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Moisture adsorption isotherms of dried mangoes at a temperature range of 25 to 45°C

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ABSTRACT

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A study was conducted to determine the adsorption isotherms of dried mangoes at different temperatures. The results showed that the adsorption isotherms of dried mangoes at different temperatures were type III according to the BET classification. At a water activity <0.50,the equilibrium moisture content of samples at a given water activity increased as the temperature decreased. But at a water activity >0.50, the equilibrium moisture content of the samples increased as the temperature increased. The adsorption isotherms were fitted with 8 two-parameter equations (Bradley, Caurie,Halsey, Henderson, Kuhn, Linear, Oswin and Smith). The Caurie, Henderson and Oswin equations gave consistently high coefficients of determination when fitted to the adsorption isotherms of dried mangoes at different temperatures. However, further evaluation of the equations using the mean relative percentage deviations showed that the Caurie equation gave the best fit for describing the sorption data. A four-parameter modified Caurie equation was derived for predicting the equilibrium moisture content of dried mangoes as a function of water activity and temperature. Using the derived equation, the water activities of dried mangoes at different temperatures and constant moisture content were determined and used for obtaining the net heat sorption. The net heat sorption for dried mango decreased with increasing moisture content and can be expressed using linear equations for moisture ranges below 15% dry basis and above 15% dry basis.

Keywords: adsorption isotherms, dried mangoes, temperature, water activity, Caurie equation, net heat of sorption

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INTRODUCTION

The Philippines has an abundant supply of seasonal fruits which are mostly consumed in their fresh form. The major Philippine fruits are bananas, pineapple, mangoes, jackfruit and papaya (Green Pages, 1996). The increasing trend in the production of these fruits also leads to heavy losses due to spoilage and improper handling after harvest. To prevent too much waste, appropriate processing technologies must be adopted to match the increasing production of fruits. Dehydration is one process that can minimize these losses. One of the most popular dehydrated fruits is the dehydrated or dried mangoes.

Dehydrated mangoes are processed as follows: a) washing of firm mangoes; b) slicing the mangoes to separate checks from seeds; c) scooping out the flesh; d) slicing laterally into 10 to 20 mm thick slices; e) soaking the slices in sugar syrup with sodium metabisulfite for at least 4 hours; f) draining of syrup; g) drying of soaked slices in cabinet dryer at 60°C for at least 8 hours; h) sweating the dehydrated slices for 1 to 2 days; i) packing the final product in thick polypropylene bags (de Leon *et al.*, 1988).

Freshly processed dehydrated mangoes contain about 35 mg of ascorbic acid per 100 g of sample (Diamante *et al.*, 2003). Hence for an average daily recommended dietary allowance (RDA) of about 70 mg ascorbic acid for Filipinos (FNRI, 1990), 100 g of dried mangoes can supply about 50% of the RDA for ascorbic acid. Ascorbic acid is essential for healthy teeth, gums and bones; builds strong body cells and blood vessels; and aids in healing wounds (Ensminger *et al.*, 1983).

The moisture sorption isotherm of a food product is an extremely important tool because it can be used to predict changes in food stability and to select appropriate packaging materials and ingredients (Diamante, 1997). For effective and easy use of the moisture sorption isotherms, accurate but simple equations are necessary. Surface physical chemistry has provided food scientists with theoretical isotherms proceeding from different molecular models that can fit various experimental sorption isotherms. Other experimental isotherms have been fitted more successfully by empirical or semi-empirical equations. Important factors in selecting a sorption isotherm equation for packaging applications are the closeness of fit to the experimental data and simplicity of the equation. Boquet *et al.*(1978) compiled two-parameter isotherm equations that are applicable to food products.

There are no published moisture adsorption isotherms at different temperatures for dried mangoes which is needed for assessing its storage stability and packaging requirements, hence this study.

The specific objectives of the study are : a) to determine the moisture adsortion isotherms of dried mangoes at different temperatures; b) to fit two-parameter equations to the moisture adsorption isotherm data; c) to derive equations that can predict the equilibrium moisture content of dried mangoes as a function of water activity and temperature; and d) to determine the net heat of sorption of the product at different moisture levels.

MATERIALS AND METHODS

Preparation of samples

Commercially produced dried mangoes (Philippine Brand Dried Mango Preserves, Profood International Corp., Mandaue City, Metro Cebu, Philippines) were obtained from a supermarket. The products were about one month old from the date of manufacture.The samples were obtained from an airconditioned supermarket with an average temperature of about 23-25°C. The dried mangoes were packaged in thick polypropylene bags and were stored in a chiller (5°C) prior to use.

The dried mangoes were taken out of their individual plastic bags, put in one big container and thoroughly mixed. The initial water activity and moisture content of representative samples at 25°C were about 0.65 and 16% (dry basis), respectively. The dried mangoes were placed in dessicators containing silica gel at 35°C to reduce the water activity level down to about 0.40 which took about a month. The samples were divided into different lots and sprayed with atomized distilled water and some were soaked in distilled water for several seconds to absorb different amounts of moisture. The different samples were placed in airtight jars and placed in constant temperature cabinets at 25, 35 and 45°C for 24 hours. This was done in order to equilibriate the moisture in the individual slices. After equilibration, five representative slices were obtained from the different lots for water activity and moisture content measurements as described below.

Water activity measurement

The water activity of the different samples was measured using the Rotronic Hygroskop BT-RS1 (rotronic AG) that has been previously calibrated. The meter is capable of measuring water activity from 0.001 to 1.000 over a temperature range of 0.5 to 50°C. Five water activity measurements for each treatment were carried out.

Moisture content determination

The moisture contents of the samples in each treatment were determined using a Yamato Model DPF-41 vacuum oven (Yamato Scientific Co., Ltd.) at 70+1)C and 760 mm Hg of vacuum for 48 hours. All measurements were carried out in 5 replications.

Curve fitting adsorption isotherms

The experimental adsorption isotherms of dried mangoes were fitted with the selected two-parameter isotherm equations used by Diamante (2001) for curve fitting the desorption isotherms of sweetened maturing coconut meat.The equations include the Bradley, Caurie, Halsey, Henderson, Kuhn, Linear, Oswin and Smith equations. Some of the equations were linearly transformed to facilitate the regression.

The best-fitting equation on high coefficient of determination (r^2) and low mean relative percentage deviation values (Boquet *et al.*, 1978; Lomauro *et al.*, 1985) was selected to model the isotherms at each given temperature following the method of Diamante (2001). The constants of the selected equation were related to temperature by linear, logarithmic, exponential and power regressions. The relationship with the highest r^2 value was chosen as the temperature function for that constant. When there was no definite trend of the constant with respect for the mathematical modeling.

Heat of adsorption of dried mangoes

The net heat of adsorption of dried mangoes was determined based on the Clansius-Clapeyron equation using the procedure of Diamante (2001).

The integral form of the equation is shown below,

$$\ln a_w = \frac{-\Delta H_s}{R\,T_k} + C \text{ -------------------------------------(1)}$$

where: a_w = water activity of the sample
H_s = net heat of sorption
R = universal gas constant (8.314 J/g-mole.K])
T_k = absolute temperature (K)
C = material constant

Plotting $\ln a_w$ against $1/T_k$ at a range of sample moisture contents and then determining the slope will yield ΔH_s (Diamante, 2001; Diamante *et al.*, 1992). The relationship between the net heat of adsorption and moisture content was derived.

RESULTS AND DISCUSSION

Adsorption isotherms of dried mangoes

The results of the experimental measurements of the equilibrium moisture contents of dried mangoes at 25, 35 and 45°C are shown in Table 1. The plot of equilibrium moisture content against water activity would yield the adsorption isotherms of dried mangoes at different temperatures (Figure 1). The adsorption isotherms of dried mangoes were type III according to the BET classification (Brunauer *et al.*, 1938). The increase in the amount of sorbed water at a given water activity with a decrease in temperature is consistent with the theory of physical adsorption (Iglesias *et al.*, 1975). However, at a water activity of about 0.50, the amount of sorbed water at a given water activity increased with increasing temperature. This phenomenon may be due to exudation (leaching) of sugars, which has been observed for a number of high-sugar dried fruits such as raisins, currants, figs, prunes, apricots and fruit jams (Sa and Sereno, 1993; Ayranci *et al.*, 1990; Tsami *et al.*, 1990; Saravacos *et al.*, 1986).

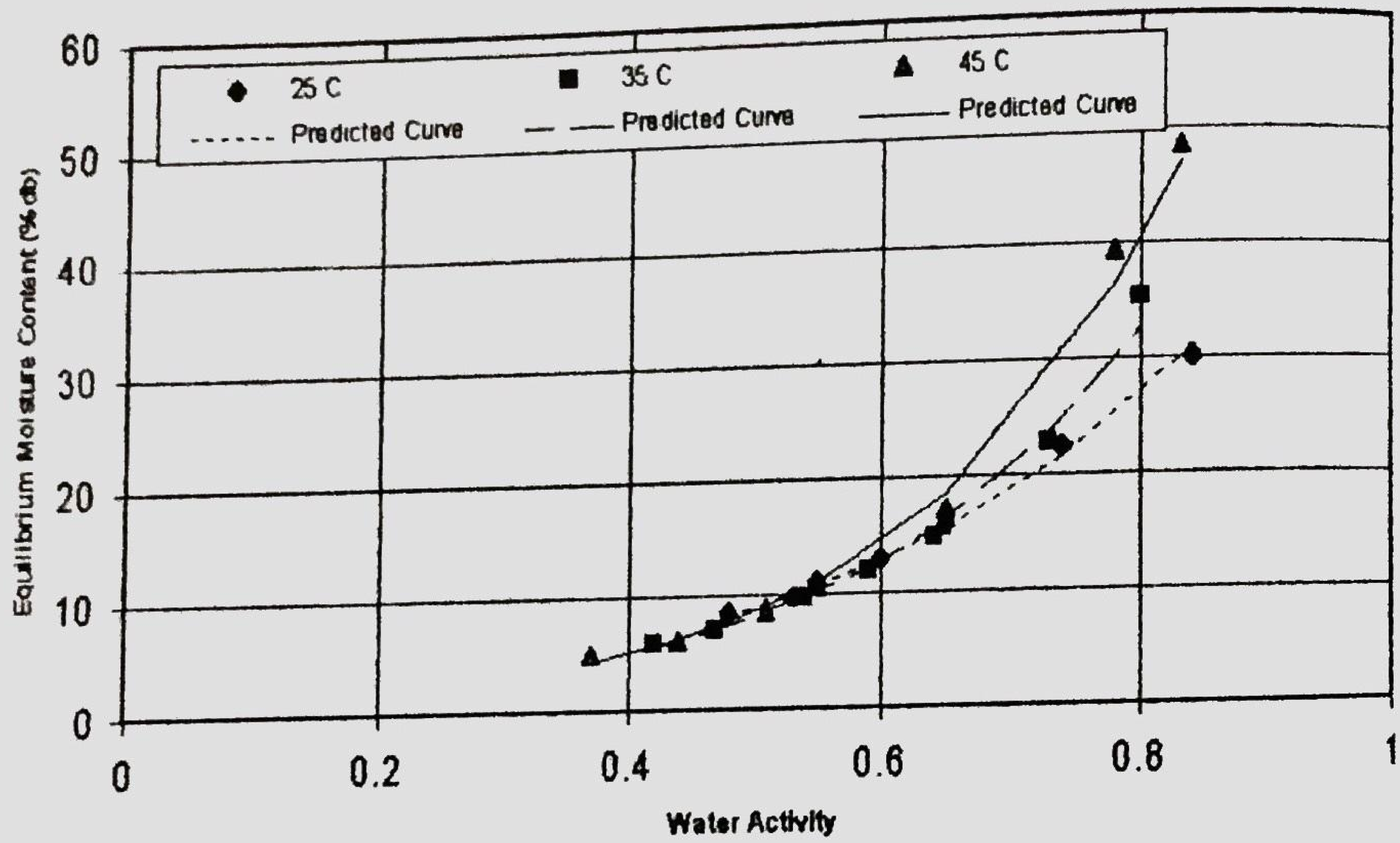

Figure 1. Adsorption isotherms of dried mangoes at different temperatures.

Table 1. Equilibrium moisture contents of dried mangoes at different water activities and temperatures

Temperature (°C)	Water Activity (aw)	Equilibrium Moisture Content (Me) (% dry basis)
25	0.48	8.38
	0.53	9.60
	0.55	11.07
	0.60	12.97
	0.65	15.72
	0.74	22.34
	0.84	29.90
35	0.42	5.93
	0.47	7.06
	0.54	9.60
	0.59	12.00
	0.64	14.71
	0.73	22.71
	0.80	35.14
45	0.37	4.93
	0.44	6.06
	0.51	8.60
	0.55	10.54
	0.65	17.14
	0.78	39.23
	0.83	48.29

Curve fitting of the adsorption isotherms

The experimental adsorption isotherms of dried mangoes at different temperatures were fitted with selected two-parameter equations as reported by Boquet *et al.* (1978). The results showed that the Caurie equation gave consistently high coefficients of determination followed closely by the Henderson and Oswin equations, respectively (Table 2). Using the derived Oswin, Caurie and Henderson equations at each temperature (Table 3), the mean relative percentage deviations (MRPD) at different temperatures were determined for each equation and summarized in Table 4. The same trend for the goodness of fit of the equations on the isotherms as in the coefficient of determination were also found. Since the MRPD values were all less than 10%, the three equations may then be used to describe the adsorption isotherms of dried mangoes at different temperatures. Boquet *et al.* (1978) found that the Henderson equation gave good fit for the adsorption isotherms of dried fruits. Lomauro *et al.* (1985) also found that the Oswin equation gave good fit on the adsorption isotherms for a number of dried fruits. Diamante (1995) reported good fits on the adsorption isotherms of copra at different temperatures for the Henderson, Oswin and Caurie equations. The adsorption isotherms of copra were also of type III according to the BET classification which probably yielded the same good fit for the three isotherm equations.

Oswin Equation: $$M_e = e^I \quad \frac{a_w}{1-a_w}$$

Caurie Equation: $$\ln M_e = I + S\ a_w$$

Henderson Equation: $$\ln(-\ln(1-a_w)) = I + S \ln M_e$$

where M_e = equilibrium moisture content
a_w = water activity

Table 2. Coefficients of determination for the different two-parameter isotherm equations as fitted on the adsorption isotherms of dried mangoes at different temperatures

Isotherm Equation	Coefficient of Determination (r^2)		
	25°C	35°C	45°C
Bradley	0.99607	0.94979	0.95536
Caurie	0.99578	0.99410	0.99429
Halsey	0.97046	0.99868	0.99388
Henderson	0.99320	0.99349	0.98930
Kuhn	0.95748	0.99877	0.99108
Linear	0.97977	0.89497	0.90019
Oswin	0.98081	0.99949	0.99548
Smith	0.99519	0.96855	0.97441

Table 3. Regression constants for the Oswin, Caurie and Henderson equations as fitted on the adsorption isotherms of dried mango

Isotherm Equation/ Temperature (°C)		Intercept (I)	Slope (S)	Coefficient of Determination (r^2)
Oswin	25	2.23268	0.75227	0.98081
	35	2.09711	1.04423	0.99949
	45	2.13601	1.13697	0.99548
Caurie	25	0.38690	3.62336	0.99578
	35	-0.21930	4.62696	0.99410
	45	-0.43607	5.16818	0.99299
Henderson	25	-2.07960	0.77848	0.99320
	35	-1.64178	0.60665	0.99349
	45	-1.56212	0.55163	0.98930

Table 4. Mean relative percentage deviations for Oswin, Caurie and Henderson equations as fitted on the adsorption isotherms of dried mangoes at different temperatures.

Isotherm Equation	Mean Relative Percentage Deviation (%)		
	25°C	35°C	45°C
Oswin	5.415	1.211	4.552
Caurie	2.271	3.791	6.159
Henderson	2.887	3.703	7.225

Temperature dependency of the adsorption isotherms

From Table 3, the regression intercept of the Oswin equation showed no trend with respect to temperature with a mean value of 2.15527. The regression slope of Oswin equation increased with temperature. The Oswin equation was modified by determining the best fit regression equation for its slope and the resulting equation is shown below,

$$M_e = e^{2.15527}\left[\frac{a_w}{1-a_w}\right]^{0.076638\,T_c^{0.71761}} \qquad \text{------------------------(2)}$$

where: T_c = isotherm temperature (°C)

Conversely, the regression intercepts and slopes of the Caurie and Henderson equations varied with temperature. However, only the Caurie equation was modified with respect to temperature since it had better fit than the Henderson equation. The regression intercept and slope were related to temperature using linear, logarithmic, exponential and power regressions and the regression equations with the highest r^2 were used to modify the Caurie equation as shown below,

$$Me = e^{(1.35071 - 0.041149Tc) + (-4.86537 + 6.09647\log Tc)\, a_w} \quad \text{-------------------(3)}$$

The MRPD values for the adsorption isotherms of dried mangoes at 25, 35 and 45°C were 7.33, 4.43 and 6.40% for the modified Oswin equation and 4.24, 9.02 and 5.37% for the modified Caurie equation, respectivley. Since the modified Caurie equation gave lower MRPD values for 25 and 45°C and less than 10% for the 35°C,this suggests that the Caurie equation can best describe the adsorption isotherms of dried mangoes at different temperatures. Diamante (2001) also found that a modified Caurie equation best described the effect of temperature on the desorption isotherms of sweetened maturing coconut.

Figure 2 shows the adsorption isotherms of dried mangoes at different temperatures as predicted using the modified Caurie equation. The plots were extrapolated beyond the water activity and temperature range of the experiments to show the effect of low water activity values and temperatures on the adsorption isotherms. Results suggest that the equilibrium moisture content of dried mangoes is affected by temperature when water activity is above 0.50. In addition, the earlier observation that a water activity of about 0.50, the amount of sorbed water at a given water activity increased with increasing temperature is clearly shown in Figure 2.

Since dried mangoes usually have water of 0.65, extra precautions should be taken such as proper packaging and lower storage temperature to ensure that the water activity degradation and browning development in dried mangoes since these reactions were found to be water activity-dependent (Diamante *et*

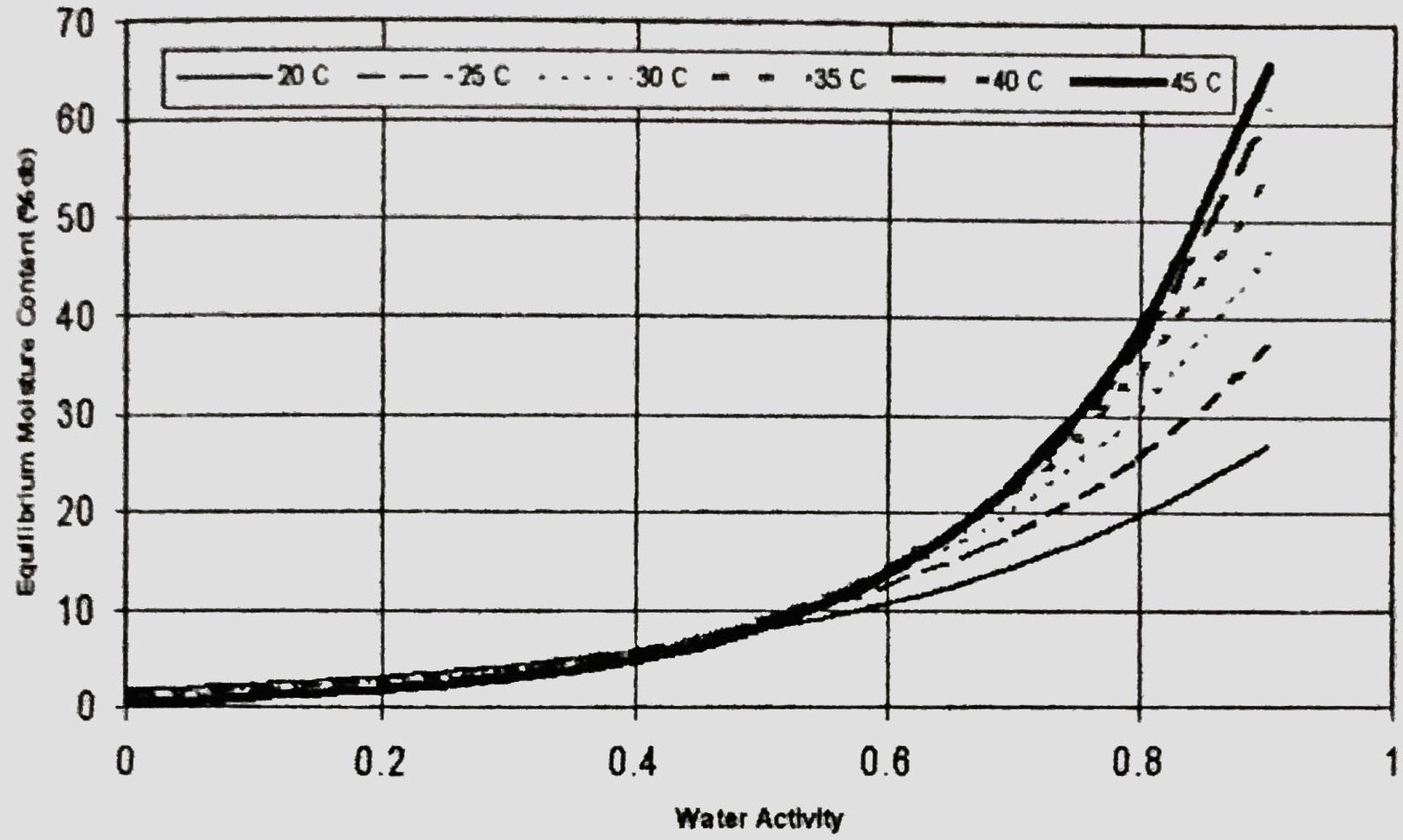

Figure 2. Adsorption isotherms of dried mangoes at different temperatures as predicted by the modified Caurie equation

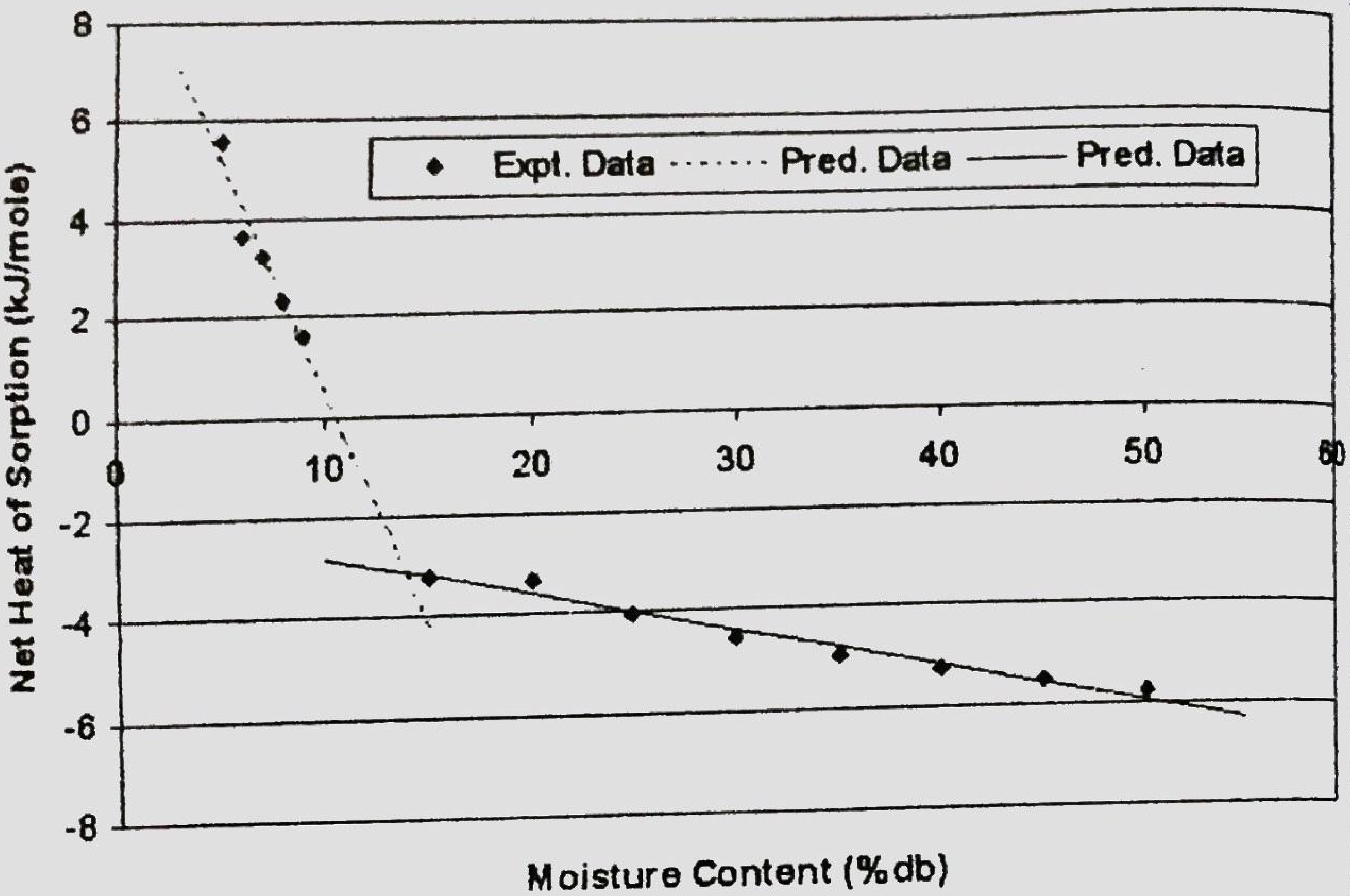

Figure 3. Net heat of sorption at different moisture content of dried mango

al., 2003).

Heat of adsorption of dried mangoes

Figure 3 shows the plot of the net heat of sorption of dried mango against moisture content. The net heat of sorption was large at low moisture content (<15% dry basis) and then decreased sharply. The same behavior was also found by Sa and Sereno (1993) for peach and quince jams, Ayranci *et al.* (1990) for dried apricot, dried fig and raisin and Saravacos *et al.* (1986) for sultana raisins. At low moisture contents (<15% dry basis), the net heat of sorption was positive, indicating an exothermic interaction. At higher moisture contents, the net heat of sorption approached zero, meaning it is equal to the heat of condensation of pure water. Slightly negative values of net heat of sorption were obtained in the high moisture region, indicating an endothermic interaction of water with the substrate (dissolution of sugars) (Saravacos *et al.*, 1986).

Linear regression equations were fitted on the net heat of adsorption as a function of moisture content (M) for two ranges as shown below,

$$\Delta H_{s1} = 9.77929 - 0.93118\ M\ (r^2 = 0.940)\quad (\text{for } M < 15\% \text{ dry basis})$$

$$\Delta H_{s2} = -2.02520 - 0.078318\ M\ (r^2 = 0.971)\quad (\text{for } M > 15\% \text{ dry basis})$$

CONCLUSION

The adsorption isotherms of dried mangoes at different temperatures were of type III according to the BET classification. At a water activity <0.50, the equilibrium moisture content activity >0.50, the equilibrium moisture content of the samples increased as the temperature increased. The Caurie equation best described the adsorption isotherms of dried mangoes at different temperatures.

The net heat of sorption for dried mango decreased with moisture content and can be expressed using linear equaitons for moisture ranges below 15% dry basis and above 15% dry basis.

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