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LOW-FREQUENCY ELECTRICAL IMPEDANCE MEAT MEASUREMENTS

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Pork meat quality assessment is a very important issue in food industry. Chemical and microbiological assays are expensive and difficult to be carried to outside laboratory. The aim of this study was to elaborate a protocol for meat degradation estimation based on bioimpedance technique which is easier to apply in field meat quality tests.
In this study we present the evolution of electrical parameters of pork meat during storage period. We investigated meat samples (size of 50 mm x 30 mm x 10 mm) from *Longissimus dorsi* muscle. Parameters evaluation was performed every three days for a period of 15 days of storage in the refrigerator at 4 ºC. Electrical analyses were conducted in triplicates. Meat samples admittance and phase angle were measured by a custom-made device at eight different frequencies logarithmically spaced between 20 Hz and 5 kHz. We used round silver chloride electrodes with diameter of 5 mm. Measurements were performed both in transversal and longitudinal directions relative to muscle fibers. We used simple electrical equivalent model for muscle tissue, consisting of one resistor and one capacitor connected in parallel. This model was characterized by shape and size independent parameters such as conductivity and relative permittivity.
The studies showed that the values of electrical and dielectric parameters are linked to meat fiber strength. Significant degradation of the meat proven by odor development and color changes is also visible by variations of the electrical parameters after 6-8 days.

Keywords: bioimpedance spectroscopy, meat quality assessment, electrical equivalent model.

INTRODUCTION

Pork loins are considered one of the most consumed types of meat, playing an important role in a balanced and healthy diet. Due to the high nutrient content, meat is a highly perishable food, so keeping it in time poses a number of issues regarding the maintenance of physicochemical qualities. Low meat quality problems such as RFN (Red Firm and Non exudative), PSE (Pale, Soft and Exudative) or DFD (Dark, Firm and Dry)[1] can occur due to dehydration, increase of membrane permeability, weakening of connective tissue[2], complex enzyme changes or microbial development[3]. Numerous biochemical, microbiological and biophysical methods have been developed to detect early degradation of meat. For example, as biochemical approach enzyme assay methods (β-hydroxyacyl-CoA dehydrogenase method - HADH[4,5]) and DNA technology[6] are commonly used. Spectroscopic methods including UV-VIS[7], MIR[8], NIR, as well as NMR[9 10] are modern approaches in the field. Bio-imaging studies including light or electron microscopy are used to study the structural integrity of the meat.

Despite the advantageous information they provide, many of these techniques have many disadvantages: they are costly, time-consuming, or even destroy the sample, requiring their transport in a specialized laboratory.

For a first rapid assessment of meat samples, a less expensive, easy to apply and portable technique is required.

Using bioimpedance measurements for meat quality control is an old practice[11], demonstrating that the technique can be used to assess ageing[2], freshness, texture, moisture[12], salt level[13] or freeze-thaw cycles[14].

Although a seemingly accessible and rapid method, measuring the electrical properties of the meat involves a series of challenges arising from electrodes polarization, tissue anisotropy or temperature dependence[15].

The aim of the present work was to analyze the meat aging by changes in electrical properties at low frequencies.

MATERIALS AND METHODS

SAMPLE PREPARATION

Fresh pork muscle (*Longissimus dorsi*) was obtained from a local slaughterhouse (Bucharest, Romania), short time after being butchered. The tenderloins samples were covered with ice and transported to the laboratory within maximum 1 h. The meat was cut into uniformly rectangular pieces (50 mm length x30 mm width x 10 mm height). Samples were cut in two variants with respect to the disposition of muscle fibers: parallel and perpendicular with the long axis of the meat. Samples were individually packed into moisture impermeable polyethylene bags, and then stored at 4°C for 15 days. Meat samples were taken for measurements at 3-day intervals. Analyses were conducted in triplicates: three slices in the direction of the fibers and the other three in perpendicular to them.

MEASUREMENT OF ELECTRICAL ADMITTANCE

Admittance was measured by a custom made device at eight different frequencies logarithmically spaced between 20 Hz and 5 kHz (20 Hz, 50 Hz, 100 Hz, 200 Hz, 500 Hz, 1000 Hz, 2000 Hz, 5000 Hz). Device performs admittance measurements simultaneously at all the eight frequencies. Admittance range is between 0 and 1000 µS, and a resolution of 0,25 µS. Measurement speed is ten readings per second for each frequency component. Admittance value is represented by a complex number. Real part represents in-phase component (resistive behavior) and imaginary part represents quadrature component (capacitive/inductive behavior).

We used two round silver chloride electrodes with diameter of 5 mm. Measurements were performed both in transversal and longitudinal directions relative to muscle fibers. Each sample measurement involved one hundred successive readings for every frequency admittance component and final values were computed as an average over all readings.

MEASUREMENT OF MEAT DIELECTRIC PROPERTIES

In Figure 1 is represented the simplified electrical model of the meat sample used in this study.

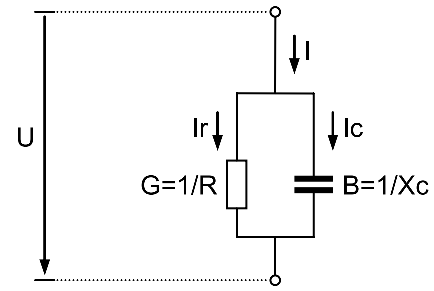

Figure 1. Electrical model of the meat sample.

The complex admittance of this circuit is:

$$Y \quad \frac{I}{U} \quad \frac{Ir \quad Ic}{U} \quad \frac{GU \quad jBU}{U} \quad G \quad jB \qquad (1)$$

where,

Y – admittance
I – current through circuit
U – voltage applied to circuit
Ic – current through capacitor
Ir – current through resistor
G – conductance
B – susceptance.

Both conductance (G) and susceptance (B) depends on several factors like:

- intrinsic electrical characteristics of the meat sample;
- frequency;
- electrodes and sample geometry.

Meat quality assessment involves analyzing dependence between conductance – frequency $G(\omega)$ and susceptance – frequency $B(\omega)$.

In order to eliminate electrode and sample geometry factor it is recommended to use conductivity $\sigma(\omega)$ and relative permittivity $\varepsilon_r(\omega)$ instead of conductance and susceptance.

Considering circular electrodes, the current path through the meat sample resembles a cylinder with same radius as the electrode and the height corresponding to sample thickness (Fig. 2).

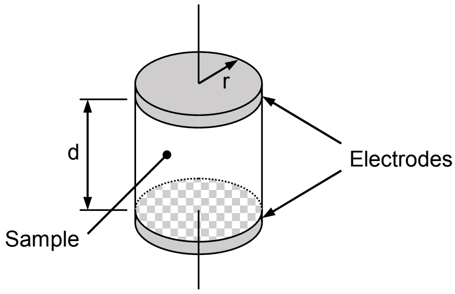

Figure 2. Electrode and sample geometry.

The resistance of a cylindrical conductor is:

$$R = \frac{d}{\sigma A} = \frac{d}{\sigma \pi r^2} \tag{2}$$

where,
R – resistance
σ – conductivity
d – average thickness of the test material
A – surface of the electrodes
r – diameter of the electrodes
and corresponding conductance:

$$G = \frac{1}{R} = \frac{\sigma \pi r^2}{d} \tag{3}$$

From the last equation we can obtain conductivity as:

$$\sigma(\omega) = \frac{G(\omega) d}{\pi r^2} \tag{4}$$

A capacitor with cylindrical dielectric has the following capacitance value:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d} = \varepsilon_0 \varepsilon_r \frac{\pi r^2}{d} \tag{5}$$

where,
ε_0 – vacuum permitivity (8.854 ×10–12 F/m)
ε_r – relative permittivity
and the corresponding susceptance is:

$$B = \omega C = \omega \varepsilon_0 \varepsilon_r \frac{\pi r^2}{d} \tag{6}$$

Relative permittivity can be obtained from the last equation as:

$$\varepsilon_r(\omega) = \frac{B(\omega) d}{\omega \varepsilon_0 \pi r^2} \tag{7}$$

EXPERIMENTAL PROCEDURE

Meat samples were removed from the refrigerator and allowed to equilibrate to ambient temperatures. The measurements were made by placing the sample between the electrodes, ensuring good contact between the electrodes and the sample (Fig. 3). The impedance and phase angle were determined both in the transverse and in the longitudinal fiber positioning.

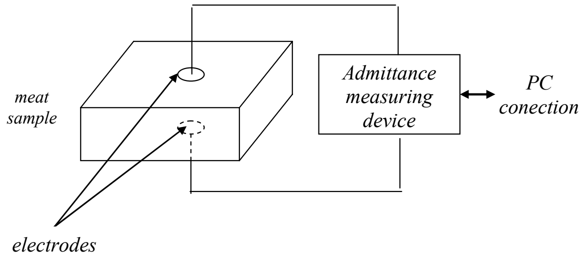

Figure 3. Schematic diagram of sample assessment.

DATA ANALYSIS

All measurements were conducted in triplicates. Statistical analysis was performed using OriginPro 8 and the results are reported as mean value ± standard deviation.

RESULTS AND DISCUSSION

The electrodes were maintained manually on the sample surface to make the best contact. To verify the effect of the electrodes pressure three tests were performed: *(i)* contact with sample without pressure (test 1); *(ii)* mean pressure without significant deformation of the sample (test 2); *(iii)* pressure with visible deformation of the sample (test 3). In each case the coefficient of variance (CV) was applied as an index to demonstrate the steadiness of the model and the testing conditions. The low CV means the steady system. Table 1 shows the results of the three pressure tests performed on the longitudinal and transversal distribution of the fibers.

Table 1

Coefficient of variance (CV) values for three pressure tests performed on the longitudinal and transversal distribution of the fibers

Frequency [Hz]	Coefficient of variance (CV)	
	longitudinal	transversal
20	3.59	2.09
50	5.22	1.64
100	5.78	1.08
200	6.39	0.98
500	5.89	1.06
1000	4.63	0.76
2000	3.71	0.57
5000	1.60	1.02

As can be observed from the table, there is no significant dependence of the measured values on the pressure applied on the electrodes. Also, a smaller variation is observed for transversally measured samples. This is due to lower deformations explained by the lower elasticity of the muscle fiber in cross-section.

ELECTRICAL ADMITTANCE RECORDINGS

The following figures show the admittance (Fig. 4, Fig. 5) and phase angle (Fig. 6, Fig. 7) measured both transversally and longitudinally on samples. We were chosen to represent only data corresponding to representative changes occurred in the evolution of parameters (day 1, day 9 and day 15).

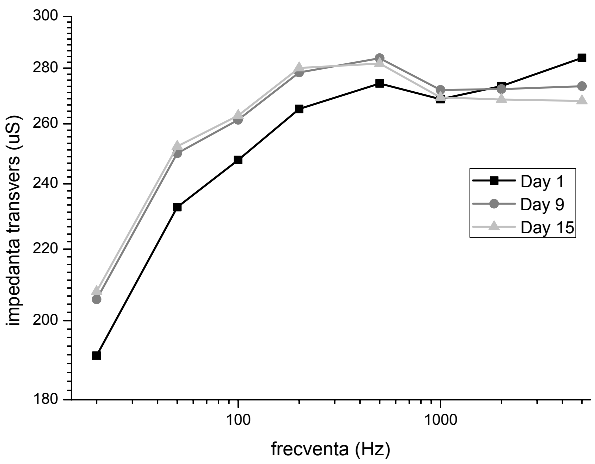

Figure 4. Admittance evolution (transverse section).

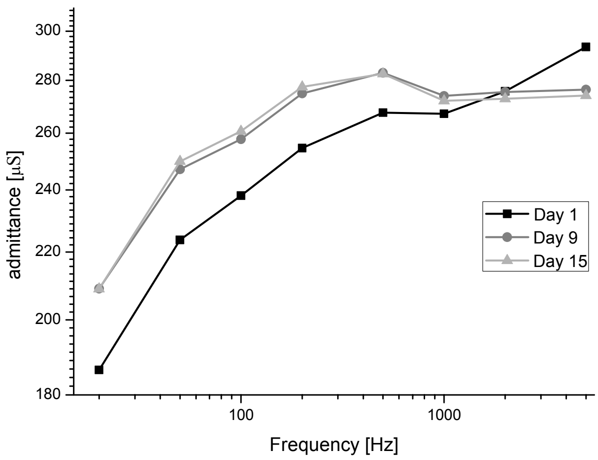

Figure 5. Admittance evolution (longitudinal section).

Significant admittance and phase angle variations occur around 6 to 8 days of storage. This time interval corresponds to initial signs of degradation (odor development) and to microbiological parameter changes.

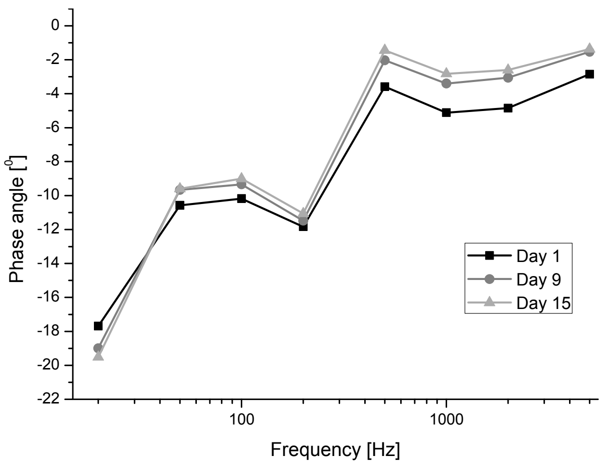

Figure 6. Phase angle (transverse section).

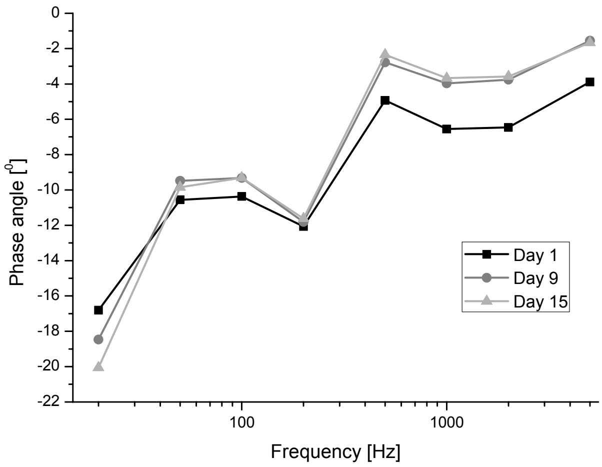

Figure 7. Phase angle (longitudinal section).

MEAT DIELECTRIC PROPERTIES RECORDINGS

In order to analyze intrinsic electrical properties of meat we computed conductivity and relative permittivity corresponding to electrical equivalent model of meat samples.

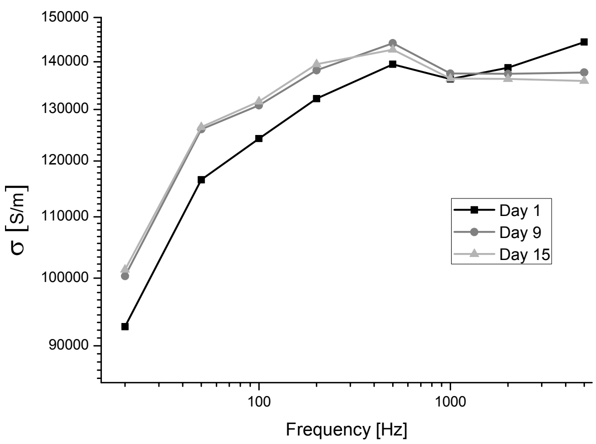

Figure 8. Conductivity evolution (transverse section).

The following figures show the conductivity (Fig. 8, Fig. 9) and relative permittivity (Fig. 10, Fig. 11) measured both transversally and longitudinally on samples. We represented data corresponding to days 1, 9 and 15 (same as in admittance and phase angle case).

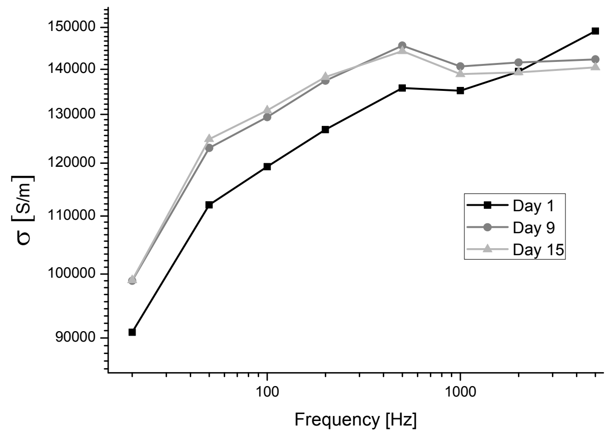

Figure 9. Conductivity evolution (longitudinal section).

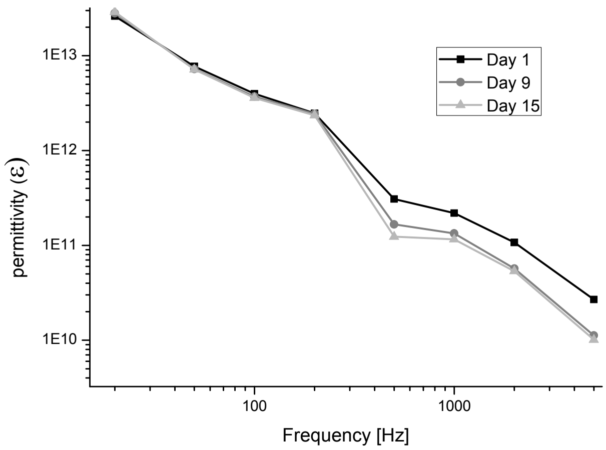

Figure 10. Permittivity evolution (transverse section).

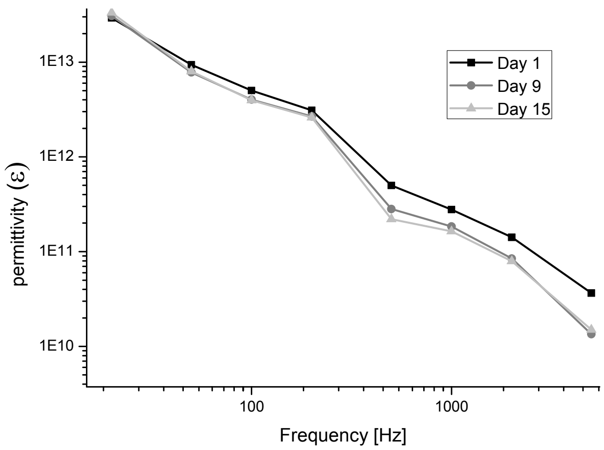

Figure 11. Permittivity evolution (longitudinal section).

Conductivity and permittivity results present same behavior over time as admittance.

CONCLUSIONS

The aim of the work presented here was to assess meat ageing states by measurement of electrical properties using a low cost device.

The studies showed that the values of electrical and dielectric parameters are linked to meat fiber strength. Biological tissues, especially muscle, are anisotropic, which leads to the need to perform both longitudinal and transverse measurements. Significant degradation of the meat proven by odor development and color changes is also visible by variations of the electrical parameters after 6–8 days.

DECLARATION OF INTERESTS

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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