MODELLING THE ELECTRICAL PROPERTIES OF MEAT MESOSTRUCTURE DURING AGEING

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Introduction

The aim of this study is to outline the use of computational modelling in order to examine and explain the electrical behaviour of electrical fields in meat tissues during ageing. We investigate whether biophysical parameters of the meat mesostructure, as meat fiber membranes permeability and intra- and extra-cellular fluids flows, could be derived from changes in electrical properties. Certain teams have carried out modeling by taking into account the structure organization and by comparing structure elements to standard elementary geometric elements (cubic and spherical) made up of dielectric walls either containing or sometimes even surrounded by conducting fluids. This approach has made it possible to reconstitute the spectral behavior in the three ranges of the Schwan classification (Schwan, 1971; Nopp et al., 1997; Ivorra, 2005). Mathematical methods of homogenization are sometimes required in order to implement modeling techniques. There is a model for each level of structure, and the output responses of these models are then used as input parameters of the higher-level structural model. This approach has been implemented to model the dielectric properties of muscle tissues (Felbacq et al., 2004)

Materials and Methods

In this study, we choose to use as elementary structure element, the hexagonal (honeycomb) as it is the most common geometrical structural element find in the nature. Furthermore, using hexagonal structure, gaps between cell membranes can be well and regularly defined. For the modeling we used COMSOL Multiphysics allowing the resolution of partial differential equations (PDEs). The mesostructure of meat was described in 2D½ (expanded volume from 2D cross section) as represented on Fig 1. The geometrical dimensions .and electrical properties for meat fibers membrane, inner and outer cell compartments, were obtained from review articles and tabulated in Table 1. Multivariate sensitivity analysis of the model was studied in varying membrane cells, extra-cellular fluid (ECF) and intra-cellular fluids (ICF) electrical properties, miming variations of these components calculated or obtained in others studies (Damez et al., 2007). Ageing could be simulated in increasing the permeability characteristics of the cell membranes by increasing the conductivity parameter and decreasing the capacitance of the membrane and in changing ECF and ICF conductivities. The electrical impedances outcoming from the model were obtained in interfacing Comsol Multiphysic with Matlab 2006b, where input parameters (electrical and geometrical) range are derived from Table 1.

Table 1 Electrical properties used to model cellular compartments and to model membranes, derived from average values published in literature (Walker, 2001)

Cellular compartment	Conductivity σ (S/m)	Relative Permittivity	Capacitance µF/cm²	Thickness µm
Extracellular space	1.1	72	--	1
Intracellular space	0.6	86	--	50 (Ø)
Membrane	3.6×10^{-5}	7	1.5	0.01

Results & Discussion

Results of the modelling are show on Fig. 2 where plots of the electrical impedance between 2 micro-needles are represented versus frequency. The spectral simulation of the impedance across meat fibers is plot ranging from 100Hz to 100 MHz. The result of the modelling of the progressive membranes deterioration, from the non-degraded state (st1) to the degraded state (st10), is plot and shows how electrical impedance behaves during ageing with the increase of the membrane permeability and the ECF /ICF mixture. The progressive overlapping of the impedances plots, in β and γ regions, fit well with the Schwan's description (Schwan, 1971) and experiments. Current flows are simulated and plotted on Fig. 3 at low frequency (1 kHz) and high frequency (10MHz) confirming hypotheses on the behavior of electric fields which at low frequencies, circumventing the myofiber membranes, the current flows in extracellular compartments, while at higher frequencies, the membranes losing their insulating properties, the current flows through both the extracellular and intracellular compartments (Damez et al., 2007).

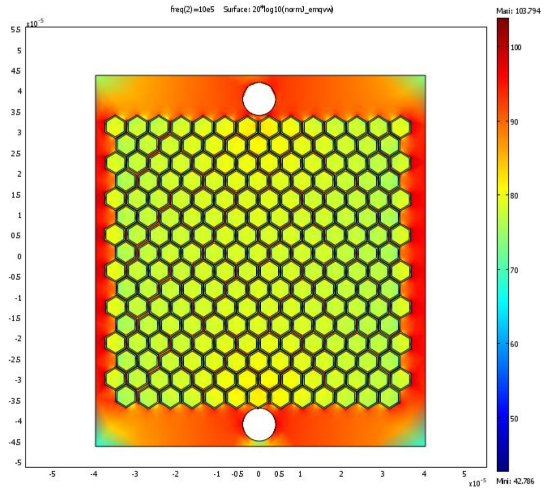

Figure 1. Representation of meat cross section with hexagonal meat fibres elements

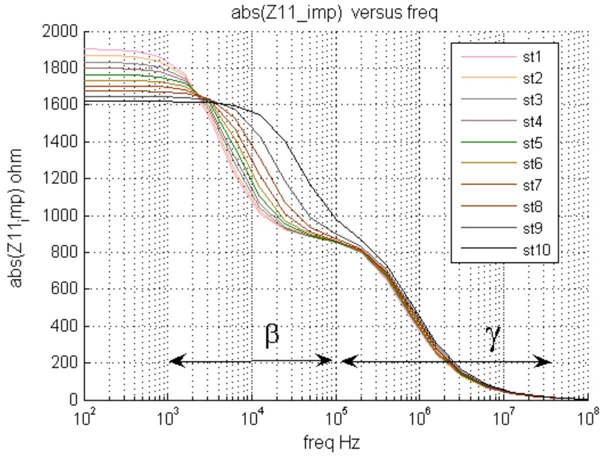

Figure 2. Simulation of impedance spectra behaviour during meat ageing

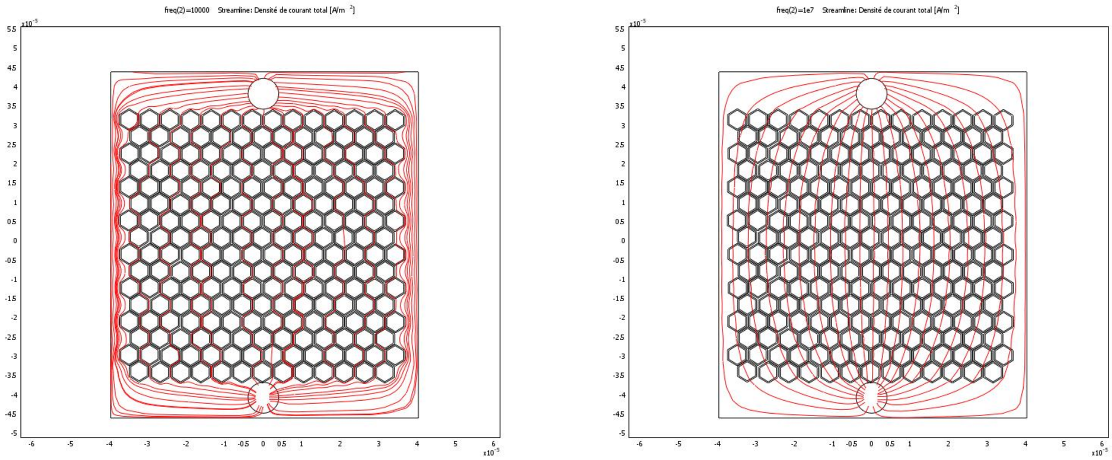

Figure 3. Simulation of the electric fields at low frequencies {10 kHz} (circumventing the meat fibers) and at high frequencies {1 MHz} (going through both the extracellular and intracellular compartments)

Conclusions

Changes in impedance spectra of meat during ageing have been simulated using computational modelling. Hexagonal elements were used to describe meat fiber structure and ageing was simulated in mimic membranes permeability and ICF-ECF mixture by changes in their electrical parameters. Results are similar to those observed in others studies and experiments and confirm hypotheses on electrical behaviour. Structural or biophysical parameters, which are difficult to measure by usual techniques, could be estimated using an inverse modelling approach in matching the outcomes of laboratory experiments and numerical simulations.

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