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Desorption isotherms and isosteric heat of desorption of previously frozen raw pork meat

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ABSTRACT

Some meat products involve drying previously frozen pork meat, which makes the knowledge of sorption characteristics very important for the design and management of meat dehydration processes. The sorption isotherms of raw pork meat from the *Biceps femoris* and *Semimembranosus* muscles were determined at four temperatures: 25, 30, 35 and 40 °C. The experimental results were modelled using the GAB (Guggenheim, Anderson and De Boer) model. The effect of temperature was also taken into account to model the experimental sorption isotherms using four models (GAB, Oswin, Halsey and Henderson). The best results were provided by the GAB model. From the experimental sorption isotherms the isosteric heats of sorption were determined. For a moisture content higher than 0.15 kg water/kg dm, the isosteric heat of meat was similar to the latent heat of vaporization for pure water. For a lower moisture content, an increase in the isosteric heat was observed when the moisture content decreased.

1. Introduction

The influence of water on food reactions and on food quality is very important because the majority of biological reactions take place in aqueous media. Water content alone does not allow the evolution of many food phenomena to be predicted; the state of the water molecules in the food matrix being a better indicator. For that purpose, considering water activity as a parameter that measures the availability of water in foods would be a good choice. At temperatures of under 50 °C and an atmospheric pressure, considering relative humidity instead of water activity constitutes an error of less than 0.20% (Jowitt et al., 1983).

For mass transfer purposes, like drying, knowing the state of thermodynamic equilibrium between the surrounding relative humidity of the air and the moisture content of the solid matter is a basic prerequisite (Comaposada, Gou, & Arnau, 2000a). More than 70 models, representative of sorption isotherms of different food products, have been proposed in the literature (Sánchez, Sanjuán, Simal, & Rosselló, 1997) and they have different degrees of complexity and mathematical characteristics. Thus, not all models are equally suitable for different computing schemes in a process. For that reason, it appears of interest to have different models available for the same isotherm, and also to know the accuracy of those models.

Some meat products involve drying. The product is mainly stabilized by decreasing water activity during the production process. For example, the cured ham drying process is made in different steps. Temperature during these steps ranges between 3 and 35 °C. And it is also important the preservation of the product in non cold rooms. The room temperature can rise to more of 40 °C during summer in some Mediterranean countries. Other dried meat products, like charqui or Mexican cecina are processed at high temperatures, 40 °C or more.

The use of thawed raw material is becoming more frequent in the cured meat product industry. For that reason, it is very important to know the sorption isotherms of previously frozen raw meat when designing and managing dehydration processes. This is especially true when determining the end of the process which guarantees economic profitability and optimal quality (Rahman, Sablani, Al-Ruzeiqi, & Guisan, 2002; Trujillo, Yeow, & Pham, 2003). To deal with the last two objectives, an optimization problem should be addressed. Thus, knowing the sorption characteristics of meat is essential in order to optimize the production of this kind of products.

One way to approach sorption characteristics is by means of the isosteric heat of sorption, which represents the energy or intermolecular bonding between water molecules and absorbing surfaces (Mulet, García-Reverter, Sanjuán, & Bon, 1999). Usually, the moisture content at which the heat of absorption is similar to that of vaporization for pure water is considered as an indicator of the free water content (Mulet, García-Pascual, Sanjuán, & García-Reverter, 2002; Mulet et al., 1999; Sánchez et al., 1997). The isosteric heat

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Nomenclature

a_w	water activity	H_n	multilayer sorption heat (kJ/kg)
A_{Ha}	Halsey model parameter, dimensionless (Eq. (5))	K	GAB model parameter, dimensionless (Eq. (1))
A_{He}	Henderson model parameter, dimensionless (Eq. (6))	K_0	GAB model parameter, dimensionless (Eq. (3))
A_{Os}	Oswin model parameter, dimensionless (Eq. (4))	L_r	pure water vaporization energy (kJ/kg)
BF	*Biceps femoris* muscle	Q^{st}	isosteric heat of desorption (kJ/kg)
B_{Ha}	Halsey model parameter, dimensionless (Eq. (5))	Q_n^{st}	net isosteric heat of desorption (kJ/kg)
B_{He}	Henderson model parameter, dimensionless (Eq. (6))	R	constant of perfect gas (8.31 kJ/kmol K)
B_{Os}	Oswin model parameter, dimensionless (Eq. (4))	SM	*Semimembranosus* muscle
C	GAB model parameter, dimensionless (Eq. (1))	T	temperature (°C, K)
C_{Ha}	Halsey model parameter, dimensionless (Eq. (5))	VAR	total percentage of explained variance
C_{Os}	Oswin model parameter, dimensionless (Eq. (4))	X	mean moisture content (kg water/kg dry matter)
C_0	GAB model parameter, dimensionless (Eq. (2))	X_m	monolayer moisture content (kg water/kg dry matter)
D_{Os}	Oswin model parameter, dimensionless (Eq. (4))	ΔH_C	GAB model parameter (kJ/kg)
H_m	monolayer sorption heat (kJ/kg)	ΔH_K	GAB model parameter (kJ/kg)

of desorption is useful in order to assess the energy needed for the drying process.

Two different methods can be used to determine the isosteric heat of desorption: the application of the Clausius–Clapeyron equation to sorption isotherms at different temperatures and the estimation by means of calorimetric techniques considering the Riedel equation (Riedel, 1977). In the literature, the Clausius–Clapeyron equation is the most widely used method (Aktas & Gürses, 2005; Delgado & Sun, 2002a; Mulet et al., 1999; Mulet et al., 2002; Singh, Rao, Anjaneyulu, & Patil, 2006; Sánchez et al., 1997). Calorimetry needs not only very accurate experimental work but also expensive equipment. Thus, this method is hardly ever used (Mulet et al., 1999; Sanjuán, García-Reverter, Bon, & Mulet, 1994; Sánchez et al., 1997).

There is little information in literature about the isosteric heat of sorption of fresh pork meat. Some authors have determined the sorption isotherm of raw meat (Delgado & Sun 2002b; Trujillo et al., 2003; Singh et al., 2006), salted meat (Comaposada et al., 2000a; Comaposada, Gou, Pakowski, & Arnau, 2000b; Comaposada, Arnau, & Gou, 2007; Lopes-Filho, Romanelli, Barboza, Gabas, & Telis-Romero, 2002) and fish (Bellagha, Sahli, Glenza, & Kechaou, 2005; Rahman et al., 2002). Nevertheless, some difficulties are encountered with moisture sorption isotherms in literature because the information about the history and pre-treatment of the food sample is frequently not properly reported (Trujillo et al., 2003). This information is relevant when comparing the sorption isotherms of similar products.

Moreover, the price fluctuations have led to some meat industries using frozen meat to guarantee lower prices and raw material availability, which is true for Spanish dry cured ham production. Since information on sorption isotherms and heat of sorption is of interest to the industry and as there is a lack of such information in the case of previously frozen meat, this situation has to be addressed. Therefore, the aim of this work is to determine the desorption isotherms at different temperatures (25, 30, 35 and 40 °C) of the two main muscles (*Biceps femoris* and *Semimembranosus)* of previously frozen pig leg, and the estimation of the isosteric heat of desorption of these two muscles.

2. Materials and methods

2.1. Raw material characterization

Two characteristic muscles of pig leg: *Biceps femoris* and *Semimembranosus* were considered. Moisture (AOAC 940.46, 1997), ash (AOAC 920.153, 1997), fat (AOAC 991.36, 1997) and protein content (AOAC 928.08, 1997) were determined. The pH of meat was measured with a pH-meter CRISON (model 507).

2.2. Sample preparation

Semimembranosus and *Biceps femoris* muscles from four different pigs were used for experimental isotherm determination. The muscles under study were cut into eight pieces. Each piece was wrapped in a plastic film and frozen at −20 °C until processing, for approximately 60 days. Meat pieces reached −20 °C between 16 and 24 h.

The pieces of meat were defrosted at 12 °C for 18 h. They were maintained at this temperature until sample preparation. For that purpose, the superficial fat was removed. After that, each meat piece was minced and spread in a very thin layer over a piece of aluminium foil (approximately 6 × 8 cm), 12 samples from each meat piece were prepared. Each meat sample was put into a hermetic glass container with silica gel at the bottom.

The drying time for every container of each sample in the silica gel atmosphere was varied in order to attain a wide range of moisture content. Some samples were dried for a longer time to obtain very low values for moisture content and water activity. For that purpose, after 9 h of drying, the 12 samples from the same meat piece were homogenized by means of a mincer and after that introduced into the silica gel atmosphere again.

After the drying process, the 12 samples of each meat piece were homogenized and kept at 4 °C in a sealed cell until the determination of water activity and moisture content, between 12 and 48 h.

2.3. Experimental sorption isotherms

Water activity was measured at four temperatures (25, 30, 35 and 40 °C) in triplicate. The value for water activity was the average of the three measurements. Three electric hygrometers (Novasina, two TH200 model and one AW SPRINT TH500 model) were used. Before measurements, the hygrometers were calibrated at 25 °C by using the standard salts provided with the equipment. Verification of measurements at 30, 35 and 40 °C were also carried out by checking water activity value of standard salts at these temperatures.

After water activity determination, moisture content (AOAC 940.46, 1997) was determined in triplicate. The moisture content considered was the average of the three replicates.

2.4. Modelling of sorption isotherms

The experimental sorption isotherm of pork meat was modelled using the GAB model, Eq. (1). The GAB equation has been found to be the one that most adequately represents the experimental data in the range of water activity which is of most practical interest in