Available online at www.sciencedirect.com
ScienceDirect
Meat Science 76 (2007) 561–567
MEAT SCIENCE
www.elsevier.com/locate/meatsci

Monitoring the ripening process of Iberian ham by computer vision on magnetic resonance imaging

Teresa Antequera [a,*], Andrés Caro [b], Pablo G. Rodríguez [b], Trinidad Pérez [a]

[a] *Tecnología de los Alimentos, Facultad Veterinaria, Universidad de Extremadura, Av. Universidad s/n, 10071 Cáceres, Spain*
[b] *Departamento de Informática, Escuela Politécnica, Universidad de Extremadura, Av. Universidad s/n, 10071 Cáceres, Spain*

Received 16 June 2006; received in revised form 11 January 2007; accepted 21 January 2007

Abstract

This paper explores the use of MRI (Magnetic Resonance Imaging) in combination with a fully automated Image Analysis method for the recognition of *Biceps Femoris* and *Semimembranosus* muscles in Iberian ham. A quantitative description of volume and a study of moisture and weight relationships during the product's ripening process are included. Three Active Contour methods (Variational Calculus, Dynamic Programming, and Greedy Algorithms) are used to recognize the *Biceps Femoris* and *Semimembranosus* muscles by means of Computer Vision techniques. The recognition of both muscles via MRI entails a low error rate (3–10%). A loss of weight in hams during the ripening process is related to a decrease in size ($r^2 = 0.992$). The high correlation implies that the information obtained by means of Computer Vision techniques can be used as a non-invasive complement to the traditional processes of ham weighing and moisture estimation.

Keywords: Ripening process; Iberian ham; Meat; Computer vision; Image analysis; Magnetic Resonance Imaging (MRI)

1. Introduction

Dry cured Iberian ham is an uncooked meat product of high sensory quality which is achieved through unique and highly appreciated sensory features, resulting from both the raw material and the traditional prolonged processing (18–24 months). A traditional processing method for Iberian ham includes three major phases: A first period (salting/post-salting) in which low temperature is combined with high relative humidity to allow for salt diffusion within the hams. A second stage at moderately raised temperatures (26–28 °C) and progressively lowered relative humidity (to 40%) in order to achieve adequate drying of the ham thighs. Finally, hams are left to mature for 12–15 months in a cellar (temperatures ranging between 10 and 22 °C with a relative humidity of about 70%). During this final ripening process, Iberian hams are exposed to drying, giving a weight loss up to a 30–32% (Ventanas & Cava, 2001), and a reduction in water content in the internal structure of between 45% and 50% (Martín et al., 1998).

Thus, the ham industry estimates the optimal ripening time by the percentage loss of weight, related to the amount of water contained in the ham muscles. The current system for weighing the hams and reference methods for estimating moisture content are manual; in addition, the dissection of the muscles necessary to determine the water content is cumbersome and destructive. Thus, it is no surprise that the meat industry has shown great interest in finding objective, consistent and non-destructive methods that may determine the optimum maturation time for Iberian ham. As an alternative to physical and chemical procedures, new non-invasive methods such as Pattern Recognition and Image Analysis techniques based on Magnetic Resonance Imaging (MRI) have recently emerged. For instance, Beavallet and Renou (1992) analyzed lipid distribution in meat by means of MRI, while Bonny et al. (2000) characterized

* Corresponding author. Tel.: +34 927 25 71 23; fax: +34 927 25 71 10.
E-mail address: tantero@unex.es (T. Antequera).

0309-1740/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.meatsci.2007.01.014

muscle structure using such techniques. More recently, Monziols et al. (2006) quantified muscle, subcutaneous fat, and inter-muscular fat in pork cuts. This technique is also used to show water distribution in relation to various meat processing activities, including freeze-thawing (Guiheneuf, Parker, Tessier, & Hall, 1997), drying (Ruiz-Cabrera, Gou, Foucat, Renou, & Daudin, 2004), and moisture and structural changes quantification during chicken meat cooking (Shaarani, Nott, & Hall, 2006). MRI, commonly used in image-based medical diagnosis, provides a discrete three dimensional (3D) data set consisting of two dimensional (2D) cuts of the object (Robb, 1985).

In the case of Iberian pork, MRI can help to classify raw loins (Cernadas et al., 2001), can be used to evaluate sensory features and intramuscular fat in cured dry loin pieces (Antequera, Muriel, Rodríguez, Cernadas, & Ruíz, 2003) and estimate intramuscular fat levels in *Biceps Femoris* and *Semimembranosus* muscles of Iberian ham (Ávila, Durán, Caro, Antequera, & Gallardo, 2005).

In contrast, there are few applications based on Image Analysis of cured ham. Froysteyn, Sorheim, Berg, and Dalen (1989) demonstrated the applicability of computed tomography (CT) for the study of salt permeation hams, and Vestergaad, Erbou, Thauland, Adler-Nissen, and Berg (2005) looked at salt distribution in cured ham by means of CT and Image Analysis. As far as we know, there are no specific studies on the ripening process of ham using MRI.

In this paper, MRI techniques are used to study ham images. In addition, we include Active Contour processing approaches to extract objects of interest in pattern recognition applications (Kass, Witkin, & Terzopoulos, 1987). An Active Contour is a model defined by a curve, relating to an energy function. This model evolves within the image up to the moment when the model adjusts to the desired object. The robustness of this technique, together with the latest technology, favour Active Contour applications to MRI in the Iberian ham ripening process. In this regard, we focus on the extent that MRI in combination with a fully automated Image Analysis method enables the effective recognition of *Biceps Femoris* and *Semimembranosus* muscles in the ham. We also aim to determine their volume during the ripening process.

2. Material and methods

2.1. Experimental design

The study was carried out with a total of 15 Iberian hams (from castrated male pigs of the Iberian pure breed), obtained as follows. During the fattening period of the Iberian pig (60 days prior to slaughter), the animals lived outdoors, exclusively feeding on acorns and pasture. Pigs were slaughtered when weighing around 140–145 kg. Hams were cut traditionally, and the ranges of isquiatic bones and their individual weights recorded (roughly 10–11 kg). The right ham of each animal was processed as follows: hams were rubbed with salt, containing about 1% potassium nitrate and placed in piles of salt at 3 °C and 80% relative humidity for 1 day/kg weight (salting). After salting the hams were washed to remove salt from the surface. After washing, the hams were hung at low temperature (4 °C ± 1) and the relative humidity was progressively lowered to 75% over 80 days to allow diffusion of salt into the hams (post-salting). The hams were then taken to a natural dryer at temperatures varying from 4 to 28 °C and 70% to 50% relative humidity during 130 days (drying). Next, the hams were left to mature for 14 months in a cellar at 10–25 °C and a relative humidity of 65–80% (matured hams).

The same hams were used at the different stages. Four stages were considered: raw hams (R), 0 days; post-salting (PS), 90 days; drying (D), 270 days; and mature hams (M), 660 days. Ham weights were recorded at each stage. Our initial analysis used 15 hams but three of them were destroyed at each stage, due to physical–chemical analysis. Thus, 12 hams were analyzed in the post-salting stage (PS), 9 in the (D) period, and 6 in the (M) stage. Muscle pieces were extracted by an expert at each stage for chemical analysis of the *Biceps Femoris* and *Semimembranosus* muscles. Fig. 1 shows the sampling procedure.

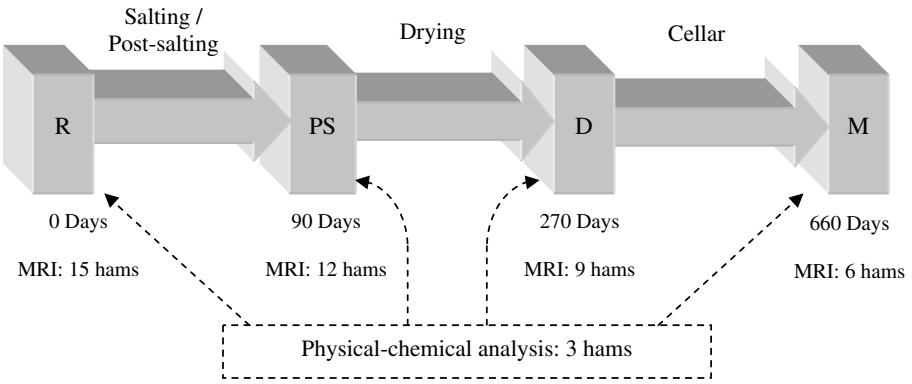

Fig. 1. View of sampling procedure: number of days from the beginning and number of hams at every stage.