Journal of Food Engineering 227 (2018) 1–10

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Analysis of MRI by fractals for prediction of sensory attributes: A case study in loin

Daniel Caballero [a, *], Teresa Antequera [a], Andrés Caro [b], José Manuel Amigo [c], Bjarne K. ErsbØll [d], Anders B. Dahl [e], Trinidad Pérez-Palacios [a]

[a] Food Technology Department, Research Institute of Meat and Meat Product (IProCar), University of Extremadura, Avda. de Las Ciencias S/N, ES-10003 Cáceres, Spain
[b] Computer Science Department, Research Institute of Meat and Meat Product (IProCar), University of Extremadura, Avda. De Las Ciencias S/N, ES-10003 Cáceres, Spain
[c] Department of Food Science, Quality and Technology, Faculty of Life Science, University of Copenhagen, Rolighedsvej 30, DK-1958, Fredriksberg C, Denmark
[d] Department of Informatics and Mathematical Modeling, Technical University of Denmark, Richard Petersen Plads, Building 324, DK-2800, Kongens Lyngby, Denmark
[e] Department of Applied Mathematics and Computer Science, Technical University of Denmark, Richard Petersen Plads, Building 324, DK-2800, Kongens Lyngby, Denmark

ARTICLE INFO

Article history:
Available online 7 February 2018

Keywords:
Fractals
MRI analysis
Data mining
Prediction
sensory traits
Meat

ABSTRACT

This study investigates the use of fractal algorithms to analyse MRI of meat products, specifically loin, in order to determine sensory parameters of loin. For that, the capability of different fractal algorithms was evaluated (Classical Fractal Algorithm, CFA; Fractal Texture Algorithm, FTA and One Point Fractal Texture Algorithm, OPFTA). Moreover, the influence of the acquisition sequence of MRI (Gradient echo, GE; Spin Echo, SE and Turbo 3D, T3D) and the predictive technique of data mining (Isotonic regression, IR and Multiple Linear regression, MLR) on the accuracy of the prediction was analysed. Results on this study firstly demonstrate the capability of fractal algorithms to analyse MRI from meat product. Different combinations of the analysed techniques can be applied for predicting most sensory attributes of loins adequately ($R > 0.5$). However, the combination of SE, OPFTA and MLR offered the most appropriate results. Thus, it could be proposed as an alternative to the traditional food technology methods.

1. Introduction

Sensory analyses are carried out to measure the sensory quality of meat and meat products, being the quantitative-descriptive analyses the most widely used (Andrés et al., 2004; Ruiz et al., 1998). Data obtained by means of sensory analysis are as reliable as those from physical–chemical determinations (García and Carrapiso, 2001). These techniques measure the characteristics that influence consumers' acceptance, such as appearance, texture, odour, taste and flavour. Sensory analyses are tedious, time consuming and require the destruction of the pieces and a trained panel. In addition, in the case of meat products, they are carried out at the end of their processing, when there is no possibility of modifications to improve some sensory traits. In the last years, the evaluation of the meat and meat products by using non-destructive methods have given a great growth (Antequera et al., 2007; Collell et al., 2011; Fantazzini et al., 2009; Manzoco et al., 2013; Pérez-Palacios et al., 2014).

In this sense Magnetic Resonance Imaging (MRI) and computer vision techniques have been proposed as an alternative or complementary technique to traditional methods, since they are non-destructive, non-invasive, non-intrusive, non-radiant ionization

Abbreviations: MRI, Magnetic resonance imaging; KDD, Knowledge discovery in databases; GE, Gradient Echo; SE, Spin Echo; T3D, Turbo 3D; RF, Radiofrequency; S/N, Signal to noise; FOV, Field of view; TE, Echo time; TR, Repetition time; CFA, Classical fractal algorithm; FTA, Fractal Texture Algorithm; UNI, Uniformity; ENT, Entropy; COR, Correlation; IDM, Inverse difference Moment; INE, Inertia; CON, Contrast; EMP, Emphasis; JC, Jorna's correlation; CS, Cluster shade; CP, Cluster prominence; OPFTA, One Point of Fractal Texture algorithm; ROI, Region of interest; HOM, Homogeneity; EFI, Efficiency; MLR, Multiple linear regression; IR, Isotonic regression; R, Correlation coefficient; MAE, Mean absolute error; PCA, Principal component analysis.

* Corresponding author.
E-mail addresses: dcaballero@unex.es (D. Caballero), tantero@unex.es (T. Antequera), andresc@unex.es (A. Caro), jmar@food.ku.dk (J.M. Amigo), bker@dtu.dk (B.K. ErsbØll), abda@dtu.dk (A.B. Dahl), triny@unex.es (T. Pérez-Palacios).

https://doi.org/10.1016/j.jfoodeng.2018.02.005
0260-8774/

and innocuous. In fact, several works have been carried out to determine quality attributes of hams (Antequera et al., 2007; Bajd et al., 2016; Caballero et al., 2016a, 2016b; Fantazzini et al., 2009; Manzoco et al., 2013; Pérez-Palacios et al., 2010, 2011; 2014) and loins (Antequera et al., 2003; Caballero et al., 2017a; Cernadas et al., 2001, 2005; Pérez-Palacios et al., 2015; 2017a) by using MRI. High field MRI scanners are frequently used in these researches, which implies high quality images but they are so expensive. In this sense, low field scanners that are cheaper could also be used for food analysis. The problem of this type of scanners is its low signal to noise ratio, being necessary the selection of an adequate sequence acquisition (Perez-Palacios et al., 2017a).

Most of these studies have used computational texture feature algorithms for analysing MRI. These algorithms integrate matrices based on second-order statistics in order to produce different computational texture features (Antequera et al., 2003; Cernadas et al., 2005). Pérez-Palacios et al. (2010, 2011) have found a relationship between computational texture features and some physico-chemical components and sensory attributes of Iberian hams.

In recent years, there is a growing interest in the use of fractal image analysis techniques instead of classical texture analysis methods. This is mainly because the image texture seeks to compress image information while the use of fractals allows the identification of recurring patterns, removing the possibility of image compression. The fractal concept studies the degree of symmetry or self-similarity found in a structure at all scales (Hibbert, 1991; Mandelbrot, 1982; Tominaga and Fujiwara, 1997; Sun et al., 2014). The most widely used algorithm is the classical fractal algorithm (CFA) (Mandelbrot, 1982), which is an implementation of Minkowski-Bouligand algorithm. CFA has been applied to characterize the microstructure of fruits and vegetables (Cárdenas-Pérez et al., 2016; Quevedo et al., 2016; Zhang et al., 2014), fish (Manera et al., 2016; Perisho et al., 2016), meat (Quevedo et al., 2013; Zapotoczny et al., 2016). However, only two studies about prediction of quality parameters of food have been found. Tsuta et al. (2002) applied them to predict the sugar content of melons and Polder et al. (2004) measured the chlorophyll of tomato by applying of fractals. Other fractal algorithms have been recently developed, fractal texture algorithm (FTA) (Caballero et al., 2017b) and one point of fractal curve texture algorithm (OPFTA) (Caballero et al., 2017c). Up to now, Caballero et al. (2017b) have applied FTA to analyse MRI from meat products in order to determine some quality characteristics non-destructively, whereas the use OPFTA in food have not been studied yet.

Data obtained from MRI analysis have been normally processed by applying usual statistical tools, such as Pearson's correlation coefficients or principal components analysis (Perez-Palacios et al., 2010). The integration of heterogeneous information with computer vision data and the analysis of this new data set by data management and database applications would be innovative and could give accurate results, playing an increasing role in furthering food research (Cortez et al., 2009; Holmes et al., 2012).

Currently, there is a growing interest in these techniques, mainly due to the decreasing cost of large storage devices and the development of robust and efficient algorithms to process these data sets (Mitchell, 1999). They are focused on extracting information from large data sets, grouped in what is known as Knowledge Discovery in Databases (KDD). Data mining is one of the data analysis stage in the KDD process, as a non-trivial process of finding knowledge and potentially useful information from data stored in repositories (Fayyad et al., 1996). It extracts hidden information by automatic or semi-automatic analysis, finding interesting unknown patterns (Sayad, 2011). There are some examples of data mining applied in quality traits of different meats (Cortez et al., 2006; Dissing et al., 2013; Song et al., 2002), and determining some quality parameters of Iberian meat products (Caballero et al., 2016a, 2016b; 2017a; Pérez-Palacios et al., 2014, 2017a).

Combining image acquisition, image analysis and data analysis, the main objective of this study was to evaluate the capability of different fractal algorithms to analyse MRI of loins in order to predict sensory attributes of this product. In addition, the prediction accuracy of combinations of different sequence acquisitions of MRI, fractal algorithms to analyse MRI and predictive techniques of data mining were analysed.

2. Material and methods

2.1. Experimental design

Fig. 1 shows the experimental design of this study. Ten fresh loins were acquired from Montesano (Jerez de los Caballeros, Badajoz, Spain). Firstly, fresh loins were scanned by MRI. When they were processed, according to the traditional curing process following the procedure described by Pérez-Palacios et al. (2017a), MRI images were also retrieved for the dry-cured loins. All these MRI images were gathered in a MRI database. These images were acquired by using three different acquisition sequences (GE, SE and T3D), described in Section 2.3 (MRI acquisition). The obtained images from the database (from fresh and dry-cured loins) were analysed using three computer vision methods based on fractals (CFA, FTA and OPFTA). These methods are based on searching repeated patterns at different sizes. Numerical information from the images were gathered in a database (Computer vision data). Details about these algorithms could be found in Section 2.4 (Computer vision techniques). Besides, a quantitative-descriptive sensory analysis was carried out in dry-cured loins (Section 2.2. Sensory analysis). Average scores from eleven sensory traits for every dry-cured loin were stored in a database (Sensory data). Then, from these two databases (Sensory data and Computer Vision data) two data selection were performed, one of them from computer vision data of fresh loins and sensory data of dry-cured loins, and the other, with data from computer vision and sensory data of dry-cured loins. Finally, data mining techniques (Section 2.5. Prediction techniques) were applied on these databases for predicting sensory attributes of dry-cured loins as a function of fractals features from MRI of fresh and dry-cured loins ($P_1 = a_1x + b_1y + c_1z$, where P_1 is a sensory trait of dry-cured loin, x, y and z are fractal features and a_1, b_1 and c_1 are the weight for each fractal features). Specifically, MLR as lineal and IR as non-lineal predictive techniques were applied in this study. Thus, each prediction equation was determined by means of eighteen combinations of sequence acquisition of MRI (SE, GE, T3D), fractal methods for analyzing the obtained MRI (CFA, FTA and OPFTA) and prediction technique of data mining (MLR, IR).

2.2. Sensory analysis

Ten dry-cured loins were assessed by a trained panel of thirteen members, using a quantitative descriptive analysis (Antequera et al., 2003). Eleven sensory traits of Iberian dry-cured loins (redness of lean, brightness of lean, marbling, odour intensity, hardness, juiciness, salty taste, flavour intensity, cured flavour, rancid flavour and flavour persistence) were assessed in a non-structured scale 0–10. Analyses were developed in tasting rooms with the conditions specified in UNE-EN ISO 8589:2010 regulation. All sessions were conducted at room temperature (22 °C) equipped with white fluorescent lighting (220–230 V, 35 W). The software used to record scores in the sensory sessions was FIZZ Network (version 2.20, Biosystems, France). For each loin, two slices