Journal of Food Engineering 119 (2013) 464–470

Contents lists available at SciVerse ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Advances in the ultrasound characterization of dry-cured meat products

Edith Corona [a], Jose V. Garcia-Perez [a,*], Tomas E. Gomez Alvarez-Arenas [b], Nicholas Watson [c], Malcolm J.W. Povey [c], Jose Benedito [a]

[a] Grupo de Análisis y Simulación de Procesos Agroalimentarios, Departamento Tecnología de Alimentos, Universitat Politècnica de València, Camí de Vera s/n, E46022 Valencia, Spain
[b] UMEDIA (Ultrasound for Medical and Industrial Applications) Research Group, CSIC, Serrano 144, 28006 Madrid, Spain
[c] School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, United Kingdom

ARTICLE INFO

Article history:
Received 15 February 2013
Received in revised form 13 May 2013
Accepted 16 June 2013
Available online 25 June 2013

Keywords:
Ultrasound
Air-coupled
Scanning acoustic microscopy
Dry-cured meat products

ABSTRACT

In this work, the feasibility of using non-contact ultrasonic techniques (air-coupled and scanning acoustic microscopy, SAM) for characterizing different dry-cured meat products was assessed. Air-coupled ultrasonic measurements were performed on vacuum packaged sliced dry-cured ham, and compared with contact measurements. The average ultrasonic velocity in dry-cured ham was 1846 ± 49 m/s and 1842 ± 42 m/s for air-coupled and contact measurements, respectively. The deviation (1% relative error) between both techniques was related to the influence of the heterogeneous structure and composition of dry-cured ham and the transducer focusing. The SAM was used to characterize dry-cured ham and chorizo samples. B-scan images for dry-cured ham and chorizo showed two dominant reflections from the sample, linked to reflections in the lean and fatty tissues. The results indicate that contact ultrasonic measurements could be replaced by the air-coupled technique, reducing the measuring time and the material handling. On the other hand, SAM technique allows the microscopic characterization of dry-cured meat products.

1. Introduction

Dry-cured meat products, such as, salchichón, chorizo, dry-cured loin or dry-cured ham, among others, are products with high quality and consumer acceptance in Spain and other Mediterranean countries. Several techniques have been developed to objectively measure the quality traits of these products. Some of the techniques frequently used are invasive, by which the structure of the product is affected (Damez and Clerjon, 2008). Thereby, non-destructive techniques are being developed for assessing the quality of dry-cured meat products affecting minimally their structure. These techniques include nuclear magnetic resonance (NMR) (Straadt et al., 2012), X-ray technologies (Santos-Garcés et al., 2010), near infrared spectroscopy (NIRS) (Håseth et al., 2012; García-Rey et al., 2005) and ultrasound (Benedito et al., 2001; Niñoles et al., 2007, 2010, 2011; Santacatalina et al., 2011). The implementation of these techniques in the meat industry could lead to a better control not only of raw materials but also intermediate and final products.

Low intensity ultrasound can provide a rapid, accurate, on-line, inexpensive and non-destructive food and process characterization (Benedito et al., 2002; Chandrapala et al., 2012; Koch et al., 2011a, 2011b). In the meat sector, ultrasonic contact measurements had been used to for the characterization of macroscopic properties, such as the composition of raw meat mixtures (Benedito et al., 2001) or the textural properties (Llull et al., 2002) and composition of fermented meat products (Simal et al., 2003). Ultrasonic measurements have a larger penetration capacity than NIR technique and has a lower cost and easiness of on-line implementation than NMR and X-rays systems. However, sometimes the use of contact ultrasonic measurements involves the need of a couplant to improve the matching between the sample and the transducer, for example in the packaged products. Thus, for those applications where the use of couplants can affect the product quality or where the time of measurement restricts the application and removal of the couplant, air-coupled ultrasonic measurements can be a reliable alternative.

Air-coupled ultrasound is a promising non-destructive technique, due to its minimally invasive nature and broad application range, including on-line application. However, the most important challenge lies in the several orders of magnitude acoustic impedance mismatch between air and materials of the transducer and the sample. The impedance mismatch causes high interfacial reflection and low acoustic transmission efficiency. This, along with the attenuation of ultrasound in the air, has hampered developing a practical non-contact ultrasound such as inspection method. Therefore, the efficiency of ultrasound transducers must be significantly improved. Even so, this technique has been used for the successfully inspection and detection of foreign bodies in

* Corresponding author. Tel.: +34 963879376.
E-mail address: jogarpe4@tal.upv.es (J.V. Garcia-Perez).

0260-8774/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jfoodeng.2013.06.023

commercially-available food products (Pallav et al., 2009) and to detect physicochemical changes of liquid beverages (Meyer et al., 2006) and variations in consistency of starchy solids (Gan et al., 2002).

On the other hand, sometimes it is necessary to obtain microscopic information of the food products, in contrast to the macroscopic information provided by most of the aforementioned ultrasonic applications. In those cases acoustic microscopy can be considered. The internal elastic properties of material can be analyzed by acoustic waves that can access deep into materials, including many that are optically opaque. Thus, acoustic boundaries generate reflections. The time of flight (TOF) of these reflections allows mapping out the surface and sub-surface structure of the sample. The amplitude and phase of the returning signal conveys mechanical information, which can reveal elastic moduli, compressibility, stress, adhesion properties, thermophysical properties and phonon transport (Parker et al., 2010). An important feature of acoustic waves is their scalability. Therefore, the scanning acoustic microscope (SAM) is a precision device which uses tightly focused ultrasound to map the acoustic contrast (scale) within a sample. SAM has been used to accurately produce an image of the internal structure of opaque materials using ultrasonic waves (Wickramasinghe, 1984). SAM generates details in a non-destructive way of the surface and sub-surface structure of materials and can be operated in transmission or reflection mode, with reflection-mode being the most common due to the use of a single transducer (Parker et al., 2010). SAM has been used to study different items, such as integrated circuits (Parker et al., 2010), multilayer films (Caner et al., 2003), flexible food packages (Ozguler et al., 1998) and biological tissues such as onion skin (Parker et al., 2010). In dry-cured meat products, SAM could be used to determine the structural distribution of the different tissues, this being particularly relevant for the fat component and would complement the measurement of the overall fat content. However, to our knowledge, no attempt has been made to apply this technology to meat products.

Therefore, the aim of this work was to compare air-coupled ultrasonic measurements to conventional contact ultrasonic measurements and to assess the feasibility of SAM for the characterization of dry-cured meat products.

2. Materials and methods

The experiments were conducted using two different non-contact ultrasonic techniques on dry-cured meat products. On one hand, air-coupled ultrasonic measurements (Fig. 1) were carried out on samples of vacuum packaged sliced dry-cured ham. These were compared with measurements performed on the same samples using conventional contact ultrasonic measurements, in order to determine if similar information is obtained and consequently if contact measurements could be replaced by air-coupled ones.

On the other hand, acoustic imaging was performed using scanning acoustic microscopy (SAM) (Fig. 2) in dry-cured ham and chorizo samples with the aim of characterizing the fat/lean structure and its distribution.

2.1. Air-coupled measurements

2.1.1. Raw material

Sliced dry-cured ham was purchased in a local market and vacuum packaged using three different package thicknesses (Thin: 5.2–7.4 mm, Medium: 7.8–10 mm and Thick: >10 mm; at least 6 packages per thickness), which are usual thicknesses found in the retail distribution of this product. Zones of measurement were marked (from 4 to 10 zones per package) and uniformly distributed on the surface of each package including zones in lean, marbled and fatty tissues. Each point was coincident with the surface of the transducers (2.5 cm^2) used in both types of ultrasonic measurements (contact and air-coupled). Packages consisted of a low-density polyethylene (LDPE) bag (thickness 90 μm, density 950 kg/m^3). Ultrasound velocity in the LDPE bag was measured at 10 MHz using a conventional through transmission and gel-coupling system, obtaining a value of 1970 m/s. As the bag is very thin and the acoustic properties of the LDPE are close to those of the packaged ham, the influence of the package on the ultrasonic measurements was considered negligible.

2.1.2. Ultrasonic contact measurements

The experimental set-up included two narrow-band ultrasonic transducers (1 MHz, 0.75″ diameter, A314S-SU, Panametrics, Walthman, MA, USA), a pulser-receiver (5058PR, Panametrics, Walthman, MA, USA) and a digital storage oscilloscope (TDS5034, Tektronix, Bearverton, Oregon, USA). A custom digital height gauge was designed and built, and linked to the computer by a RS232 interface to measure the sample thickness with a precision of ±0.01 mm. The ultrasonic velocity in the zones of measurement was computed in triplicate from the time of flight obtained from the signal (average of five signal acquisitions), and the thickness provided by the height gauge. The ultrasonic velocity was measured at 6 °C in a temperature-controlled chamber (±0.1 °C) (AEC330R, Infrico, Spain).

2.1.3. Ultrasonic air-coupled measurements

The experimental set-up (Fig. 1) consists of a couple of specially designed and built air-coupled transducers (Gómez Álvarez-Arenas, 2004), with center frequency of 0.75 MHz (constructed in UMEDIA (CSIC), Madrid), with two-way insertion loss of −30 dB and 75% bandwidth. Active element is a 1–3 piezocomposite disk, 20 mm diameter, made of piezoelectric fibers embedded in an epoxy matrix (65 vol.% concentration of ceramic). Matching to the air is achieved by attaching a stack of three quarter-wavelength matching layers. Finally, a backing of epoxy resin loaded with tungsten particles is added. The two transducers used were positioned in opposition. The transmitter was driven by a negative square semi cycle tuned to the center frequency of the transducers with amplitude of 200 V (P/R 4077, Panametrics, Waltham, MA, USA). This transducer transmits an ultrasonic signal that travels across the air–gap between transmitter and receiver and is eventually detected by the receiver. This transducer converts the ultrasonic wave into an electrical signal. This signal is then amplified and filtered by the receiver and digitized in a digital oscilloscope (TDS5034, Tektronix, Bearverton, Oregon, USA).

The measuring procedure is as follows. First the signal received without any sample is acquired and Fast Fourier Transform (FFT) is calculated. Both FFT amplitude $A_0(\omega)$ and signal amplitude in the time domain $S_0(t)$ are stored as references. Then the sample is put in between the transducers at normal incidence. Fig. 3 shows some of the measured signals.

Then, amplitude of the FFT of the through transmitted signal and all reverberations within the sample $A(\omega)$ is calculated. Both $A(\omega)$ and the signal amplitude in the time domain $S(t)$ are stored. The insertion loss (IL) is then calculated. IL is defined as:

$$\mathrm{IL} = \frac{20}{\log\left(\frac{A(\omega)}{A_0(\omega)}\right)} \tag{1}$$

Some of the measurements are shown in Fig. 4. The pattern of thickness resonances is clearly observed in all cases.

To calculate the time of flight of the ultrasound in the sample, first the cross-correlation of $S_0(t)$ and $S(t)$ is computed, then the