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Study of Water Desorption Isotherms from Cocoa Beans (Theobroma Cacao L.) of Cameroon

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Abstract

The aim of this work was the determination of desorption isotherms from cocoa beans at different temperatures (20°C, 30°C, 35°C, 40°C and 45°C), moisture ratio (10% and 90%). Gravimetric method and different temperatures were used to get the experimental moisture ratio at equilibrium. Experimental data were adjusted to mathematical isotherm models frequently used for the hygroscopic representation of agricultural products. Cocoa beans varied from 0 to 13% moisture ratio equilibrium. Obtained results showed that the moisture ratio at equilibrium decreases as temperature increases for the same relative humidity. Statistical parameters, modified the Oswin model, GAB, Iglesias Chirife Hasley and Chungs Pfost modified model better represented hygroscopic balance for cocoa beans than Henderson modified and Harkings Jura models. Desorption isotherm models are important for the determination of desorption energy and drying models. The desorption isotherms of cocoa beans were satisfactorily modeled by modified Oswin, GAB, Iglesias, Chirife, Halsey, and modified Chungs Pfost, which can be used as tools in the prediction and optimization of storage conditions in a wide range of water activities and temperatures.

Keywords: Desorption Isotherm, Moisture Ratio At Equilibrium, Relative Humidity, Temperature, Mathematical Models, Cocoa Beans.

Introduction

Cocoa is an agricultural product that occupies a very important place in world market. This opportunity brings out an important added value during marketing by mastering drying techniques and product preservation. This is why the knowledge of water activity in cocoa beans is of considerable interest to the conservation technology of the latter (Akmel et al., 2015). Hence the determination of the desorption isotherm of cocoa beans is an essential step in the drying and conservation process when facilitating the determination of moisture ratio at equilibrium. However, relatives who work on desorption isotherm of cocoa beans from the Sub Saharan Africa particularly from Cameroon are very scare (Kakou et al., 2015). Perfect knowledge of desorption isotherm imposes to improve cocoa beans properties while producing them. This desorption isotherms offer precious information on hygroscopic balance of coca beans (Ahouannou et al., 2010).

This step is essential and improves the relation between moisture ratio of cocoa beans at equilibrium, relative humidity and temperature. Deduction of drying and conservation time is by the way possible (Ahouannou et al., 2010; Domian et al., 2018).

This work presents experimental and theoretical analysis of desorption isotherm data at 25°C, 30°C, 35°C, 40°C and 45°C. Different mathematical equations are used as adjusted theoretical models to represent desorption isotherms of cocoa beans. Theoretical models are established to discuss desorption isotherms (Nsouandélé et al., 2018; Benhamou et al., 2010).

2. Material And Methods

2.1. Description Of Experimental Device

The gravimetric static method with discontinuous control of sample mass was used for the determination of desorption isotherms (Kakou et al., 2015; Ahouannou et al., 2010; Nsouandélé et al., 2018; Simo-Tagne et al., 2016; Martinez-Las Heras et al., 2014; Wolf et al., 1985). This method uses saline solutions to keep constant water activity, while atmospheric conditions (Temperature and relative humidity) of the flasks and samples are at equilibrium. Saline solutions cover an interval between 10 to 90% as indicated by Prette et al., 2013 and Koua et al., 2014.

Two samples of cocoa beans fermented under banana leaves for six (06) days from the harvest of Kiiki (village situated in the Mbam and Inoubou

Sub Division in the Centre Region of Cameroon) producers, were put in each flask above the saline solutions, in a stabilized atmosphere and relative humidity. This experiment was carried out using a brand electronic balance with ± 0.01g precision, and an oven operating in forces convection for drying test ± 1°C precision (Figure 1).

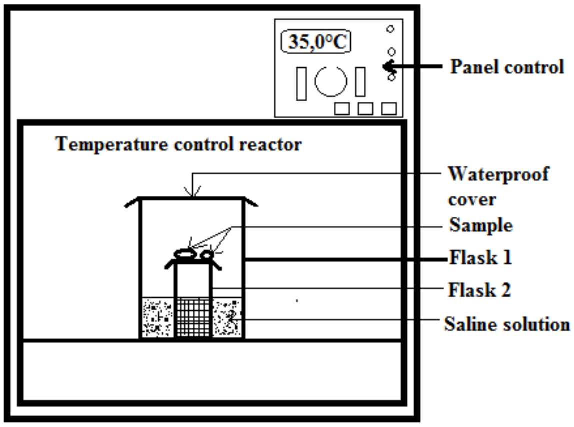

Figure 1: Experimental device for the determination of isothermal desorption point

2.2. Determination of desorption isotherms

The procedure followed to obtain these points consisted of varying relative humidity of the air in the enclosure at a constant temperature. Thus, from pair value (*T*, *Hr*), climatic environment conditions are defined. Since it is about desorption isotherms, relative humidity value is considered in the range of 92 to 10% (Kakou et al., 2015; Prette et al., 2013; Koua et al., 2014). To each atmospheric relative humidity value is associated a new climatic environment condition: new equilibrium point (Hr, Xeq). When different equilibrium masses are obtained, tested samples are taken again and then immediately put in the oven at 100°C (Figure 2). This operation favors the obtention of dry extracts, which under this condition undergo the total loss of free and bound water molecules (Collazos-Escobar et al., 2019; Kouhila et al., 2001). Samples are regularly weighed until their mass no longer varies: dry extract is obtained. Measured mass (*Ms)* of each sample is considered as anhydrous. From this parameter, different moisture ratio at equilibrium for each sample was defined. Product equilibrium moisture content is estimated using mathematical relation (1) (Kakou et al., 2015; Nsouandélé et al., 2018; Benhamou et al., 2010; Wolf et al., 1985).

$$X_{eq} = \frac{M_{eq} - M_s}{M_s} \qquad (1)$$

X_{eq} : Sample moisture ratio at equilibrium on dry basis (%),

M_{eq} : Mass of tested cocoa beans at equilibrium (g),

M_s : Mass of anhydrous tested cocoa beans at equilibrium (g),

For given temperature, different pairs (Xeq, Hr), enable to draw experimental desorption isotherms of studied products. (Xeq, Hr) pairs gave adsorption isotherms points.

Table 1: Standard values of sulphuric acid for each Aw sample

Sulphuric acid (%)	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
Hr **(25°C)**	0.9342	0.8785	0.7410	0.6452	0.5626	0.3538	0.2639	0.1124	0.0480
Hr **(30°C)**	0.9380	0.87384	0.74390	0.6496	0.5656	0.3551	0.2700	0.1520	0.0580
Hr **(35°C)**	0.9407	0.87592	0.74780	0.6584	0.5671	0.3592	0.2735	0.1568	0.0607
Hr **(40°C)**	0.9492	0.87856	0.74873	0.6675	0.5748	0.3669	0.2780	0.1870	0.0690
Hr **(45°C)**	0.9545	0.88157	0.7541	0.6712	0.5832	0.3704	0.2854	0.1886	0.0706

Figure 2: Experimental apparatus for desorption isotherms

2.3 Modelization of isotherms

To facilitate experimental sorption points analysis, six (6) mathematical models were used to describe and fit desorption isotherms of cocoa beans (Mousa et al., 2012; Bhouri et al., 2014; Akoy et al., 2013; Trignan, 1991). Table 2 presents different mathematical sorption isotherms models used for cocoa beans study. To obtain parameter related to immersed samples under defied conditions, a linear form is deduced, except for the GAB model where a polynomial of power 2 model is used as suggested by Akoy et al., 2013.

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Table 2: Mathematical sorption models

Isotherms	Expression	linear and nonlinear forms and plot	References
GAB (Guggenheim-Anderson-de-Boer)	$X_{eq} = \frac{K.C.X_0.Hr}{(1-K.Hr)(1-K.Hr+C.K}$ $C = C_0 \exp(\Delta H_c / RT)$ $K = K_0 \exp(\Delta H_k / RT)$ $X_m = X_0 \exp(E_a / RT)$	$\frac{Hr}{X_{eq}} = \frac{1}{CKX_m} + \frac{C-2}{CX_m} Hr + K \frac{1-C}{CX_m} Hr^2$ Plot : $\frac{Hr}{X_{eq}}$ vs Hr	Kamenan et al., 2017 ; Kouhila et al., 2001&2002
Iglesias, Chirife, Halsey	$X_{eq} = A(T\ln(1/Hr))^{-B}$	$\ln(X_{eq}) = \ln A - B\ln(T) - B\ln(-\ln($ Plot : $\ln(X_{eq})$ vs $\ln(-(Hr))$	Ahouamou et al., 2010; Kamenan et al., 2017 ; Kouhila et al., 2001
Modified Oswin	$X_{eq} = (A+BT)\left(\frac{Hr}{1-Hr}\right)^{1/C}$	$\ln(X_{eq}) = \ln(A+BT) + \frac{1}{C}\ln\left(\frac{Hr}{1-Hr}\right.$ Plot : $\ln(X_{eq})$ vs $\ln(Hr/(1-Hr))$	Kamenan et al., 2017 ; Ahouamou et al., 2010 ; Kouhila et al., 2002
Modified Henderson	$Hr = 1-\exp(-A.(T+B)X$	$\ln(-\ln(1-Hr)) = \ln(A(T+B)) + C\,\mathrm{l}$ Plot : $\ln(-\ln(1-Hr))$ vs $\ln(X_{eq})$	Koua et al., 2014 Brou et al., 2013 ; Kouhila et al., 2001
Modified Chungs, Pfost	$Hr = \exp\left(\frac{A.\exp(-BX_{eq})}{T+C}\right)$	$X_{eq} = -\frac{1}{B}\ln\left(\frac{T+C}{A}\right) - \frac{1}{B}\ln(-\ln(Hr))$ Plot : X_{eq} vs $\ln(-\ln(Hr))$	Kamenan et al., 2017 ; Koua et al., 2014 ; Kouhila et al., 2001
Harkings, Jura	$X_{eq} = \left(\frac{-B}{\ln(Hr)-A}\right)^{1/2}$	$\frac{1}{\ln(X_{eq})} = \frac{2A}{B} - \frac{2}{B}\ln(Hr)$ Plot : $\frac{1}{\ln(X_{eq})}$ vs $\ln(Hr)$	Brou et al., 2013; Ahouamou et al., 2010; Kouhila et al., 2001

2.3.1 Determination of different parameters (X_0, C_0, K_0, A, B et C)

Parameters X0, C_0, K_0, A, B et C, of different mathematical model where determined by identification at experimental desorption points, minimizing the sum of Mean Square Deviation (MSD) (2).

$$EQM = \frac{1}{N}\sum_1^N \left| X_{eqi,\exp} - X_{eqi,pre} \right|^2 \tag{2}$$

With : $X_{eqi,\exp}$ i^{th} : Experimental moisture ratio at equilibrium (% ms : dry substance),

$X_{eqi,pre}$ i^{th} : Predicted moisture ratio at equilibrium (% ms), *N*: quantity of experimental points.

To evaluate the reliability of each model to represent experimental isotherms, the square Mean Error (SME) given in equation (4) is used and evaluated for the entire experimentation at studied temperatures.

2.3.2 Statistical analysis

Statistical correlation methods and regression analysis are used to evaluate the reliability of each model to represent experimental isotherms. Regression analysis was estimated via Excel 2013 software using non-linear GRG algorithm. The correlation ratio (r) and SME were the main selective criteria of the best desorption isotherm mathematical model (Ahouannou et al., 2010; Nsouandélé et al., 2018; Simo-Tagne et al., 2016; Benhamou et al., 2010). The best model will be the one presenting the highest r value and the lowest SME value (Benhamou et al., 2010; Trignan, 1991).

$$r = \frac{\sum\left(X_{eqi,\exp} - \bar{X}_{eqi,\exp}\right)\left(X_{eqi,\mathrm{pre}} - \bar{X}_{eqi,\mathrm{pre}}\right)}{\sqrt{\sum\left(X_{eqi,\exp} - \bar{X}_{eqi,\exp}\right)^2\left(X_{eqi,\mathrm{pre}} - \bar{X}_{eqi,\mathrm{pre}}\right)^2}}$$

(3)

$$EMR = \frac{100}{N}\sum_1^N \left|\frac{X_{eqi,\exp} - X_{eqi,pre}}{X_{eqi,pre}}\right|$$

(4)

With : $X_{eqi,\exp}\ i^{th}$: Experimental moisture ratio at equilibrium (% ms),

$\bar{X}_{eqi,\exp} = \frac{1}{N}\sum_1^N X_{eqi,\exp}\ i^{th}$: Mean square experimental ratio,

$X_{eqi,\exp}$: i^{th} : Predicted moisture ratio at equilibrium (% ms),

$\bar{X}_{eqi,\mathrm{pre}} = \frac{1}{N}\sum_1^N X_{eqi,\mathrm{pre}}$: Predicted moisture ratio,

N : Number of experimental points, d_f : Regression model degree of freedom

$\mathrm{d}_f = N - n$: Number of variables for each model.

3. Results And Discussion

3.1. Experimental Results

Experimental moisture ratio values at equilibrium for two (02) samples of fermented cocoa beans as function of relative humidity of the medium for the five (05) studied temperatures 25°C, 30°C, 35°C, 40°C et 45°C, are illustrated in figures 3 and 4. Isotherms at these different temperatures look same with a sigmoidal form. The graphs were obtained from experimental desorption isotherms shows two inflection points that limit three zones of different desorption. These results are as those obtained by (Kakou et al., 2015; Ahouannou et al., 2010; Oliveira et al., 2011). These observations accordingly to other authors look same and concordant desorption isotherms of agro-industrial product, aromatic and medicinal plants, (Akmel et al., 2015; Kakou et al., 2015; Kouhila et al., 2001; Oliveira et al., 2011; Kouhila et al., 2002; Iglisias et al., 1976).

Experimental graphs obtained showed that for, specific water activity, moisture ratio at equilibrium goes different considering relative humidity and temperature. This is perfectly in agreement with many results from other authors with biological products (Oliveira et al., 2011).

Figures 3 and 4 show respectively, the graphs of experimental desorption isotherms (samples 1 and 2) of cocoa beans, according to relative humidity for the five-given temperatures.

Desorption isotherms decrease with temperature. Hence, moisture ratio decreases when temperature increases. These results show that, for specific water activity, moisture ratio at equilibrium decreases when temperature increases, according to obtained results on agri-food products (Domian et al., 2018). This behavior can explain how temperature affects the mobility of water molecules and dynamic equilibrium between water vapor and adsorbed phase. Moisture ratio at equilibrium increases by the way when there is a high activity of water at all temperatures. This status can be associated to excitation state of water molecules. This behavior is characteristic for products with high soluble components, such as sugars.

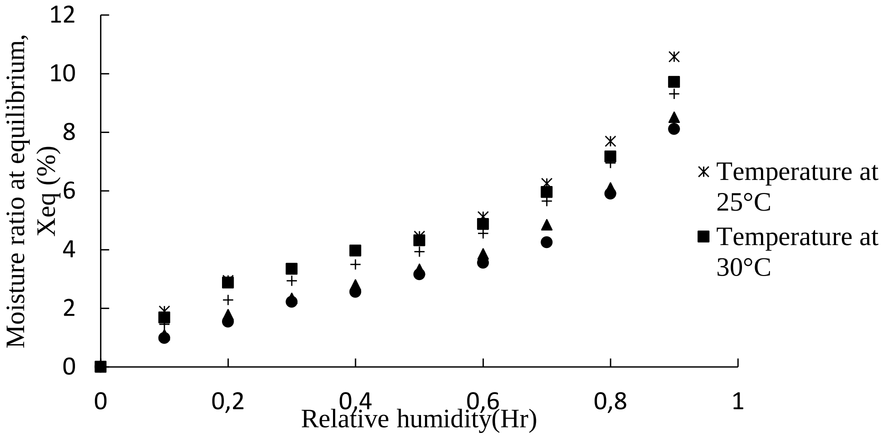

Figure 3: Desorption isotherms of cocoa beans at different temperatures for sample 1

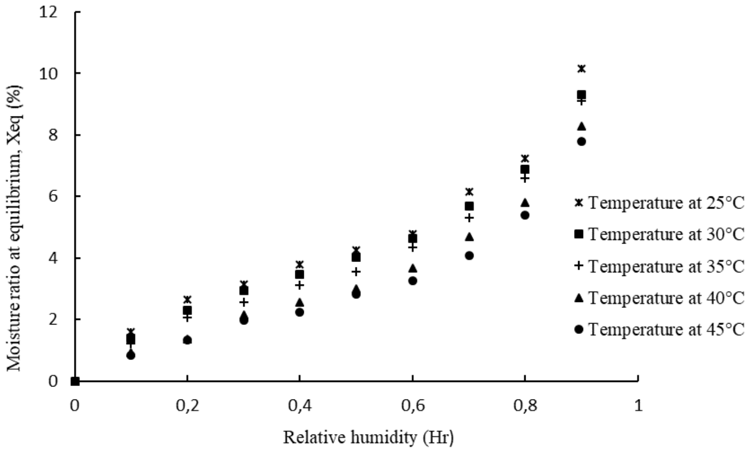

Figure 4: Desorption isotherms of cocoa beans at different temperatures for sample 2

Figures 3 and 4 showing the desorption process on cocoa beans samples require and force to find mathematical models to take into account during drying process of cocoa beans at different temperatures. Within the most used mathematical models, Oswin modified models, GAB, Iglesias Chirife Halsey model, Henderson modified model, Chungs Pfost modified model, Harkings Jura model with X_0, A, B et C parameters, usually optimize the fitting of experimental points for almost all agri-food products in water specific activity. Hence experimental results enable the determination of basic parameters from a required estimation method.

3.2 Estimation of model's parameters

Table 3 presents mathematical model's parameters of desorption isotherms used and studied statistical criteria applied to cocoa beans. It appears correlation ratio r, adjusted MSD and SME corresponding to each mathematical model. As temperature increases, there is a decrease in number of parameters.

Five temperatures (25, 30, 35, 40 et 45°C) for Iglesias Chirife Halsey, and Chungs Pfost models, Oswin and GAB models present low estimation errors MSD, SME than modified Henderson and Harkings Jura models. However, MSD and SME estimation errors values for GAB model are similar to those of Halsey. Hence, Iglesias Chirife Halsey, and Chungs Pfost models, followed by Oswin and GAB models seem to be more appropriate to describe desorption isotherm of dried cocoa beans.

Table 3 analysis shows that tested models give good results as different correlation ratio r are very high at different temperatures. By the way correlation ratio values close to 1 confirmed that experimental results fit very well the different models. They varied from 0.9342 to 0.9969 at 25°C, from

0.9417 to 0.9968 at 30 °C, from 0.9956 to 0.9972 at 35°C, from 0.9406 to 0.9980 at 40°C, and from 0.9312 to 0.9950 at 45 °C. However, modified Oswin, GAB, Iglesias Chirife Halsey, and modified Chungs Pfost models, have the most interesting results and closer to the experimentation. They give the best correlation ratio r and MSD value close to 0 at all the considered temperatures comparatively to modified Henderson and Harkings Jura models. In addition, the past models give wide range of validity integrating relative humidity obtained during processes comparatively to modified Henderson and Harkings Jura models.

3.3. Desorption isotherms modeling of cocoa beans

Figures 5 to 10 show moisture ratio experimental value at equilibrium for each sample and respectively theoretical graphs models of Oswin, de GAB, Iglesias, Chirife, Halsey, Chungs Pfost, Henderson and Harkings Jura at different temperatures as function of relative humidity. Most theoretical models' parameters are similar to experimental ones especially concerning relative humidity between 10 to 80%.

Table 3: Statistical criteria and adjusted parameters

Models	Parameters	25°C	30°C	35°C	40°C	45°C
Modified Oswin	A	4.318	3.962	3.874	3.595	3.562
	B	0.004	0.008	0.015	0.259	0.161
	C	0.459	0.451	0.436	0.421	0.415
	r	0.9825	0.9947	0.9912	0.9896	0.9850
	MSD	3.18 E-04	1.45 E-04	1.92 E-04	2.07 E-04	7.40 E-05
	SME	8.894	8.525	8.161	8.498	8.716
GAB	X_0	2.432	2.235	2.218	2.127	2.123
	C_0	16980.214	78401.245	78615.351	78624.361	78709.915
	K_0	0.898	0.881	0.876	0.871	0.870
	r	0.9695	0.9683	0.9628	0.9666	0.9619
	MSD	4.35 E-03	9.69 E-03	5.26 E-03	1.01 E-03	7.40 E-03
	SME	10.456	10.652	10.817	10.211	10.324
Iglesias, Chirife, Halsey	A	4146.563	3918.593	3819.712	3742.283	3687.189
	B	2.452	2.418	2.341	2.298	2.256
	r	0.9967	0.9968	0.9952	0.9946	0.9950
	MSD	1.52 E-04	1.15 E-04	1.39 E-04	2.25 E-04	4.32 E-05
	SME	6.257	6.428	6.427	6.318	6.142
Modified Henderson	A	0.243	0.221	0.208	0.193	0.184
	B	0.915	1.017	1.125	1.177	1.203
	C	1.245	1.326	1.453	1.498	1.519
	r	0.9512	0.9647	0.9488	0.9556	0.9559
	MSD	2.35 E-03	1.10 E -03	3.45 E-03	8.86 E-04	1.68 E-04
	SME	6.118	9.815	9.098	9.030	9.251
Modified Chungs, Pfost	A	54.840	69.577	91.754	120.518	135.473
	B	0.433	0.451	0.478	0.482	0.497
	C	-207.205	-187.805	-178.95	-169.183	-158.993

	r	0.9969	0.9967	0.9972	0.9980	0.9910
	MSD	1.49 E-04	1.45 E-04	1.92 E-04	2.07 E-04	7.40 E-04
	SME	6.465	6.445	6.282	6.241	6.121
Harkings, Jura	A	13.654	16.525	10.629	10.829	10.629
	B	0.1308	0.0698	0.0618	0.0598	0.0618
	r	0.9342	0.9447	0.9356	0.9456	0.9312
	MSD	5.12 E-03	1.10 E -03	5.32 E-03	8.86 E-03	1.68 E-03
	SME	11.423	11.586	11.602	11.459	11.237

There a good description of experimental values by theoretical models. These figures showed that moisture ratio at equilibrium and temperature follow opposite directions. The above six figures presented the best description of sigmoidal form between [0%, 20%] intervals for concave curves, [20%, 70%] for linear curves and [70%, 100%] for convex curves.

Modified Oswin, GAB, Iglesias, Chirife, Halsey, modified Chungs Pfost, desorption isotherms models presented in figures 10 to 13 are similar to those obtained by Ahouannou et al., 2010; Kamenan et al., 2017; Akmel et al., 2015. Modified Henderson and Harkings Jura models obtained are by the way similar to (Akmel et al., 2015).

Desorption isotherms models presented in figures 5 to 8 are fitted experimental models when those on figure 14 and 15 do not fit exactly on modified Henderson and Harkings Jura desorption isotherms models. Figures 6 and 7 graphs are identic to those of other authors (Kakou et al., 2015; Kamenan et al., 2017; Ahouannou et al., 2010; Medeiros et al., 2006) who used Harkings, Oswin and de GAB as functions of relative humidity between 15% and 85%.

Using same temperature, desorption isotherms models of Iglesias, Chirife, Halsey, and modified Chungs Pfost (figures 7 and 8) fit experimental ones than modified Henderson and Harkings Jura models (figures 9 and 10). Days of fermentation of cocoa beans can then be explained using desorption isotherms models. These results accordingly to literature lead to undergo the importance of desorption isotherms and the determination of desorption heat drying models.

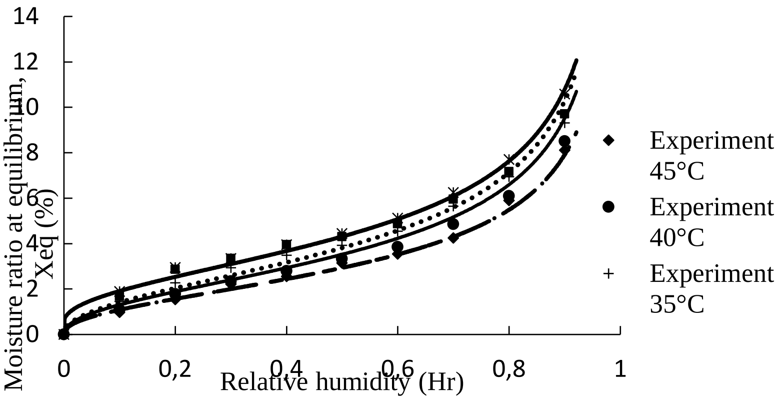

Figure 5: Experimental values vs adjusted modified Oswin model at different temperatures

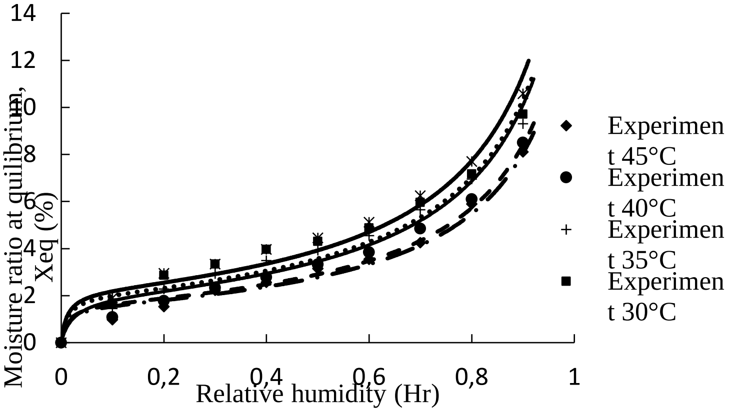

Figure 6: Experimental values vs adjusted GAB model at different temperatures

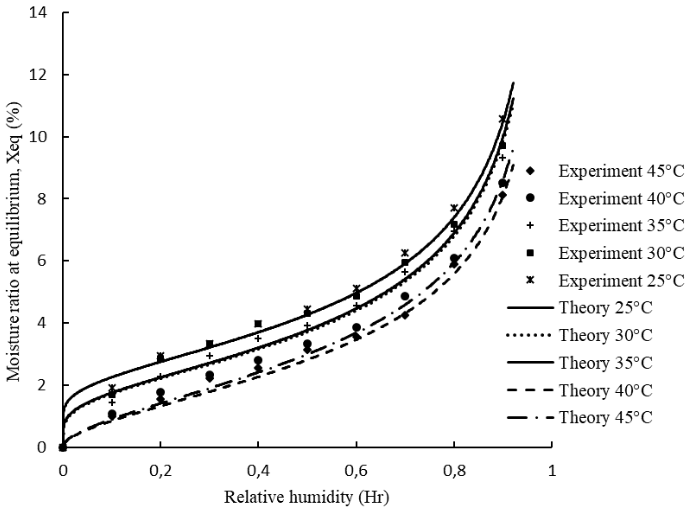

Figure 7: Experimental values vs adjusted Iglesias, Hasley model at different temperatures

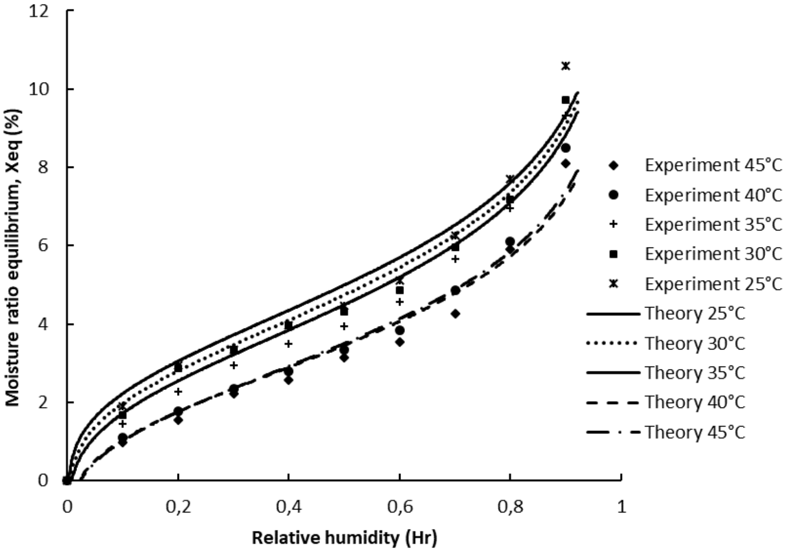

Figure 8: Experimental values vs adjusted Chung and Pfost model at different temperatures

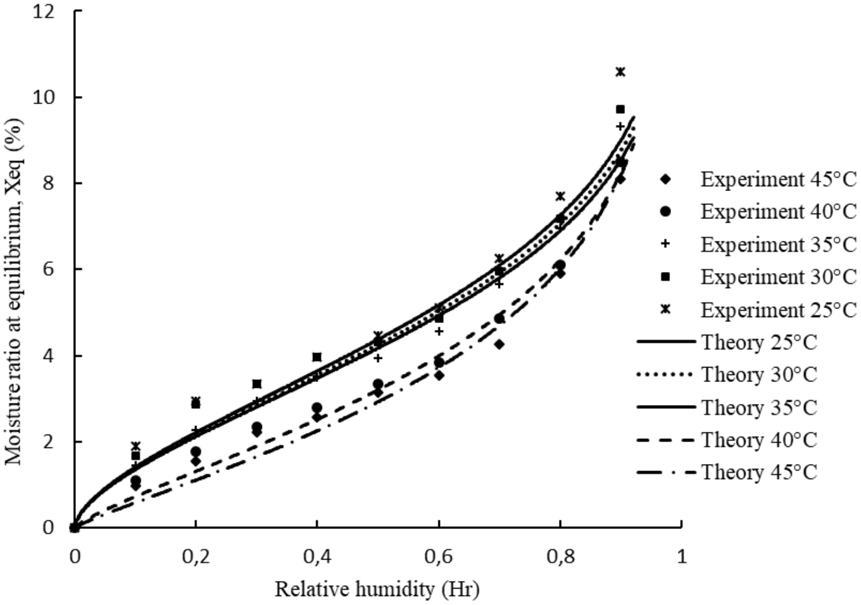

Figure 9: Experimental values vs adjusted modified Henderson model at different temperatures

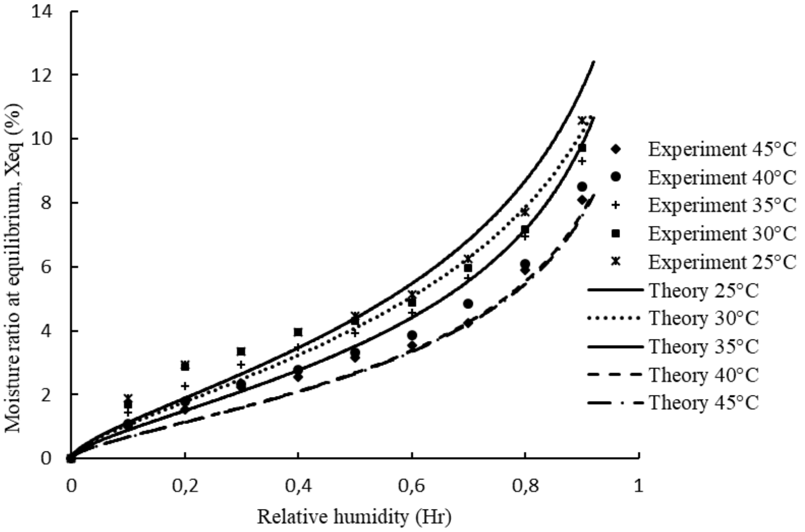

Figure 10: Experimental values vs adjusted Harkings and Jura model at different temperatures.

3.4 Cocoa beans theoretical modeling desorption isotherms

Figures 11, 12, 13, 14 and 15 show theoretical curves at different temperatures of Oswin modified, GAB, Iglesias, Chirife and Halsey, Chungs Pfost modified, Henderson modified, and Harkings Jura models. It appears that hygroscopic equilibrium of cocoa beans varies between 0 and 14% of relative humidity. Theoretical results predict well cocoa beans behavior. These graphs show for low relative humidity values (less than 20%) concave curves. These explain the first layer diffusion of water molecules on the surface of the solid skeleton, binding energy is very important as water is diffused. At intermediates relative humidity (between 25 and 85%) curves seem to be linear. The slope explains water molecules behavior that are fixed to others, binding energy being low. Finally, high relative humidity (close to 100%) presents convex curves. The last molecules of water are bonded on surface irregularities, hence capillary condensation and low binding energy. These desorption isotherms showed an inflection point and split into three different desorption regions, (Oswin, 1946; Pfost et al., 1976; Harking et Jura, 1944; Henderson, 1952; Brou et al., 2013).

- The first region **(Hr < 20 %)** corresponds to water action highly bonded to the microporous structure. Water molecules are bonded on surface functional groups.
- On the second region **(20%<Hr<70%) monolayer formation continues when water molecules are bonded on those previously adsorbed to form**

a poly molecular layer. Water adsorbed mass molecules seemed to increase linearly.

- A third region (Hr>70%) is where the partial water vapor pressure is high and porous solid structure is occupied by multilayer water molecules. Water bonds with the solid becomes weak and multilayer on micropores join to form capillary water.

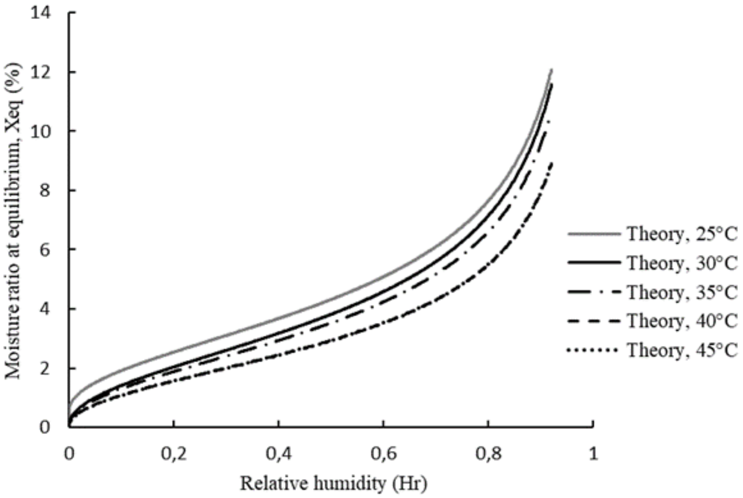

Figure 11: Oswin modified models at different temperatures

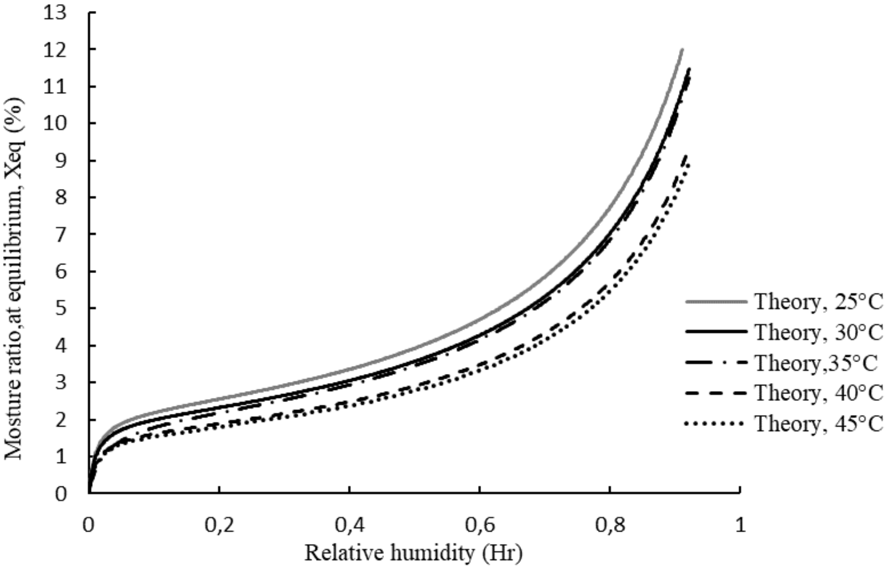

Figure 12: GAB models at different temperatures

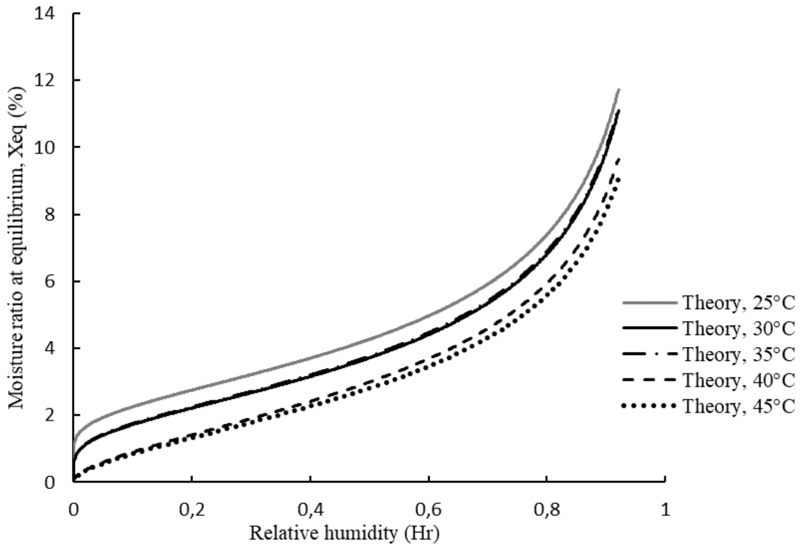

Figure 13: Iglesias, Hasley models at different temperatures

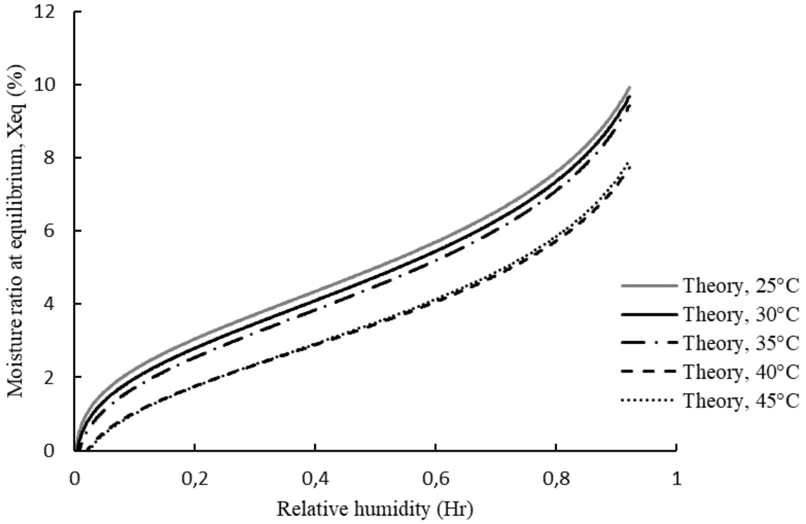

Figure 14: Chung Pfost modified models at different temperatures

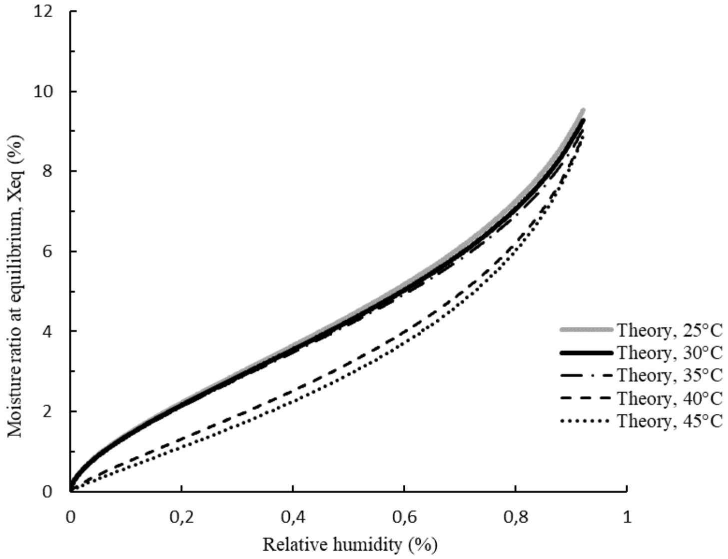

Figure 15: Henderson modified models at different temperatures

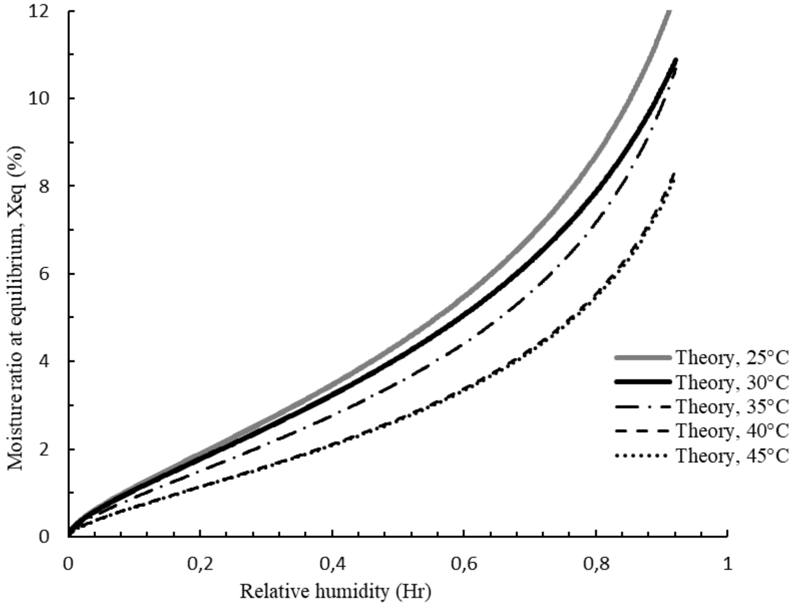

Figure 16: Theoretical Harkings et Jura models at different temperatures

4. Conclusion

Desorption isotherms of cocoa beans were experimentally and theoretically obtained using six different mathematical models at five temperatures (25°C, 30°C, 35°C, 40°C and 45°C).

These desorption isotherms are theoretical mathematical models of Oswin, GAB, Iglesias, Chirife, Halsey, Chungs Pfost, Henderson, and Harkings Jura plotted considering experimental values.

It is observed that predicted Iglesias, Chirife, Halsey, and modified Chungs Pfost fitted well experimental values for activities between 10 to 90% followed by modified Oswin and GAB considerably fitting experimental values for activities between 10 to 30% even more for activities between30 to 70% , and finally modified Henderson and Harkings Jura models which fitted very well experimental values that requested more fermentation days. Relations between moisture ratio at equilibrium and relative humidity of cocoa beans at different temperatures were established. It appears form those results that for specific water activity, moisture ratio at equilibrium decreases when temperature increases; hence moisture ratio at equilibrium increases when water activity increases at all considered temperatures. These theoretical mathematical models favored the estimation of moisture ratio at equilibrium values of cocoa beans at different relative humidity values frorm studied ones. Obtained results facilitates the utilization of mathematical desorption isotherms models as a function of humidity at equilibrium for cocoa beans.

The unanimous consideration of previous results is the small moisture ratio value at equilibrium and relative humidity for cocoa beans. Water vapor pressure will always be lower than saturation water vapor pressure for a given temperature. It appears that the behavior of hygroscopic equilibrium of cocoa beans varies between 0% and 14% of humidity.

This behavior that influences desorption isotherms is further related to capillary forces which seem to keep water in the liquid phase. Moisture ratio at equilibrium increases as relative humidity increases. The increase in molecules pressure which lays the increase of relative humidity is due to the increase of water molecules which favor their diffusion in pores.

All the collected results in the work permits to constitute a data basis for modeling and simulation of cocoa beans drying processes. Desorption isotherms of cocoa beans were satisfactorily modeled by the modified Oswin, GAB, Iglesias, Chirife, Halsey and modified Chungs Pfost, which can be used as tools in the prediction and optimization of storage conditions in a wide range of water activities and temperatures. They allow a physical interpretation of desorption phenomena from considered hypothesis. However, it was considered that all sorption sites are homogenous (same affinity) and independent.

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