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X-ray absorptiometry for non-destructive monitoring of the salt uptake in bone-in raw hams during salting

E. Fulladosa*, I. Muñoz, X. Serra, J. Arnau, P. Gou

IRTA, XaRTA, Food Technology, Finca Camps i Armet, E-17121 Monells, Girona, Spain

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ABSTRACT

Salt uptake variability in dry-cured ham batches is a problem for the dry-cured ham industry because part of the hams have either an excess or a lack of salt and therefore are more prone to sensory defects. The aim of this study was to evaluate the feasibility of an X-ray inspector for a non-destructive, on line determination of the salt uptake in entire bone-in hams during the salting procedure. Moreover, its usefulness in combination with a modified salting procedure to reduce the salt content and within batch variability was evaluated in an industrial case study. Predictive models for salt content, accurate enough for classification purposes (RMSEV = 0.210–0.257%), were developed using only one X-ray energy (50 kV). The use of an X-ray inspector in combination with slight modifications of the process allowed the reduction of the average salt content a 13.75% and 26.67% and a within-batch standard deviation from 0.45% to 0.21% or 0.26% depending on the reduced target salt content.

1. Introduction

Dry-cured ham is a traditional product of many countries which is mainly stabilized by the addition of NaCl at refrigeration temperature. Within-batch and batch-to-batch salt content variation is a problem for the dry-cured ham industry. An excessive amount of salt produces a too salty taste, but an insufficient amount of salt causes sensory defects such as pastiness and product softness (Benedini, Parolari, Toscani, & Virgili, 2012; García-Garrido, Quiles-Zafra, Tapiador, & Luque de Castro, 1999; Gou, Morales, Serra, Guàrdia, & Arnau, 2008; Ruiz-Ramírez, Arnau, Serra, & Gou, 2005) that can affect consumer acceptability (Morales, Guerrero, Aguiar, Guàrdia, & Gou, 2013). Thus, the objective of dry-cured ham producers is to obtain homogeneous batches of hams with the desired amount of salt. Nevertheless, it is difficult to control all the factors causing salt-uptake variation. Raw ham characteristics (García-Rey, García-Garrido, Quiles-Zafra, Tapiador, & Luque de Castro, 2004; Guerrero, Gou, & Arnau, 1999) and pre-treatments such as skin-trimming and pressing of raw material (Garcia-Gil et al., 2011), the freezing/thawing processes and elaboration conditions (Garcia-Gil, Muñoz, Santos-Garcés, Arnau, & Gou, 2014) all affect salt uptake, causing high salt content variation in dry-cured ham. Furthermore, reducing the salt content variability, both within batch and batch-to-batch, is even more important not only when dry-cured ham producers want to include the 'reduced sodium' claim in their products (Regulation EC 1924/2006) but also to avoid sensory defects and microbiological safety problems due to an insufficient amount of salt.

The development of manufacturing processes to accelerate salt diffusion (Fulladosa, Serra, Gou, & Arnau, 2009; Marriott, Graham, Shaffer, & Phelps, 1987) and equipment for raw ham classification (Serra et al., 2011) can help to optimize the elaboration process and reduce batch variability. Another possible solution for reducing salt uptake variability could be the characterization of hams during the salting process using non-destructive technologies that allowed the adaptation of the salt content of hams to the desired values.

X-ray-based technologies are among the most promising non-destructive technologies for determining meat composition (Fulladosa, Garcia-Gil, Santos-Garcés, Font i Furnols, Muñoz & Gou, 2011). The combination of the information obtained from scanning samples at two different energies is the basis of edical devices such as Dual Energy X-ray Absorptiometry (DXA). DXA is useful when measuring the percentage of fat and lean tissue (Marcoux, Bernier, & Pomar, 2003; Mercier et al., 2006; Mitchell, Scholz, Pursel, & Evock-Clover, 1998) and to determine the chemical composition of pork and beef (Brienne, Denoyelle, Baussart, & Daudin, 2001). Hansen et al. (2003) demonstrated that a non-medical instrument composed of two separated X-ray sources, allows the prediction of the fat content of meat trimmings without bones in plastic containers with a high accuracy. However, this technology only

* Corresponding author. Tel.: +34 972 630 052; fax: +34 972 630 373.
E-mail address: elena.fulladosa@irta.cat (E. Fulladosa).

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measures the X-ray attenuation in one direction, obtaining 2-D images. The presence of very dense objects, such as bones, makes it difficult to predict fat or salt content with this technology because bones attenuate the incident energy much more than other ham components. Moreover, samples with the same composition but different thicknesses produce different X-ray attenuations which can incorrectly be attributed to different sample compositions, if thickness is not taken into account. No studies regarding salt content determination using dual X-ray absorptiometry in meat products have been found so far. Only X-ray computed tomography (CT), which rotates around the sample obtaining information from different planes, has been used to predict salt, water and fat contents in bone-in dry-cured ham (Fulladosa, Santos-Garcés, Picouet, & Gou, 2010; Santos-Garcés, Muñoz, Gou, Garcia-Gil, & Fulladosa, 2014; Sørheim & Berg, 1987; Vestergaard, Risum, & Adler-Nissen, 2004) which has been used to optimize elaboration processes (Håseth, Sørheim, Høy, & Egelandsdal, 2012; Santos-Garcés, Muñoz, Gou, Sala, & Fulladosa, 2012), to study salt diffusivity (Picouet, Gou, Fulladosa, Santos-Garcés, & Arnau, 2013) along with others. However at present, CT and DXA technologies are only available in medical devices which are unsuitable for industrial environments and do not operate at the required production rate. Therefore the development of industrial equipment should take these requirements into account.

The aim of the present study was to evaluate the feasibility of an X-ray inspector for predicting the salt uptake in bone-in raw hams during the salting process by using the information obtained from one or a combination of different tube-voltage settings. The influence of fat content or ham type on the accuracy of the predictions was also evaluated. Furthermore, the usefulness of an X-ray inspector in combination with a modified salting procedure, with the aim of reducing the salt content and the within-batch variation, was evaluated in an industrial case study.

2. Material and methods

2.1. X-ray technology and scanning conditions

X-ray technology is based on the physical principle of X-ray attenuation (Eq (1)):

$$I = I_0 e^{-\mu d} \quad (1)$$

where I is the intensity of the transmitted radiation (the radiation exiting from the tissue which is measured by the instrument), I_0 is the intensity of the incident radiation (entering the tissue), μ is the so-called total linear attenuation coefficient of the tissue, and d is the tissue thickness. The attenuation coefficient μ is determined by the atomic number and density of the tissue; the higher the atomic number and density, the higher the attenuation coefficient (Pietrobelli, Formica, Wang, & Heymsfield, 1996). Thus, variation of meat composition (i.e salt, water and fat contents) influences this parameter. In addition, attenuation coefficient (μ) is also dependent on the incident X-ray energy.

A commercially available X-ray inspector model X20V G90 (Multiscan technologies, S.L, Cocentaina, Spain) was used to scan the hams. This X-ray system consists of a conveyor belt which moves the sample through X-rays which are emitted from below the samples and the transmitted X-rays are measured at the upper part of the equipment. The system uses low-energy X-rays to obtain images (matrices of X-ray attenuation values of 4000 × 1280 pixels) of the scanned object in the horizontal plane at a constant speed. Matrices of attenuation values are different depending on the density and thickness of the sample. The higher the thickness and the salt content, the darker the obtained image is (Fig. 1).

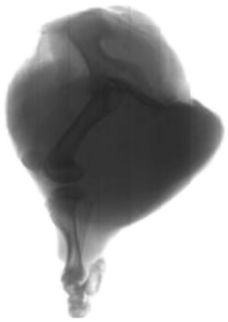

Fig. 1. Image from a ham obtained using an X-ray inspector. Different grey tones represent different X-ray attenuation values.

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 all the hams in exactly the same position in order to be able to compare the obtained matrices of values.

2.2. Samples used to develop and validate the models to predict the salt content in hams during salting and post-salting stages

Fifty-four hams from crosses of Duroc, Large White and Landrace breeds (White hams) and 40 hams from crosses with at least 50% Iberian breed (Iberian hams) were obtained from different commercial slaughterhouses in order to have a wide range of fat content.

All the hams were weighed and salted according to the standard dry-cured ham elaboration process. The hams were manually rubbed with the following mixture (g/kg of raw ham): 0.15 g KNO_3, 0.15 g $NaNO_2$, 1.0 g dextrose, 0.5 g sodium ascorbate and 10 g NaCl and were equally divided into five batches. All the hams were pile salted with a layer of salt (4.7% ± 0.17%) of at least 10 cm and kept for 2, 4, 7, 11 or 16 days at 3 ± 2 °C and 85% ± 5% relative humidity (RH) in order to obtain a wide range of salt content, i.e. high variation in salt uptake. After salting, the hams were washed with water at 15 ± 1 °C, weighed, scanned using the X-ray inspector, and then vacuum packaged. After 40 days of storage at 3 ± 2 °C, all the hams were dissected following the methodology established by Walstra and Merkus (1995). Hams were dissected into the major parts: bones, skin, lean tissue and fat tissue. The lean and fat tissue were then minced together and homogenized in a bowl chopper. The salt, water and fat contents of the mixture were analytically determined.

In order to develop and validate the predictive models for salt content, the hams were divided into a calibration and a validation set. The hams were then sorted according to the measured salt content and subsequently distributed alternately: two hams for the calibration set and one ham for the validation set. Therefore ensuring that both calibration and validation sets covered a similar range of salt content and contained hams from different genetic origins which provided a similar range of fat content in both sets of hams (Table 1). Specific models for White hams were also developed following the same procedure described above.

2.3. Chemical analysis

All analyses were performed in triplicate. Water content was analysed by drying at 103 ± 2 °C until reaching a constant weight (AOAC, 1990); the analytical standard error was 0.19%. Chloride content was determined according to ISO 1841-2 (1996) using a potentiometric titrator 785 DMP Titrino (Metrohm AG, Herisau, Switzerland) and expressed as salt content; the analytical standard