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Non-destructive determination of fat content in green hams using ultrasound and X-rays

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ABSTRACT

This work addresses the use of ultrasound (US) and medical dual energy X-ray absorptiometry methods to predict the fat content in green pork hams. Ultrasonic velocity (υ) and X-ray absorption were measured in 78 green hams. An increase in the fat content involved an increase in υ and a decrease in the X-ray attenuation measured at 2 °C. Models developed to predict the fat content from the ultrasonic velocity or X-ray parameters provided errors of 2.97% and 4.65%, respectively. The combination of both US and X-ray technologies did not improve prediction accuracy. These models allowed green hams to be classified into three levels of fatness, with 88.5% and 65.4% of the hams correctly classified when using models based on ultrasonic and X-ray parameters, respectively. Therefore, US and X-rays emerge as useful quality control technologies with which to estimate the fat content in green pork hams.

1. Introduction

The total fat content of green (raw) hams is a key issue, since it affects the processing of both cooked and dry-cured hams. In cooked hams, intramuscular fat can affect the binding strength and consumer acceptability. In dry-cured hams, the fat content has a great influence on the salt uptake during the salting process (Cierach & Modzelewska-Kapitula, 2011) and on the weight losses during drying (Čandek-Potokar & Škrlep, 2012; Garcia-Gil et al., 2012). The development of online non-invasive technologies as a means of predicting the fat content in green hams is of special interest for the meat industry, since they would make it possible to classify the product into different fat categories which would allow the elaboration processes to be optimized. These techniques need to be robust and cost-effective for being used in the industry.

New techniques are being tested for carrying out the non-destructive determination of the composition of the meat products. For live animals and carcass inspection, reliable ultrasonic devices are available for the measurement of lean and fat content (Miles, Fisher, Fursey, & Page, 1987; Miles, Fursey, Page, & Fisher, 1990), as well as the depth of subcutaneous fat, in particular sites of the animal. Miles and Fursey (1977) related the ultrasonic velocity to the fat content of meat muscles, comminuted tissue, meat mixtures and dehydrated muscles. In this regard, Koch et al. (2011) estimated the intramuscular fat content of porcine *Longissimus dorsi* muscle by using ultrasound velocity and attenuation. Corona, García-Pérez, Ventanas, and Benedito (2014) and Benedito, Carcel, Rosello, and Mulet (2001) have also used ultrasound to determine the composition of a formulated dry-cured pork meat product (sausage) and raw pork meat mixtures, respectively. Most of the aforementioned ultrasonic studies rely on the measurement of the ultrasonic velocity, because it is the simplest and most reliable ultrasonic measurement. However, each ultrasonic measurement provides information on a reduced area of the sample which implies that, if large samples are to be analyzed, multiple measurements are required. Moreover, the results are largely dependent on the temperature and anisotropy of meat tissues (Miles & Fursey, 1977). In this regard, other non-destructive techniques, such as X-rays, do not require a precise temperature control.

There are several X-ray technologies that, based on the differential X-ray attenuation produced by the different tissue density, permit meat composition to be determined. X-ray computed tomography has been used to predict the lean/fat content in animal carcasses (Vester-Christensen et al., 2009) and bone-in green hams (Picouet, Muñoz, Fulladosa, Daumas, & Gou, 2014) and to determine the intramuscular fat content of meat (Font-i-Furnols, Brun, Tous, & Gispert, 2013). Brienne, Denoyelle, Baussart, and Daudin (2001) used Medical Dual Energy X-ray Absorptiometry (DEXA) to predict the fat content in pork meat/fat mixtures and beef muscles. Although a low correlation was observed between the percentage of fat obtained through chemical analyses and the percentage estimated from the Beer–Lambert equation, they proposed different corrections and obtained an improvement. However, corrections are specific for each sample format and DEXA equipment. Mercier et al. (2006) used the ratio between the coefficients of attenuation of the two X-ray energy levels obtained with a medical

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DEXA to predict the fat content in legs of lamb carcasses. The predictions underestimated the fat content, probably because dissected fat was used instead of chemically analyzed fat for predictive model development. López-Campos, Larsen, Prieto, Juárez, and Aalhus (2013) reported that DEXA technology may also be useful for the objective estimation of the intramuscular fat content in beef. Nevertheless, the medical devices used in the aforementioned studies are not suitable for working in industrial environments at the required speed. In this sense, other authors demonstrated that non-medical X-ray instruments also allow the online determination of the salt uptake in whole bone-in hams during the salting procedure (Fulladosa, Muñoz, Serra, Arnau, & Gou, 2014) and the accurate estimation of the fat content of boned and packaged meat trimmings (Hansen et al., 2003).

Nevertheless, more research is needed before using ultrasound and DEXA technologies to determine the composition of products in which the fat is not uniformly distributed or that contain bones. Fat content determination in whole pieces, such as green bone-in hams, is still a challenge because among others the presence of bones and the existence of different muscles with a high degree of heterogeneity in terms of their fat content and distribution. Besides, combining the information obtained from acoustic and electromagnetic waves as a means of achieving more accurate predictions is worth investigating. Thus, the aim of the present study was to analyze the ability of ultrasound and DEXA techniques to predict both separately and jointly the fat content of green hams and to determine the feasibility of using them for industrial classification purposes.

2. Material and methods

2.1. Samples

Thirty nine green hams from 'White' pigs (crosses containing Duroc (CDU) or Large White (CLW)), average weight 11.1 ± 0.8 kg, and 39 green hams from 'Iberian' pigs (crosses containing at least 50% Iberian breed (CIB)), average weight 10.6 ± 1.2 kg, were purchased in 2 different slaughterhouses. The hams were taken to the pilot plant in refrigerated storage and kept at 2 ± 2 °C for less than 2 days before the non-destructive measurements were conducted. The different genetic source of the hams allowed for a wide range of fat contents.

2.2. Ultrasonic measurements

A specific device was designed and assembled for ultrasonic measurements; it mainly consisted of a couple of narrow-band ultrasonic transducers (1 MHz, 0.75″ crystal diameter, A314S-SU model, Panametrics, Waltham, MA, USA), a pulser-receiver (Model 5058PR, Panametrics, Waltham, MA, USA) and a digital oscilloscope (Tektronix, TDS5034, Digital phosphor oscilloscope. Tektronix Inc. Bearverton, OR, USA). A digital height (192-633 Serie, Mitutoyo, Japan) gage was linked to the computer by a RS 232 interface in order to measure the sample thickness (±0.01 mm) (Fig. 1A).

The ultrasonic velocity was calculated from the time of flight (an average of 3 signal acquisitions) and the sample thickness. In order to assess the ultrasonic velocity, the system delay was taken into account, which was determined from the pulse transit time measured across a set of methacrylate cylinders of different thicknesses. The delay time was then obtained from the intercept on the y-axis of the time versus thickness graph.

The ultrasonic measurements were taken in three zones of the ham (FC, BE and C), as shown in Fig. 1A. The number of experimental measurements carried out in each zone depended on the hams' surface and weight. On average, 20 measurements were carried out in the cushion (C) and 5 in the fore cushion (FC) and butt end (BE). Measurements were carried out in triplicate. The hams were kept at 2 ± 2 °C for 24 h before the ultrasonic velocity was measured in place. The ultrasonic velocity in the ham was calculated as the average of the 30 ultrasonic velocities measured in all the ham zones. The average ultrasonic velocity was correlated to the fat content of the green hams.

2.3. X-ray absorptiometry measurements

A commercially available X-ray inspector model X20V G90 (Multiscan technologies, S.L, Cocentaina, Spain) was used to scan the samples at 2 °C. X-rays were emitted from below the samples and the transmitted X-rays were measured in the upper part of the equipment while a conveyor belt moves the sample through at 0.33 m s^{-1} (Fig. 1B). The device uses low-energy X-rays to obtain images (matrixes of values, 4000 × 1280 pixels) of the scanned object in the horizontal plane. Samples were scanned at three different voltages and intensities, specifically 90 kV and 4 mA, 70 kV and 8 mA and 50 kV and 15 mA, in exactly the same position and location in order to combine the information obtained from the three matrixes of values. Matrixes of attenuation values were imported and analyzed using a specific Matlab code (MATLAB, Ver. 7.7.0, The Mathworks Inc., Natick, MA, USA).

The global X-ray attenuation value (A) for each sample and used energy was obtained by the following equation:

$$A = -\mathrm{Ln}\cdot\frac{\sum I_{(i;j)}}{\sum I_{0(i;j)}}. \quad (1)$$

Where I is the energy of the radiation transmitted through each pixel of the matrix (i;j); I_0 is the energy of the incident radiation to each pixel of the matrix (i;j); i ranges from 1 to 4000 and j ranges from 1 to 1280. Therefore, attenuation values for measurements carried out at 50, 70 and 90 kV were obtained (A_{50}, A_{70} and A_{90}).

According to the Beer–Lambert law, X-ray attenuation is proportional to the thickness and composition of the sample (n components):

$$A = L\cdot\sum_{i=1}^{n}\varepsilon_i\cdot c_i = \frac{L}{V}\cdot\sum_{i=1}^{n}\varepsilon_i\cdot M_i. \quad (2)$$

Where L is the sample thickness (m), V is the sample volume (m^3), ε_i is the absorptivity coefficient of component i (m^2 kg^{-1}), which is dependent on the X-ray energy, and c_i and M_i are the concentration (kg m^{-3}) and the mass (kg) of absorbing component i, respectively.

Eq. (2) can be converted into Eq. (3) by dividing by the ham weight (M_t):

$$\frac{A\cdot V}{L\cdot M_t} = \sum_{i=1}^{n}\varepsilon_i\cdot X_i \quad (3)$$

where X_i is the mass fraction of component i.

Since hams do not have a uniform thickness, an average thickness was estimated as the ratio between V and the sample surface in the scan (S). Then, a new parameter (A_T) can be calculated from Eq. (3):

$$A_T = \frac{A\cdot S}{M_t} = \sum_{i=1}^{n}\varepsilon_i\cdot X_i. \quad (4)$$

The correlation between A_T, obtained at different voltages (A_{T50}, A_{T70} and A_{T90}), with the fat content was analyzed.

2.4. Dissection and chemical analysis

After the ultrasound and X-ray measurements, the lean and fat tissues for each ham were dissected, weighed and minced together. Afterwards, the fat and moisture contents of the mixture were determined. The moisture was analyzed by drying at 103 ± 2 °C until reaching constant weight (ISO, 1442, 1997). The total fat content was estimated by near infrared spectroscopy using a FoodScanTM Lab (Foss Analytical, Dinamarca) according to AOAC (2007). All analyses