

Glass transition and sorption properties of Köftür: a dehydrated fruit-based product

Nesimi AKTAŞ^{1*} , Kamil Emre GERÇEKASLAN¹

Abstract

This study was conducted to determine the glass transition temperature (T_g) using Differential Scanning Calorimetry (DSC) and sorption characteristics of köftür, a dehydrated fruit-based product. T_g of was found to be $24.5\text{ }^\circ\text{C} \pm 0.30$. Sorption isotherms were determined at 5, 15 and 25 $^\circ\text{C}$ using nine different salt solutions. The data were then applied to 11 different sorption equations, among which Iglesias-Chirife and Peleg equations revealed the best fitting, and experimental data indicated that the sorption isotherms of köftür exhibits Type-III characteristics.

Keywords: Köftür; sorption isotherm; differential scanning calorimetry; glass transition temperature.

Practical Application: Determinations of moisture sorption isotherms and isosteric heat have great importance for the preservation of dried fruit-based products. Moreover, the glass transition temperature is also another quality aspect in such products that play crucial role for determining the storage temperature.

1 Introduction

Grapes are a popular agricultural crop all over the world and great economical and nutritional importance. Grape production currently amounts to more than 77,438,929 tons per year in the world. China produces the majority of the world's grapes, with an annual grape production of 14,842,680 tons. Italy, USA, France, and Spain produce with annual productions amounts of 8,201,914, 7,097,723, 6,247,034, 5,934,239 tons, respectively. Turkey produces 4,000,000 tons grapes annually, which fall it into the top sixth grape-producing country in the world (Food and Agriculture Organization of the United Nations, 2017). Many products with different content and characteristics are produced by using different production methods from grapes. Concentrated grape juice (molasses), köftür or köfter (wheat flour or starch-grape juice gel), and grape leather (pestil) are among the most desired grape-based products in the Central Anatolia. Although grape is cultivated in various regions, köftür in Turkey is mainly produced in the city of Nevşehir, which is located in the center of Cappadocia. Because of its high caloric and high nutritional value, köftür is generally known as a winter dessert and consumed with walnuts.

One of the biggest challenges for the food industry is to develop new ready-to-eat products (snacks) made by fruits to fulfill consumer's demands, while protecting their nutritional qualities. Fruit-based dehydrated products, consumed as snacks or desserts or, generally have a shelf life of more than 7 months and do not require to be stored at cooling temperatures (-1°C to 8°C) (Demarchi et al., 2014). Dehydrated fruit products are mainly composed of low molecular weight carbohydrates. Such carbohydrates generally have affinity for the surrounding water vapor which make the final product highly hygroscopic and sticky. High hygroscopicity and stickiness could often times be a problem for such products during handling, packaging and storage

(Valenzuela & Aguilera, 2015). Therefore, knowing the T_g and sorption data for such materials is gained importance in recent years for predicting the condition and the manner of food during distribution, storage and processing (Saavedra-Leos et al., 2012).

Since the water activity (a_w) alone is insufficient to describe the second-order transitions of change-in-state in foods, the phenomenon of glass transition along with a_w , physical and chemical changes can be possibly applied as integrated approaches to determine food stability during food manufacturing, specifically in processing and storage. Glass transition that is depicted as a discontinuity in electrical, mechanical, physical, and thermal properties of a material is a second-order transition that is both time- and temperature-dependent (Balasubramanian et al., 2016). T_g can also be described as the temperature point where an amorphous materials alters from the glassy state to the rubbery state. In a glassy state, molecular movement is highly restricted because of the high viscosity. Moreover, the water in this state is dynamically immobile and does not catalyze and participate in any chemical reactions. Thus, T_g is generally considered as a reference temperature to evaluate the quality characteristics (stability and safety) of foods during storage as well as to determine the shelf-life. T_g also impacts the sticking, caking, agglomeration, collapse, crystallization, oxidative reactions, nonenzymatic color changes, and microbial stability of foods (Rahman, 2006). Furthermore, when the temperature is higher than T_g , the quality of foodstuffs is significantly changed, with a considerable decrease in viscosity, and as a result, reactants become more mobile and could possibly more easily take part in deterioration reactions (Roos & Drusch, 2016).

For predicting the physical condition of solid foods and the state of water that act as a solvent in biochemical reactions and

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¹Food Engineering Department, Engineering and Architecture Faculty, Nevşehir Hacı Bektaş Veli University, Nevşehir, Turkey

*Corresponding author: naktas@nevsehir.edu.tr

play a role in microbial activity, a_w and T_g are two important tools (Sadeghi et al., 2016). Thus, establishing the changes in moisture content during storage of foods as well as thermodynamic conditions of foods are important to determine their quality attributes. There has been no research report conducted on determining the moisture sorption isotherms and T_g value of köftür. Therefore, the objectives of this study were 1) to determine the water sorption isotherms of köftür at 5, 15 and 25°C, 2) to find mathematical equations which allow an accurate prediction of the isotherms, 3) to calculate the net isosteric heat of sorption, and 4) to determine T_g value of köftür by DSC, 5) to reveal the textural properties of köftür.

2 Materials and methods

2.1 Materials

Köftür samples produced with triplicate on separate processing days with a constant thickness produced by the same production technique were used in this study that were purchased from Bahtiyar Dogan Food Co. (Nevşehir, Turkey). manufactured by boiling of grape molasses and wheat flour, followed by dehydration of the mixture. Köftür is a highly popular product which is consumed as snack or dessert in Turkey. The block diagram of köftür production is shown in Figure 1. As shown in Figure 1, grape molasses are mixed with wheat flour, and heated by continuous stirring. Thickened mix are poured to trays, cooled, divided, dried, bloomed and stored. The storage period of köftür takes approximately 15 days, after which the product becomes ready for consumption.

2.2 Methods

Physicochemical characteristics of Köftür samples

To determine the moisture content, the samples had been kept in a vacuum drying chamber at 70°C until no more weight change was observed. The ash contents were determined by incineration in a furnace at 600°C for 24 h. The pH values of samples were determined by measuring the pH value of köftür homogeniate with pH meter that was prepared by homogenizing 10 g of sample with 100 ml of distilled water using Ultra-Turrax for 1 min. The titratable acidity was determined by weighing 10g of the sample which was diluted to about 100ml with water and titrated to 8.2 pH end point with 0.1 N NaOH. The results were calculated as % citric acid. The a_w instrument (Novasina AG, LabMaster a_w , Switzerland) was used to determine the a_w of the samples. The instrument was calibrated with six different salt solutions at 25°C before using. The special plastic containers containing the sample were placed in the measuring chamber of the instrument and the a_w values were determined at 25°C. The colors of the köftür samples were measured using a Minolta (CR-400, Minolta Co, Osaka, Japan) colorimeter with which L^* , a^* and b^* values were obtained.

Determination of T_g

T_g value was determined using DSC (DSC 6000, Perkin Elmer, USA) equipped with a intracooler cooling accessory. The DSC was calibrated using indium and mercury standards,

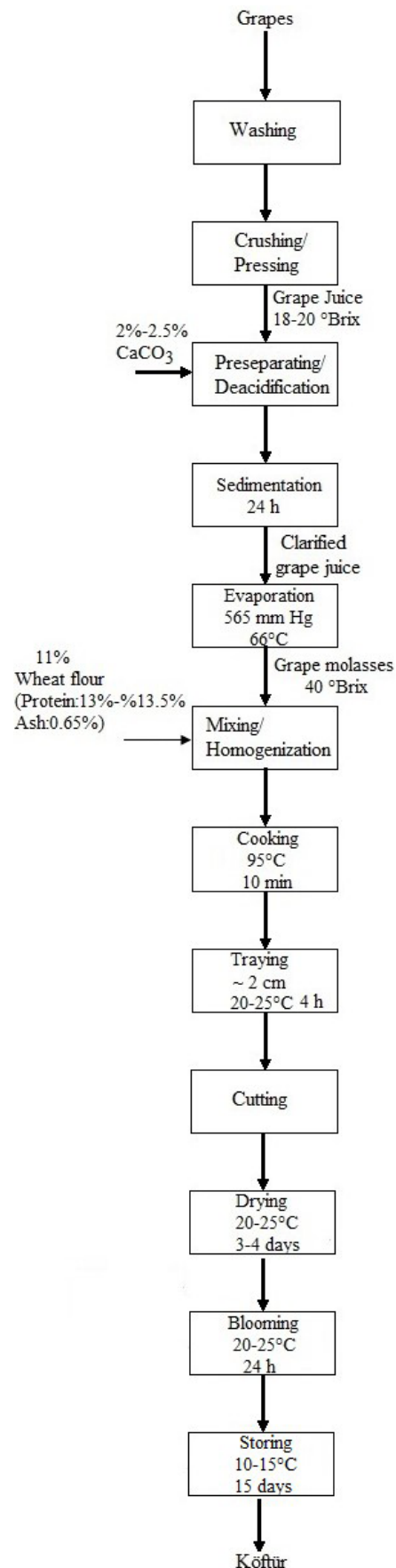


Figure 1. Block diagram of köftür production.

with onset temperatures of 156.6 °C and -38.87 °C, respectively. 10 mg of köftür samples were transferred into DSC pans (product number 03190029, Perkin Elmer, USA), that is then hermetically sealed, and put into the DSC at room temperature. An empty pan was also placed as a reference. Samples were then cooled from 20 °C to -60 °C at 5 °C/min, held for 30 min, and then scanned from -60 °C to 120 °C at 5 °C/min. Each shift on DSC curve was analyzed for the onset (T_{go}), mid (T_{gm}), and end of glass transition (T_{ge}). T_g is reported as the midpoint of the step.

Adsorption isotherms

The adsorption isotherms were established by using an isopiestic method. Briefly, prior to the determination of adsorption isotherms, the samples were dried to a water content of 4-5% in a vacuum drying cabinet at 35 °C. Desiccators having saturated salt solutions that provide a_w value of 0.1 - 0.9 were used for obtaining moisture sorption isotherms at 5 °C, 15 °C and 25 °C. The dried samples (50 mg) were weighed into weighing glass bottles. Then, they were kept half-opened in desiccators having salt solutions with different relative humidity for 7 days, thereby allowing the samples to reach the same water activity of the medium. In order to prevent the microbial growth of the samples, crystalline thymol was placed in the desiccators. Thereafter, the weight gain was measured by weighing the samples taken from the desiccator. The moisture contents of the samples were determined by vacuum drying cabinet at 70±1 °C until they reach to a constant weight. Moisture contents were given as kg water/kg dry matter. Previously described (Bell & Labuza, 2000) saturated salt solutions and relative humidity media (11.30% LiCl, 23.11% CH₃COOK, 33.07% MgCl₂, 43.16% K₂CO₃, 54.38% Mg(NO₃)₂, 65.40% NaNO₂, 75.47% NaCl, 85.11% KCl and 90.69% BaCl₂) were prepared one week before placing the samples and mixed every day to allow them to gain stability. All measurements were triplicated.

Fitting of adsorption data to isotherm equations

A great number of mathematical models are present to be availed of depicting the water sorption isotherms of foods, however, none of those models fail to provide accurate results concerning to the whole range of a_w as well as all type of food. Moreover, it is almost impossible to find a one model that fits all of the events due to the complexity of food components; instead, various models have been suggested and checked for fit to experimental data. Therefore, in this study, the data obtained were implemented to different isotherm equations that were as follows: Iglesias-Chirife, Oswin, BET, Harkins-Jura, Smith, Freundlich, Halsey, GAB, Peleg, modified Chung-Pfost, modified Oswin. The determination coefficient (R^2) and mean relative percentage deviation (P) were determined in order to make sure that the applied Equations 1 and 2 reveal good fits for the experimental data studied.

$$R^2 = 1 - \frac{\text{Residual sum of squares}}{\text{Corrected sum of squares}} \quad (1)$$

$$P = \frac{100}{n} \sum_{i=1}^n \frac{|X_i - X_{pi}|}{X_i} \quad (2)$$

where X_{pi} , predicted, and X_i , experimental moisture contents. If the P values of the model was below 10%, it was considered acceptable (Ansari et al., 2011; Mrad et al., 2012).

Isosteric heat of adsorption

The isosteric heats of adsorption were determined from experimental data by using Equation 3 obtained from the Clausius-Clapeyron equation.

$$\frac{d \ln a_w}{d \left[\frac{1}{T} \right]} = - \frac{Q_n^{st}}{R} \quad (3)$$

The net sorption isosteric heat Q_n^{st} were obtained from the slope after plotting $\ln a_w$ versus $1/T$ at certain constant values of moisture content. In order to be able to use this method, sorption isotherms determined at more than two temperatures are required as the simplifications for Equation 3 were made.

The isosteric heat of sorption (Q^{st}) is determined using Equation 4, where L_r is the latent heat of vaporization for pure water. For L_r , a mean value (2466.18 J/g) was taken at a temperature range of 5-25 °C.

$$Q^{st} = Q_n^{st} + L_r \quad (4)$$

Statistical Analyses

Complete randomized design was used in order to establish and conduct the study. All analyses were triplicated. Statistical analyses were done using SPSS 22 for Windows (SPSS Inc., Chicago, IL, USA). Mean differences were tested using Duncan's multiple range tests ($P < 0.05$) to see whether or not they are statistically different.

3 Results and discussion

3.1 Physicochemical analysis of köftür samples

The physicochemical analysis results were shown in Table 1. Moisture content of the köftür samples is similar to the results in the study conducted by Goksel et al. (2013). The researchers reported that the moisture content of köftür samples varies depending on the drying temperature and the added starch amount. The pH values were close to the values determined by Goksel et al. (2013). The microbiological, chemical and physical stability of foods depends on the a_w . a_w acts a major role in controlling the physicochemical properties of the processed product. It is used as an important criterion for microbial stability in dried products. Considering the a_w value determined in the köftür (Table 1), it can be seen that the a_w value is lower than the a_w required for the development of many microorganisms. Most bacteria have a minimum a_w value of 0.90, molds 0.85 to 0.60, and yeasts 0.91 to 0.88. L^* , a^* , and b^* values of the köftür samples are given in Table 1. Compared to the results of the research conducted by Goksel et al. (2013), L^* values were lower (4.08-12.63), a^* values higher (3.19-5.55) and b^* values were similar (4.45-8.53).

3.2 T_g value of Köftür

A typical thermal curve of köftür samples heated from -60 °C to 120 °C is shown in Figure 2. Ice formation during cooling and melting endotherm belonging to ice during heating were

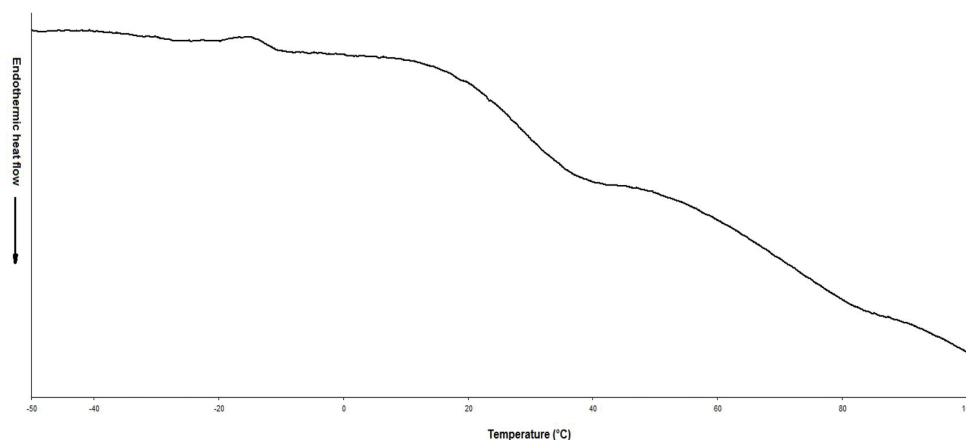


Figure 2. Representative DSC curve of köftür samples from each other.

Table 1. Physicochemical, T_g and TPA characteristics of köftür samples.

pH	6.09±0.04
Titrateable acidity (% citric acid)	0.08±0.06
Moisture (%)	33.96±0.13
Ash (%)	0.78±0.01
a_w	0.772±0.01
L^*	25.89±0.22
a^*	1.56±0.02
b^*	6.42±0.06
T_{go1} (°C)	-14.88±0.27
T_{gm1} (°C)	-12.72±0.15
T_{ge1} (°C)	-8.53±0.45
T_{go2} (°C)	7.58±0.06
T_{gm2} (°C)	24.50±0.19
T_{ge2} (°C)	42.84±0.31

not observed which is characteristics of amorphous materials. Two shifts were detected on the DSC thermal curve. The first transition corresponds to the glass transition of the branched points or more mobile constituent, and the second transition refers to the glass transition of the backbone of a large polymer or less mobile component. Detected T_g values of shifts are shown in Table 1. The T_g value of köftür was determined as 24.50 °C ±0.19 from DSC curves. This result indicates that the köftür should be stored at a temperature of less than 24.50 °C. T_g value of amorphous materials at rubbery state has been studied by Roos & Drusch (2016). However, to the best of our knowledge, no report has been made on the importance of T_g and its effects on the stability of köftür. The T_g of the fruit products reported in the literature vary significantly from each other. Reported values for strawberry, blueberry, raspberry and blackberry, for freeze-dried camu-camu pulp, for mango powder, for anhydrous raspberry powder, for apple puree powder, for peer at 30 °C, for dried fig, for date powder were 34.66 °C, 21.79 °C, 47.63 °C, 40.01 °C, -62.7 °C, 62 °C, 19.2 °C, 33.1 °C, 23.5 °C, -18 °C, 20.8 °C, respectively, (Khalloufi et al., 2000; Silva et al.,

2006; Jaya 7 Das 2009; Syamaladevi et al., 2009; Jakubczyk et al., 2010; Mrad et al., 2012; Badii et al., 2014; Sadeghi et al., 2016).

3.3 Adsorption isotherms

Adsorption isotherms of köftür determined at three different temperatures are given in Figure 3. The isotherms revealed a typical type-III shape according to the BET classification. This type is commonly seen in food materials containing high sugar content and corresponds to multilayer formation. (Figure 3). In this type of adsorption, the extent of interaction between the adsorbate layer and the adsorbent is greater than the adsorbate-adsorbent interaction, and so as the adsorption proceeds, additional adsorption occurs. At all a_w levels, köftür absorbed relatively little amounts of water, and, as expected, the sorption of water considerably increased when the a_w increased. Similar results were observed for different dried fruits and high-sugar foods by several other researchers (Falade & Aworh, 2004; Kaya & Kahyaoglu, 2005; Torezan et al., 2007; Vega-Galvez et al., 2009; Jakubczyk et al., 2010; Mrad et al., 2012; Prasantha & Amunogoda, 2013; Demarchi et al., 2014; Sadeghi et al., 2016). At low a_w 's, adsorption occurs as physical sorption on the most active locations of the biopolymer. The water in this a_w range can be adsorbed only into surface hydroxyl (-OH) sites of crystalline sugar, as confirmed by Falade & Aworh (2004).

On the other hand, in the intermediate a_w range, sorption occurs in less active sites and then gradual dissolution could possible start to occur, which may result in a precise exudation of sugars in solution at high a_w values (Tsami et al., 1990). The sudden increase of sorption which was seen when a_w increased was mainly could be attributed to the dissolution of sugars that resulted in an escalation in the number of adsorption sites as a result of the breakage to amorphous sugar of the crystalline structures of sugar (Falade & Aworh, 2004).

The increase in temperature caused a reduction in the equilibrium moisture content (Figure 3). The differences of equilibrium moisture contents between three temperatures were found statistically significant ($P<0.05$). This tendency formed by the increase in temperature could be ascribed to the excitation states of water molecules. In addition to an escalation in the

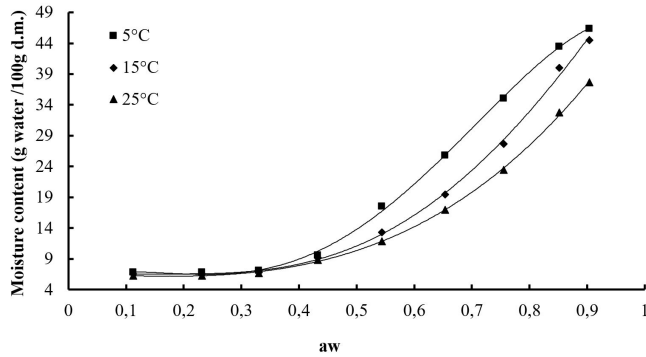


Figure 3. Moisture adsorption isotherms of köftür samples at 5 °C, 15 °C and 25 °C.

kinetic energy of the molecules that also leads to increases of molecular mobility, a rise in the temperature causes a reduction in the attractive forces between molecules. Therefore, at low temperature values, water molecules having slow molecular mobility are bound more easily to convenient binding sites on surface and promotes an increase in the degree of water sorption by the product with decreasing temperature at the given a_w (Quirijns et al., 2005; Ansari et al., 2011; Mbarga et al., 2017).

3.4 Fitting of adsorption data to various isotherm equations

The lowest P values for the isotherm equations at 5 °C, 15 °C and 25 °C were obtained when Iglesias-Chirife equation was used, which was followed by Peleg, Halsey, GAB, Smith, Modified Oswin, Oswin, Harkins-Jura, BET, Modified Chung-Pfost, and Freundlich equations, respectively (Tables 2). In this present study, Iglesias-Chirife and Peleg equations revealed the best fitting. Thus, the surface force distribution in this adsorption system seems to cause the adsorbed film to behave like a liquid in a two-dimensional state, as previously stated (Bell & Labuza, 2000). The proposed equation was described to adequately equilibrate the water contents for seventeen isotherms composed of nine different high-sugar foods, including, peach, pineapple, banana, pear, strawberry and grapefruit (Iglesias & Chirife, 1978).

Compared to the a_w range of 0.1-0.9 in terms of fit to the BET equation, the adsorption data obtained in the range of 0.1–0.55 a_w was found to fit better the BET model (Table 2). This agrees with report that the model of BET is the best fit for this a_w range (Labuza et al., 1985). For the model of BET in the a_w range 0.1–0.55 at 5, 15 and 25 °C P were found to be 17.80, 11.40, 8.20, respectively. The high P values obtained in the 0.1-0.9 a_w range could be attributed to the existence of multiple mechanisms for sorption.

The monolayer water contents (shown as m_0 from the BET equation, and m_m from the GAB equation) are shown in Table 2. Above monolayer moisture content, which is assessed as a critical water content could result some deteriorations in foods such as activity of enzymes, non-enzymatic browning and lipid oxidation.

However, below monolayer moisture contents where water is strictly adsorbed to the food, water is not able to serve as a

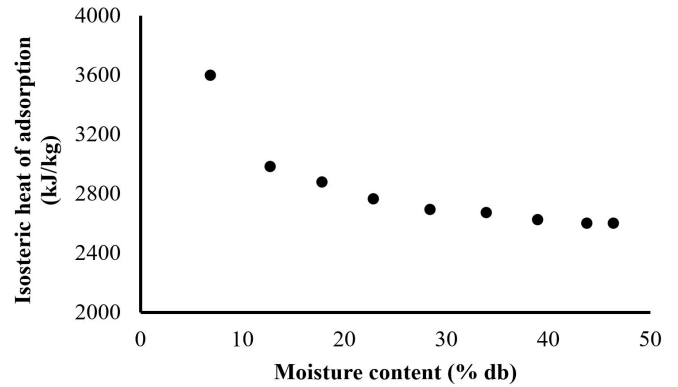


Figure 4. Isothermic heat of adsorption of the köftür.

solvent or substrate in any reaction except for lipid oxidation. When temperature increased, monolayer moisture content decreased (Table 2). The decrease in the content of monolayer moisture could result in a drop in the abundance of active sites because of the physical and chemical alterations caused by temperature. This agrees with previous reports (Falade & Aworh, 2004; Vega-Galvez et al., 2009; Ansari et al., 2011; Mrad et al., 2012; Prasantha & Amunogoda, 2013; Badii et al., 2014; Mbarga et al., 2017). m_0 content in the BET isotherm equation could be an indicator for the affinity of polar sites to water vapour. Moreover, lower m_0 values were calculated when BET equation was used, compared to those calculated in the GAB at all temperatures tested. This finding is also in an agreement with the findings reported by other researchers (Timmermann et al., 2001; Mrad et al., 2012). These differences can be attributed that the model of BET mainly focuses on surface adsorption in the first layer, whereas the model of GAB also considers sorbed water properties in the region of multilayer (Bell & Labuza, 2000). High C values in the BET model could be attributed to the existence of interaction between water and dehydrated köftür surface. c and K' constants used in the GAB equation are associated with the energies of interaction between the first and further molecules at the sorption sites. K' is more entropic in, whereas c is more enthalpic nature.

3.5 Isothermic heat of adsorption

The adsorption isothermic heat is shown in Figure 4. When the moisture content increased, a decrease in sorption energy was observed. This could be attributed to the fact that the adsorption at first takes place in the most active and accessible sites that involve elevated energies of interaction. Once these sites are engaged, adsorption to the less active sites having poorer interaction energies starts (Sanchez et al., 1997). At low water content, binding seems to be predominantly controlled by Van der Waals forces and hydrogen bonding occurring between the adsorbent surface (köftür) and water molecules. Similar findings were also observed for dehydrated mango and jackfruit (Prasantha & Amunogoda, 2013), raw beef, raw and cooked chicken, yeast, rice, grapefruit, pineapple, apple pectin, (Iglesias et al., 1989), mulberry (Maskan & Gögüş, 1998), and pomegranate arils (Mundada & Hathan, 2012). At low water

Table 2. Estimated parameters for several models for isotherms of köftür samples at different temperatures.

Isotherm equation	a_w (range)	Temperature(°C)	Constant parameters	Determination coefficient (R^2)	P (%)
Iglesias and Chirife $\ln \left(m + (m^2 + m_{0.5})^{\frac{1}{2}} \right) = p + b(a_w)$	0.1-0.9	5	b= 2.74 p= 2.08	0.949	0.27
		15	b= 2.61 p= 2.02	0.947	0.30
		25	b= 2.38 p= 2.04	0.948	0.29
Oswin $\ln m = \ln k + n \ln \left(\frac{a_w}{1-a_w} \right)$	0.1-0.9	5	n= 0.56 k= 14.86	0.907	21.33
		15	n= 0.54 k= 13.25	0.924	16.23
		25	n= 0.50 k= 12.06	0.930	14.11
BET $\frac{a_w}{m(1-a_w)} = \frac{1}{(m_0 c)} + \frac{(c-1)}{(m_0 c)} a_w$	0.1-0.9 / 0.1-0.5	5	C=327/18.21 $m_0 = 6.12/6.60$	0.736/0.903	20.55/17.80
		15	C= -87.09/25.50 $m_0 = 5.47/5.77$	0.847/0.930	14.00/11.40
		25	C= -17.01/47.62 $m_0 = 4.90/5.25$	0.868/0.969	21.44/8.20
Harkins-Jura $\frac{1}{m^2} = \left(\frac{B}{A} \right) - \left(\frac{1}{A} \right) \log a_w$	0.1-0.9	5	A= 33.67 B= -0.04	0.855	30.55
		15	A= 32.36 B= -0.02	0.861	19.88
		25	A= 30.39 B= -0.01	0.876	17.44
Smith $m = W_b - W \ln(1-a_w)$	0.1-0.9	5	W= 20.78 $W_b = 1.63$	0.965	17.78
		15	W= 19.09 $W_b = 0.56$	0.978	16.66
		25	W= 15.48 $W_b = 1.52$	0.983	12.80
Freundlich $\ln m = \ln k + \frac{1}{n} \ln a_w$	0.1-0.9	5	n= 0.94 k= 38.73	0.790	31.78
		15	n= 0.94 k= 38.73	0.763	36.22
		25	n= 0.94 k= 38.73	0.766	41.56
Halsey $\ln m = \left[\frac{1}{n} \ln C \right] - \left(\frac{1}{n} \right) \ln \left[\ln \frac{1}{a_w} \right]$	0.1-0.9	5	n= 1.30 c= 20.78	0.925	22.33
		15	n= 1.35 c= 20.28	0.960	12.68
		25	n= 1.46 c= 23.55	0.967	10.67

Table 2. Continued...

Isotherm equation	a_w (range)	Temperature(°C)	Constant parameters	Determination coefficient (R ²)	P (%)
GAB	0.1-0.9	5	$m_m=7.27$ $c=1.00$	0.625	22.00
$\frac{a_w}{m} = \alpha a_w^2 + \beta a_w + \gamma$			$K'=10.50$		
$m_m = \left[\frac{-1}{(4\alpha\gamma - \beta^2)} \right]^{\frac{1}{2}}$					
$C = \left[\beta - \frac{\left(\frac{1}{m_m} \right)}{(-2\gamma)} \right]$		15	$m_m=5.92$	0.829	14.28
$K = \frac{1}{m_m C \gamma}$			$c=1.00$ $K'=26.39$		
		25	$m_m=5.62$ $c=0.97$ $K'=31.09$	0.858	10.89
Peleg	0.1-0.9	5	A= 52.08 B= 2.35 C= 1.59 D= -0.64	0.934	10.73
$M = A a_w^B + C a_w^D$		15	A= 50.82 B= 3.10 C= 4.40 D= -0.17	0.977	5.55
		25	A= 45.32 B= 3.16 C= 4.93 D= -0.11	1.000	2.03
Modified Chung-Pfost	0.1-0.9	5	a= 95.38 b= 37.53 c= 0.06	0.946	30.89
$M = -\frac{1}{c} \ln \left[\frac{(t+b) \ln(a_w)}{-a} \right]$		15	a= 48.71 b= 7.79 c= 0.07	0.934	30.33
		25	a= 358.88 b= 127.71 c= 0.09	0.939	23.49
Modified Oswin	0.1-0.9	5	A= 9.03x10 ⁴ B= -1.80x10 ⁴ C= 0.51	0.938	22.89
$M = (A + Bt) \left(\frac{a_w}{1-a_w} \right)^C$		15	A= 3.05x10 ⁴ B= -2.03x10 ³ C= 0.56	0.972	14.87
		25	A= 3.23x10 ⁴ B= -1.29x10 ³ C= 0.53	0.979	11.72

content, intermolecular interaction energy between the water molecules and polysaccharides is approximately 4-6 kJ/mol (Hardy et al., 2002). At intermediate water content, neighboring water molecules interact with the water molecules in the monolayer by hydrogen bonding. The bonding energy of this interaction is 1 to 3 kJ/mol. The water in the last portion of the sorption isotherm is the least strongly bound and most mobile water in foods. The water molecules of this region are held by capillary forces whose energy varies between 0 and 0.3 kJ/mol (Hardy et al., 2002).

4 Conclusion

The results obtained in this study clearly indicates that sorption isotherms of köftür were type III isotherm pattern that is commonly observed in high sugar content food products. The equilibrium moisture content relationship of the köftür samples in the studied temperatures were best described by the Iglesias-Chirife and Peleg models. Based on DSC results revealed that köftür should be stored at a temperature below 24 °C in order to preserve its quality attributes.

Nomenclature			
a_w	water activity	R^2	determination coefficient
Q_n^{st}	net isosteric heat of sorption (J/g)	P	mean relative percentage deviation
Q^{st}	isosteric heat of sorption (J/g)	DSC	Differential Scanning Calorimetry
R	universal gas constant (8.314 J/g K)	T_g	glass transition temperature
T	temperature (K)	T_{go1}	onset temperature of first transition (°C)
L_r	latent heat of vaporization of pure water (J/g)	T_{gm1}	midpoint temperature of first transition (°C)
BET	Brunauer-Emmett-Teller	T_{ge1}	endset temperature of first transition (°C)
GAB	Guggenheim-Anderson-deBoer	T_{go2}	onset temperature of second transition (°C)
m	moisture content (kg water/100 kg dry matter)	T_{gm2}	midpoint temperature of second transition (°C)
m_o	monolayer moisture content for BET	T_{ge2}	endset temperature of second transition (°C)
m_m	monolayer moisture content for GAB	TPA	Texture Profile Analysis
a, b, c, k, n, p, A, B, C, D, K', W, W _b	constant parameters for the isotherm equations	N	Newton

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