Meat Science 90 (2012) 636–642

Contents lists available at SciVerse ScienceDirect

Meat Science

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

In-situ Iberian pig carcass classification using a micro-electro-mechanical system (MEMS)-based near infrared (NIR) spectrometer

E. Zamora-Rojas *, D. Pérez-Marín, E. De Pedro-Sanz, J.E. Guerrero-Ginel, A. Garrido-Varo

Department of Animal Production, Non-destructive Sensor Unit, Faculty of Agricultural and Forestry Engineering, University of Córdoba, Agrifood Campus of International Excellence (ceiA3), Campus Rabanales, N-IV, km 396, Córdoba 14014, Spain

ARTICLE INFO

Article history:
Received 18 July 2011
Received in revised form 3 October 2011
Accepted 13 October 2011

Keywords:
Iberian pig
In-situ analysis
NIRS
Authentication
Feeding regime
MEMS device

ABSTRACT

Iberian pig (IP) products are gourmet foods highly appreciated at international markets, reaching high prices, because of its exquisite flavors. At present, there aren't practical and affordable analytical methods which can authenticate every single piece put on the market. This paper reports on the performance of a handheld micro-electro-mechanical system (MEMS)-based spectrometer (1600–2400 nm) for authentication–classification of individual IP carcasses into different commercial categories. Performance (accuracy and instrumental design) of the instrument was compared with that of high-resolution NIRS monochromators (400–2500 nm). A total of 300 carcasses of IPs raised under different feeding regimes ("Acorn", "*Recebo*" and "Feed") were analyzed in three modes (intact fat in the carcass, skin-free subcutaneous fat samples and melted fat samples). The best classification results for the MEMS instrument were: 93.9% "Acorn" carcasses correctly classified, 96.4% "Feed" and 60.6% "*Recebo*", respectively. Evaluation of model performance confirmed the suitability of the handheld device for individual, fast, non-destructive, low-cost analysis of IP carcasses on the slaughterhouse line.

1. Introduction

Iberian pork products are high-quality products enjoying worldwide prestige due to their exceptional organoleptic and health-related properties (Cava, Ventanas, Ruiz, Andrés, & Antequera, 2000 and Ventanas, Ruiz, García, & Ventanas, 2007). In recent years, moreover, the agro-sylvo-pastoral production system traditionally used to produce these high-quality products has provided a "sustainable" and "natural" label to the Iberian pork products. Spanish legislation classifies Iberian pig (IP) products into different categories depending on the feeding regime and production system involved (BOE, 2007): "Acorn" (i.e. free-range animals fed on grass and acorns), "*Recebo*" (i.e. animals fed on acorns and grass supplemented with compound feeds in an outdoor system) and "Feed" (i.e. animals fed on compound feeds in an intensive system). The terms "Acorn", "*Recebo*" and "Feed" are used in the paper to refer to samples from animals belonging to each of the three commercial categories; "Acorn" category being the highest priced, followed by "*Recebo*" and then by "Feed".

These categories reflect the impact of the feeding regime – particularly during the final fattening stage – on fatty acid composition and fat distribution in tissues (Carraspiso, Bonilla, & García, 2003; Petrón, Muriel, Timón, Martín, & Antequera, 2004; Daza et al., 2006a and Garrido & De Pedro, 2007), an impact also influenced by other factors such as genotype, gender, feeding regime during the period before the late fattening stage, age at the beginning of fattening, age and weight at the slaughter, environmental and rearing conditions (Pérez-Serrano, 2008 and Bonneau & Lebret, 2010). Iberian pork products share a characteristic high unsaturated/saturated fatty acid ratio and extraordinary sensory attributes. Moreover, feeding regime influences the quality, contributing to the existence of different price premiums for each category in the Spanish and international markets.

The official quality-control systems used for determining the IP feeding regime are based on on-farm inspection and laboratory analysis of the fatty-acid composition of melted subcutaneous fat using gas chromatography (GC) (BOE, 2007). However, these methods are costly and time-consuming, and only provide information on batches of animals rather than individual pigs. Production is constantly increasing, and demand is growing (Daza, Olivares, Rey, Ruiz, & López-Bote, 2006b); rigorous control procedures are therefore required to ensure the traceability, authentication and quality of Iberian pork products, in order to guarantee product homogeneity and satisfy consumer expectations.

Innovative analytical methods and technologies are increasingly being researched for the classification of IP products by genotype or feeding regime such as DNA tests, gas chromatography (GC) analysis for fatty acid profile, gas chromatography–mass spectroscopy (GS–MS) or electronic nose for volatile compound analysis, high performance liquid chromatography (HPLC) combined with GC to detect and quantify hydrocarbons, antioxidants and/or triacylglycerols, ultrasonic measurements, isotopic analysis, image texture analysis

* Corresponding author at: Campus Rabanales, N-IV, km 396, 14014 Córdoba, Spain. Tel./fax: +34 957 21 85 55.
E-mail address: e.zamora@uco.es (E. Zamora-Rojas).

0309-1740/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.meatsci.2011.10.006

based on magnetic resonance imaging (MRI) and ion mobility spectroscopy (IMS). Most of the studies in the literature on this topic have mainly been concerned with the ability of a given method or technology to differentiate between the extreme categories "Acorn" and "Feed", and do not include samples of the "*Recebo*" group, whose intermediate nature renders classification more complex.

Each of these techniques shows certain advantages and disadvantages, but they all have major barriers for widespread use in the IP industry: time-consuming, analysis cost, complexity or destruction of the samples (not the case for ultrasonic or imaging techniques). However, an objective, low cost and real time control system for the authentication of individual ham pieces would enable farmers to be paid by animal, with the premium appropriate to the commercial category, rather than by batches whose commercial composition may vary; it would also ensure rigorous internal production-quality controls enabling more efficient marketing decisions. At the same time, a more objective certification system would boost consumer confidence.

Over the last decades, Near Infrared Spectroscopy (NIRS) has shown its potential for meat analysis (Prevolnik, Candek-Potokar, & Skorjanc, 2004; Prieto, Roehe, Lavín, Batten, & Andrés, 2009 and Weeranantanaphan, Downey, Allen, & Sun, 2011) more specifically for the classification of IP products by feeding regime. Early papers in the field showed the high precision and accuracy of NIRS multivariate models for the prediction of fatty acids and discrimination of the feeding regime by analyzing melted fat taken from IP carcasses and using monochromator instruments (De Pedro, Garrido, Bares, Casillas, & Murray, 1992; De Pedro, Garrido, Lobo, Dardenne, & Murray, 1995; Hervás, Garrido, Lucena, García, & De Pedro, 1994; García-Olmo, Garrido-Varo, & De Pedro, 2001; García-Olmo, Garrido-Varo, & De Pedro, 2009; Fernández-Cábanas, Garrido-Varo, García-Olmo, De Pedro-Sanz, & Dardenne, 2007; Pérez-Marín, Garrido-Varo, De Pedro, & Guerrero-Ginel, 2007 and Arce et al., 2009). At present, several official laboratories are using this technology to provide support to producers and industries of the IP sector replacing gas chromatography (GC) analysis. Later, several authors (García-Olmo, Garrido, & De Pedro, 1998; González-Martín, González-Pérez, Hernández-Méndez, & Álvarez-García, 2003 and Pérez-Marín, De Pedro, Guerrero-Ginel, & Garrido-Varo, 2009) demonstrated the viability of NIRS analysis of intact fat or adipose tissue using monochromator instruments equipped with a remote fiber optic probe. These studies have not only shown the potential of NIRS technology to replace the more expensive and time demanding GC analysis of the IP fat, but also its ability to use NIRS spectra information "per se" for a more accurate classification of IP carcasses in the existing commercial categories (Hervás et al., 1994; De Pedro et al., 1995 and García-Olmo et al., 2009). More recently a study assessed the viability of the on-line NIRS analysis of carcasses and live animals in the slaughterhouse using a portable instrument with a fiber optic accessory (Pérez-Marín et al., 2009). However, the instrument has the limitations of high cost and time required for measurements and also technical limitations due to its weight (5.6 kg), external reference or the fiber optic accessory; longer distance, less sensitivity.

New portable handheld devices, combining small size, robustness, low cost and ease of use, have appeared over the last few years. These enable NIRS technology to be implemented in environments for which traditional instrument designs are unsuitable. Near-infrared spectrometers using micro-electro-mechanical systems (MEMS) technology provide several specific advantages. The combination of MEMS with transform mathematics such as digital transform spectroscopy (DTS) produces powerful spectrometers. A MEMS chip, equipped with a fixed diffraction grating, can constitute a rapidly-programmable high-contrast pixilated optical reflector working as a tunable spectral filter, and combined with a single detector can reduce equipment costs and eliminates detector noise. Additionally, the robust design with non-moving parts makes the instrument particularly useful for in-situ measurements (Day et al., 2005 and Wolffenbuttel, 2005). This technology represents a shift for industrial spectroscopy applications, opening up new scope for spectroscopic sensors (Crocombe, 2004).

The aim of the present study was to evaluate a handheld MEMS-NIRS instrument for in-situ classification of individual IP carcasses by feeding regime in the slaughterhouse, comparing its performance with that of high-resolution monochromators and assessing its value for practical use in the IP industry. The high-resolution NIR spectrometers used for comparison purposes are those that are used at-line in laboratories and some IP industries, either for the analysis of melted fat or intact adipose tissue.

2. Materials and methods

2.1. Sample set

Three hundred Iberian pig carcasses (Pure Iberian and Iberian-Duroc crossbreds) from two commercial Spanish slaughterhouses were analyzed. Pigs were slaughtered over two seasons (2008/2009 and 2009/2010), at the age of 12 months for the "Feed" animals and 14 months for the other categories; average weight was 160 kg. One hundred pigs were drawn from each of the three feeding regimes: "Acorn", "*Recebo*" and "Feed"; authentication of the feeding regime was monitored by trained personnel in on-field inspection.

2.2. NIRS measurements

Spectra were collected using a handheld instrument of particular value for in-situ applications, and also using high-resolution monochromators for comparative purposes:

1. A handheld micro-electro-mechanical system (MEMS) digital transform spectrometer (2 kg weight) (Phazir 1624, Polychromix Inc., Wilmington, MA, USA), working in reflectance mode in the spectral range 1600–2400 nm with a non-constant interval of around 8 nm (pixel resolution 8 nm, optical resolution 12 nm). Sensor integration time was 600 ms. The device is equipped with quartz protection to prevent dirt accumulation. Transverse sections of intact subcutaneous fat were obtained directly from the tail insertion area of carcasses around 2 hours post-slaughter chilled in a temperature controlled chamber (Fig. 1). Four spectra per carcass were collected over the sample area. Sample temperature during measurements at the slaughterhouse was 15–18 °C.
2. Two Foss NIRSystems (FNS) 6500 spectrometers (Foss-NIRSystems Inc., Sylver Spring, MD, USA), one equipped with a fiber optic for intact analysis of subcutaneous tissue and another equipped with a spinning module for melted subcutaneous fat analysis were used for comparison purposes. The instruments operate in the spectral range 400–2500 nm with a spectral resolution of 2 nm. Two sample presentation modes were evaluated in the laboratory: skin-free transverse sections of subcutaneous adipose tissue and melted fat samples. Melted fat samples were prepared following De Pedro, Casillas, and Miranda (1997) and analyzed using folded-transmission gold reflector cups with a pathlength of 0.1 mm. Samples were obtained from the same area as for the MEMS measurements, and were stored at −20 °C until 24 h before at-line NIRS analysis in the laboratory. Duplicate spectra were collected. Sample temperature in the laboratory was 18–20 °C.

2.3. Data pre-treatment

Chemometric calculations were performed using different software packages: WinISI package ver 1.50 (Infrasoft International, Port Matilda, PA, USA) for performing spectral repeatability analysis, principal component analysis, and PLS2 discriminant analysis; and