Determination of salt content in various depth of pork chop by electrical impedance spectroscopy

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Abstract. The salt concentration was determined inside of pork chop both by electrical impedance spectroscopy and by a conventional chemical method (according to Mohr). The pork chop in various depths (4 mm, 10 mm, 20 mm and 25 mm) was punctured with two stainless steel electrodes. The length of electrodes was 60 mm, and they were insulated along the length except 1 cm section on the end, so the measurement of impedance was realized in various depths. The magnitude and phase angle of impedance were measured with a HP 4284A and a HP 4285A LCR meters from 30 Hz up to 1 MHz and from 75 kHz up to 30 MHz frequency range, respectively at 1 V voltage. The distance between the electrodes was 1 cm. The impedance magnitude decreased as the salt concentration increased. The magnitude of open-short corrected impedance values at various frequencies (10 kHz, 100 kHz, 125 kHz, 1.1 MHz and 8 MHz) showed a good correlation with salt content determined by chemical procedure. The electrical impedance spectroscopy seems a prospective method for determination the salt concentration inside of meat in various depths during the curing procedure.

1. Introduction
Salting has mostly been used for meat preservation due to the achieved reduction in water activity and microbial growth effect inside meat products. Nowadays the healthy lifestyle and the healthy eating demand to minimize the salt intake. Therefore the salt concentration should be enough high (4.5-8 %) to avoid the microbial growth and should be enough low (not higher than 5-7 %) to provide the healthy eating

In practice the conventional curing processes of pork meat are realized by experience, the salt concentration inside of meat piece is measured usually only at the end of curing and only with destructive chemical methods. There is great importance to find a quick, non-destructive and low cost method for measurement of salt concentration inside of pork meat during various curing processes.

The electrical impedance of biological – both plant, and animal – tissue gives a characteristic spectrum in frequency range from 10 Hz up to 100 MHz \cite{1}. The quality of meat during post-mortem ageing can be characterized by various impedance parameters \cite{2}. Some parameters can give information about the quality of meat \cite{2,3,4} and the integrity of cell membranes \cite{2,4}, other parameters can be used for predicting the sodium chloride content inside meat piece \cite{5,6}.
In this work the impedance spectrum of pork chop was determined daily over four days curing process. The spectra in four different depths were measured with a home made electrode. The salt content of the different part of pork chop was determined with a conventional chemical procedure. A mathematical relationship between salinity and impedance magnitude was found.

2. Materials and Methods
A pork chop (24 hours after rigor mortis, pH24=5.8) was purchased on the local market. Four, each 9 cm length piece were cut from the chop transversally to the fibre direction and these pieces were put into sodium chloride solution of 16 %. Daily over the four days period a piece was taken out from curing solution and the impedance spectrum in four various depths – 4, 10, 20 and 25 mm - was measured in three various side of piece – on the two sides and on the top covered a thin fat layer perpendicular to the fibre. The diffusion coefficient of sodium chloride in meat is 2.5*10^{-10} m^2/s [7].

After impedance measurement the chop was sliced and the salt content on each side and in each depth of measurement was determined with a conventional chemical method according Mohr [7].

Two precision LCR meters – Hewlet-Packard 4824A and 4825A, were used for determination of impedance spectra in frequency range from 20 Hz up to 1 MHz, and from 75 kHz up to 30 MHz frequency range, respectively. The measured spectra were open-short corrected in order to eliminate the stray capacitance and inductance above 100 kHz. The level of measuring voltage was 1 volt. The length of electrodes was 60 mm, and they were insulated along the length except 1 cm section on the end, so the measurement of impedance was realized in various depths. The distance between the two electrodes was 1 cm, the electrical field strength is 10^2 V/m which is enough low not to cause physiological changes in membrane.

3. Results and Discussion
At the beginning of the experiment, on the 0th day (not shown) the impedance magnitude on each place and in each depth was relative high – about 100 ohm – at frequencies higher than 10 kHz. Over time of curing process the magnitude of impedance gradually decreased at frequencies higher 10 kHz, at first in the least depth, then in other depths (figure 1a). In lower frequency range (below 1 kHz) the high impedance magnitude is caused probably by electrode polarization [1]. The phase angle of the impedance in the function of frequencies also showed a gradually shift (figure 1b) during curing process, as the salt content increased inside the pork chop piece.

In the cured meat the salt concentration varied from 3 up to 9 m/m % (g NaCl/ 100g cured meat). The salt content increased inside of pork chop during the curing process (figure 2a). The salt concentration in 4 mm depth practically reached the saturation value during the first day. In other depths the salt content gradually increased during the curing process. Concentration data on figure 2a are the average of concentrations obtained from the both sides of pork chop. The salt concentrations determined from the upper part of meat piece (not shown) had lower values, because the thin fat layer slowed the salt diffusion. The change of salt content in various depths at various times can be described with diffusion of salt molecules.

The impedance magnitude in frequency range from 10 kHz up to 30 MHz can be used for characterization of salt content inside of meat (figure 1a). The change of impedance magnitude in the function of curing time and depth was determined at frequencies of 10 kHz, 100 kHz, 125 kHz, 1.1 MHz and 8 MHz. The functions were similar to each other. Typically the impedance magnitude decreased as the salt content increased (figure 2b) according to other experiments [5,6].
Figure 1. The impedance magnitude (a) and phase angle (b) as the function of frequency in a pork chop piece on the third day of curing process. The meat was punctured with electrodes on the side perpendicular to the fibres and the depth of measurement place was varied from 4 mm to 25 mm.

Figure 2. The salt concentration (a) and impedance magnitude (b) at 1.1 MHz frequency at various depths in pork chop side perpendicular to the fibres and at various time of curing process.

The change of impedance magnitude at 1.1 MHz in the function of depth was different for different days of measurement (figure 2b). In depth 4 mm – very near to the surface – the impedance magnitude decreased during the first two days of curing process to a value, which remained constant during the whole experiment. In other depths (10 mm, 20 mm and 25 mm) the decrease of impedance magnitude could be observed in all days of curing process.
In the impedance magnitude decrease the higher rate at lower salt concentration (2-4 m/m %) and the lower rate at higher salt concentration (5-9 m/m %) [8] can be explained by hydration of proteins at lower salt concentration and by shrinkage of membranes at higher salt concentrations [7]. The various diffusion processes make difficult the fit of a general diffusion model to change of salt concentration. So an exponential connection between the impedance magnitude, $Z$, and the salt concentration, $c$, (figure 3) independently from the place of impedance measurement was found:

$$Z = 440\Omega + c^{2.5/m*m} + 5\Omega$$

In the future this mathematical relationship can be the basis of a quick and non-destructive quality tester of meat during the curing processes.

4. Conclusion

The magnitude of electrical impedance at 1.1 MHz frequency inside pork meat depends on the salt content. On the basis of this observation a quick, non-destructive impedance meter can be constructed for detection the salt content inside of meat during a curing process.

References

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