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The effect of encapsulants on the heat of sorption in vacuum-dried cajá powder[1]

Efeito de encapsulantes no calor de sorção do pó de cajá desidratado à vácuo

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ABSTRACT - Equilibrium moisture data from the powdered pulp of *Spondias mombin*, L., both with and without additives - 58% maltodextrin (MD) or 58% gum arabic (GA) - were determined at 20, 30, 40 and 50 °C, using the static gravimetric method for a water activity range of 0.06 to 0.90. The resulting isotherms were sigmoidal and typical Type III, with the Guggenheim-Anderson-de-Boer model (GAB) adjusted to the experimental data for equilibrium moisture vs water activity. The addition of additives was shown to affect the isotherms in such a way that, for the same water activity, samples of CP+GA and CP+MD showed a lower equilibrium moisture content and were not affected by the variations in temperature. The isosteric heat of sorption for the cajá powder with additives was greater (less negative) than that of the cajá powder with no additives, suggesting that polar sites in the product without the addition of GA or MD are more active. An empirical exponential relationship can describe the dependence of the heat of sorption as a function of the moisture content of the material.

Key words: Isotherms. Maltodextrin. Gum arabic Water activity.

RESUMO - Dados de umidade de equilíbrio do pó da poupa de cajá (PC) (*Spondias mombin*, L.) com e sem aditivos - 58% de maltodextrina (MD) ou 58% de goma arábica (GA) - foram determinadas em 20; 30; 40 e 50 °C, utilizando o método gravimétrico estática numa faixa de atividade de água de 0,06 a 0,90. As isotermas obtidas foram sigmóide, típica tipo III, e o modelo Guggenhein-Anderson-de Boer (GAB) foi ajustado aos dados experimentais de umidade de equilíbrio *versus* atividade de água. A adição de aditivos mostrou afetar as isotermas de tal forma que, na mesma atividade de água, amostras PC + GA e PC + MD apresentaram menor teor de umidade de equilíbrio e não foram afetadas pela variação da temperatura. Os calores isostéricos de sorção para os pós de cajá com aditivos foram superiores (menos negativo) do que os do pó do cajá sem aditivo, sugerindo que existem sitios polares mais ativos no produto sem adição de GA ou MD. Uma relação exponencial empírica pode descrever a dependência do calor de sorção em função de teor de umidade do material.

Palavras-chave: Isotermas. Maltodextrina. Goma arábica. Atividade de água.

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INTRODUCTION

Spondias mombin L., known locally as the cajá, is a small, aromatic, ovoid fruit, 3.2 to 4 cm long and 2.5 cm wide. It is a native fruit found in the forests of south-eastern Mexico, and of Peru and Brazil. The fruit is popular, and used in the preparation of soft drinks, cachaças and liqueurs. Like most regional fruits, the cajá is harvested during short periods of the year, and its consumption is restricted to its place of production. As such, obtaining products of the cajá with a longer shelf life would allow marketing to be extended to other regions, and the products to be exported. The consumption of commercial products from regional fruits, such as the pulp, juice and yogurt of the cupuaçu and cajá, has increased in recent years in Brazil, due to their accessibility and ease of preparation, however, one marketing alternative could be in the form of dried powder. In addition to its aromatic characteristics and exotic taste, the cajá is a great source of vitamin A. According to Silva *et al*., the pulp of the cajá (*Spondias lutea* L.), together with the skin, has a high carotenoid content, higher than that of the cashew, guava and some varieties of papaya. Generally, the following values for physico-chemical parameters are determined in the cajá: pH 2.50-2.99, soluble solids 7.5-8.8 °Brix, acidity as citric acid 0.39-1.09 g/100 g, reducing sugars 2.70-4.53 g/100 g and ascorbic acid 5.24-8.87 mg/100 g.

Powdered fruit juices, and other products with a high sugar content, present technical difficulties due to their high hygroscopicity and thermoplasticity at high temperatures and humidity (GOULA; ADAMOPOULOS, 2008). For this reason, the addition of maltodextrin, gums and other substances, such as pectins and carboxymethyl cellulose, have been used in the production of powdered juice (BHUSARI; MUZAFFAR; KUMAR, 2014; OBEROI; SOGI, 2015; SAMBORSKA; GAJEK; KAMINSKA-DWORZNICKA, 2015; TONON; BRABET; HUBINGER, 2008). Oliveira, Costa and Afonso (2014) studied the moisture adsorption isotherms and the physico-chemical characterisation of freeze-dried whole cajá pulp powder and of the powder with added maltodextrin.

Knowledge of water sorption isotherms and isosteric heat is important for designing the various stages of food processing, such as drying, storage and the selection of packaging. The curves of the pure components help in calculating drying time and predicting the behaviour of the components that are used produce the processed food, in addition to selecting suitable material for packaging, evaluating variations in moisture during storage, and estimating the shelf life of the products at low humidity (LOMAURO; BAKSHI; LABUZA, 1985).

Mathematical models to evaluate water sorption behaviour in food can be found in the literature. Some are presented in the work of Edrisi Sormoli and Langrish (2015). Several of these models are based on theories of sorption mechanisms; others are purely empirical or semi-empirical. The criterion used to select the most appropriate model is the degree of adjustment to the experimental data and the physical significance.

The aim of this study was to determine experimentally water-vapour sorption isotherms in dehydrated Cajá juice obtained by vacuum drying at a temperature range of 20 to 50 °C, and to analyse the effect adding maltodextrin and gum arabic on the thermodynamic properties of water-vapour sorption.

MATERIALS AND METHODS

The fruit from which the pulp was obtained had the following characteristics: °Brix 8.0±0.4, pulp 43.3±1.1 g/100 g, pH 2.45±0.02, citric acid 0.94±0.01 g/100 g, and density 1.0442±0.0032 g.cm^{-3}. A pilot depulper was used to obtain the pulp, which was passed through a 1.6 mm sieve.

A commercial aqueous maltodextrin solution, MOR-REX® 1920 (Corn Products Brazil), was prepared at a 70% concentration by mass in distilled water at 40 °C using a mechanical stirrer. This solution was added to the cajá pulp in such a way that the mass ratio between the maltodextrin solution and the pulp was 58% dry basis (58 g maltodextrin/100 g total solids). According to the manufacturer's technical specifications, MOR-REX® 1920 maltodextrin has $17.0 \leq DE \leq 19.9$.

A similar procedure was used to prepare the cajá pulp with 58% by mass gum arabic (GA) (Synth, Brazil) on a dry basis (58 g Arabica gum/100 g total solids). Cajá pulp, with and without additives, was dried in stainless steel trays in a vacuum chamber (88 kPa, 60 °C) for 48 h. The dried product was ground using a porcelain hammer.

The static gravimetric method was used to obtain the sorption isotherms, for which the equilibrium moisture content of the dried pulp was determined for different water activities at temperatures of 20, 30, 40 and 50 °C (Jowit *et al*., 1983). Ten saturated salt solutions were prepared, which cover the range of water activity between 0.06 and 0.9. Each saturated solution was transferred to individual glass desiccators, so that the amount of solution reached a height of 1.5 cm. Samples of around 1 g of pulp were weighed in triplicate in small plastic containers placed on a tripod inside the desiccators, which were hermetically sealed and placed in a temperature controlled chamber. The samples were weighed periodically until reaching equilibrium, considered to be when the difference in weight between each consecutive weighing does not exceed 0.1%. The time required to reach equilibrium was 4 to 5 weeks. Equilibrium moisture was determined in a vacuum oven at 60 °C for 48 hours (ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS, 1990).

To adjust the experimental data of the water-vapour sorption isotherms of each of the dried products, the GAB (Guggenheim-Anderson-de Boer) equation was used. This model is expressed by the equation:

$$X = \frac{(C-1).K.a_w.X_m}{1+(C-1).K.a_w} + \frac{K.a_w.X_m}{1-K.a_w} \qquad (1)$$

where: X_m is the moisture content (dry basis) corresponding to the monolayer (BET), and C and K are constants related to the effect of temperature.

$$C = C_G \exp\left(\frac{\Delta H_c}{RT}\right) \qquad (2)$$

$$K = K_G \exp\left(\frac{\Delta H_k}{RT}\right) \qquad (3)$$

where: ΔH_c e ΔH_k are functions of the heat of sorption of water: $\Delta H_c = H_m - H_n$ and $\Delta H_k = \lambda - H_n$. In the above equations, CG and KG are constants adjusted for temperature, Hm and Hn are respectively the heat of sorption of the monolayer and multilayer, λ the latent heat of condensation of pure water.

To estimate the parameters, the experimental data were adjusted to the mathematical model using the ‘Nonlinear Curve Fit’ function of the OriginPro 8 software (OriginLab Corporation, USA). The adjustment to the function was assessed from the correlation coefficient (R^2) and the residual sum of squares (RSS).

The isosteric heat of sorption, or enthalpy of sorption (q_{st}), is defined as the difference between the total heat of sorption (Q_{st}) and the latent heat of vaporisation of water. This was determined by equation (4), derived from the Clausius-Clapeyron equation (RIZVI, 1995):

$$\left.\frac{\partial \ln(a_w)}{\partial(1/T)}\right|_X = \frac{Q_{st}-\lambda}{R} = \frac{q_{st}}{R} \qquad (4)$$

where: a_w is the water activity, T is the absolute temperature, R is the universal gas constant, Q_{st} is the total heat of desorption of the moist solid, and λ is the latent heat of vaporisation of pure water.

Isosteric heat is a molar quantity derived from the dependence on temperature shown by the sorption isotherm. For its application, it is necessary to measure the isotherms at two or more temperatures. Tsami *et al.* (1990) present an empirical exponential relationship between the isosteric heat of sorption and the moisture content. This is shown in equation (5).

$$q_{st} = q_0 \exp\left(-X_{eq}/X_0\right) \qquad (5)$$

where: q_0 is the isosteric heat of sorption of the molecular water monolayer, X_{eq} is the equilibrium moisture content, and X_0 is the initial moisture content of the food material.

RESULTS AND DISCUSSION

The equilibrium moisture content, as a function of the water activity of the cajá powder with and without additives at different temperatures, is shown in Table 1. The mean values obtained in triplicate are shown, with a maximum error of 6%.

In order to adjust the experimental equilibrium moisture data as a function of water activity, the GAB model was selected; this is widely used for food, especially

Table 1 - Experimental equilibrium moisture (kg H_2O/kg dry matter) for powdered cajá pulp

Temperature (ºC)	CP		CP+MD		CP+GA	
	a_w	X_{eq}	a_w	Xeq	a_w	X_{eq}
20	0.070	0.112	0.070	0.029	0.070	0.040
	0.113	0.138	0.113	0.038	0.113	0.050
	0.246	0.183	0.246	0.067	0.246	0.080
	0.331	0.208	0.331	0.074	0.331	0.092
	0.446	0.253	0.446	0.100	0.446	0.115
	0.547	0.306	0.547	0.117	0.547	0.137
	0.655	0.384	0.655	0.171	0.655	0.187
	0.754	0.517	0.754	0.207	0.754	0.250
	0.853	0.757	0.853	0.297	0.853	0.368
	0.907	0.897	0.907	0.444	0.907	0.512

Continuation Table 1

30	0.069	0.096	0.069	0.025	0.069	0.037
	0.112	0.117	0.112	0.035	0.112	0.045
	0.223	0.179	0.223	0.058	0.223	0.067
	0.324	0.196	0.324	0.072	0.324	0.082
	0.439	0.240	0.439	0.093	0.439	0.113
	0.526	0.273	0.526	0.109	0.526	0.133
	0.635	0.394	0.635	0.149	0.635	0.177
	0.756	0.500	0.756	0.213	0.756	0.251
	0.835	0.646	0.835	0.284	0.835	0.347
	0.900	0.980	0.900	0.410	0.900	0.506
40	0.066	0.088	0.066	0.021	0.066	0.028
	0.111	0.114	0.111	0.032	0.111	0.040
	0.206	0.160	0.206	0.050	0.206	0.065
	0.319	0.199	0.319	0.068	0.319	0.081
	0.432	0.245	0.432	0.089	0.432	0.104
	0.506	0.275	0.506	0.105	0.506	0.119
	0.615	0.360	0.615	0.137	0.615	0.172
	0.753	0.520	0.753	0.212	0.753	0.243
	0.82	0.648	0.82	0.280	0.82	0.313
	0.893	0.920	0.893	0.382	0.893	0.505
50	0.059	0.076	0.059	0.016	0.059	0.023
	0.110	0.103	0.110	0.026	0.110	0.037
	0.189	0.138	0.189	0.044	0.189	0.054
	0.314	0.179	0.314	0.061	0.314	0.078
	0.432	0.240	0.432	0.083	0.432	0.103
	0.489	0.266	0.489	0.093	0.489	0.117
	0.599	0.341	0.599	0.136	0.599	0.153
	0.746	0.501	0.746	0.198	0.746	0.244
	0.809	0.626	0.809	0.249	0.809	0.319
	0.884	0.882	0.884	0.396	0.884	0.442

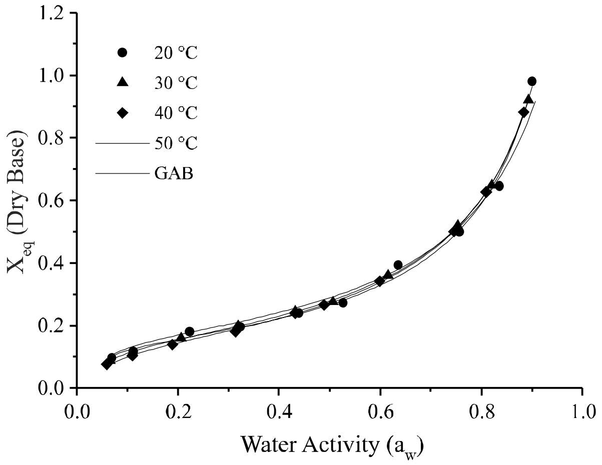
CP - Cajá powder; MD - Maltodextrin; GA - Gum arabic

fruit (GABAS *et al*., 2007; LAVOYER *et al*., 2013; TELIS; SOBRAL; TELIS_ROMERO, 2006). Figure 1 shows the experimental sorption isotherms for the cajá powder at each temperature under study, with their respective adjustments to the GAB model. As can be seen, according to Brunauer's classification (RIZVI, 1995), the behaviour of each curve was type III. The results of the non-linear regression for the fit of the GAB model to the experimental data are shown in Tables 2, 3 and 4.

The results obtained in this work in relation to the fit of the GAB model at different temperatures, agree with the limiting values of the C and K constants suggested by Lewicki (1997), based on a mathematical analysis of the model. In order to ensure a good description of the sigmoidal isotherms and meet the requirements of the BET model, as well as ensuring that the calculation of monolayer moisture (X_m) does not differ by ±15.5% from the true value, the author makes clear that the constants should assume a value in the range of between $0.24 \leq K \leq 1$ and $5.67 \leq C \leq \infty$.

The true value of monolayer moisture (X_m) is of particular interest, as it indicates the amount of water that is strongly adsorbed at specific surface sites of the food material, and is considered the optimal value to ensure

Figure 1 - Isotherms of cajá powder at different temperatures



stability. For pure cajá, the results show values in the range of between 14.7 to 16.7% (dry basis), with a tendency to decrease as the temperature increases from 20 to 50 °C. Nicoleti, Telis-Romero and Telis (2001) found X_m values for pineapple pieces of between 6.3 and 13.2% (dry basis), in a desorption experiment at temperatures in the range of 40 to 70 °C, whereas Telis and Sobral (2001) obtained X_m values of 7.2% (dry basis) for desorption at 25 °C in the freeze-dried product. Hubinger *et al*. (1992) compared the adsorption isotherms of pineapple pieces for vacuum drying and freeze drying. Those authors did not adjust the experimental data to any model, as they found that, for the same water activity, the freeze-dried samples had a higher equilibrium moisture content than did the vacuum-dried samples. These differences were mainly seen for an a_w >0.25, which is far above the corresponding a_w of

Table 2 - Estimated parameters of the GAB model for the powdered cajá pulp at different temperatures

Parameter	Temperature			
	20 ºC	30 ºC	40 ºC	50 ºC
C	22.22	26.78	16.46	12.51
K	0.904	0.944	0.928	0.931
X_m	0.167	0.147	0.160	0.158
SSR	0.0023	$3.48x10^{-4}$	$1.40x10^{-4}$	$1.34x10^{-4}$
R^2	0.995	0.994	0.999	0.999

Table 3 - Estimated parameters of the GAB model for the powdered cajá pulp with 58% Maltodextrina at different temperatures

Parameter	Temperature			
	20 ºC	30 ºC	40 ºC	50 ºC
C	13.18	8.78	5.41	6.64
K	0.951	0.943	0.925	0.968
X_m	0.061	0.063	0.070	0.058
SSR	$7.69x10^{-4}$	$4.92x10^{-5}$	$1.17x10^{-4}$	$2.21x10^{-4}$
R^2	0.994	0.999	0.999	0.998

Table 4 - Estimated parameters of the GAB model for the powdered cajá pulp with 58% gum arabic at different temperatures

Parameter	Temperature			
	20 ºC	30 ºC	40 ºC	50 ºC
C	14.78	10.77	10.81	5.51
K	0.948	0.954	0.971	0.937
X_m	0.0724	0.0726	0.0676	0.0793
SSR	$7.24x10^{-5}$	$6.01x10^{-5}$	$3.64x10^{-4}$	$1.57x10^{-4}$
R^2	0.999	0.999	0.998	0.999

the monolayer. The differences between the X_m values obtained for fruit in different studies can be attributed to variations in the composition of the raw material, especially the sugar content. For a few other fruits, such as the blueberry (VEGA-GÁLVEZ *et al*., 2009), borojó (*Alibertia patinoi*) (RODRÍGUEZ-BERNAL *et al*., 2015), loquat and quince (MOREIRA *et al*., 2008), values were found in the range of 10.9 to 15.2% (dry basis), similar to the X_m values found in this work.

Strong adsorbent-adsorbate interactions, which are exothermic, are favoured at low temperatures, causing an increase in parameter C for a decrease in temperature, adjusting to equation (2), which describes the dependence of C on temperature. Similar results were found in this work: an increase in temperature of from 20 to 50 °C produces a decrease in the value of C in all samples. However, Iglesias and Chirife (1982) evaluated 30 foods and found that in 74% of them, the value of C was reduced with the increase in temperature, probably due to irreversible changes associated with temperature increases, such as enzyme reactions and protein denaturation.

The K value provides a measure of the interaction between the multilayer water molecules and the adsorbent, and its value tends to lie between the energy of the molecules in the monolayer and that of liquid water. If K is equal to 1, the multilayers have the properties of liquid water, and the sorption behaviour can be modelled by the BET equation (PEREZ-ALONSO *et al*., 2006). The K values of the powdered pure cajá pulp showed slight variations in the range of 0.904 to 0.944.

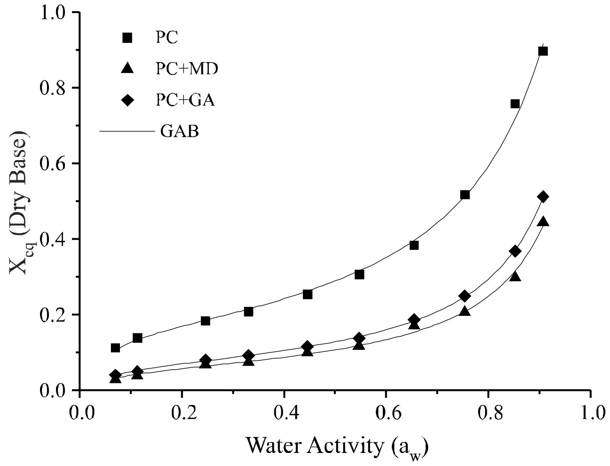
With consistent water activity there is usually a tendency for the equilibrium moisture content to decrease for an increase in temperature. The amount of decrease depends on the nature or composition of the food (RIZVI, 1995). It can be seen that in the case of the cajá powder, this behaviour was not very pronounced, perhaps due to the physical or chemical changes that occur during the drying process of the powdered pulp, since it is known that isotherms are influenced by composition, physical structure (crystalline or amorphous) and pre-treatment, as in the case of processed food.

Gabas, Menegalli and Telis-Romero (2000) reported that, for the plum, the temperature dependence of the isotherms was different for the pulp and skin. Their results showed that the isotherms of the pulp were slightly temperature-dependent, while those obtained for the skin were clearly non-dependent on this variable.

No intersection of the isotherms or inverse effect of the temperature was seen for the powdered cajá pulp, but there was a tendency towards crossover in high water activity. Some studies have reported crossover as a function of temperature in water activity greater than 0.7, for products with a high sugar content, such as fruit (TELIS-ROMERO *et al*., 2005); this can be explained by the increase in solubility of sugars in water caused by the increase in temperature.

The isotherms obtained for the powdered cajá pulp containing maltodextrin and gum arabic are also type III sigmoidal isotherms. However, considerable differences were found between the isotherms of cajá powder with an additive (MD or GA) and cajá powder with no additives. Such behaviour is clearly seen in Figure 2, which shows the effect of the additives at 20°C. The equilibrium moisture of the samples containing additive was significantly less than that of the pure cajá for a given water activity. Similar behaviour was seen by Gabas *et al.* (2007) and by Silva *et al*. (2006) respectively, for pineapple and camu-camu (*Myrciaria dubia*) pulp encapsulated with maltodextrin.

Figure 2 - Influence of the addition of MD and GA on the sorption isotherms of dried cajá pulp at 20 °C



The results of adjusting the GAB model show that the isotherms of the pulp with additives show lower values for monolayer moisture than those of the pure pulp.

Samples of dried cajá powder with the addition of maltodextrin (CP+MD) showed values for X_m of between 6.1 and 7.0% (dry basis), while samples with gum arabic (CP+GA) showed a range for X_m of 6.76 to 7.93% (dry basis). The monolayer values for the materials (CP+MD and CP+GA) showed no clear dependence on temperature.

Perez-Alonso *et al*. (2006) obtained values for X_m of between 6.96 and 7.35% (dry basis) for pure maltodextrin (DE 10), and between 8.11 and 11.00% (dry basis) for gum arabic, in temperatures ranging from 25 to 40 °C, values similar to those found in this work, given that the samples of CP+MD had lower values for X_m than the samples of

CP+GA. Silva *et al*. (2006) found that the addition of 30% maltodextrin DE 20 to camu-camu pulp reduces the X_m from 15.8 to 6.5% (dry basis); a similar effect was seen with the cajá pulp. Righetto and Netto (2005) calculated monolayer water values of between 4.52 and 5.43% (dry basis) for spray-dried acerola juice with 20% maltodextrin DE25 at temperatures of 25, 35 and 45 °C. Those authors found only small differences in X_m when using 20% gum arabic instead of maltodextrin: the values for monolayer moisture content varied from 4.80 to 5.44% (dry basis), but showed a tendency to decrease with the increase in temperature, as was seen with maltodextrin. Acerola juice encapsulated with gum arabic showed X_m to be dependent on temperature, unlike the behaviour described by Perez-Alonso *et al*. (2006) using the same encapsulant.

For the samples of CP+MD, parameter C decreased from 13.18 at 20 °C to 6.64 at 50 °C, while for the samples of CP+GA, the values fell from 14.78 at 20 °C to 5.51 at 50 °C. Perez-Alonso *et al*. (2006) obtained similar values of between 5.26 and 18.83 for C with the addition of maltodextrin and gum arabic. Those authors found different behaviour for C as a function of temperature: for GA, there was an increase in C, and for MD, a reduction with the increase in temperature, which can be attributed to C having no physical significance, and the variation with temperature being the possible result of mathematical compensation between C and K. Righetto and Netto (2005) also found irregular variations in C with temperature for samples of maltodextrin. On the other hand, samples with gum arabic showed a clear reduction in C for increases in temperature. Silva *et al*. (2006) found that maltodextrin reduces the value of C in camu-camu pulp, an effect that was also seen in this study.

Parameter K was practically unaffected by the presence of additives, showing values of between 0.937 and 0.971 for samples of CP+GA, and between 0.925 and 0.968 for samples of CP+MD. Righetto and Netto (2005) saw no variation in K related to the presence of additives, whereas Perez-Alonso *et al*. (2006) found a general slight decrease in the values of K, which were higher for GA than for MD, a fact that was also seen in dried cajá with the same additives as those under evaluation in this study.

The presence of additives in the cajá pulp probably modifies the balance of hydrophilic/hydrophobic sites, promoting the adsorption of a smaller amount of water. Considering the addition of biopolymers, the water sorption processes also involve structural changes in the matrix due to swelling (PEREZ-ALONSO *et al*., 2006). Adhikari *et al*. (2004) found that maltodextrin alters surface adhesion in sugars with low molecular weight, and in organic acids, preventing them from remaining on the walls of the drying equipment, and as such is considered an effective additive in these processes based on various parameters, such as hygroscopicity, degree of agglomeration, degree of dispersion, fluidity and adhesion, which have been defined as quality parameters in vacuum-dried mango powder. According to Righetto and Netto (2005), the stability of systems containing MD or GA could be related to temperature and water activity through the glass transition temperature, Tg, since the stickiness was seen at temperatures close to Tg, and disappeared at less than 20 °C above Tg. This can be confirmed in the work of Silva *et al*. (2006), who measured the Tg of camu-camu pulp with and without MD for the same values of a_w, and attributed the stabilising effect of maltodextrin on the observed increase in the glass transition temperature.

It is important to note that the dextrose equivalent of maltodextrin has a direct influence on the glass transition temperature of the system, with lower DE values leading to higher values for Tg. This point should be considered when comparing the results obtained in different studies, since MD has been used as an additive in the drying process with maltodextrins presenting DE values of from 10 (PEREZ-ALONSO *et al*., 2006) to 25 (RIGHETTO; NETTO, 2005).

The dependence of isosteric water sorption (q_{st}) on moisture content for powdered cajá pulp with and without additives is shown in (Figure 3). These curves show the amount of heat required to remove the water from the cajá powder from a moisture content of 0.3 kg/kg dry basis to 0.025 kg/kg. For low moisture values (<0.1 kg/kg dry basis), the values of q^{st} (kJ/mol) are highly negative, which means that sorption is a spontaneous reaction. The more-negative values for qst indicate a greater degree of water bound to the surface of the food. For most of the moisture range, q_{st} values for CP samples are lower (more negative) than those calculated for the samples of CP+GA and CP+MD, which means that the amount of bound water in the powdered pure cajá is greater than in the presence of encapsulating agents. As the moisture content decreases, the samples containing additives show a rapid reduction in q_{st}, so that the curves reach an almost similar, highly negative value for a moisture content of 0.025 kg/kg (dry basis). For moisture levels greater than 0.1 kg/kg (dry basis), the q_{st} showed positive values in the cajá pulp with encapsulating materials, especially CP+MD. It should be noted that for a moisture content of less than 0.2 kg/kg (dry basis), the increased negativity of the isosteric heat of sorption should be considered when calculating the energy required for the drying process, which is generally lower for powders with encapsulating agents. It is assumed that for a moisture content greater than 0.3 kg/kg (dry basis), differences in q_{st} for all samples tend to disappear. The behaviour shown in Figure 3 can be explained in terms of the plasticising effect of the water molecules. The work of Telis and Sobral (2001) demonstrated that an increase in moisture content of around 30% (dry basis) caused a significant reduction in the glass transition temperature of freeze-dried pineapple pulp of from 63 to -70 °C. On the other hand, the addition of self-assembly molecular weight compounds such as MD and GA should effectively minimise the high plasticising effect.

The experimental values of q_{st} fit Equation (5), from which the constants q_0 and X_0 were obtained. Table 5 shows these values together with the correlation coefficient (R^2).

In general, the values of the correlation coefficient (R^2) were satisfactory. The calculated values of q_0 were higher for CP and CP+GA than for CP+MD, probably due to the strong interactions of the food components with the first water molecule of the monolayer in this type of product.

Figure 3 - Influence of encapsulants on the isosteric heat of sorption of the powdered cajá pulp

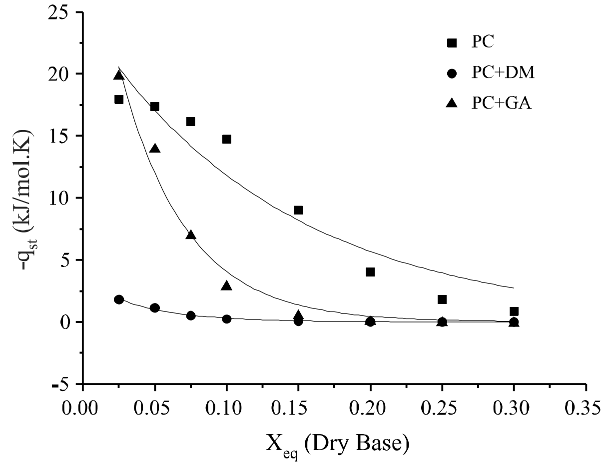


Table 5 - Parameters estimated by Tsami's equation (Eq. 5) for all samples

Sample	q_0 (kJ/mol)	X_0 (% dry basis)	R^2
Cajá	24.60	0.3143	0.903
Cajá + Maltodextrin	3.38	0.0959	0.990
Cajá + Gum arabic	35.44	0.1063	0.980

CONCLUSIONS

1. The GAB model for isotherms was suitable for describing experimental data for cajá powder with and without additives (CP; CP+GA; CP+MD);
2. For the same water activity, samples of CP+GA and CP+MD showed a lower equilibrium moisture content and were less affected by the change in temperature;
3. The isosteric heat of sorption of the cajá powder with additives was greater (less negative) than for the pure pulp powder, suggesting that in the product with no addition of GA or MD there are more active polar sites.

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