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MESOSTRUCTURE ASSESSED BY ALTERNING CURRENT SPECTROSCOPY DURING MEAT AGEING

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Introduction

Since different types of tissues exhibit different conductivity parameters, numerous studies have been carried out for many years to characterize biological tissues by means of their electrical properties. Impedance measurements observed with increasing frequencies are mainly attributed to changes in membrane conductivity and ion and charged molecules mobility (mainly ions Na+, K+, CL-). Equivalent circuits with passive electrical components are frequently used as a support model for presentation and analyses of the behavior of tissue submitted to electrical fields. An attempt to describe electrical model is the Fricke's model. In this model the elements are resistive and capacitive. It is composed of a resistive element (Rp), corresponding to the extracellular electrolyte, placed in parallel with a capacitive element (Cs), corresponding to insulating membranes in series, and a resistive element (Rs) corresponding to intracellular electrolytes (Fig. 1). Impedance measurements can be explained using this model: most of the current flows around the cell at lower frequencies without being able to penetrate into the cell, at higher frequencies the membrane is no longer an impediment and the

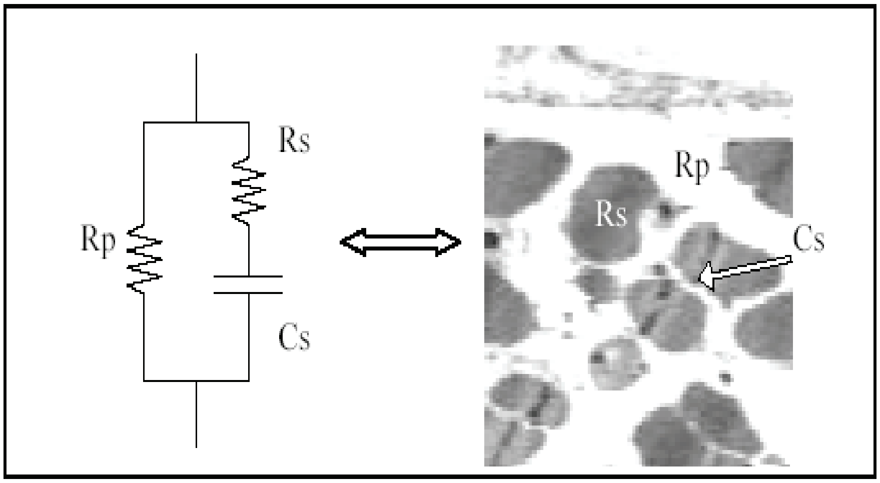

FIGURE 1 Intra- and extracellular conduction, Rs, Rp and membrane capacitance Cs with the equivalent electrical Fricke's model.

current flows both through the extra- and intracellular compartments. Since ageing induces structural change, particularly on membrane integrity, the insulating properties of membranes decrease, intra- and extracellular electrolytes are mixed which modifie electrical properties . A method presented here has been developed to monitor and explain the change in tissue conductivity in preferential directions.

Objectives

The main objective of this study is to evaluate the optimal meat ageing duration by means of electrical measurements. In this study, we tried to use equivalent electrical circuit parameters to characterize change in beef meat mesostructure. In previous study, we observed that meat electrical parameters are anisotropic and depend of meat fiber orientation [Damez et al., 2000] and so strongly correlate to meat ageing. Herein we try to replace the traditional rheological texture measurement with a non-invasive electrical measurement. In this study we established a model that permitted to calculate parameters corresponding to structural components at the cell level.

Methodology

Impedance measurements were made with a probe composed of 2 electrodes spaced 5cm (ϕ=0.6 mm; L= 5 mm) allowing measurements longitudinally and transversally to the fiber direction. Measurements were made with a HP 4194A Impedance/Gain-Phase analyzer at a frequency range between 1 KHz and 1.5 MHz. The meat samples were 3 types of beef muscle, Rectus abdominis (RA), Semimembranosus (SM) and Semitendinosus (ST) from 7 cows at different post-mortem times (PM+days), 2, 3, 6, 9, 14, 20 and 29 days of ageing.

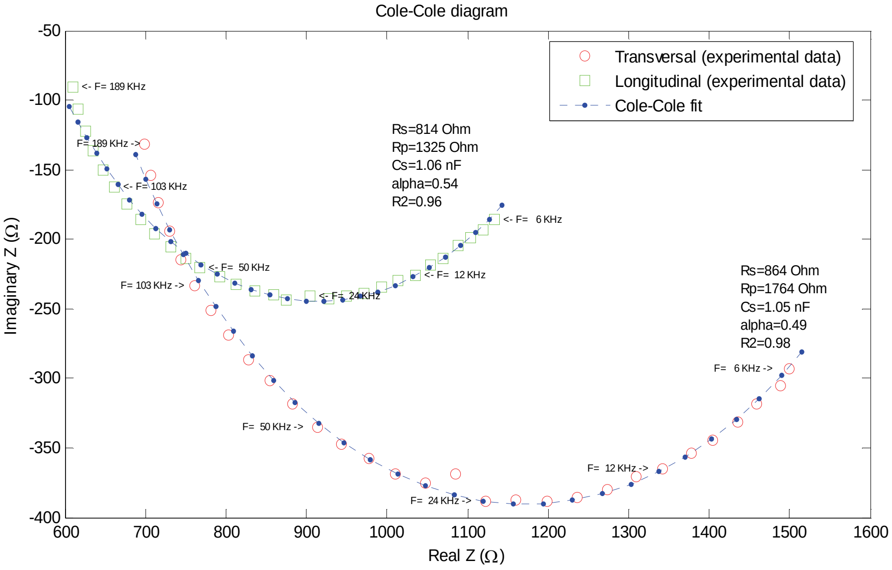

FIGURE 2 Typical Cole-Cole diagram and calculated conduction parameters on two orthogonal fiber directions.

Resistive and capacitive electrical properties are modeled using an adapted Cole-Cole relaxation equation (Fig. 2)[Cole & Cole, 1941][Foster & Schwan, 1989].

The impedance Z is a complex function of alterning current frequency *f* so that

$Z = R_\infty + \frac{(\mathrm{R}_0 - \mathrm{R}_\infty)}{1+(i\omega\tau)^{1-\alpha}}$ where, $\omega=2\pi f$, R_0 and R_∞ are respectively the impedance at very low and very high frequency, and the dimensionless exponent α a constant correcting the non strict capacitive comportment of membranes due to dielectric losses.

From the Fricke's model, τ=(Rs+Rp)Cs, R_0 = Rp and $\mathrm{R}_\infty = \frac{\mathrm{Rp\,Rs}}{\mathrm{Rp}+\mathrm{Rs}}$.

For fitting, we have implemented an improved algorithm derivate from the *fminsearch* function of Matlab R14 based on Nelder-Mead simplex method. This fitting gives a very good result as it gives a fit on each data point. Ageing is characterized with a rheological compression test using the method described by Lepetit and Bufiere (1995).

Results & Discussion

Conduction parameters are obtained by the data fitting method using Fricke's model. Dielectric calculated parameters are summarized in Table 1. It is important to note that parameters in longitudinal and transversal fibers directions are highly different. Resistance of extracellular space in the transversal direction (RpT) is higher than resistance in the longitudinal direction (RpL), which can be explained by the longer path of current flow. Capacitive element Cs is almost the same in both directions and decreases with ageing that is in agreement with the rupture of cellular membrane. Resistance of intracellular spaces (Rs) is almost the same in transversal and longitudinal directions and increase with ageing denoting that intracellular space becomes less conductive.

Conclusions

The method presented here has been developed to monitor and explain the changes in tissue conductivity in preferential directions during the ageing process. Correlations between calculated electrical parameters and compression strain remain low, but calculated parameters agreed with the behavior of the meat structure and could be useful to determine cell membrane state and intra- and extracellular state at different postmortem stages.

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Tables and Figures

TABLE 1 Calculated dielectric parameters of meat samples from different muscles, Rectus abdominis (RA), Semimembranosus (SM) and Semitendinosus (ST) at different post-mortem times (PM+days).

	Longitudinal impedance			**Transversal impedance**			**Compression strain**
	Rs (Ω)	**Rp (Ω)**	**Cs (nF)**	**Rs (Ω)**	**Rp (Ω)**	**Cs (nF)**	**20% (N/cm^2)**
RA PM+02	813	1881	2.09	878	2302	2.24	26.56
RA PM+02	1039	2325	1.96	820	2980	2.34	49.19
RA PM+03	714	2012	2.25	712	2561	2.61	20.19
RA PM+03	979	2216	1.78	1399	3550	1.49	34.06
RA PM+06	1002	1291	1.65	808	1410	1.94	11.28
RA PM+14	817	1311	1.94	765	1452	2.05	6.03
RA PM+20	1721	683	0.36	1544	746	0.38	18.86
RA PM+29	3755	636	0.29	2998	724	0.35	20.29
SM PM+02	1745	601	0.37	1843	603	0.30	18.12
SM PM+02	1395	664	0.74	1255	643	0.37	13.46
SM PM+03	2019	687	0.36	2103	694	0.34	18.90
SM PM+03	4508	497	0.50	4772	534	0.56	16.65
SM PM+06	3413	547	0.59	3447	574	0.40	4.74
SM PM+06	3427	617	0.25	1918	655	0.92	5.18
SM PM+06	3589	599	0.18	2827	684	0.75	4.84
SM PM+14	2800	667	0.29	2586	685	0.29	7.40
SM PM+14	4107	724	0.69	2064	710	0.36	5.16
ST PM+02	914	814	1.20	916	768	2.22	27.76
ST PM+06	1052	1378	1.11	1027	1476	1.29	7.41
ST PM+14	1901	763	1.68	1783	734	1.95	5.86