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Low-frequency dielectric spectrum to determine pork meat quality

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ABSTRACT

The use of dielectric spectra to determine meat quality classes (PSE, DFD, RFN) in porcine muscle during postmortem period was evaluated. The changes in dielectric properties during meat ageing were also analyzed for each meat quality class. For these purposes, dielectric spectra were measured from 100 Hz to 0.4 MHz in parallel and in perpendicular to muscle fiber directions. Significant differences ($p<0.05$) in dielectric constant and loss factor among classes were observed at 24 and 48 h post-mortem. Thus, the use of dielectric properties to detect low meat qualities is more reliable at 24 h after slaughtering. Moreover, two indexes for evaluating meat ageing were developed from dielectric properties with good results. This research is the first step for developing a sensor based on electromagnetic waves at radio frequencies for controlling pork meat quality. The results are promising and some definite frequencies are demonstrated to be useful for these purposes.

Industrial Relevance: The results of this research article are demonstrated to be useful for discriminating low meat qualities (PSE and DFD meats). Thus, the industrial relevance is clear in this case because the detection of low meat qualities is identified as one of the most important challenges of meat industry nowadays. On the other hand, basing on the results of the present paper it is possible to develop a prototype for industrial applications. Moreover, two possible Indexes are developed in the present paper for determining meat freshness which also can be considered important from an industrial point of view. All this determinations were made by using dielectric spectroscopy which can be considered an emerging technology. For all these reasons we are sending to this journal “Innovative Food Science and Emerging Technologies” our results.

1. Introduction

The incidence of pork meat quality problems such as PSE (Pale, Soft and Exudative) or DFD (Dark, Firm and Dry), are still one of the main meat industry challenges (Stetzer & McKeith, 2003). PSE meats have pale color, soft texture and high exudation; these characteristics make this kind of meats unsuitable for processing (Damez, Clerjon, Abouelkaram, & Lepetit, 2008). On the other hand, DFD meats have high ultimate pH, and thus, are very susceptible to spoiling (Damez et al., 2008; Lawrie, 1998). The early detection of low quality meats is an important issue for meat industry in order to reduce economic losses and to proportionate the best destination to meat carcasses. Many efforts are being made in the search for accurate and non-destructive methods of meat quality assessment (Bertram, Andersen, & Karlsson, 2001; Byrne, Downey, Troy, & Buckley, 1998; Damez & Clerjon, 2008; Monin, 1998; Tan, 2004). In this context, sensors based on electromagnetic radiation appear as an interesting option which fulfils these requirements and can provide important information about biological tissues such as meats.

The complex permittivity (ε_r) is the dielectric property which describes the behavior of the food when it is subjected to an electromagnetic field (Metaxas & Meredith, 1993; Nelson & Datta, 2001). Complex permittivity is defined by the next equation:

$$\varepsilon_r = \varepsilon' - j \cdot \varepsilon'' \qquad (1)$$

In this equation, $j = \sqrt{-1}$. The real part of complex permittivity is called dielectric constant (ε') and the imaginary part is called loss factor (ε''). The dielectric constant is related with the capacitance of the material and its ability to store energy (polarization). Foods are non-ideal dielectrics and polarization has associated dissipation phenomena producing energy absorptions and the decay of dielectric constant. The parameter which reflects the absorption and dissipation of electromagnetic energy is the loss factor (Castro-Giráldez et al., 2009).

Biological tissues can be considered nonmagnetic materials which electrical properties are a consequence of their composition and their structure. The most important components which influence the dielectric properties of tissues are mainly ions, and the most important source of dipolar moments are the water tissue molecules

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and also the proteins and lipids which form the membranes and cell interfaces (Rigaud, Morucci, & Chauveau, 1996). The movement of the charges induces a conduction effect, and the polarization of the dipoles results in dielectric relaxation phenomena (Rigaud et al., 1996). The conductivity of most tissues rises from low values at low frequencies that depend strongly on the volume fraction of extracellular fluid up to a plateau in the 10–100 MHz frequency range which mainly corresponds to conductivity of intra and extracellular ions (Castro-Giráldez et al., 2009). Then, conductivity rises dramatically due to the dielectric relaxation of water (Rigaud et al., 1996) (Fig. 1). This increase in conductivity is associated with a decrease in permittivity from very high values at low frequencies in different steps called dispersions. It is important to highlight that these dispersions are not produced instantaneously and are characterized by the correspondent relaxation phenomena (Schwan, 1988). In biological systems, there are three main dispersions (α,β,γ) (Schwan, 1957) (Fig. 1). The dispersions are related to three relaxation phenomena and determine three frequency ranges (Pethig & Kell, 1987). The γ-dispersion is located at high frequencies (>100 MHz) and is mainly due to the permanent dipole relaxation of small molecules, mainly free water which is the main constituent of muscle tissues. The β-dispersion, from few KHz to MHz, is mainly caused by the Maxwell–Wagner effect. This phenomenon is typical of inhomogeneous materials and is due to interface polarization of biological membrane systems. It can be postulated that it is a measure of cell membrane integrity during meat ageing due to the decrease of its insulating properties (Ghatass, Soliman, & Mohamed, 2008). The α-dispersion, from few Hz to few KHz, is associated with the polarization phenomena in the electrical double layer of the tissues (Foster & Schwan, 1989). Moreover, another mechanism associated with membrane permeability (ion passage in tissue) was investigated (Kuang, 1996).

Muscle ageing involves lot of complex biochemical and physicochemical processes which influence its structure. These processes include the action of proteases, an increase in membrane permeability and the weakening of connective tissue (Damez et al., 2008). These physical changes during postmortem time are expected to change the dielectric properties of the samples, so studying the electrical behavior of biological tissues can provide unique information about the meat state (Kuang & Nelson, 1997; Pethig & Kell, 1987; Schwan, 1957). On the other hand, low quality meats are characterized by different postmortem metabolisms from RFN (Red Firm and Non-exudative) meats (Bowker, Grant, Forrest, & Gerrard, 2000; Lawrie, 1998). PSE muscle is related to fast pH decrease, cellular breakdown, and an increase in extracellular fluid, thus, conductivity of this kind of meats is expected to be higher than normal muscle (Guerrero et al., 2004; Oliver, Gispert, Tibau, & Diestre, 1991). On the other hand, DFD meats are characterized by an abnormal pH evolution which directly affects the muscle structure (Wulf, Emnett, Leheska, & Moeller, 2002) and therefore, the dielectric properties. So, studying the dielectric properties of fresh meat is expected to be a useful tool to discriminate low meat qualities.

Some applications of dielectric spectroscopy at low frequencies have been reported in meat and meat products. Damez et al. (2008) reported a method to early assessment of beef meat ageing by studying the electrical anisotropy behavior of the product. Other authors (Gómez-Sánchez, Aristizábal-Botero, Barragán-Arango, & Felice, 2009) propose an index (inherent electrical anisotropy: IEA) to quantify the degradation of the muscle due to the aging process. Some studies were made in order to discriminate DFD meats by using electrical measurements but the results were non promising (Forrest et al., 2000; Garrido, Pedauye, Banon, & Laencina, 1994; Guerrero et al., 2004; Jaud, Weisse, Gehlen, & Fischer, 1992). PSE detection was very difficult during early postmortem because of the rapid metabolic modifications which affect structure and therefore the electrical properties (Bendall & Swatland, 1988; Kleibel, Pfüzner, & Krause, 1983). These measurements were also used in order to evaluate fat content (Altmann & Pliquett, 2006; Bejerholm & Barton-Gade, 1986; Madsen, Borggaard, Rasmussen, & Christensen, 1999; Marchello, Slanger, & Carlson, 1999; Slanger & Marchello, 1994; Swantek, Crenshaw, Marchello, & Lukaski, 1992) and to evaluate the level of aging (Damez, Clerjon, Abouelkaram, & Lepetit, 2006; Faure et al., 1972; Lepetit & Hamel, 1998; Lepetit, Salé, Favier, & Dalle, 2002; Lepetit et al., 2006) or to evaluate meat tenderness (Byrne, Troy, & Buckley, 2000).

The aim of the present work was to analyze the low frequency spectra of the different meat quality classes, trying to further understand each dispersion phenomenon. Moreover, the viability of using electric properties of meat to discriminate low meat qualities (PSE and DFD) was analyzed due to the fact that these properties are influenced by interfacial phenomenon and consequently by meat

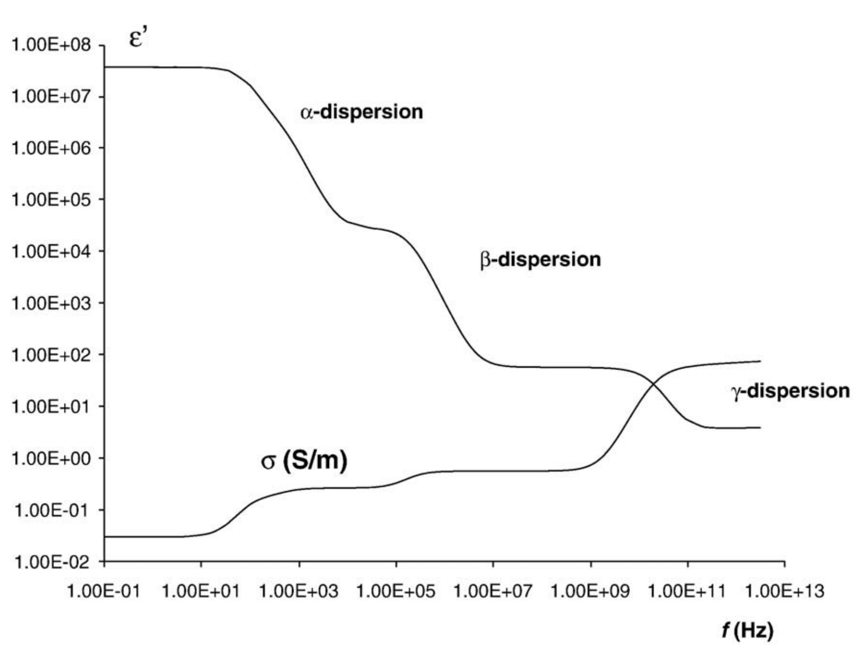

Fig. 1. Ideal representation of electric conductivity (S/m) and dielectric constant spectra in biological tissue.