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X-ray absorptiometry and ultrasound technologies for non-destructive compositional analysis of dry-cured ham

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ABSTRACT

The characterization of dry-cured ham according to salt and fat contents is of great interest to industry and consumers. In this study, the feasibility of using non-destructive technologies such as X-rays and ultrasound (US) for this purpose was evaluated in dry-cured ham portions. Predictive models for fat and salt contents were based on the measurement of X-ray attenuation at different incident energies and the US velocity when the ham was at 2 and 15 °C. A semi-empirical model based on the US measurements was also developed. Salt content was better predicted by X-ray technology (RMSEV = 0.43%) than US (RMSEV = 0.69%) and their combination had little impact on the accuracy of the prediction. US predicted fat content slightly better (RMSEV = 6.70%) than X-rays (RMSEV = 7.00%), and their combination increased the accuracy of the prediction (RMSEV = 5.60%). Using the best models, 81% of samples were correctly classified into three salt content categories with X-rays whereas 71% of samples were correctly classified into three fat content categories by combining X-rays and US.

1. Introduction

The characterization of food products according to their composition is of interest to industry in order to provide consumers with nutritionally defined products. Well-characterized products allow consumers to choose foodstuffs according to their needs and/or preferences. Besides, the selection of products with a lower salt or fat content than the conventional ones may have a special relevance. In this regard, nutritional claims such as "reduced salt" (25% less salt in comparison to standard salt content on the market) or "reduced fat content" (30% less fat in comparison to standard fat content on the market) may have competitive advantages. However, information, such as 'reduced salt content' or 'reduced fat content', should be confirmed in order to ensure compliance with European regulations (Regulation 1924/2006). In the case of entire pieces of meat, such as dry-cured ham, this characterization is of special complexity since the variation of fat and salt contents within batch, batch-to-batch or even within one ham is high. Variations in the global salt content of the product at the end of the process is due to both the raw ham characteristics and the salting process conditions (Garcia-Gil et al., 2011; Guerrero et al., 2004; Picouet et al., 2013).

Recently, several non-destructive technologies based on near infrared spectroscopy (Gou et al., 2013), dielectric time domain reflectometry (Fulladosa et al., 2013; Rubio-Celorio et al., 2015) and hyperspectral imaging (Liu et al., 2014) have arisen as useful techniques to determine salt and water contents and water activity (a_w) in dry-cured ham. However, these technologies only analyze the composition of the outermost layers of a product (because of their limited penetration capacity), which is not representative of the whole piece. Mincing of the sample would be necessary to obtain representative homogeneous surfaces which allow the measurement of the average composition of a whole meat piece. In contrast, resonance magnetic imaging (Fantazzini et al., 2009) or computed tomography (Fulladosa et al., 2010; Håseth et al., 2012; Santos-Garcés et al., 2010, 2014) are able to non-invasively predict the composition of any point of a piece, but nowadays they are not currently applicable on-line on an industrial scale due to their high security requirements and cost. Other technologies based on X-ray absorptiometry and ultrasound (US) can be applied on-line and could be useful to predict the composition of entire pieces of ham. X-ray absorptiometry has previously been used to determine carcass and raw meat composition (Brienne et al., 2001; Hansen et al., 2003). US has also previously been used to determine the composition of meat-based products (Simal et al., 2003) and characterize the texture and sensory traits of subcutaneous fat from dry-cured hams (Niñoles et al., 2008). Nevertheless, no

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studies using these technologies for salt or fat content determination in dry-cured ham were found in the literature.

The aim of the present study was to evaluate the prediction accuracy of salt and fat contents in dry-cured hams by means of X-ray and ultrasound technologies and to study the viability of a classification system of dry-cured hams according to a predicted composition.

2. Materials and methods

2.1. Samples

Forty-six hams from different breeds and origins were selected/elaborated in order to obtain a wide range of salt and fat contents. Nineteen green hams from pigs consisting of crosses of Large White and Landrace breeds (W, White hams), characterized by a lower fat content than IB hams, were purchased at different commercial slaughterhouses. The W hams were salted for 0.6, 0.7, 0.8, 1.1, 1.2, 1.3, 1.4 and 1.5 days/kg of green ham in order to obtain a wide variation of salt contents and followed a traditional drying process (Gou et al. (2012). When the drying process had finished, 27 commercial dry-cured hams from pigs consisting of at least 50% Iberian breed (IB, Iberian hams) characterized by a high fat content were selected at the end of the salting process according to their salt and fat contents, using computed tomography equipment (Santos-Garcés et al., 2012). All the hams, W and IB, were boned, trimmed of skin and external yellow subcutaneous fat and lean according to the common practices in industry, formatted in blocks of constant thickness (76.3 ± 3.5 mm) and divided into six portions ($n = 276$) for further X-ray analysis. After X-ray measurements, the ham portions were individually vacuum packed in plastic bags before US measurements were carried out.

2.2. X-ray absorptiometry (X-ray)

A X-ray inspector model X20V G90 (Multiscan technologies, S.L, Cocentaina, Spain) was used to scan the dry-cured ham portions (Fig. 1A). X-rays were emitted from below the samples and the transmitted X-rays were measured at the upper part of the device while a conveyor belt moved the sample through it. The system used low-energy X-rays to obtain images (matrices of attenuation values, 4000 × 1280 pixels) of the scanned object at a horizontal plane with a constant speed (20 m/min). Three different voltages and intensities, specifically 90 kV and 4 mA, 70 kV and 8 mA and 50 kV and 15 mA, were used to scan the ham portions each one in exactly the same position.

Matrices of attenuation values were imported from the X-ray inspector device. The global X-ray attenuation value (A) of the sample was obtained by the following equation:

$$A = -\sum Ln\left(\frac{I(i;j)}{I_o(i;j)}\right) \quad (1)$$

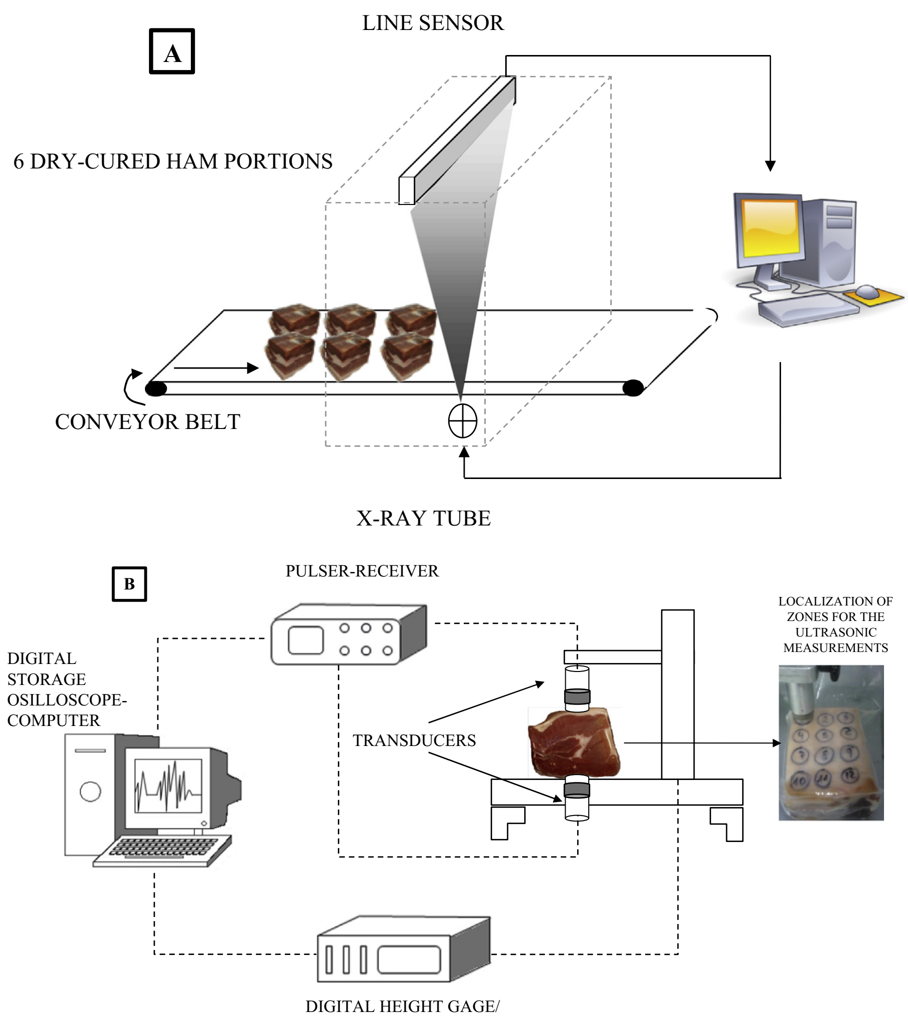

Fig. 1. Experimental set-up used for the X-ray (A) and ultrasonic (B) measurements.