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Equilibrium isotherms and isosteric heat of pepper variety bico (*Capsicum chinense* Jacq.)

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ABSTRACT. During processing, the storage requires attention, since the moisture content is a major factor that influences the quality of raw materials and manufactured products. Equilibrium isotherm represents the relationship between the material moisture content and water activity for a given temperature, providing important information for use in industrial operations such as drying and storage. This study aimed to determine the equilibrium isotherms of peppers variety bico (*Capsicum chinense* Jacq.) in whole and paste forms, calculate the isosteric heat of desorption and determine its behavior. To this end, we used six mathematical models to fit experimental data of desorption isotherms. The GAB model fitted well the experimental desorption data of pepper variety bico, in paste and whole forms. The isosteric heat obtained for the whole form was higher than for the paste form.

Keywords: shape, moisture content, GAB model, isosteric heat.

Isotérmicas de equilíbrio e calor isostérico de pimenta variedade bico (*Capsicum chinense* Jacq.)

RESUMO. Uma das precauções a serem tomadas durante o processamento de pimenta está no armazenamento, uma vez que o teor de umidade é um fator importante que influencia a qualidade da matéria-prima e do produto fabricado. Isotérmicas de equilíbrio são a relação entre o teor de umidade e atividade de água do material para uma determinada temperatura, fornecendo informações importantes para o uso em operações industriais como a secagem e o armazenamento. O objetivo deste estudo foi determinar as isotermas de equilíbrio em pimentas, variedade bico inteiras (*Capsicum chinense* Jacq.) e em forma de pasta, calcular o calor de isostérico de dessorção e determinar o seu comportamento. Neste trabalho foram utilizados seis modelos matemáticos para realizar o ajuste de dados experimentais de isotérmicas de dessorção. O modelo de GAB ajustou-se adequadamente aos dados experimentais de dessorção de pimenta, variedade bico para ambas as formas, pasta e inteira. O calor isostérico obtido para a forma inteira foi maior do que a forma de pasta.

Palavras-chave: forma, conteúdo de umidade, modelo de GAB, calor isostérico.

Introduction

Peppers are used as food plants, which produce the spicy/heating sensation due to its chemical components, able to stimulate the taste buds in the mouth. There are basically two genera of popular peppers, *Piper* and *Capsicum* (BONTEMPO, 2007). The genus Piper is represented by seeds of plants of the family Piperaceae, the black pepper (*Piper nigrum* L.) is the most common. The genus *Capsicum* belongs to the family Solanaceae and includes about 20-30 species, and according to Medina et al. (2006) in this genus stand out the species *Capsicum annuum* L., *Capsicum frutescens* L., *Capsicum chinense* Jacq., *Capsicum pubescens* L. and *Capsicum baccatum* L.

The species *Capsicum chinense* Jacq. is characterized by producing fruit ranging from 1.0 to 13.0 cm long, with spherical to elongated shape and having assorted colors, for example, orange, yellow, red or brown (SMITH; HEISER, 1957). This species has, on average, a fairly simple composition, containing 80-85% water and the remaining 20-15% is composed of protein, carbohydrate, fat and minerals (TBCA-USP, 2011).

Cultivation of peppers occurs in virtually all regions of the country and is one of the best examples of family farming and small farmer-agribusiness integration. Besides the domestic market, part of the Brazilian pepper is exported in different forms, such as paprika, paste, canned and dried plants (EMBRAPA, 2010; REIFSCHNEIDER, 2000).

Most foods, as well as peppers, contain about 80% water and are therefore highly perishable. To minimize losses it is important to know the water content curves of the product, expressed as weight of water per unit mass of dry food vs. its water activity (a_w) at a given temperature. Such curves are called sorption isotherms. The plots of sorption isotherms provides information relevant to hydration and dehydration/drying processing of food, and also can be used to assess and monitor the stability of food products during storage (BOBBIO; BOBBIO, 2001; DAMODARAN et al., 2010). Many authors studied the isotherms of food materials, such as Arévalo-Pinedo et al. (2006), Cassini et al. (2006), Ghodake et al. (2007), Goula et al. (2008), Iguedjtal et al. (2007), Jamali et al. (2006), Mohamed et al. (2005) and Moraga et al. (2006).

The energy required to remove a specific volume of water bound to a material is higher than that used to vaporize an equal amount of free water under the same conditions of temperature and pressure, the difference in energy is called as isosteric heat of sorption, which is considered an indicator of the intermolecular attractive forces between the sorption sites and water vapor. Knowledge of the isosteric heat as a function of equilibrium moisture content is essential in studies of drying and storage of agricultural products (GHODAKE et al., 2007; WANG; BRENNAN, 1991). The sorption characteristics, such as the isosteric heat, can be altered or affected by different factors related to processing and transformation of raw material, including the shape and temperature of the product.

The major interest of the food industry in products made from pepper has driven the research related to methods of processing and preservation (CORNEJO et al., 2005; LANNES et al., 2007). In the last decade the study of pepper varieties gained the attention of many research groups and industries interested in getting high quality products. However, there have been a limited number of studies published in the literature, as the above mentioned review. Thus, it becomes of great interest to study the sorption isotherms of pepper *Capsicum chinense* Jacq. variety bico/biquinho.

Given the importance of understanding the hygroscopic behavior of products with high moisture content, as in the case of peppers, this work examined the influence of shape on the sorption isotherms of the pepper variety ‘bico/biquinho’ (*Capsicum chinense* Jacq .) as well as to calculate and determine the isosteric heat of sorption.

Material and methods

This study was conducted at the Laboratory of Agroindustrial Engineering and Processing, belonging to the Technology Center of Mato Grosso (CTMAT), State University of Mato Grosso/Campus Deputado Estadual Renê Barbour (UNEMAT) in Barra do Bugres, Mato Grosso State.

The raw material used was the pepper variety ‘bico’ (*Capsicum chinense* Jacq.) produced and marketed in the midnorth region of Mato Grosso State, where is located the municipality of Barra do Bugres.

Peppers were selected and cleaned by immersion in a solution of 100 mL L^{-1} sodium hypochlorite for 20 minutes and washed in tap water to remove the excess of sanitizing solution. Subsequently they were immersed in 15% sodium benzoate for 30 minutes, in order to retain the characteristics of the raw material during the experiment by preventing the action of microorganisms (PAGLARINI et al., 2013).

In order to determine the influence of the processing on the isotherms, the raw material was prepared in two ways, paste form and whole fruit; the paste form was produced with the aid of a Philips Walita food processor RI 7743. Next, three samples of each form was separated, each one weighing 5 g, to determine the initial moisture content by the direct drying method in oven at 105°C for 3 hours, according to the methodology of the Instituto Adolfo Lutz (IAL, 2005). Finally, the samples, paste and whole fruit, were packed in low density polyethylene under refrigeration until the time of use in the experiments, with a maximum storage period of about 2 weeks.

After these treatments, samples were weighed to a value of approximately 3 g, and placed in triplicate on small plastic containers of approximately 3 cm in diameter and 2 cm in height, which were put on plastic tripods, with a height approximately 5 cm, in sealed glass containers, with a size of approximately 8 cm in diameter and 13 cm height, to which was added 200 mL sulfuric acid (H_2SO_4), at concentrations that guaranteed constant relative humidity; it is thus the static gravimetric method.

The experimental design was completely randomized in a factorial 2 x 4 x 11, with two levels of form, four temperature levels (20, 30, 40 and

50°C) and eleven levels of sulfuric acid concentration (20, 25, 30, 35, 40, 45, 50, 55, 60, 65 and 70%), each one carried out in triplicate. The water activity (a_w) on the basis of temperatures and acid concentrations were obtained according to Perry and Chilton (1983).

Glass containers remained in the incubator until reaching constant mass. To this end, the samples were weighed periodically on an OHAUS electronic balance, model Adventurer Pro (AV264CP) accurate to 0.001 g, to determine whether the samples have reached such a condition of equilibrium, in other words, when there was no variation in its mass between two consecutive weighings. The first weighing was done after seven days, the second and third at days ten and fourteen, but not all experiments reached constant weight within fourteen days of observation, requiring new weighing every three days until reaching equilibrium.

After achieved the equilibrium conditions, samples were subjected to direct drying method according to the methodology of the Instituto Adolfo Lutz (IAL, 2005). Subsequently, the mathematical models in Table 1 were fitted to the experimental data by nonlinear regression analysis.

Table 1. Main models used to describe the isotherms of food.

Designation of the model	Model	Source	
GAB	$X_e = \frac{X_m\ C\ K\ a_w}{(1\text{-}K\ a_w)(1\text{-}K\ a_w + C\ K\ a_w)}$	Vásquez et al. (2003)	(1)
Henderson and Thompson	$X_e = \left[\frac{\ln\left(\frac{1}{1-a_w}\right)}{a\ (T+b)}\right]^{\frac{1}{c}}$	Fiorentin et al. (2010)	(2)
Henderson	$X_e = \left[a\left(\frac{1}{T}\right)\ln\left(\frac{1}{1-a_w}\right)\right]^{\frac{1}{c}}$	García-Pérez et al. (2008)	(3)
Halsey	$X_e = a\left[T\ \ln\left(\frac{1}{a_w}\right)\right]^{\frac{-1}{c}}$	Halsey (1948)	(4)
Chen and Clayton	$X_e = \left(\frac{1}{-\ c\ T^D}\right)\ln\left(\frac{\ln a_w}{-\ b\ T^a}\right)$	Park et al. (2008)	(5)
Luikov	$X_e = \frac{a}{1+b\ T\ \ln\left(\frac{1}{a_w}\right)}$	Luz et al. (2006)	(6)

Where in: T - temperature (°C); X_e- equilibrium moisture content, d. b.; a_w- Water Activity; $C = c * exp^{\left(\frac{D}{T}\right)}$; $K = a * exp^{\left(\frac{E}{T}\right)}$; X_m - humidity in the monolayer, d.b.; a, b, c, D - tuning parameter.

The experimental data were compared with calculated values by mathematical models, analyzing the coefficients of determination (R^2) and the estimated average error (SE), according to the equation 7, to determine which model best fits the results.

$$SE = \sqrt{\frac{\sum (Y - Y_0)^2}{GLR}} \quad (7)$$

where:

Y - experimentally observed value,

Y_0 - value calculated by the model;

GLR - degrees of freedom of the model.

To calculate the isosteric heat (QST) a linear regression of data was run between the natural logarithm of water activity and the reciprocal of temperature at different equilibrium moisture content, and then the Clausius-Clapeyron equation (equation 8) was applied to it.

$$Q_{ST} = -\ R\left[\frac{\partial(\ln a_w)}{\partial(1/T)}\right] \quad (8)$$

where in:

Q_{ST} - isosteric heat (kJ kg^{-1});

a_w - Activity of water,

T - Temperature (K),

R - universal gas constant (0.4618 kJ kg K^{-1}).

The latent heat of vaporization of free water was calculated for the average temperature of the experiments, according to the method adopted by Ascheri et al. (2009) with a value of 43.5 kJ kg^{-1}.

To predict the behavior of the isosteric heat of sorption as a function of moisture content, we used the model of Hubinger et al., (2009), according to the equation 9.

$$Q_{st} = A + B{\star}\exp\left(\frac{-X_e}{C}\right) \quad (9)$$

where:

A, B and C = model parameter setting.

Results and discussion

Tables 2 and 3 show the experimental values for the desorption isotherms of 'bico' pepper, in paste and whole forms, subjected to environmental conditions in acid solutions ranging from 4.3 to 88.8% and temperature of 20, 30, 40 and 50°C.

Table 2. Equilibrium moisture content (X_e) for 'bico' pepper in whole form, in the desorption phase (acidic solutions), and water activity (a_w), for temperatures of 20, 30, 40 and 50°C

Temperature (°C)							
20		30		40		50	
a_w	X_e	a_w	X_e	a_w	X_e	a_w	X_e
0.878	0.735	0.873	0.582	0.878	0.574	0.888	0.352
0.816	0.494	0.817	0.401	0.824	0.306	0.829	0.251
0.749	0.302	0.747	0.227	0.753	0.208	0.770	0.207
0.665	0.212	0.666	0.195	0.674	0.181	0.681	0.173
0.568	0.161	0.565	0.155	0.574	0.151	0.582	0.134
0.458	0.147	0.461	0.143	0.470	0.138	0.483	0.133
0.355	0.151	0.355	0.131	0.366	0.121	0.380	0.113
0.258	0.139	0.260	0.124	0.267	0.120	0.280	0.117
0.167	0.133	0.170	0.126	0.178	0.106	0.189	0.099
0.093	0.123	0.097	0.118	0.102	0.108	0.110	0.100
0.043	0.118	0.045	0.114	0.049	0.096	0.055	0.082

Table 3. Equilibrium moisture content (X_e) for 'bico' pepper in paste form, in the desorption phase (acidic solutions), and water activity (a_w), for temperatures of 20, 30, 40 and 50°C

Temperature (°C)							
20		30		40		50	
a_w	X_e	a_w	X_e	a_w	X_e	a_w	X_e
0.878	0.386	0.873	0.342	0.878	0.289	0.888	0.246
0.816	0.283	0.817	0.259	0.824	0.206	0.829	0.185
0.749	0.199	0.747	0.180	0.753	0.162	0.770	0.148
0.665	0.134	0.666	0.136	0.674	0.122	0.681	0.109
0.568	0.120	0.565	0.116	0.574	0.111	0.582	0.099
0.458	0.118	0.461	0.103	0.470	0.102	0.483	0.081
0.355	0.110	0.355	0.098	0.366	0.093	0.380	0.080
0.258	0.105	0.260	0.095	0.267	0.099	0.280	0.077
0.167	0.104	0.170	0.098	0.178	0.091	0.189	0.076
0.093	0.098	0.097	0.093	0.102	0.092	0.110	0.072
0.043	0.092	0.045	0.089	0.049	0.088	0.055	0.069

The equilibrium moisture in desorption isotherms of paste pepper ranged from 0.386 to 0.070, at water activities of 0.878 and 0.055 and at temperatures of 20 and 50°C, respectively, while the equilibrium moisture for the whole pepper form ranged from 0.735 to 0.096 as shown in Table 3 and Table 2, respectively. The equilibrium moisture content decreases, in both forms studied, with increasing temperature at different water activities. This phenomenon occurs because the increase in temperature causes the rise of the kinetic energy associated with water molecules from the product, resulting in reduced forces of attraction, and consequently a release of water molecules as vapor. Similar behavior was observed by several authors (GAZOR; CHAJI, 2010; MOREIRA et al., 2010, 2010a; ROSA et al., 2010).

From these data, we generated curves of equilibrium of sorption isotherms, which showed sigmoidal shapes, according to Figure 1, characteristic of fibrous materials with high initial moisture content, which is the case of 'bico' pepper, with water contents ranging from 80 to 85%. The same result was observed by Kaleemullah and Kailappan (2004), Vega-Gálvez et al. (2007) and Yazdani et al. (2006), with isotherms of chili pepper, red bell pepper (var. Lamuyo) and pistachio nuts, respectively.

The mathematical modeling of the isotherms of pepper in whole and paste forms was performed by nonlinear regression of the models presented in Table 1. Table 4 lists the values of correlation coefficients (R^2) and the estimated average error (SE) for each model, temperatures and pepper forms used in this study.

The values of the correlation coefficient (R^2) and the average error estimate (SE), calculated for each model indicated that the mathematical model of Guggeheim, Anderson and de Boer (GAB) showed the best fit to the experimental data, satisfactorily representing the phenomenon of desorption, as can be seen in Figure 2. According to Ribeiro and Seravalli (2004) this model is used to predict equilibrium isotherms of biological materials with high water content.

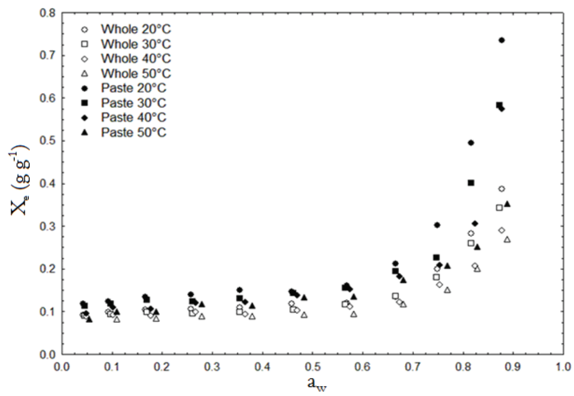

Figure 1. Desorption isotherms of 'bico' pepper in the whole and paste forms, at temperatures of 20, 30, 40 and 50°C.

Table 4. Correlation coefficients (R^2) and estimated average error (SE) for the models, temperatures and pepper forms used in this study

Model	Temperature (°C)	Whole R^2 (%)	Whole SE (%)	Paste R^2 (%)	Paste SE (%)
GAB	20	98.77	3.956	97.01	2.949
	30	97.76	4.044	97.25	2.486
	40	96.54	4.728	95.03	2.554
	50	98.24	1.965	97.69	1.367
Henderson Thompson	20	90.92	9.154	84.94	5.557
	30	83.42	8.221	85.14	4.843
	40	85.05	8.266	82.25	4.042
	50	87.72	3.070	88.22	2.177
Henderson	20	90.92	8.630	84.98	5.239
	30	90.92	7.751	85.18	4.566
	40	85.05	7.793	82.25	3.811
	50	87.72	2.894	88.22	2.052
Halsey	20	96.84	5.164	95.17	3.048
	30	95.29	4.756	95.40	2.609
	40	93.82	5.129	94.90	2.271
	50	96.95	1.476	96.92	1.074
Chen e Clayton	20	84.02	12.746	85.58	5.820
	30	83.42	9.811	86.28	4.990
	40	81.63	9.708	86.11	3.863
	50	89.90	2.994	91.51	1.993
Luikov	20	96.10	5.734	90.33	4.259
	30	93.32	5.638	90.18	3.763
	40	91.93	5.833	85.32	3.529
	50	90.69	2.539	89.04	1.984

A similar result was found by Kaymak-Ertekin and Sultanoglu (2001) who verified that the GAB model accurately described the isotherms of bell pepper in an environment containing salt solutions, and also verified the inverse relationship between the temperatures studied and the equilibrium moisture content of samples in addition to the direct proportionality between the equilibrium moisture content of food and water activity.

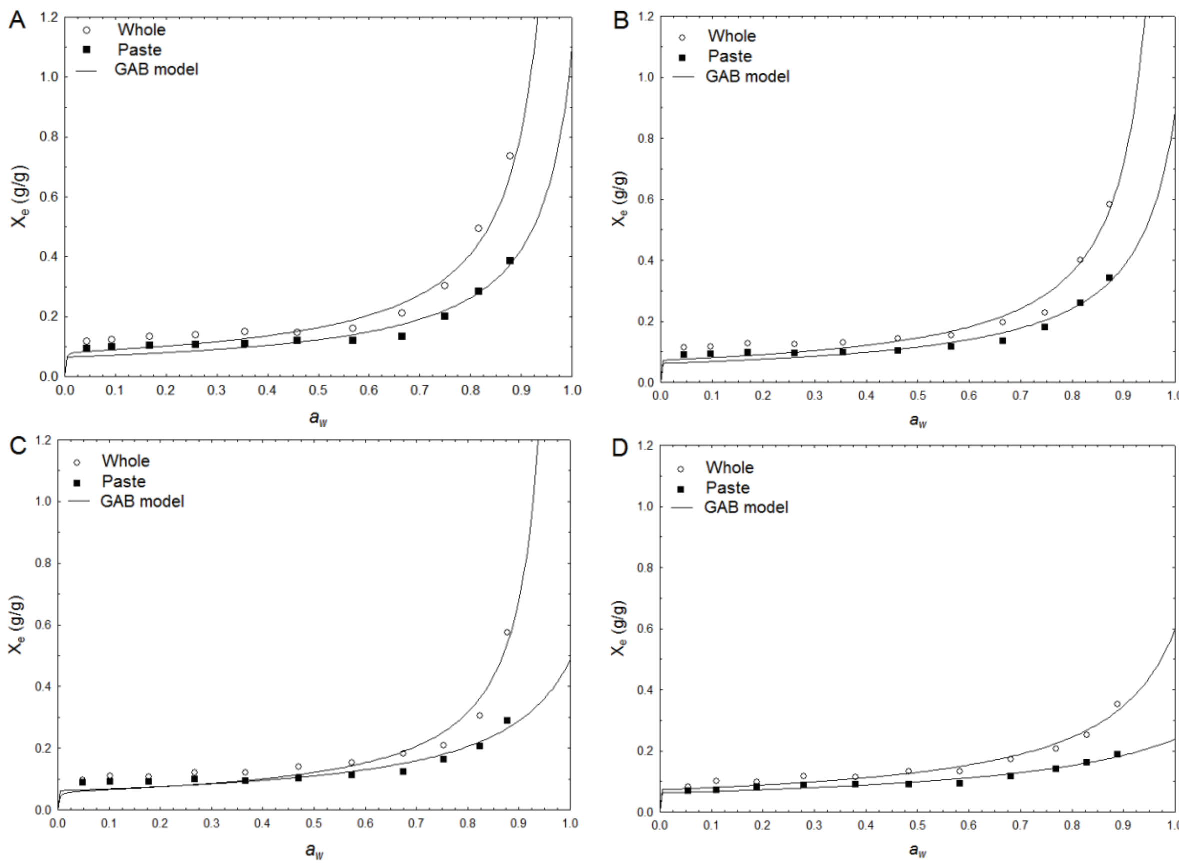

Figure 2. GAB model fit to the desorption isotherm of pepper in the whole and paste forms, at temperatures of 20 (A), 30 (B), 40 (C) and 50°C (D).

Vega-Gálvez et al. (2007) analyzed the sorption isotherms of bell pepper at temperatures of 10, 20 and 30°C in a range of water activity from 0.10 to 0.96 and also found that temperature directly influences the equilibrium moisture of the desorption isotherms, and in addition they noticed the direct proportionality between the equilibrium moisture content and water activity.

In general, the equilibrium moisture content decreases to a given value of water activity at a given temperature for both the whole and the paste forms of pepper. Such behavior is evident for the pepper paste in the range of water activity from 0.5 to 0.9 and the range of equilibrium moisture content (0.3 to 0.70 g g^{-1}), and at water activity of 0.6 to 0.9 range and equilibrium moisture content from 0.2 to 0.4 g g^{-1} for the whole pepper.

Table 5 shows the parameters calculated from the nonlinear regression of experimental data of equilibrium moisture content, for the GAB model in temperatures and forms studied.

From Figure 3 and Table 5, the values of moisture in the monolayer (X_m) obtained by the GAB model ranged from 0.65 to 0.51 (g g^{-1}) for the paste and from 0.082 to 0.060 (g g^{-1}) for the whole pepper, at temperatures from 20 to 50°C. Kaymak-Ertekin and Sultanoglu (2001), in studies with red bell pepper, observed that the monolayer moisture ranged from 0.038 to 0.113 (g g^{-1}) for the temperature range 30-50°C. Similar values were observed by Scala and Crapiste (2008) when analyzing desorption isotherms of bell pepper.

Table 5. Parameters calculated for the GAB model to the desorption isotherm of pepper in whole and paste forms, at temperatures of 20, 30, 40 and 50°C.

Form	Temperature (°C)	a	X_m	C	d	E
Whole	20	0.0240	0.082	142.384	39.025	74.589
	30	0.1140	0.073	812.479	68.234	65.086
	40	0.0900	0.060	253.276	26.418	96.852
	50	2.9220	0.073	10173.223	398.775	-60.126
Paste	20	0.1630	0.065	2601.74	126.649	34.985
	30	1.6790	0.062	8808.22	278.615	-17.721
	40	16.700	0.062	13581.22	455.497	-118.11
	50	53.44	0.051	17713.34	360.75	-205.29

It is noticed that the monolayer moisture for whole pepper is lower than for pepper in the paste form. Such behavior can be explained by the natural skin of the fruit, which is intended to prevent moisture loss, because otherwise, in the absence of this protection, the fruit could have a reduction in its moisture in low humidity environments (DAMODARAN et al., 2010).

The isosteric heat (Q_{ST}) or heat of sorption, was determined from the curves of isosteric sorption, which comprises all the natural logarithm of water activity, ln (a_w), for specific values of equilibrium moisture content as a function of reciprocal values of absolute temperature (K^{-1}) for the desorption isotherms as shown in Figure 3A and Figure 3B.

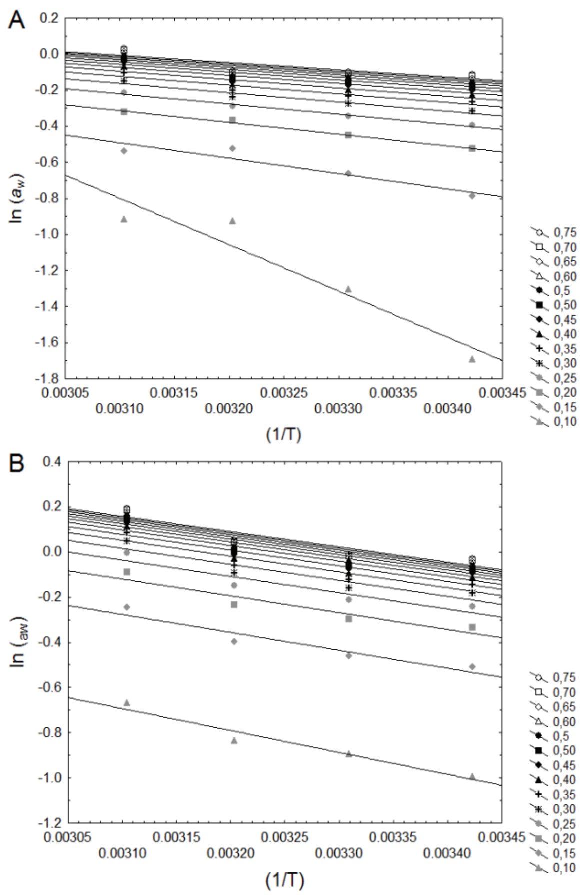

Figure 3. Curves of the logarithm of water activity, ln (a_w), for specific values of equilibrium moisture content as a function of inverse of absolute temperature (K^{-1}) to pepper in the whole (A) and paste forms (B)

The value of the heat of desorption (Q_{ST}) for each moisture content corresponds to the coefficient of the slope, multiplied by the universal gas constant, R = 0.4618 kJ $kg^{-1}K^{-1}$, as described by the Clausius – Clapeyron equation. Table 6 shows the calculated values for the heat of desorption for 'bico' pepper and their respective equilibrium moisture content.

Heat of desorption (Q_{ST}) reduced with increasing moisture, in other words, the lower the moisture of the material during the desorption, the more energy is required to evaporate water connected to the structure of the biological material.

Table 6. Values of the heat of desorption (Q_{ST}) for pepper variety 'bico' in the whole and paste form.

Equilibrium moisture (g g^{-1})	Whole	Paste
	Q_{st} (kJ kg^{-1})	Q_{st} (kJ kg^{-1})
0.75	185.28	132.84
0.70	187.40	133.31
0.65	189.89	133.85
0.60	192.85	134.48
0.55	196.44	135.28
0.50	200.87	136.24
0.45	206.25	137.45
0.40	213.79	139.02
0.35	223.76	141.14
0.30	238.14	144.15
0.25	260.68	148.78
0.20	301.09	156.80
0.15	394.76	174.13
0.10	855.34	238.21

According to Hubinger et al., (2009), as the equilibrium moisture content decreases, the value of the isosteric heat increases, as well as the water retention capacity of the food, due to an increasing concentration of fats, proteins and salts in the aqueous phase of the food. The monomolecular layer is more strongly linked to the polar groups of these substances, called active sites, gradually forming rigid and highly ordered structures, which require more energy to be broken and release water molecules in the form of steam. However, during food processing, the availability of active sites decreases and the isosteric heat value approaches to that of water in the pure state.

Moreover, the amount of heat of desorption in the paste form of pepper at the equilibrium moisture content of 0.75 g g^{-1}, is about 5.60 kJ mol^{-1} (for the universal gas constant equal to 8.314 $kJk^{-1}mol^{-1}$), a value close to 5.02 kJ mol^{-1} registered by Reis et al. (2011) when studied the drying kinetics of cumari-do-pará pepper (*Capsicum chinense* Jacq.) at an initial moisture content of 82.69%. This closeness between the values indicates that the isosteric heat is a good parameter for the study and/or development of dryers.

The model of Hubinger et al. (2009) resulted in coefficients of determination (R^2) for the pepper in paste and whole forms of 99.4 and 99.46%, respectively, showing a good fit to experimental data. The calculated parameters for this model are presented in Table 7.

Table 7. Calculated parameters for the model of Hubinger et al. (2009) for pepper variety 'bico' in whole and paste forms.

Parameter	Whole	Paste
A	204.8744	136.2889
B	5524.434	526.9246
C	0.046537	0.060249

Figure 4 illustrates the model of Hubinger et al. (2009) to the experimental data of isosteric heat obtained from the curves of the natural logarithm of water activity, ln (a_w), for specific values of equilibrium moisture content as a function of inverse absolute temperature (K^{-1}) for pepper in whole and paste forms.

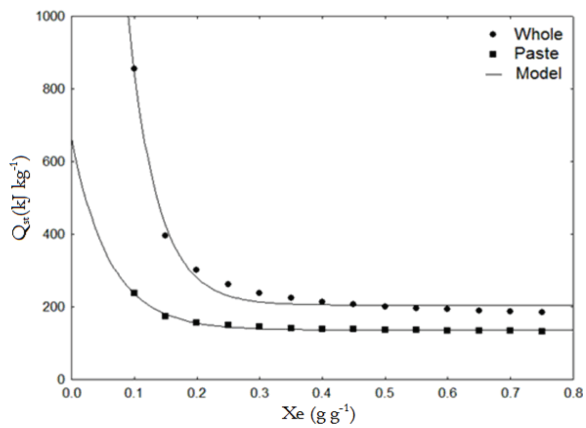

Figure 4. Fit of the model of Hubinger et al. (2009) to the experimental data of isosteric heat for pepper variety 'bico' in whole and paste forms

The isosteric heat tended to approach the value of latent heat of vaporization of free water (43.5 kJ kg^{-1}) as the water content of the product increases, for both paste and whole pepper forms (Figure 4). According to Wang and Brennan (1991), the isosteric heat approaching the value of the latent heat of vaporization of free water is an indicative of the presence of free water in the product. It is observed that the values of isosteric heat for the paste form of pepper were closer to the value of pure water, because the processing of the fruit caused the liberation of active sites and, therefore, of water molecules, thus decreasing the amount of energy required to evaporate a water molecule.

The processing of pepper, in paste or whole forms, influenced the values of equilibrium moisture content, as well as the values of isosteric heat of desorption. The pepper in the whole form requires much more energy than the paste form, which may be explained by the formation of a film on the outer peel of the dry product, due to differences between internal and external temperatures, hindering the heat transfer and concentrating all moisture within the fruit, thus requiring more energy for removing the moisture.

Conclusion

The isotherms of pepper variety 'bico', in paste and whole forms, show a sigmoidal shape, typical of fibrous foods with high initial moisture content. The values of Q_{ST} decreases with increasing moisture, for both conditions studied, ranging from 132.84 to 238.21 kJ kg for paste form and from 185.28 to 855.34 kJ kg^{-1} for the whole form. The Hubinger et al. (2009) model shows a good fit to experimental data for both forms of pepper. The form studied influences the values of equilibrium moisture content, as well as the values of isosteric heat of desorption. The bico pepper, in the whole form, requires much more energy during the drying process.

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