Journal of Food Engineering 166 (2015) 148–155

Contents lists available at ScienceDirect

Journal of Food Engineering

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

# Computer image analysis as a tool for classifying marbling: A case study in dry-cured ham

Israel Muñoz *, Marc Rubio-Celorio, Núria Garcia-Gil, Maria Dolors Guàrdia, Elena Fulladosa

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

ARTICLE INFO

*Article history:*
Received 18 February 2015
Received in revised form 22 April 2015
Accepted 2 June 2015
Available online 3 June 2015

*Keywords:*
Marbling
Dry-cured ham
Image analysis
Pattern recognition
Neural Networks
Support Vector Machines
Non-destructive classification

ABSTRACT

Marbling in sliced dry-cured ham affects consumer acceptability and the sensory quality of the product. This study presents an automated marbling grading system of dry-cured ham slices which allows for the characterization and classification of the product. Firstly, a sensory marbling grading scale was developed by a panel of experts who did not only take into account the amount of visual fat content, but also the distribution of the fat flecks. This scale was used for the design of an automatic classification system of dry-cured ham based on segmenting intramuscular fat. 643 regions of interest (ROI) of the slice were categorized by a panel of experts using the marbling grading scale and later segmented by the computer system. From the segmented ROI, 48 features (geometrical and textural) were extracted. Using all the data several classifiers were built using two machine learning techniques namely Support Vector Machines (SVM) and Neural Networks (NN). Different feature selection algorithms were tested to select the optimal subset of features. Results show that with a reduced number of features, 89% of the samples could be correctly classified. Performance was better for SVM algorithms than for NN.



## 1. Introduction

Marbling is one of the characteristics influencing the acceptability of meat and meat products (Antequera et al., 1992; Ventanas et al., 2007; Morales et al., 2013). Intramuscular fat (IMF) can be defined as the fat located throughout skeletal muscle, whereas marbling can be defined as the amount and spatial distribution of the visible fat, which appears as fine flecks in the muscle giving it an appearance similar to marble (Cernadas et al., 2002). IMF is moderately related to the amount of marbling or visual fat (Faucitano et al., 2004). Differences in eating quality can be attributed to the fat distribution in meat rather than to the total intramuscular fat content (Albrecht et al., 1996). It is not only the amount but also the spatial distribution of intramuscular fat streaks – the marbling – which have an effect on the sensory attributes of dry-cured ham and are used to characterize and classify the product (Cernadas et al., 2002). Marbling score determination has traditionally been performed by panels of trained judges, using descriptive analysis methods. The evaluation of marbling in the pork industry relies mainly on subjective comparison with raw pork meat marbling standards or pictures such as those used by the National Pork Producers Council panelist employees (NPPC, 1999). The National Pork Producers Council marbling standards show pictures of pork samples containing low to high intramuscular fat content with standardized numerical marbling scores from 1.0 (devoid) to 10.0 (abundant). However, the visual assessment leads to inconsistencies in pork quality from different companies, increases labour costs, has low repeatability, and is easily influenced by environmental and human factors.

Dry-cured ham is especially appreciated for its sensory properties. However, there is only a five score reference scale available (http://www.irta.cat/ca-ES/RIT/Noticies/Documents/Jornada_pernil_sensojam_guiametodologica_def.pdf) which permits a rough evaluation and classification of the product. Therefore, it will be of interest to have a more specific reference scale to evaluate marbling since this development can be used as the basis for the development of fast, non-destructive methods which will allow for an online characterization of marbling on an industrial scale.

Computer image analysis (CIA) has emerged as a reliable alternative for the marbling assessment of different food products. CIA, which includes capturing, processing and analyzing of images, allows the rapid and objective assessment of visual characteristics of the product, as well as quality features that cannot be visually differentiated by human inspection, i.e., structural and textural characteristics (Mendoza et al., 2009) through the extraction of suitable features (Brosnan and Sun, 2004). McDonald and Chen (1991) used video image processing to estimate marbling scores

* Corresponding author.
*E-mail address:* israel.munoz@irta.cat (I. Muñoz).

http://dx.doi.org/10.1016/j.jfoodeng.2015.06.004
0260-8774/

in beef ribeyes. More recently, a segmentation based approach was reported by Jackman et al. (2009) which used K-means clustering to segment images of beef *Longissimus dorsi* muscle into background, lean muscle, and intra muscular fat areas. One of the most usual techniques for marbling detection is line detection algorithms. Faucitano et al. (2005) evaluated marbling by enhancing the color contrast of pork meat samples using chemical pre-treatments and line detection algorithms. They found significant correlations between the percentage of areas detected as marbling with respect to the muscle area and the number of areas/cm$^2$. They also found that neither large nor small detected flecks are representative of marbling content. Liu et al. (2012) also used a line detection algorithm for determining a marbling score of pork loins. In dry cured ham, Cernadas et al. (2002) used a multi-scale line detection framework for the recognition of fat streaks showing promising results. Widiyanto et al. (2013) were able to obtain good estimations of the fat content of slices of dry-cured ham using fuzzy c-means and bias field estimation.

Pattern recognition has been widely used in combination with CIA for classification tasks. Pattern recognition consists of extracting a set of features (geometric, texture, etc.) from the segmented image and assigning a category out of a given set of categories to the data obtained. A model is built using this data in combination with one of the existing techniques of pattern recognition. New images are then classified applying the model to the features extracted from the segmentation of these images. In quality assessment of foodstuffs, several pattern recognition techniques have been used for quality evaluation. For example, Cano Marchal et al. (2013) used Support Vector Machines and Neural Networks for the evaluation of olive oil impurities in virgin oil using CIA. However, no studies have been found in the literature available which applies CIA for the classification of dry-cured ham slices based on marbling. Marbling assessment in dry-cured ham is of great interest to industry as it defines the quality of the product and its commercial value. Therefore, it is important to establish a basis for the development of industrial systems to assess marbling in this product.

The main objective of this research was to define a precise marbling reference scale for sliced dry-cured ham and to develop a system to objectively classify slices into the categories of this reference scale using CIA in combination with pattern recognition techniques.

## 2. Materials and methods

### 2.1. Sampling

180 commercial dry-cured hams obtained from different ham producers which were crosses from different pig breeds (Large White, Landrace, Duroc and Iberian) were taken in order to obtain a batch of hams with a wide range of marbling. A 2 cm thick slice containing *Semimembranous* (SM), *Semitendinosus* (ST) and *Biceps femoris* (BF) muscles was obtained at 10 cm from the aitch bone in the distal direction (at the widest part of the ham) and packed into plastic bags of polyamide/polyethylene (oxygen permeability of 50 cm$^3$/m$^2$/24 h at 23 °C and water permeability of 2.6 g/m$^2$/24 h at 23 °C and 85% RH, Sacoliva® S.L., Spain).

### 2.2. Chemical analysis

A total of 22 muscles (BF, SM and ST) of different dry-cured ham slices, representative of the whole reference marbling scale, were selected. Three muscles were selected for each marbling score except for the scores 7 and 8, in which only 2 muscles were selected due to the lack of samples. Total fat content was measured in duplicate by Soxtec extraction (Soxtec HT 6-1043 and Service Unit 1046) according to ISO 1443 (1973). The analytical standard deviation of the method was 0.32%.

### 2.3. Image acquisition

High quality images were acquired with a photographic system that included a calibrated digital camera Canon EOS 50D with a picture resolution of 15.1 megapixels and an objective Canon EF-S 18–200 mm f/3,5–5,6 IS. The camera was mounted onto a photographic bench in the middle of a black closet (1.06 m × 1.06 m × 2.50 m) and a circle of 8 equidistant halogen lights Solux Q50MR16 CG/47/36°12 V/50 W/4700 K (Eiko Ltd., Shawnee, Kansas, E.U.A.) to obtain a correct lighting environment for image capture which ensured consistent color and lighting. White balance was carried out with a white card (Lastolite) in order to electronically adjust the color reproduction without showing color dominants.

The camera was connected to a PC into which the images with RAW format were uploaded. Dry-cured ham slices were positioned 30 cm below the camera lens. An image of the entire slice surface was taken against a uniform black background. Both sides of the dry-cured ham slices were photographed ($n = 360$) and all the images were taken during the same session. Capture One PRO 5.0 software (Phase One A/S Inc., Frederiksberg, Denmark) was used to carry out the white balance of the RAW images and digitalize them to 667 × 1000 pixels resulting in a .tif file with 16 bits color and 4 MB. This was considered to be high enough in quality for computer image analysis. With this setting one pixel of the image corresponded to 0.3968 mm$^2$. With the aim of obtaining the maximum fidelity to the samples for the sensory analysis of marbling, the computer screen was calibrated so that the colors of the images were as close as possible to the colors of the samples (NEC Multisync LCD 2690 WUXI$^2$).

### 2.4. Sensory analysis

Sensory analysis (marbling evaluation) of the samples was carried out by six trained panellists (ISO 8586-2: 2012) and consisted of a visual assessment of the marbling of SM, BF and ST muscles from 362 acquired images. BF and SM were selected because they are considered to be the most representative muscles of dry-cured ham (Arnau et al., 1995; Boadas et al., 2001). Only for marbling reference scale development, ST muscle was also used because the BF and SM muscle did not reach high values of marbling. Marbling was scored by consensus by means of scoring scale from 1 (minimum marbling) to 10 (maximum marbling) at intervals of 0.5. When scoring marbling, the panellists did not only focus on the total amount of marbling, but also on the distribution of the fat streaks through the muscle and the union with the subcutaneous fat. Marbling evaluation was performed in triplicate by the expert panellists showing a standard deviation of 0.5 point score. From all the analyzed samples a 9 point marbling scale (from 1 to 9) was developed.

### 2.5. Image analysis and segmentation

Regions of interest (ROIs) corresponding to the BF and SM muscles were manually selected from the images using a program written in Matlab (Fig. 1). A total of 643 ROIs were evaluated (2 muscles (BF and SM) × 362 slices – 81 muscles discarded). Some ROIs were discarded from the study due to defects on the surface (such as cuts and phosphate crystals) which made them unsuitable for the CIA. Although ST muscles were used to develop the reference marbling scale, they were not used for classification purposes because of the different marbling characteristics of this muscle in