ELECTRICAL PROPERTIES OF MEAT

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Abstract: The aim of current study is to determine and evaluate the impedance properties of meat depending on varying frequencies, freezing the samples and orientation of electrodes relative to myofibers. Slices of pork chop and chicken breast were used as experimental samples. Measurements were performed in frequency range 20 Hz ÷ 1 MHz.

Keywords: impedance, pork, chicken

1. INTRODUCTION

The electrical properties of biological tissues have been of interest for over a century for many reasons [1, 2]. They determine the pathways of current flow through the body and, thus, are very important in the analysis of a wide range of biomedical applications such as functional electrical stimulation and the diagnosis and treatment of various physiological conditions with weak electric currents, radio-frequency hyperthermia, electrocardiography, and others [2]. Knowledge of these electrical properties can lead to understanding of underlying biological processes. Indeed, biological impedance studies have long been important in electrophysiology and biophysics.

Today, bioimpedance measurements provide an important method for the noninvasive investigation of tissue structure and properties or for monitoring physiological changes (i.e. ‘‘static’’ or ‘‘dynamic’’ human organism properties) [3].

A microscopic description of impedance is complicated due to the variety of cell shapes and their distribution inside the tissue, as well as different properties of the extracellular media. Therefore, a macroscopic approach is more often used to characterize field distribution in biological systems. Moreover, even on a macroscopic level, the electrical properties are complicated. They can depend on the orientation of tissue relative to the applied field (directional anisotropy), the frequency of the applied field (the tissue is neither a perfect dielectric nor a perfect conductor) [1].

2. BIOLOGICAL MATERIALS IN ELECTRIC FIELD

Electrical properties of any material, including biological tissues, can be broadly separated into two categories: conducting and insulating. In a conductor, the electric charges move freely in response to application of electric field, whereas in an insulator (dielectric), the charges are fixed and not free to move. When considering electrical properties, we deal with some basic magnitudes. Electrical conductivity is the ability of a substance to conduct electric current. Resistivity is the inverse of conductivity and is linked with impedance. Electrical impedance is the combined opposition to the flow of current offered by the resistive, capacitive, and inductive components. Electrical resistivity of a material is defined as the resistance to the current passing across a 1-cm cube of material [4].

If a conductor is placed in an electric field, charges will move within the conductor until the interior field is zero. In the case of an insulator, no free charges exist, so the migration of charge does not occur. In polar materials, however, the positive and negative charge centers in the molecules do not coincide. An electric dipole moment, p, is said to exist. An applied field, E_0, tends to orient the dipoles and produces a field inside the dielectric, E_P, which opposes the applied field. This process is called polarization.

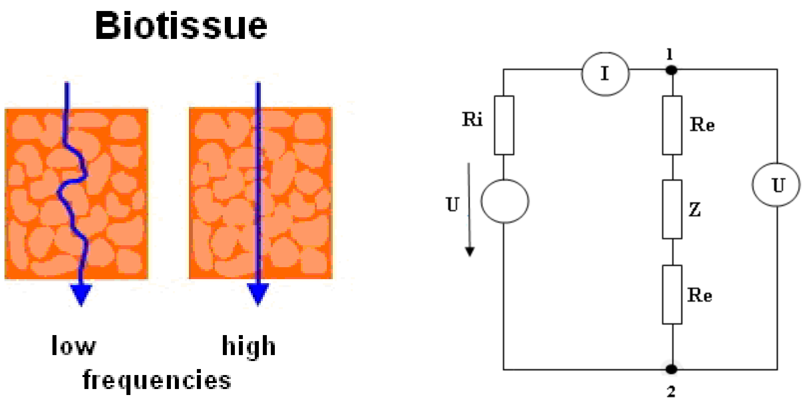
Most materials contain a combination of orientable dipoles and relatively free charges so that the electric field is reduced in any material relative to its free-space value. The net field inside the material, E, is then

$$E = E_0 - E_P. \qquad (1)$$

The net field is lowered by a significant amount relative to the applied field if the material is an insulator and is essentially zero for a good conductor. This reduction is characterized by a factor ε_r, which is called the relative permittivity or dielectric constant, according to

$$E = \frac{E_0}{\varepsilon_r}. \qquad (2)$$

In practice, most materials, including biological tissues, have some characteristics of both insulators and conductors because they contain dipoles as well as charges that can move in a restricted manner. For materials that are heterogeneous in structure, charges may become trapped at interfaces. As positive and negative ions move in opposite directions under the applied field, internal charge separations can then result within the material, producing an effective internal polarization that acts like a very large dipole (Fig. 1a).



a) **b)**

Figure 1: a) Current flow in biotissue for low and high frequencies;
b) Electric model of biotissue.

A simple model for a real material, such as tissue, would be a parallel combination of the capacitor and conductor (Fig. 1b). At low frequencies the material will behave like a conductor, but capacitive effects will become more important at higher frequencies. For most materials, however, these material properties are not constant, but vary with the frequency of the applied signal. At low frequencies, it is relatively easy for the dipoles to orient in response to the change in the applied field, whereas the charge carriers travel larger distance over which a greater opportunity exists for trapping at a defect or interface. The permittivity is relatively high and the conductivity is relatively low. As the frequency increases, the dipoles are less able to follow the changes in the applied field, and the corresponding polarization disappears. In contrast, the charge carriers sample shorter distances during each half-cycle and are less likely to be trapped. As frequency increases, the permittivity decreases and, because trapping becomes less important, the conductivity increases.

Some biological materials, such as bone and skeletal muscle, are distinctly anisotropic. Therefore, when referring to published conductivity and permittivity values, we need to check the orientation of the electrodes relative to the major axis of the tissue (e.g., longitudinal, transversal, or a combination of both). For example, muscles are composed of fibers that are very large individual cells and are aligned in the direction of muscle contraction. Electrical conduction along the length of the fiber is thus significantly easier than conduction between the fibers in the extracellular matrix because the extracellular matrix is less conductive than the cell. Therefore, muscle tissue manifests typical anisotropic electric properties. The longitudinal conductivity is significantly higher than the transverse conductivity [2].

3. THE DESCRIPTION OF METHOD AND RESULTS

The objective of this work was to investigate the impedance changes during successive degradation of meat. The slices of pork chop and chicken breast were used as samples. Measurement could be generally provided by two- and/or four electrode method. Here two-electrode setup has been used to generate the current *I* in the circuit and to measure voltage *V* between electrodes (Fig. 2). The current passing through sample and the output root mean square (RMS) voltage across meat samples were measured with a impedance analyzer (HP 4284A). Electrodes were prepared from stainless steel needles (diameter of 0,5 mm). The distance between electrodes as well as a depth of their incision was controlled.

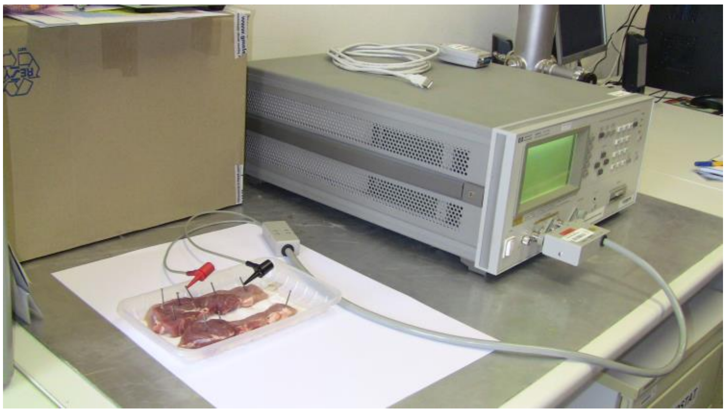


Figure 2: Two-electrode measurement setup.

3.1. IMPEDANCE MEASUREMENT OF PORK

Fresh slice of pork chop was investigated. Measurements were performed at room temperature four times (curves Z1 – Z4) during 3 days. Figure 3 presents the impedance of pork with increasing frequency. It is obvious from the graph that sharp fall of impedance takes place in the range of first 500 Hz, then it changes only slightly.

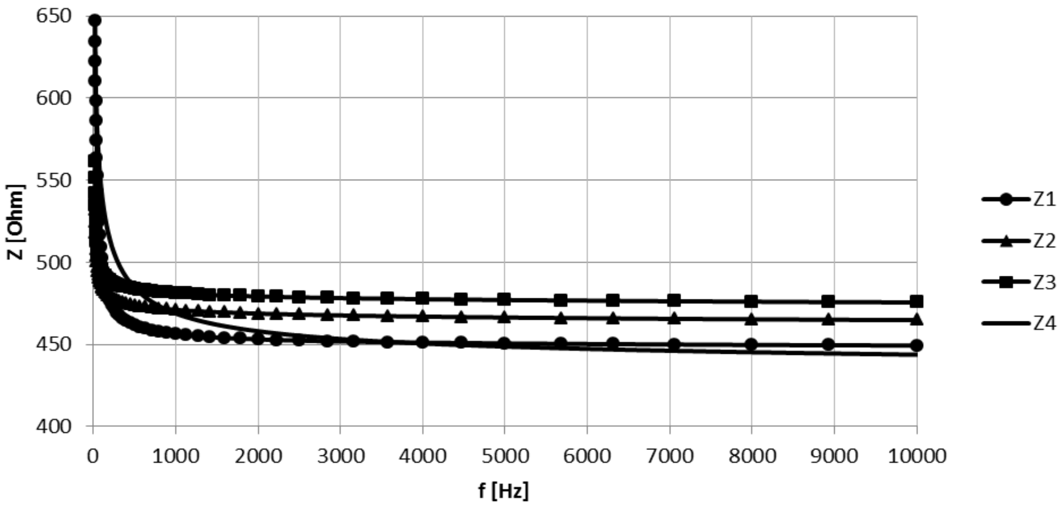


Figure 3: Impedance of pork chop sample.

3.2. THE INFLUENCE OF CUT DIRECTION

This experiment was carried out with chicken breast meat. Chicken is electrically anisotropic, which means that its electrical properties should change depending on the direction of the electrical field in the sample. The first slice of chicken was cut along the fiber direction, the second – across it. It means that in the first case the electrodes were oriented across fibers (Z across), in the second – along them (Z along). Measurements were performed several times, figure 4 represents the results for sample after the fourth day of this experiment.

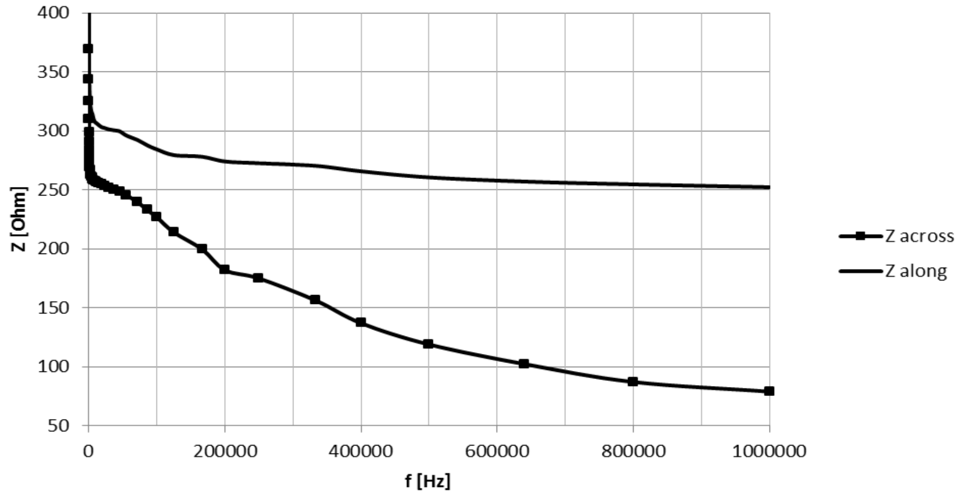


Figure 4: Impedance of chicken depending on the cut direction.

It is obvious that for the case when electrodes were oriented across fibers, impedance was higher. The results indicated that the impedance across myofibers in chicken was, on the average, about 60 % higher than along myofibers.

3.3. THE INFLUENCE OF FREEZING

The chicken samples were stored in a freezer at temperature t_1 = -18°C for night. Frozen chicken samples were allowed to defrost during two hours in the refrigerator set at t_2 = 4°C. The first measurement was performed with frozen chicken, the second – with defrosted meat at the room temperature, figure 5 shows the impedance values for this experiment.

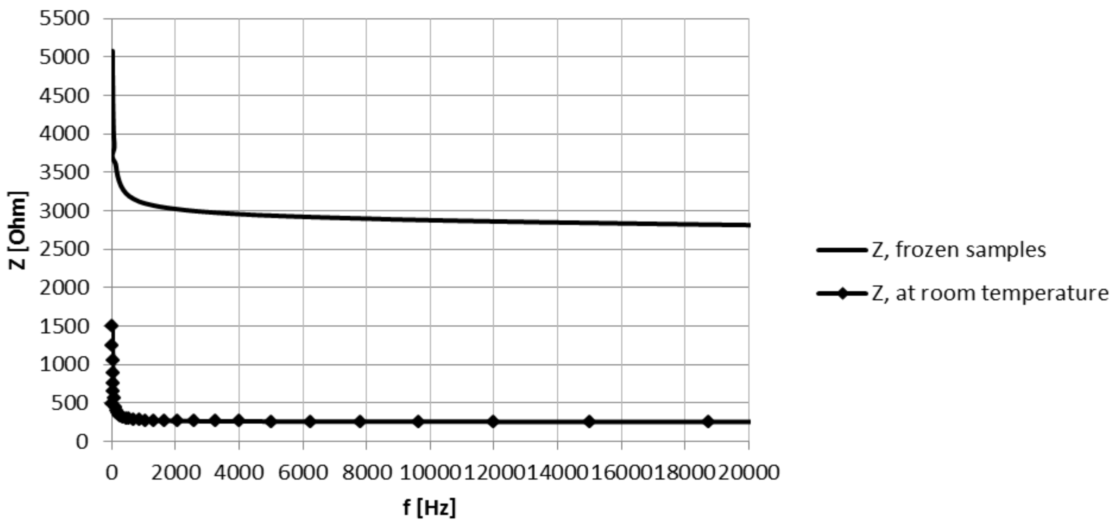


Figure 5: Impedance of chicken breast meat.

There are significant differences between these two curves. It could be caused by ice crystals formed in samples, the degree of thawing, possible membrane injuries during freezing phase.

4. CONCLUSION

In this work electrical properties of pork chop and chicken breast samples were investigated. It turned out that at low frequencies a sharp drop of impedance appears, at higher frequencies it changes slightly. This effect is connected with the ability of dipoles to orient in response to electrical field changing.

Impedance depends on the direction of cut as well. The case with electrodes oriented across myofibers gives us much higher values.

And finally, the influence of sample freezing was also considered. Impedance of frozen chicken was much higher, that can be explained by presence of ice crystals and injuries of cell membranes.

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REFERENCES

[1] Barbosa-Cánovas, G.V., Juliano, P., Peleg, M.: Engineering properties of foods, 2006, s. 32. In: http://www.eolss.net/ebooks/Sample%20Chapters/C10/E5-10-01.pdf

[2] Miklavič, D., Pavšelj, N., Hart, F. X.: Electric properties of tissues. Wiley Encyclopedia of Biomedical Engineering, 2006, s. 12. ISBN: 978-0-471-74036-0

[3] Damez, J.L., Clerjon, S., Abouelkaram, S., Lepetit, J.: Dielectric behavior of beef meat in the 1–1500kHz range: Simulation with the Fricke/Cole–Cole model, Meat Science, vol. 77, issue 4, 2007, p. 512-519

[4] Mahapatra, A. K., Jones, B. L., Nguyen, C. N., Kannan, G.: Experimental Determination of the Electrical Resistivity of Beef. In: American Society of Agricultural and Biological Engineers Annual International Meeting, 2007