were used to model the isotherms using regression analysis, under Excel 2013 software, using the nonlinear GRG solver algorithm. Hygroscopic equilibrium is obtained after 25 days for the SB system versus 35 for the TB for the last equilibrium point. The isotherms obtained are sigmoidal type II. The GAB model showed the best agreement between the experimental data and those predicted (r = 0.995; 0.998 and 0.999 / respectively for 25, 30 and 35 °C). The water content of the mono-molecular layer of the sample stored in TB is 2.151 % at 25 °C; 1.809% at 30 °C and 1.404% at 35 °C. For the sample stored in SB, it is 2.261% at 25 °C; 2, 255 % at 30 °C and 2.053 % at 35 °C. The net isosteric heat of adsorption tends to zero at high water contents (0.026 KJ / mol at 3.58% water). The linearity between enthalpy (net isosteric heat) and differential adsorption entropy shows their compensation.

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INTRODUCTION

The conservation of foodstuffs during the post-harvest phase is a major concern for producers, mainly in rural areas (Kakou *et al,* 2015). Indeed, most of our diet is made up of agricultural products such as maize (Zea mays), seasonal and highly perishable (Touz and Merzaia-Blama, 2008). It ranks second among the cereals cultivated after rice in the Ivory Coast. Its annual national production increased from 654,738 tonnes in 2013 to 680,000 tonnes in 2014, for a total sown area of 327,800 ha (FAOSTAT, 2014). Along with other cereals and tubers, it is the main staple food and also an important source of income for populations, towns and countryside (Kouakou *et al,* 2010). Despite this importance, producers are faced with problems of post-harvest losses during storage (CMA / AOC, 2015). However, after harvest, maize is stored in unfavorable conditions and structures, thus favoring its attack by insects, rodents and the development of molds (Fandohan *et al,* 2003; Waongo *et al,* 2013). These losses are considerable and are estimated at between 20 and 30% after only a few months of storage using unsuitable traditional methods and not respecting good storage practices (Noudjou-Wandji, 2007; Gueye *et al,* 2012).

Most of the time, crops are contaminated with mycotoxins from toxigenic molds, which results in the reduction of the amount of food available (Yiannikouris and Jouany, 2002). To effectively control these pests, producers nowadays resort to triple bagging (TB) systems, which is increasingly used to secure the stock of various agricultural seeds such as maize over a long period (Kakou *et al,* 2015, Doualaye, 2016). Moreover, in order to optimize the storage conditions of the product so as to ensure its physicochemical and microbiological stability, the determination of the sorption isotherms is a necessity (Ahouannou *et al,* 2010; Koko *et al,* 2018). Knowledge of water activity and sorption-desorption isotherms are of great importance in the food industry, food storage and preservation (Multon, 1982; Boudhrioua, 2004). In fact, isotherms provide important information on the hygroscopic balance of a product because they allow us to know the stability range of the product after drying and thus provide information on the types of water present in the product. This equilibrium is characterized from these curves, the experimental determination of which requires a large number of measurements (Kouhila *et al,* 1999). During the last two decades, a large number of works have focused on the study of sorption isotherms of food products (Bolin, 1980), the influence of temperature on isotherms (Labuza *et al,* 1985; Ayranci *et al,* 1990) and the study of mathematical models describing sorption isotherms (Chirifie *et al,* 1983; Kim *et al,* 1985; Maroulis *et al,* 1988). However, very little work has been done to determine the water absorption isotherms of corn kernels. The purpose of this study is to help improve the storage of corn kernels. It aims to assess the evolution of the hygroscopic behavior of corn kernels packaged in single and triple bagging systems, using the static gravimetric method at temperatures of 25, 30 and 35°C. Specifically, it is about:

- Establish the water absorption isotherms of the corn kernels.
- Characterize the isotherms (type, water content of the mono-molecular layer)
- Model the water absorption isotherms of corn kernels
- Quantify the iso-steric heat and the free enthalpy

MATERIALS AND METHODS

Biological material: The biological material used consists of corn kernels (Zea mays), dried of yellow morphotype bought at the wholesale market in the town of katiola (8 ° 08 '15"N; 5 ° 06' 07"W), located 55 km from Bouaké in Ivory Coast. The corn kernels were dried in the sun just after harvest, and then transported in 120 kg bags to the laboratory for a five-month conservation by the technique of simple bagging (SB) and triple bagging (TB).

Experimental procedure for producing adsorption isotherms: The determination of the absorption isotherms of the corn kernels was carried out by the static gravimetric method which consisted of using 24 airtight jars divided into 3 groups of 8 for each sample (Akmel *et al,* 2009). In the jars of each group, solutions of sulfuric acid (200 mL) were added at increasing concentrations (20, 30, 40, 50, 60, 70, 80, 90%) (Kakou *et al,* 2015). The water activities of sulfuric acid at these different concentrations were determined using an activimeter (HP 23-AW-A-SET-40). Five (5g) of corn powder were weighed in stainless cups then placed on glass supports in the different jars. The grinding of the samples allows the free circulation of water molecules (in the case of most food products), to accelerate the exchanges, without modifying the end point of equilibrium. The samples are stabilized in temperature and in humidity in ovens at 25, 30 and 35 ° C (Figure 1). These temperatures were chosen because the average temperature variation in Côte d'Ivoire is between 18 and 37 ° C (Anonymous 1, 2018). The samples were weighed at regular intervals of 48 h until the mass no longer varied, they were then assumed to be in equilibrium with ambient air at (T, RH). Equilibrium is considered to be achieved when the variation in mass between two successive measurements is less than or equal to 0.001g. At the end of each experiment, the samples are taken and then immediately placed in the drying oven set at 103 ° C ± 2. This operation makes it possible to obtain the dry extracts of the samples studied, which under this condition undergo the total loss of free and bound waters they contain (Ahouannou *et al,* 2010). The samples were regularly weighed until their mass stabilized (0.001g) then the dry extract was obtained (Belhamidi *et al,* 1999). Thus, the mass measured for each sample is considered to be the dry mass (Ms). From this parameter obtained, the different water contents at equilibrium of the samples were defined. The Xeq equilibrium water content is deduced from the following equations (Kakou *et al,* 2015):

$$Xi = \frac{Mi - MS}{MS} \times 100 \qquad \text{...........(1)}$$

$$Xeq = \frac{M}{Mi}(Xi + 100) - 100 \qquad \text{........(2)}$$

With: Mi: mass of the product at the initial time (g), M: mass of the product at time t (g), Ms: dry mass of the product (g), Xi: water content of the product at the initial instant (% Ms), Xeq: equilibrium water content of the product (% material Ms).

Figure 1. Experimental device for the determination of adsorption isotherms

Modeling of adsorption isotherms: Several mathematical models, empirical relationships, describe the relationship between equilibrium water content, equilibrium relative humidity and temperature. Eight different models found in the literature can be studied: Modified Henderson, Modified Chung-Pfost, Modified Oswin, Modified Halsey, GAB, Langmuir, and Modified BET. The aim is to determine the most suitable model (s) for the description of the sorption isotherms of our product. (Touati, 2008).

Determination of parameters (Xm, A, B and C): The parameters Xm, A, B and C, of the different models were determined by identification with the experimental absorption curves, by minimizing the sum of the Mean Quadratic Deviations:

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{Xeqi,exp - Xeqi,pre}{Xeqi,exp}\right|^2 \qquad \text{............(3)}$$

With: Xeqi, exp: equilibrium experimental water content (% ms: dry matter), Xeqi, pre: predicted equilibrium water content (% ms), N: Number of experimental points

Statistical analyzes: Modeling adsorption isotherms requires statistical methods of regression and correlation analyzes. Regression analysis was performed, under Excel 2013 software, using the nonlinear GRG solver algorithm. The correlation coefficient (r) was the first criterion for selecting the best model to describe the absorption curves (Inci and

Dursun, 2004). In addition to r, calculations of the values of RME (Relative Mean Error) and MSD (Mean Squared Deviation) were used to justify the choice of the model (Sun and Woods, 1994). The best model is the one with the largest r-value (close to 1) and the smallest RME and MSD values (close to zero) (Benhamou *et al,* 2010).

$$r = \sqrt{\frac{\sum_{i=1}^{N} Xeqi,pre - \bar{X}eqi,exp)^2}{\sum_{i=1}^{N}(Xeqi,pre - \bar{X}eqi,exp)^2}} \quad \ldots\ldots\ldots\ldots(4)$$

$$MSD = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{Xeqi,exp - Xeqi,pre}{Xeqi,exp}\right| \quad \ldots\ldots\ldots\ldots(5)$$

RESULTS

Characterization of isotherms: The equilibrium water content (Xeq) of the corn sample stored in single bagging (SB) and the equilibrium water content (Xeq) of the corn sample stored in a triple bagging system (TB) have been determined. The results are shown in Table 2. On analysis of the table, the water contents at equilibrium vary between 9.635 to 0.273% for SB and 6.673 to 0.023% for TB. The hygroscopic equilibrium of the sample stored in the triple bagging system is reached after 35 days while that stored in single bagging is reached after 25 days. The sorption curves experimentally obtained for each sample at 25 °C, 30 °C and 35 °C are shown in Figures 2 and 3. They all show type II sigmoidal shapes. Figures 2 and 3 present in the same reference, the adsorption isotherms of the corn kernels stored in the single bagging (SB) and triple bagging (TB) systems determined at temperatures of 25, 30 and 35 °C. In general, the isotherms obtained at high temperature are lower than those obtained at low temperature. In addition, the equilibrium water content of each corn sample decreases with increasing temperature, at the same water activity. The water content therefore varies depending on the temperature. The experimental points of the equilibrium water content (Xeq) of the two corn samples (SB and TB) for the three temperatures (25, 30 and 35°C) were analyzed by the eight (08) models described in the literature. Tables 3 and 4 present some characteristics of the adsorption isotherms of the two samples of corn (type of isotherm and water content of the monolayer noted Xm).

Table 1. Mathematical models used

MODELS	MATHEMATICAL EQUATIONS	COEFFICIENTS AND PARAMETERS
G.A.B (Van der Berg and Bruin, 1981)	$X = \frac{X_m * C * K * aw}{((1-K.aw)*(1-K.aw+C.K.aw)}$	Xm, K, C
BET (Brumauer, Emmet et Teller, 1983)	$X = \frac{X_m * C * K * aw}{((1-K.aw)*(1-K.aw+C.aw)}$	Xm, C, aw
Hasley (Hasley, 1948)	$X = \left(\frac{A}{\ln\left(\frac{1}{aw}\right)}\right)^{1/B}$	A, B
Henderson (Henderson, 1952)	$X = \left(\frac{-\ln(1-aw)}{A}\right)^{1/B}$	A, B
Iglesias-Cherif (Iglesias et al., 1978)	$X = A + B\left(\frac{aw}{1-aw}\right)$	A, B
Oswin (Oswin, 1946)	$X = A\left(\frac{a_w}{1-aw}\right)^c$	A, C
Caurie (Caurie, 1970)	$X = e^{(a+b.aw)}$	a, b
Smith (Smith, 1946)	$X = C_1 - C_2.\ln(1-aw)$	C_1, C_2

Table 2. Equilibrium water content (Xeq) for the adsorption isotherm of samples stored in single bagging (SB) and triple bagging (TB)

Temperatures	Aw	Xeq *SE* (%)	*TES* (%)
25°C	0.876	9.635	6.674
	0.750	7.037	3.992
	0.567	4.239	2.745
	0.354	2.979	2.053
	0.167	2.435	1.446
	0.432	3.218	2.281
	0.053	2.009	1.033
	0.004	0.752	0.429
30°C	0.874	8.689	5.871
	0.748	6.200	3.186
	0.566	3.196	2.172
	0.355	2.202	1.598
	0.170	1.818	1.101
	0.452	2.486	1.823
	0.058	1.461	0.746
	0.004	0.537	0.245
35°C	0.876	7.969	5.170
	0.751	5.185	2.564
	0.570	2.151	1.616
	0.361	1.320	1.012
	0.174	1.145	0.674
	0.475	1.551	1.274
	0.064	0.905	0.379
	0.005	0.274	0.024

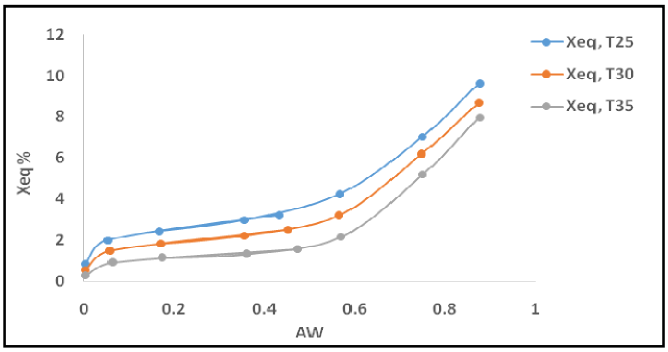

Figure 2. Experimental absorption isotherms at different temperatures of the corn sample stored in simple bagging (SB)

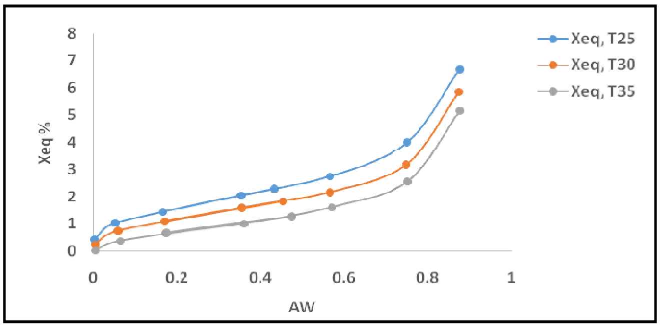

Figure 3. Experimental absorption isotherms at different temperatures of the corn sample stored in triple bagging (TB)

Table 3. Values of the estimated parameters and statistical choice criteria (SB)

		Temperatures		
	Parameters	25°C	30°C	35°C
BET	Xm	2.270	2.263	2.259
	C	92.065	94.577	93.541
	r	0.995	0.996	0.995
	MSE	0.007	0.03	0.029
	MSD	13.582	12.437	12.859
GAB	Xm	2.261	2.255	2.254
	C	15936.79	15969.18	15965.54
	K	0.93	0.93	0.931
	r	0.999	1.000	1.000
	MSE	0.039	0.021	0.005
	MSD	12.304	11.293	11.838
Chung et Pfost	A	3.137	3.130	3.124
	B	0.322	0.322	0.322
	r	0.994	0.994	0.994
	MSE	0.005	0.031	0.056
	MSD	13.197	11.847	11.244
Harking and Jura	A	11.262	10.871	10.927
	B	15.826	15.736	15.661
	r	0.994	0.994	0.994
	MSE	0.006	0.020	0.026
	MSD	12.679	10.481	10.852
Henderson	A	2.911	2.889	2.887
	B	0.288	0.294	0.302
	r	0.996	0.995	0.995
	MSE	0.005	-0.004	0.008
	MSD	11.595	14.942	13.657
Smith	A	-0.431	-0.430	-0.429
	B	-6.230	-6.226	-6.241
	r	0.996	0.994	0.994
	MSE	0.011	0.067	0.024
	MSD	12.915	12.481	10.371
Hasley	A	3987.788	3874.263	3834.587
	B	2.352	2.365	2.347
	X0	2.767	2.826	2.811
	r	0.993	0.995	0.995
	MSE	0.052	0.06	0.067
	MSD	13.595	10.955	13.458
Oswin Modifié	A	4.000	3.991	4.000
	B	0.499	0.477	0.525
	r	0.994	0.994	0.995
	MSE	0.038	0.004	0.042
	MSD	11.998	12.461	10.481

For both samples, the values of Xm determined by the B.E.T equation are relatively close to those determined by the G.A.B. The values of Xm for the TB sample are 2.151 and 2.179 g / g of maize at 20°C, 1.809 and 1.819 g / g of maize at 30°C, 1.404 and 1.410 g / g of maize at 35°C for ATM and BET models, respectively. The values of Xm for the SB sample are 2.261 and 2.270 g / g of corn at 20°C, 2.255 and 2.263 g / g of corn at 30°C; 2.254 and 2.259 g / g corn at 35°C for the G.A.B and B.E.T models respectively. Note that the water content of the mono molecular layer decreases when the temperature rises from 25 to 35°C in general. In addition, the values of the parameter C of the G.A.B model varied from 15774.32 and 16044.34 for the TB sample and from 15936.79 and 15969.17 for the SB sample (Tables 3and 4).

Table 4. Values of the estimated parameters and statistical selection criteria (TB)

		Temperature		
	Parameters	25°C	30°C	35°C
BET	Xm	2.179	1.819	1.410
	C	94.133	95.197	92.159
	r	0.995	0.996	0.995
	MSE	0.021	0.022	0.001
	MSD	14.583	11.163	10.936
GAB	Xm	2.151	1.809	1.404
	C	15874.13	15774.32	16044.34
	K	0.93	0.928	0.929
	r	0.999	1.000	0.994
	MSE	0.006	0.037	0.022
	MSD	9.037	10.51	13.366
Chung et Pfost	A	3.114	3.123	3.132
	B	0.324	0.322	0.322
	r	0.997	0.991	0.995
	MSE	0.040	0.012	0.038
	MSD	12.566	14.788	13.374
Harking and Jura	A	11.057	11.06	11.112
	B	15.725	15.829	15.526
	r	0.995	0.996	0.995
	MSE	0.017	0.047	0.006
	MSD	12.39	12.697	12.864
Henderson	A	2.873	2.896	2.9
	B	0.298	0.301	0.288
	r	0.997	0.995	0.996
	MSE	0.04	0.059	0.005
	MSD	11.84	14.248	16.374
Smith	A	-0.431	-0.430	-0.429
	B	-6.230	-6.229	-6.222
	r	0.994	0.996	0.996
	MSE	0.047	0.034	0.013
	MSD	11.005	9.285	11.385
Hasley	A	3996.133	3944.776	3925.175
	B	2.375	2.356	2.369
	X0	2.789	2.822	2.789
	r	0.995	0.996	0.994
	MSE	0.026	0.02	0.021
	MSD	11.236	13.264	12.495
Oswin Modifié	A	4.000	3.985	3.982
	B	0.502	0.568	0.472
	r	0.996	0.996	0.997
	MSE	0.004	0.034	0.034
	MSD	14.183	11.829	11.809

Tables 3 and 4 present the values of all the parameters of the various equations used and the criteria for the statistical choice of the appropriate model describing the isotherms of absorption of corn grains. For the sample stored in TB, the correlation coefficients r obtained varied between 0.994 and 0.999 for 25°C, between 0.991 and 1.000 for 30°C and between 0.994 and 0.996 for 35°C. The correlation coefficients r obtained with the sample stored in single bagging (SB) varied between 0.993 and 0.999 for 25°C, between 0.994 and 1.000 for 30°C and between 0.994 and 1.000. They are all high for different temperatures. The analysis of the parameters of the eight (8) empirical models used for each sample shows that the GAB model gave higher correlation coefficients r than the other models (0.999; 1.000 and 0.994 respectively for 25, 30 and 35°C for the TB sample and 0.999; 1.000 and 1.000 respectively for 25, 30 and 35°C for the SB sample. In terms of estimation errors (MSE and MSD), the lowest values are obtained in the G.A.B model for the two samples at three temperatures (20, 30 and 35°C). Thus, the GAB model seems to be the most suitable for describing the adsorption isotherms of corn kernels.stored in TB.

Residues with the GAB model

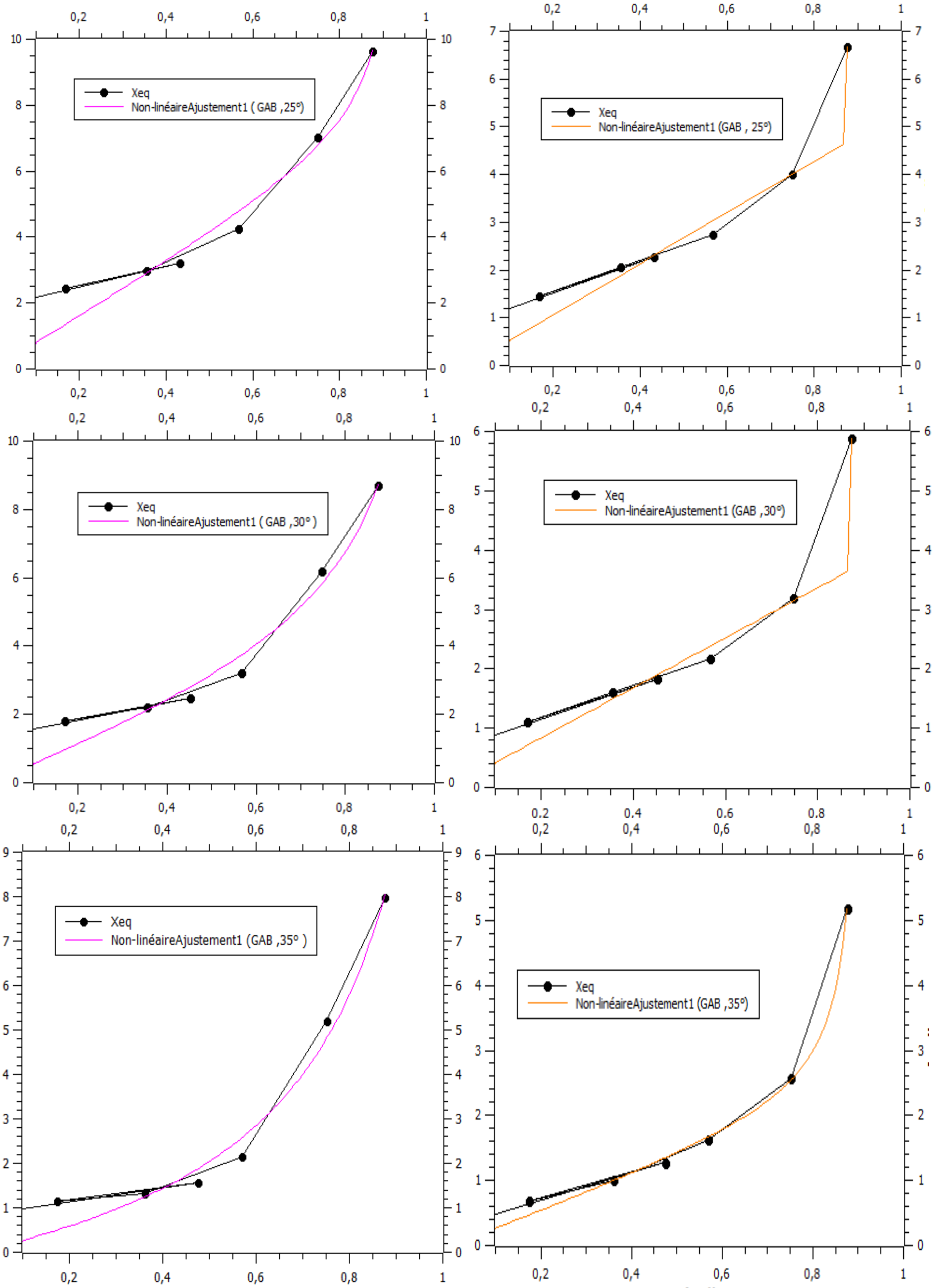

Figure 4. Modeling of adsorption isotherms and residues from GAB at 25, 30 and 35°C

Thermodynamic properties

Net isosteric heat and differential entropy: The net isosteric heat (qst) and differential entropy (ΔS) of adsorption of dry corn grains were calculated from the adsorption isosteres. Figure 10 shows the net isosteric heat (qst) and differential entropy (ΔS) of adsorption of dried corn kernels, respectively, after storage at temperatures between 25 and 35°C. These curves show that for high water contents (> 6 %), the net isosteric heat and the differential entropy (ΔS) of adsorption tend towards zero.

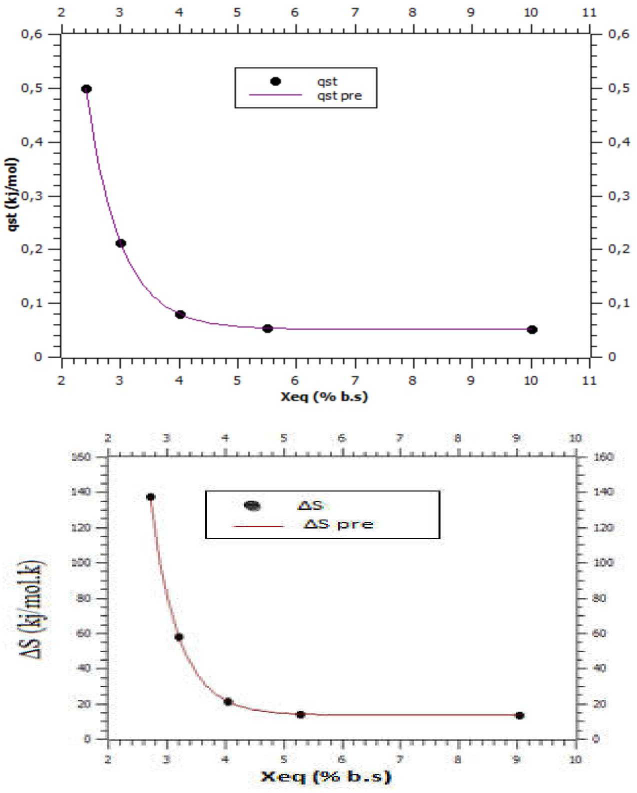

Figure 5. Isosteric heat (qst) (A) and differential entropy (ΔS) (B) of adsorption of dried corn kernels after storage

The experimental data of net isosteric heat (qst) and differential entropy (ΔS) were satisfactorily correlated (r = 0.9984) according to the following relationships:

qst =0,0045 + 27.754 Exp (-2.085 Xéq) KJ.mol^{-1}

ΔS =18,459 + 12236.631 Exp (-1.987 Xéq) J.mol^{-1}

Compensation theory: Figure 6 presents the enthalpy / entropy compensation theory of dried corn kernels. This curve shows a linearity between enthalpy (net isosteric heat) and differential adsorption entropy. The isokinetic temperature Tβ is 0.0035 K and the free energy ΔGβ is 0.0087 J / mol.

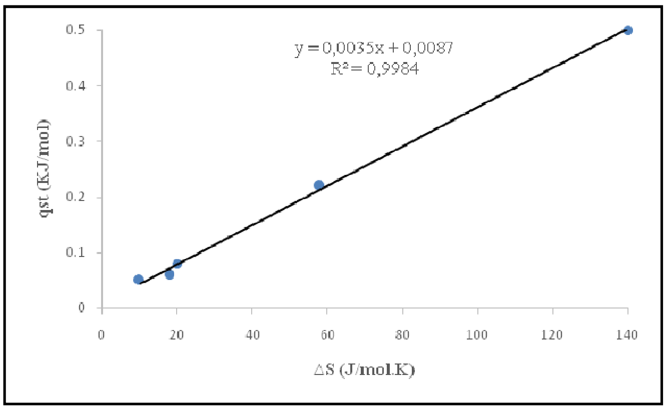

Figure 6. Enthalpy / entropy compensation theory of corn kernels

DISCUSSION

A high water content of corn kernels could promote chemical and enzymatic reactions and the development of microorganisms leading to deterioration of the product (Kouadio *et al,* 2015). Indeed, this water content of food products plays a primordial role in preservation (Cheftel and Cheftel, 1984). It therefore appears essential to determine the minimum water content that can promote the conservation of the corn kernels. This is how the absorption isotherms of maize were determined and characterized. Furthermore, the hygroscopic equilibrium of these samples was obtained after 25 days for the sample stored in single bagging and 35 days for the sample stored in triple bagging. These times are in agreement with those reported by kakou *et al,* 2015 who had to work on the isotherm of cocoa beans in which hygroscopic equilibrium was reached after 33 days for the last points of the curve. This difference in daylight observed between the two samples could be explained by the two conditioning methods. Isotherms are particularly important for determining the minimum water content of a product (Janot, 2008). Moreover, the absorption curves obtained at different temperatures made it possible to observe a decrease in the equilibrium water content of the different samples of corn with the increase in temperature. Kakou *et al,* 2015 explain this by the increase in thermal agitation. Indeed, at high temperature, the state of excitation is stronger and favors the reduction of the forces of attraction of molecules between them (Kouhila *et al,* 2002). One of the characteristics of isotherms is the type and water content of the monolayer. The type of corn kernel adsorption isotherm is determined by considering the values of parameter C of the G.A.B. When the parameter C ≥ 10, the isotherm is type II and when C ≤ 10, the isotherm is type III (Medeiros *et al,* 2006).

The results of this study revealed values of the parameter C greater than 10 for the different temperatures. Therefore, the isotherms obtained with the two samples are of type II with a characteristic sigmoidal shape. This type of adsorption isotherm has also been observed in the kernels of Irvingia gabonensis (Koko *et al,* 2018). This implies the formation of a monolayer, then a multilayer (Danion, 2004). In addition, this type of isotherm is characteristic of the hygroscopic behavior of most food products (Ahouannou *et al,* 2010). These results are in agreement with the behavior of biological products (Kouhila *et al,* 2002 ; Lahsasni *et al,* 2003). A second determined characteristic is the water content of the mono molecular layer (Xm). In this regard, the evaluation of the Xm parameters of the G.A.B model made it possible to reveal the water contents of the monolayer. Thus, at storage temperatures ranging from 25 to 35 °C, the water content Xm is 2.151 to 1.404% DM for the sample stored in TB and 2.261 to 2.254% DM for the sample in SB. The difference between the two values of the water content of the monolayer is therefore significant. This difference could therefore also be explained by the preservation technique applied to these two samples. In fact, the sample stored in TB was not in contact with the ambient air because it was coated in a series of three bags which will therefore promote a low water uptake of the corn kernels. On the other hand, the sample stored in a simple bag was more in contact with the external environment, thus leading to a rapid uptake in humidity and a strong presence of water at the level of the mono molecular layers of the corn kernels. The values of Xm obtained will therefore make it possible to ensure ideal conservation of the corn kernels. Indeed, the loss in the quality of dehydrated products, due to chemical reactions, microorganisms and insects is negligible below the value of the water content of the monolayer (kakou *et al,* 2015). In addition, (Karel *et al,* 1975) observed that at or below this value, chemical spoilage reactions are weak and the stability of the products is satisfactory during storage. In addition, several food products have an optimum water content for which the stability is maximum. This is the case for dates with 6.52% (Ferradji *et al,* 2008) and cocoa beans (2.12%). The water content of the monolayer (Xm) recorded with the sample stored in TB would therefore be this optimum value for corn kernels. It is less than the water content of the sample monolayer stored in a single bag. Thus, these maize samples will be more vulnerable to spoilage during storage. To improve the shelf life of these gains, it would be desirable to preserve them by the triple sorting system so as to obtain a maximum value of Xm of the order of 2.151 - 1.404%. The different absorption isotherms determined experimentally at temperatures of 25, 30 and 35°C were fitted by eight empirical models. Taking into account the largest correlation coefficient r and the smallest error estimates (MSE and EMR), the models best describing the experimental points were chosen. Analysis of these selection criteria revealed that G.A.B's model provides the best fit at 25, 30 and 35°C. Indeed, he gave at these temperatures, the largest r and the smallest error estimates.

These results are in agreement with many works carried out on sorption isotherms where the GAB model simulated better, over a large range of water activity, experimental data (Ahouannou *et al,* 2010; Sandoval and Barriero, 2002). Determining the sorption isotherms is an essential step and a privileged means of determining the final water content to be achieved in order to optimize the storage and drying conditions of these products. They also provide valuable information on the hygroscopic balance of the product to be stored. G.A.B's model, which better describes the adsorption isotherms of corn kernels, allows us to understand and predict the behavior of the kernels during storage or preservation at a given temperature. The net isosteric heat and the differential entropy of adsorption tend to zero as the water content of different corn samples increases. This illustrates the strong bond of water with the substrate, isosteric heat of absorption (Qs) becoming negligible compared to latent heat at high humidities. The existence of polar sites of high activity in maize which are covered with water molecules forming the mono-molecular layer (Tasmi, 1991) could explain this fact. According to other authors (Boki *et al,* 1990; Salgado *et al,* 1994), this phenomenon due to the fact that in a very restricted range of humidity, when the water content increases, certain products swell and promote opening of new strong bond adsorption sites, which increases isosteric heat. The enthalpy-entropy compensation process thermodynamically manifests the structuring-destructuring of water. The knowledge of the change in isosteric heat, and therefore also of the change in differential entropy, calculated from the Gibbs-Helmholtz equation, is interesting, because it offers an additional level of information to characterize the association of two molecules. Thus, the positive value of free energy (+ ΔG) shows that the adsorption process is not spontaneous (Benhamou *et al,* 2010).

Conclusion

The present study was carried out in order to determine the adsorption isotherms of corn kernels that were preserved by the TB and SB system in order to appreciate and identify the best preservation technique. The adsorption isotherms were determined by the static gravimetric method for three temperatures (25 °C, 30 °C and 35 °C). It emerges from this study that hygroscopic equilibrium is obtained after 35 days for the sample stored in TB and 25 days for the sample stored in SB. The adsorption isotherms determined are type II with a characteristic sigmoidal shape for the two corn samples. In addition, the equilibrium water content decreases with increasing temperature for a given water activity. The GAB model predicted the hygroscopic behavior of each corn sample ((r = 0.999; 1.000; 1.000 / 0.999; 1.000; 0.994 respectively for the single and triple bagged samples). The water content of the mono layer -molecular of the sample stored inTB (2.151 % at 25 °C, 1.809 % at 30 °C and 1.404 % at 35 °C) is lower than that of the sample stored inSB (2.261 % at 25 °C; 2.255 % at 30 °C and 2.053 % at 35 °C). To improve the shelf life of these corn kernels, they should be preserved after drying by the TB technique so as to reach a value of monolayer less than or equal to that of the water content of the monolayer (Xm) of the samples stored in TB.

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