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Modeling salt diffusion in Iberian ham by applying MRI and data mining

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ABSTRACT

Salt content analysis is needed to ensure a healthy level of sodium in foods. In Iberian hams, this is laborious, time consuming and destructive analysis. This study proposes the use of an active contour algorithm combined with computational textures on Magnetic Resonance Imaging (MRI) to analyze salt diffusion in Iberian hams in a non-destructive way. Data mining techniques (OneR, J48 decision tree, and multiple linear regression) were tested for i) classifying ham muscles and processing stages as a function of salt diffusion and ii) predicting salt content. The proposed methods are useful to differentiate the images of different muscles and stages of processing. For classification purposes, the best procedure is applying the J48 decision tree on the Gray Level Co-Occurrence Matrix (GLCM) method (77.88–79.21% of correct classification). For predicting salt content, the application of multiple linear regression on GLCM methods is accurate ($R^2 = 0.972–0.994$ and MAE = 0.007–0.044). Then, MRI, computational algorithms and data mining allow determining salt diffusion in Iberian hams in a non-destructive way.

1. Introduction

Salt content influences the sensory characteristics of ham, mainly texture and taste attributes (Pérez-Palacios et al., 2011a). The salt also influences on the activity of muscle enzymes and the protein solubilisation, and, consequently, on the texture and flavour of the final product (Toldrá et al., 1997). When the salt content is lacking, values of water activity does not decreased and microbial growth occur, leading to putrefactions in the ham, with the consequent economic loss (Córdoba et al., 2001). The Iberian ham processing is based on salt deposition and its further distribution into the piece at low temperatures (3–4 °C) and high relative humidity (around 90%), followed by partial dehydration. The salting stage aims to bring into the ham an adequate salt quantity. This step takes about 1 day per kilogram of ham. After salting, the temperature increases from 4 to 8 °C and the relative humidity decreases around 75% (Pérez-Palacios et al., 2011b): this is the post-salting stage. It takes around 90 days in Iberian hams. During this step, salt should be distributed in the whole piece, reaching outer and inner muscles (Andrés and Ruiz, 2001). Once the post-salting is finished, and thus, the ham is stabilized microbiologically, at the following stages (drying and cellar) the temperature increases to allow the development of the quality characteristics of the Iberian ham.

Most studies in the literature analyzed the salt content at the end of the processing of hams, however it is necessary to guarantee an adequate quantity of salt in the whole ham at the end of the post-salting step in order to get the microbial stabilization of the thigh. In the ham industry, the analysis of salt content is usually carried out by the official method for meat and meat products (AOAC, 2000; reference 971.19). It consists of mixing the sample with water and ethyl alcohol. After successive centrifugations the final extract is obtained and further measured with a volumetric analysis by precipitation. This technique is laborious and time consuming and requires destroying the piece. At this respect, some researchers have studied the salt diffusion in different pork muscles by using Magnetic Resonance Imaging (MRI), a non-destructive, non-invasive, non-intrusive and innocuous technique. Most of

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Abbreviations

MRI	Magnetic Resonance Imaging
B	*Biceps femoris* muscle
S	*Semimembranosus* muscle
KDD	Knowledge discovery in databases
BPS	Beginning of the post-salting stage
EPS	End of the post-salting stage
R	Real boundary
AC	Active contours-segmented boundary
ROI	Region of interest
GLCM	Gray level co-occurrence matrix
HC	Haralick correlation
IDM	Inverse difference moment
CS	Cluster shade
CP	Cluster prominence
GLRLM	Gray level run length method
SRE	Short run emphasis
LRE	Long run emphasis
GLNU	Gray level non-uniformity
RLNU	Run length non-uniformity
RP	Run percentage
NGLDM	Neighbouring gray level dependence method
SNE	Small number emphasis
LNE	Large number emphasis
NNU	Number non-uniformity
SM	Second moment
WEKA	Waikato environment for knowledge analysis
RBS	Rule-based Systems
OneR	One Rule
MLR	Multiple Linear Regression

these studies were carried out by using ^{23}Na-MRI. Guiheneuf et al. (1997) used the time-course acquisition of ^{23}Na-MRI profiles to study inter-diffusion of sodium ions into a cylindrical pork sample. A model study on movements of sodium ions in pork loin during brining was carried out by Vestergaard et al. (2005) using ^{23}Na MRI. These authors proved successful results for quantification of salt concentration by one-dimensional ^{23}Na MRI profiling at values above 0.9 g NaCl/100 g sample in the meat. Hansen et al. (2008) determined NaCl diffusion coefficient ($3^{-7} \times 10^{-10}$ m^2 s^{-1}) by using ^{23}Na MRI in porcine Longissimus dorsi and Semitendinosus muscle. Fantazzini et al. (2005, 2009) used ^{1}H MRI and NMR relaxometry analysis, showing that T1 and T2 maps are suitable tools to investigate non-destructively salt in inner layers of cured muscles.

MRI has also been proposed to study other characteristics in hams as an alternative to physico-chemical procedures. Fantazzini et al. (2009) used this technique to obtain information on moisture and salt distribution throughout the process of Italian dry-cured- hams. Recently, predictive models have been proposed for estimating water activity, moisture, salt content and proteolysis extent in Italian dry-cured hams on the basis of the MR signal intensity (Manzoco et al., 2013).

In Iberian hams, shape recognition techniques, such as Active contours, have also been applied on MRI to identify the Biceps femoris and Semimembranosus muscles, determining the volume of the muscle and estimating ham weight and moisture (Antequera et al., 2007; Caro et al., 2001). Moreover, computational texture feature algorithms have been applied to MRI, allowing differentiating fresh and dry-cured Iberian hams according to the pig feeding background (Pérez-Palacios et al., 2010a, 2011b). In addition, sensory traits in Iberian dry-cured hams were predicted from computational texture features obtained from MRI of fresh hams (Pérez-Palacios et al., 2010b). The calculation of intramuscular fat levels of Iberian ham has also been attempted by using computer vision algorithms on MRI (Ávila et al., 2005; Caro et al., 2003; Pérez-Palacios et al., 2014).

Several and heterogeneous data sets could be obtained after applying physico-chemical analysis to hams and computer algorithms on MRI. Frequently, significant information is hidden in these data sets, which could be found by using Knowledge Discovery in Databases (KDD) techniques (Fayyad et al., 1996). Data mining is an important part of KDD, mainly related to the non-trivial process of finding knowledge and potentially useful information from data stored in repositories. It is a multi-disciplinary field which tries to describe and predict data by exploring and analyzing large volumes of data (Sayad, 2011). The main groups in data mining tasks are related to descriptive and predictive techniques. The first ones have the ability to classify and infer new values based on actual data. With the second techniques, future models can be predicted from current data by trend analysis (Witten and Frank, 2005; Wu et al., 2008). Interest in data mining has been growing quickly due to the need of processing larger and larger amounts of data, and the increase in computing power, enabling the use of intensive computational methods for data analysis (Mitchell, 1999).

As our knowledge, in the scientific literature there are some studies applying data mining on food. Song (Song et al., 2002) and Cortez (Cortez et al., 2006) used this computing technique to predict quality traits in beef and lamb, respectively. It has also been used to predict the salt content and water activity in porcine meat (Liu et al., 2013) or to measure color distribution in salmon fillet (Wu et al., 2012) or to model wine preferences (Cortez et al., 2009). Holmes (Holmes et al., 2012) applied data mining to detect fruits and vegetables contaminated with pesticide and to identify these products as a function of their origin country. Batista (Batista et al., 2012) classified honey samples as a function of their chemical elements. Recently, Perez- Palacios (Pérez-Palacios et al., 2014) applied data mining to estimate quality traits in Iberian hams.

Taking into account the importance of modeling non-destructively the salt diffusion at the end of the post-salting stage of hams and that there are not studies using MRI and data mining to fit it, this paper aimed to analyze the salt diffusion in Iberian ham by means of computational texture features on MRI using data mining techniques. This goal was tried to be achieved in two ways: i) classifying Iberian ham muscles and times of the post-salting stage as a function of salt diffusion and ii) predicting salt content at the end of the post-salting step by means of computational texture features on MRI. For that, the changes of computational textures on MRI caused by the salt diffusion in the ham were studied, and data from chemical analysis were correlated with computational texture features on MRI at the beginning and at the end of the post-salting stage.

2. Material and methods

2.1. Experimental design

This study was carried out with 20 Iberian thighs from the same