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Application of the magnetic induction technique for the non-destructive assessment of salt gain after the salting process of Parma ham

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ABSTRACT

The fast and non-destructive inspection of salt uptake after the salting phase of dry-cured ham process still remains a goal to allow the optimization of the salting process.

This work aims to show the capability of a single frequency, magnetic induction (MI) system, to predict salt (NaCl) content of whole hams after the salting stage. MI system is based on the measurement of the perturbation caused by an alternating excitation magnetic field on a conductive sample; the perturbation is typically detected by measuring the current induced in a suitable receiver coil. One hundred and fifty-nine hams were scanned by the MI scanner before and after the salting phase. Hams were dissected, separated into muscle and fat parts, and analysed for salt content (potentiometric method). Predictive models (multi-linear regression analysis) of the salt gain in hams were developed, based on output signals generated by the MI system. The model including independent variables given by scanning ham when raw and after the salting, achieved the best accuracy ($R^2 = 0.89$; RMSEC = 0.19%). It was concluded that variations in electrical conductivity originated by different salt content and revealed by magnetic induction have potential application to predict the salt content inside entire bone-in hams after salting process.

1. Introduction

Salting treatment of dry-cured ham is a key processing step, since it determines the salt content in final outcome. Moreover it is a tricky phase because it is affected by single and combined factors like ham shape, size, fatness, meat quality, environmental conditions, salt grain, and overall salting procedures.

Currently, in line with the recommendation from the World Health Organization (WHO, 2006, 2009) to reduce sodium consumption, there is a trend towards reducing salt content in dry-cured ham (Armenteros, Aristoy, Barat, & Toldrá, 2012; Dall Aaslyng, Vestergaard, & Granly Koch, 2014; Martuscelli, Lupieri, Chaves-Lopez, Mastrocola, & Pittia, 2015; Ripollés, Campagnol, Armenteros, Aristoy, & Toldrá, 2011). If the current target is a reduced and homogeneous salt content, it is important to optimize the dry-salting treatment of hams by non-destructive, fast and affordable control techniques.

In recent years, non-destructive technologies based on low intensity ultrasound and electromagnetic radiation at different frequency ranges, such as X-rays or near-infrared (NIR) spectroscopy, were investigated as quality control techniques in ham industry. The application of NIR spectroscopy to salt content analysis, was traditionally restricted to ground sample or outermost layer of ham (Colell, Gou, Arnau, & Comaposada, 2011). More recently NIR spectroscopy was applied to measure salt and sodium content in dry-cured ham slices (Campos, Mussons, Antolin, Debán, & Pardo, 2017; Gou et al., 2013). Technologies based on X-ray absorptiometry and ultrasound (US) proved to be useful to monitor the dry-salting phase as well as to predict the salt gain. The fast US through-transmission mode was applied online to *Biceps femoris* muscle (de Prados, García-Pérez, & Benedito, 2016) and to ham by the ultrasonic pulse echo mode (de Prados, García-Pérez, & Benedito, 2017). By the X-ray absorptiometry, salt content in

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entire bone-in hams (Fulladosa, Muñoz, Serra, Arnau, & Gou, 2015) and ham portions (Fulladosa, de Prados et al. 2015) can be non-invasively predicted. Furthermore, computed tomography is used to study salt content and distribution in muscles of entire ham scanned at different stages of dry-curing process (Fulladosa, Santos-Garcés, Picouet, & Gou, 2010; Håseth, Sørheim, Høy, & Egelandsdal, 2012; Picouet, Gou, Fulladosa, Sandos-Garcés, & Arnau, 2013; Santos-Garcés, Muñoz, Gou, Garcia-Gil, & Fulladosa, 2014). However, most of the above-mentioned techniques have drawbacks for application at industrial level such as high cost, size of the equipment, need of skilled operators.

Electrical impedance has become of interest as a fast, straightforward and affordable technology for the estimation of salt in food (Kaltenecker, Szöllösi, Friedrich, & Vozáry, 2013; Ma et al., 2016; Masot et al., 2010; Rizo et al., 2013). Some authors, in studies performed on products of animal origin like salted pork and salmon, demonstrated that, through the application of an excitation frequency in the range 1.0–1.1 MHz, there is an association between salt content and signals related to electrical impedance or conductivity (Chevalier, Ossart, & Ghommidh, 2006; Karásková et al., 2011). However, abovementioned measurements are invasive and time consuming, since they are based on the use of contact electrodes, which touch or puncture the sample to obtain the measure of impedance between electrodes.

Magnetic induction is a non-contact technology which uses induction to obtain electrical parameters from the sample, eliminating the need for electrodes and their related drawbacks. A primary excitation magnetic field is used to induce eddy currents across the sample at test; these currents in turn produce a secondary magnetic field detectable with a suitable set of receiver coils to sense the amplitude and phase of the magnetic field generated in the inspection volume. By measuring the current induced in the receiver coils, and taking into account the spatial arrangement of the coils with respect to the sample, it is possible to determine its dielectric and conductive properties.

Recent works explored the possibility of using magnetic induction technology in food industry: multi-frequency system have been used to investigate the electrical conductivity spectra of various agricultural produce (Barai, Watson, Griffiths, & Patz, 2012; O'Toole et al., 2015), while single-frequency system was used to determine the decayed proportion of apples (Euring, Russ, Wilke, & Grupa, 2011).

Due to the different dielectric properties of fat and muscular tissue, the same principle has been applied to estimate the fat and lean content in green hams (Serra & Fulladosa, 2011; Simoncini et al., 2012). In this respect, different responses to an externally applied magnetic field are expected from hams with different salt content. In this work the ability of a single frequency magnetic induction system to give quantitative information concerning salt gain in whole hams after the salting step was investigated. Salting treatments were carried out with the scope of calibrating and validating the MI system for the prediction of salt content in whole hams after salting, in a fast and non-invasive way.

2. Materials and methods

2.1. Magnetic induction (MI) system

Fig. 1 shows the MI scanner (Lenz Instruments S.L., Barcelona, Spain) used to measure the dielectric and conductive properties of hams. The system mainly consists of a sensor head, a conveyor band, and an electronic system. A desktop computer system (host PC) interfaces with the operator.

The sensor-head integrates two sets of coils enclosed in a metallic box for magnetic field confinement, and to prevent electromagnetic interferences. A first set of excitation coils is arranged to generate a homogeneous and time-dependent primary magnetic field (intensity = 1 μT) within the inspection volume (45 cm width, 27 cm height, and 60 cm length). Moreover, a second set of receiving coils senses the perturbation of the magnetic field caused by the ham, as it passes through the inspection volume. An electronic driving circuit generates a radiofrequency signal, which feeds the excitation coils. Moreover, a high-gain low-noise amplifier circuit is used to sense current generated at the receiver coils, as a result of the secondary field induced by the ham sample. The signals obtained at the receiver coils are deconvolved, using a digital electronic board, integrating a signal demodulator, to obtain an output response signal that is proportional to the average conductivity of the sample.

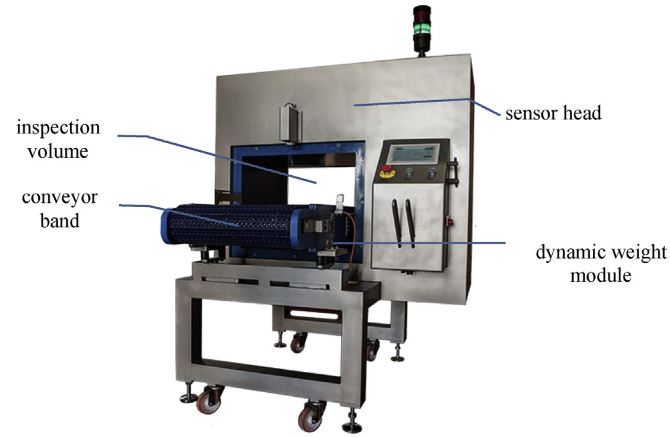

Fig. 1. Image of the single-frequency Magnetic Induction system.

The system includes a conveyor band (150 cm long and 45 cm wide) to automatically drive the ham into the inspection volume, through the detector head, in a rapid (4 s), simple, and reproducible way. The scanner incorporates also a dynamic weight device capable to weight the ham with an accuracy of ±10 g.

The MI scanner can be operated into the RAW or SALTED modes. In the RAW mode, the scanner automatically adjusts its internal parameters to optimize itself for the determination of the average conductivity of fresh hams; likewise, the SALTED mode allows the scanner to readjust the operational parameters to maximize its sensitivity to determine the conductivity of hams after salting. To ensure the reliability of the measurements and an accurate performance, the scanner was calibrated before each test. The calibration of the system aims to correct the phase mismatch introduced by the receiver coils and electronic components. This correction is typically performed by measuring the response generated by a ferrite sample, which must be in-phase with the excitation field.

2.2. Sample preparation

A total of 159 fresh hams were selected from the same local dry-cured ham factory operating in accordance with tutelary regulations of Parma ham manufacturing (Protected Designation of Origin, General Rules and Dossier, Reg. EEC n° 2081/92 of July, 14th 1992; Prosciutto di Parma, Reg. (EC) No 1208/2013).

At 48 h post mortem hams were scanned with the MI system installed at the ham factory. To avoid possible drifts associated to variations in sample temperature, hams were tempered at 3 ± 0.5 °C and temperature tested with the thermometer ebro TFX 410 Pt1000 inserted into *Semimembranosus* muscle (5 cm depth).