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Ultrasonic characterization and online monitoring of pork meat dry salting process

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A B S T R A C T

Bearing in mind the highly variable salt content in dry-cured meat products with anatomical integrity, such as pork loin or ham, non-destructive salt content characterization and the online monitoring of dry salting are highly relevant for industrial purposes. This study explores the ability of low-intensity ultrasound to monitor the dry salting of pork *Biceps femoris* (BF) and *Longissimus dorsi* (LD) online, as well as to estimate the salt content, both in these muscles and in hams. For this purpose, meat samples were dry salted for up to 16 d at 2 °C. During the salting of the muscles, the ultrasonic velocity was continuously measured at time intervals of 5 min, while in the hams it was measured before and after salting. The ultrasonic velocity increased progressively during the salting due to salt gain and water loss, reaching a velocity variation (ΔV) of 46.8 m/s after 16 d of dry salting for hams and 59.5 and 30.6 m/s after 48 h of dry salting for LD and BF, respectively. Accurate correlations between salt gain and ΔV were obtained ($R^2 = 0.903$ in LD-BF muscles and $R^2 = 0.758$ in hams), which allowed the assessment of the salt content with an average estimation error of 0.4% w.b. for both muscles and hams. Further research should investigate the use of the time of flight obtained through the pulse-echo mode, instead of the ultrasonic velocity, in order to improve the industrial applicability.

1. Introduction

Salting is one of the most ancient preservation methods used on meat products, such as ham, loin, bacon and sausages (Binkerd & Kolari, 1975). In the salting process, the fresh meat is stabilized due to a combined effect of the salt gain and the water loss. Salt is a multifunctional ingredient that affects both the food safety and quality. Meat products without anatomical integrity, such as dry-cured sausages, are formulated and a known quantity of salt is added to the minced meat. However, in meat products with anatomical integrity, salting is a complex and critical process due to the fact that it is affected by many factors, some of which cannot be controlled.

In the meat industry, dry salting is the most commonly-used salting process for the whole anatomical piece meat products and consists of covering the meat with coarse salt (Barat, Grau, Pagan-Moreno, & Fito, 2004). Usually, several salt/product layers are superimposed (Ventanas, 2001) and a particular salting time, temperature and relative humidity conditions are established for an entire batch (Bello, 2008; Jurado, Carrapiso, García, & Timón, 2002). Consequently, the salt content of meat pieces in the same batch varies greatly, not only due to the salting process itself but also to the heterogeneity in the weight, shape, composition and structure of the fresh meat (Čandek-Potokar & Škrlep, 2012; Castro-Giráldez, Fito, & Fito, 2010; Gou, Composada, & Arnau, 2004; Ramírez & Cava, 2007; Reig, Aristoy, & Toldrá, 2013). The variability linked to the dry salting process arises from the non-homogeneous ambient conditions of the salting chamber, the different position in the salting layers, the formation of brine between the sample surface and the dry salt and the size of the salt crystals, among other factors (Albarracín, Sánchez, Grau, & Barat, 2011; Barat et al., 2004; Van Nguyen, Arason, Thorarinsdottir, Thorkelsson, & Gudmundsdottir, 2010). As a consequence of the variable salt absorption in meat pieces from the same batch, the behavior of each salted piece is different in the subsequent stages of the product manufacturing process, which gives rise to heterogeneous sensory and nutritional characteristics of the final batch (Garcia-Gil, Muñoz, Santos-Garcés, Arnau, & Gou, 2014). In addition, due to the above-mentioned variability in the salting process, meat products are commonly over-salted to ensure the product's

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safety, which increases the energy consumption, lengthens the process time and has a great impact on the product quality (Garcia-Gil et al., 2012). Thus, the online monitoring of the salt content of meat products during salting could be a useful tool in the meat industry with which to describe the salt evolution and to determine the optimal salting time, according to the salt content targeted for each particular piece.

The online monitoring of the salting process, as well as the salt content characterization, should be addressed through non-destructive and non-invasive techniques, such as low-intensity ultrasound technology. Ultrasonic velocity, acoustic impedance and the attenuation coefficient have been used to assess the physicochemical properties, such as the composition, structure and physical state, of many foods (Damez & Clerjon, 2008; Hæggström & Luukkala, 2001; Mulet, Benedito, Bon, & Sanjuan, 1999; Schöck & Becker, 2010). In the meat industry, ultrasound velocity has been used to estimate the intramuscular fat content in beef samples (Whittaker, Park, Thane, Miller, & Savell, 1992), to classify fresh hams according to the fat level (De Prados et al., 2015a) and to characterize formulated dry-cured meat products according to the breed and diet of the pigs (Niñoles, Clemente, Ventanas, & Benedito, 2007; Niñoles, Sanjuan, Ventanas, & Benedito, 2008) and the fat content (Corona, García-Pérez, Ventanas, & Benedito, 2014). Additionally, a recent study has demonstrated the relationship between the ultrasonic velocity measured in dry-cured hams and their salt content (Fulladosa et al., 2015a). De Prados, García-Pérez, and Benedito (2015b) studied the feasibility of using low intensity ultrasound to predict the salt content in pork meat samples (*Biceps femoris* and *Longissimus dorsi*) by measuring the ultrasonic velocity before and after salting by the through-transmission method. However, to our knowledge, the ultrasonic through-transmission method has not been applied either to predict the salt gain in meat products with great structural complexity, such as whole hams, or to perform the online evaluation of the salt gain evolution in meat muscles during dry salting.

Therefore, the aim of the present study was to investigate the ability of low intensity ultrasound to perform the online monitoring of pork meat (*B. femoris* and *L. dorsi*) dry salting. The capacity of the ultrasonic models to estimate the salt content in both muscles and in dry salted whole hams was also assessed.

2. Materials and methods

2.1. Meat sampling

Fifteen fresh *L. dorsi* (LD) and *B. femoris* (BF) pork muscles from *Large White* breed pigs were obtained from a local market. Muscles were selected with a pH ranging between 6.4 and 5.5. In both muscles, the subcutaneous fat and external connective tissue were removed. Samples of 20 ± 2 cm in length (L) and 1.0 ± 0.1 kg were obtained from each muscle, keeping the original width (Z) and thickness (T) of the muscle (Fig. 1). Meat muscles were used for the online monitoring of dry salting and the salt gain estimation using ultrasound.

Additionally, thirty hams from the *Large White* breed, with an average weight of 11.2 ± 0.5 kg, were purchased in a slaughterhouse. The hams were used to estimate salt gain by measuring the ultrasonic properties before and after the salting process.

2.2. Dry salting experiments

Dry salting experiments were carried out on LD and BF muscles by covering the sample with 6 kg of coarse salt (NaCl moisturized at 10% w/w) at 2 ± 1 °C in a cold chamber (AEC330r, Infrico, Spain) (Fig. 2). Fresh samples and salt were previously stored for 24 h at 2 °C for the purposes of tempering. Three replicates were carried out for each salting time (6, 12, 24, 36 and 48 h) for both LD and BF muscles.

In the case of hams, all of them were salted following the standard dry-cured ham elaboration process. Thus, the hams were pile-salted with a layer of coarse salt (NaCl moisturized at 10% w/w) at least 10 cm thick and kept for 2, 4, 7, 11 and 16 d at 2 ± 2 °C and 85 ± 5% relative humidity, in order to obtain a wide salt content range. Six hams were considered for each salting time.

2.3. Ultrasound measurements

The experimental set-up consisted of a pair of narrow-band ultrasonic transducers (1 MHz, 0.5″ crystal diameter, A303S model, Panametrics, Waltham, MA, USA, for the ultrasonic measurements in LD and BF muscles and 1 MHz, 0.75″ crystal diameter, A314S-SU model, Panametrics, Waltham, MA, USA, for the ultrasonic measurements in hams), a digital storage oscilloscope (Tektronix TDS5034, Digital phosphor oscilloscope. Tektronix Inc. Bearverton, OR, USA) and a pulser-receiver (Model 5058 PR, Panametrics, Waltham, MA, USA). A custom designed digital height gage, linked to the computer by an RS232 interface, was used to measure the sample's thickness with a precision of ± 0.01 mm.

Fig. 2 shows the experimental set-up used for the measurement of the ultrasonic velocity during the dry salting experiments on LD and BF muscles. For the purposes of carrying out the ultrasonic measurements while the LD and BF meat was being salted, the sample was placed on 2 kg of salt inside a plastic container ($30 \times 25 \times 15$ cm) (Fig. 2) and the transducers were coupled to the sample's thickness. Next, three temperature sensors were introduced; one was placed in the sample, one in the salt and the third one close to the transducer and the rest of the salt was added until the sample was covered. In this case, the transducers used had a small contact surface (A303S model, 1.77 cm^2) so as to maximize the contact area between the meat sample and the salt. The ultrasonic velocity (V) was measured by the through-transmission mode at time intervals of 5 min. Due to the fact that the meat sample shrinks during salting, the position of the upper transducer was manually adjusted both initially and during the process with a force of 1N to maintain the contact between the sample and the transducers.

As a consequence of the difficulty of implementing the ultrasonic online measurements in whole hams salted in piles, the V was measured by the through-transmission mode at 2 °C in a temperature-controlled chamber before and after salting in 3 sections of the hams. Thus, 20 measurements were carried out in the cushion (C) and 5 in the fore cushion (FC) and the butt end (BE) sections (Fig. 1). The hams were kept at 2 ± 2 °C for 24 h before the ultrasonic velocity was measured. The ultrasonic velocity in each ham was calculated as the average of the 30 ultrasonic velocities measured in every ham zone.

The V was computed from the time of flight (TOF) (averaged for 5 signals) and the sample's thickness (T) by using specific software programmed in Visual Basic (VB 6.0 Microsoft™). The variation of ultrasonic velocity (ΔV) was calculated as the difference between the initial V in the samples and the V for a particular time ($\Delta V = V_t - V_{0h}$). The time of flight variation (ΔTOF) was also considered to be related with compositional changes during salting.

2.4. Determination of fat, water and salt contents

After dry salting, the excess salt was removed from the surface of the LD and BF samples and a cross slice (SL) of the samples (153.7 ± 44.0 g), including the ultrasonic measurement zone, was