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Quality Assessment of Chicken Meat by Analysis-Of-Variance Method.

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ABSTRACT

Assessment of chicken meat and liver freshness has been carried out based on obtained variance curves of electrical resistance, capacitance and impedance of the pectoral and leg muscles as well as liver of broiler chickens within the AC frequency range of 0.1-1000 kHz. The polarization indices of chicken's tissues were determined at different storage conditions. The electrical parameters were obtained by means of LCR meter E7-20 using steel needle electrodes. It was revealed that the storage of muscle tissues at 4^{0}C for 7 days led to a significant increase in the steepness of the resistance variance curves. The increase in the steepness for liver was observed on the first day, while decreasing over subsequent days. Polarization indices were changed accordingly. Storage of carcasses for 7 days led to an increase of the measured parameter from 4.1 to 12.7 for thigh, and from 5.0 to 15.3 - for pectoral muscle. Noted parameter for the liver increased from 5.5 to 6.4 during the first 24 hours and then decreased to 4.8 during the subsequent 7 days. Straight-through freezing process of liver led to reduction of the parameter from 5.2 to 1.1. The obtained data allow concluding that the employed method can be used successfully for rapid assessment of chicken meat quality.
Keywords: meat freshness, quality indicators, rapid assessment of meat quality, biological membranes, electrical conductivity of animal tissues.

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INTRODUCTION

Poultry breeding is a sector that is dynamically developing in Russia. Thus, in 1999, the leadership in the meat market was taken by beef production, which amounted to 29.2%, while poultry meat production volume was 22.0%, and pork production - 19.7%. In 2010 the proportion of poultry meat in total meat production has increased to 33.7%, and as of 2012 reached 42% [Bobyleva, G. A., 2013]. According to the branch program "Development of poultry farming in Russian Federation for 2013-2015", the poultry meat production volume by 2020 should be increased to 4.5 million tons.

In this regard, preserving the quality of manufactured products, and primarily its freshness, becomes an urgent issue. The final quality of the product is affected by the temperature of storage, handling, and gutting. For poultry this is an urgent problem. Retail network receives poultry carcasses and by-products in chilled and frozen condition. A consumer makes own choice according to his preferences. Consumer market research shows that most customers prefer frozen meat, whereas the choice in favor of chilled meat is made only in the case when consumers are interested to spend minimum time on cooking.

However, the palatability traits and nutritional value of chilled meat is much higher than that of frozen meat. The point is that meat is characterized by "maturity", which is attained after the slaughter of the animal and poultry. The stiffness of the muscles changes within 2-3 hours after slaughter, increasing by about a quarter due to the carcass setting. When purchasing a chicken breast, frozen in this condition, we get quite rough and hard meat, which is significantly less absorbed by our organism.

The meat becomes fully matured, tender and juicy in 10 days after slaughter only if stored at 0^0C. This condition is sufficient for a gradual softening of the muscle tissue. Such chilled meat is supplied in bulk in various retail outlets and restaurants, where receives the highest rating of testers, who highly appreciate its tenderness and taste. Therefore, in the near future chilled poultry meat will be more in demand by consumers. This circumstance necessitates the need to develop approaches for assessing the quality of poultry meat during storage. One of such approaches is the use of biophysical methods [Nelson S. O., 2008].

Biological tissues are heterogeneous media consisting of the cells and intercellular space filled with electrolyte (electrical conductor). Their peculiarity consists in the presence of electrical insulators, which in animal products are the membranes, bones, tendons, etc. Therefore, these heterogenic structures are capable of electric polarization. The cause of such polarization is the spatial separation under the action of the electrical potential energy that accumulates at the membranes, as well as rotation of the large dipoles (macromolecules dissolved in the cytoplasm and interstitial fluid) in electric field. These phenomena determine the capacitive properties of biological tissues – they behave like a capacitor. Therefore, the electrical resistance of living tissues is formed from the ohmic (active) and capacitive (reactive) resistances and is called complex resistance or impedance [Magda E. A., Plutakhin G. A., 2009; Tarusov B. N., 1938; S. Trabelsi, 2015].

The parameters of technical resistors and capacitors – electrical resistance and capacitance – do not dependent on the frequency of applied alternating electric voltage. In biological tissues both parameters are reduced with the increase in frequency. Noted dependencies of the resistance and capacitance on the frequency are called variance. Considering active and reactive resistances, we are dealing with a variance of the impedance, which is especially pronounced at low (10-1000 Hz) and high (25 MHz to 9 GHz) frequencies [Golev I. M., Korotkov L. N., 2013]. The main characteristic of the variance curves is their steepness, which is usually estimated by the polarization index (PI), which is the ratio between the resistance at a frequency of 10^4 Hz (R_4) and the resistance at a frequency of 10^6 Hz (R_6). The polarization index is successfully used to determine the viability of animals and plant tissues, as well as to assess the condition of biological tissue at transplantation [Plekhanov, S.E. et al., 2013; Bera, T.K., Nagaraju, J., 2011; Euring F. Et al., 2011].

In the course of poultry products manufacturing, food industry supplies the market with the products of deep raw meat processing - dressed chicken and semi-finished meat products. The latter include chicken leg quarters, chicken breast, liver, heart, and stomach. Pan-ready poultry carcasses and semi-finished products are sold frozen and chilled. After slaughter, the poultry's tissues undergo profound biochemical processes that change the qualitative indicators of the product. These changes are reflected in physical parameters, which can be easily measured. Changes in the muscle tissue during storage affect the meat quality. During storage of meat after slaughter it is subjected to autolysis or self-digestion, which is the destruction of a tissue cell through the chemical reactions under the action of its own enzymes. These reactions change the chemical composition of tissues that affects their physical characteristics. It was shown previously that during the storage of beef in vacuum packaging at 4°C over 50 days, the conductivity of meat was significantly decreased within the frequency range from 10 kHz to 1 MHz [Bera T. K., 2014]. Similarly, for example, the conductivity of goat meat depends on the slaughter technology. At proper slaughtering the meat resistance is lower than that obtained at technology violation due to high loss of circulating blood during the slaughter [Mohiri A. Et al., 2012].

Later another method of "impedance spectroscopy" was theoretically justified [Aleynikov A.F., et al. 2012; Shyam N. J. et al., 2011]. This method has several advantages in terms of evaluating the freshness of meat: it is simple, fast, efficient, reliable, practical and non-destructive.

The objective of the present work was to study the possibility of determining the quality of broiler chickens meat and liver when stored in the cold, as well as after freezing and thawing, employing tissue resistance measurement method within the frequency range 10^2-10^6 Hz.

MATERIALS AND METHODS

Three 42-day-old broiler chickens reared at the JSC "Poultry Breeding Plant "Russia" (Krasnodar Territory), were used in the research. Slaughter and evisceration was carried out at the Department of Biotechnology, Biochemistry and Biophysics of the Kuban State Agrarian University. Further research was conducted on chicken leg quarters, breasts and liver, which was divided into two equal parts. The electrodes injection sites on obtained semi-finished products were marked on the day of slaughter. The measurements of the required electric parameters of the pectoral and leg muscles as well as liver were carried out immediately after the slaughter. After that, the analyzed samples were packed in zip-locked polythene bags and placed in cooling chamber (+4^{0}C) or freezing chamber -20^{0}C) of the refrigerator. The storage time in the freezing chamber was two days. Defrost of semi-finished products was carried out in air at room temperature for 5 hours. After obtaining the electrical parameters of the samples, they were frozen repeatedly for 48 hours.

To determine the electrical parameters of muscles and liver (active resistance R, capacitance C, and impedance Z) we used LCR meter E7-20 with two steel electrodes 0.7 mm in diameter and 20 mm in length, which were injected in a sample flash. Measurements were performed every 24 hours for seven days. Each sample was subjected to three measurements at the marked locations. The obtained results were statistically processed by Microsoft Excel 2010.

Discrete frequencies selected for the research ranged from 0.1 to 1000 kHz. The values of discrete frequencies were selected based on convenience of switching on the LCR meter.

RESULTS AND DISCUSSION

Different electrode systems are usually used in the measurements of electrical parameters of biological objects. In present experiments, the four-electrode system was used for estimation of the impedance and the phase shift between current and voltage [T. K. Bera, J. Nagaraju, 2011]. We used steel needle electrodes that simplified the design and were convenient for mass measurements.

The electrical conductivity of biological tissues is a complex value, resulting from active (conductivity of electrolytes, composing their structure) and reactive (electric capacitance of lipid membranes) components. The membranes of native tissues are intact and have a high resistance and capacitance. When the tissue dies, the permeability of membranes for electrolytes increases, and they lose their dielectric properties that change their capacitive properties. The polarization index, introduced by Tarusov, depends on the type of tissue and its physiological condition and tends to unity at its destruction.

We have investigated the electrical parameters of two types of tissues – pectoral and leg muscles as well as liver of the same broiler chickens. A week-long duration in our experiments was chosen due to the fact that seven days after the slaughter the meat and liver, kept in the refrigerator, had signs of deterioration.

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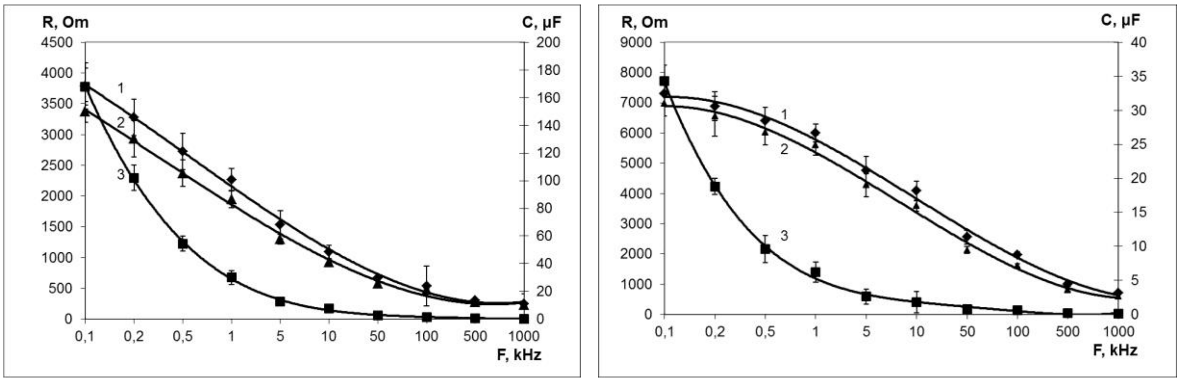
Figure 1 presents the variance curves of the resistance, electric capacitance and impedance of the pectoral muscle (A) and liver (B) of broiler chickens, obtained on the day of slaughter. Analyzing these curves, we can note the following. All curves behave similarly: with increasing frequency of electric current the values of all three measured parameters decrease monotonically. The resistance and impedance of the liver at a frequency of 0.1 kHz is twice higher than the similar values measured in muscles. On the contrary, at this frequency the capacitance of muscles is higher by almost five times. The shape of the impedance and resistance curves differ insignificantly that implies that the capacity reactance at all frequencies has small values. For thigh, the results were similar to those for pectoral muscles. Therefore, the article presents the only data on variance of the tissue resistance, which is a fairly comprehensive index used to calculate tissues polarization coefficients.



A B

Figure 1: Variance curves of resistance (1), impedance (2) and the capacitance (3) for pectoral muscle (A) and liver (B) of broiler chickens at a day of slaughter.

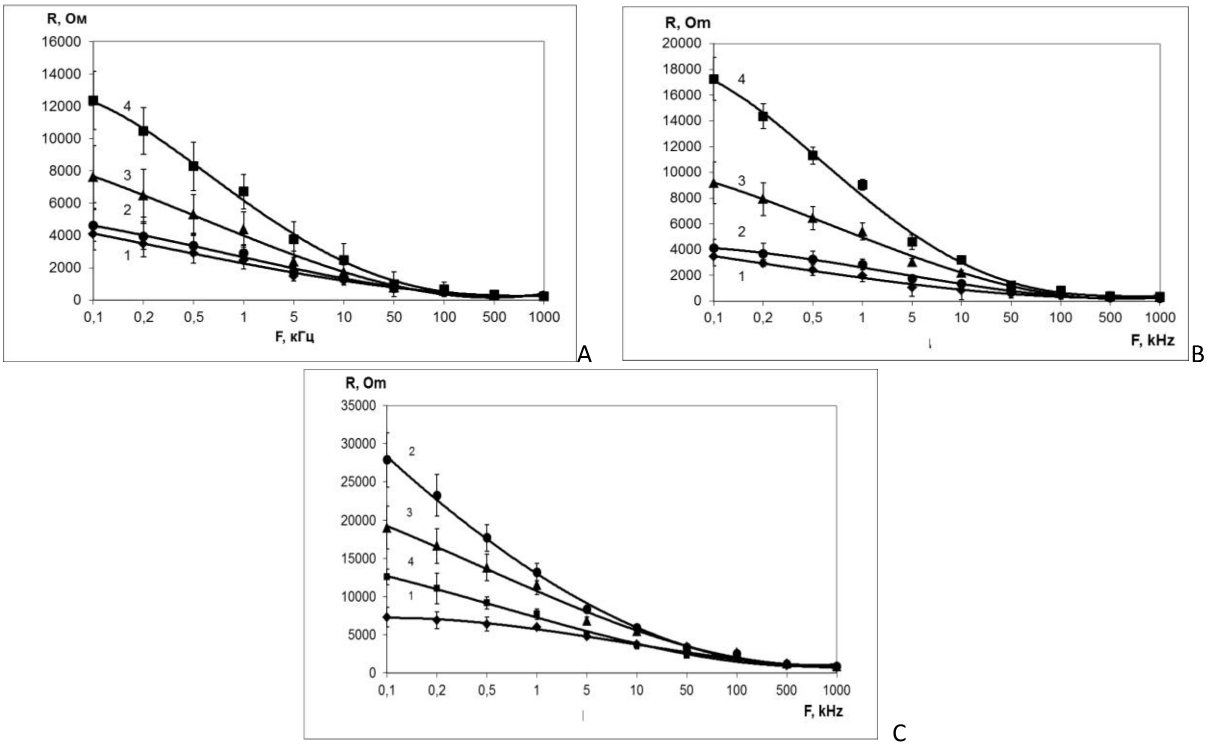


Figure 2: Resistance variance of the pectoral (A), leg (B) muscles and liver (C) of broiler chickens in weekly storage at +4^{0}C: 1 – the day of slaughter; 2 – 24 hours after slaughter; 3 – after 96 hours; and 4 – after 168 hours.

During storage in the cooling chamber, the meat was undergoing the phase of maturation, characterized by changing in its chemical composition, caused by the decay of muscle glycogen, the accumulation of lactic acid, etc. Characteristic indicator of meat rigidity is a lower water-holding capacity of muscle tissue. Apparently, these processes led to an increase in electrical resistance over the entire range of frequencies, which follows from Fig. 2. In order not to overload the figure, it presents just a part of the variance curves obtained on the day of slaughter, as well as after the first, fourth and seventh days of storage.

During the storage period, the resistance within the frequency range of 0.1-100 kHz monotonically increased. On the day of slaughter, the resistances of the leg and pectoral muscles were close to each other at a frequency of 0.1 kHz, equal to about 4 kOhm, slightly increasing through the day. On the fourth day the resistance of both muscles increased by factor of two. At the end of the storage period, for the pectoral muscle the resistance was about 12 kOhm, while for leg muscle – 17 kOhm. Thus, when storing, the impedance at low frequencies increases in proportion to the storage time over a period of seven days. Similar results were obtained by the authors with regard to the beef meat; at 50-day beef storage, the electrical conductivity (inverse of resistance) was reduced [Ghatass Z. F., 2008].

The nature of the variance curves for liver differs. The first day of storage resulted in the growth of the resistance at a frequency of 0.1 kHz from 7 to 27 kOhm, i.e. by almost 4 times. A further increase of storage period led to decrease in resistance. Differences in resistance variance curves behavior for muscles and liver, apparently, are related to the cellular structure of these tissues.

The second distinguishing feature was the difference in the change of the polarization indices of muscles and liver during the storage. As is obvious from Fig. 3, the polarization index of the liver after the first day increased from 5.5 to 6.4. After three days it started to decline and by the end of the experimental period was reduced to 4.8.

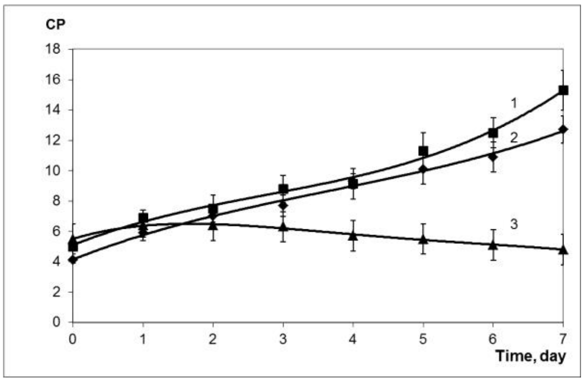


Figure 3: Dependence of the polarization indices of the pectoral muscle (1), leg muscle (2), and liver (3) of broiler chicken on the storage time at +4^{0}C.

During freezing of meat and meat products, a phase transition of water into ice takes place that results in the destruction of cell membranes. This leads to changes in the physical characteristics of the product and increase in the concentration of substances diluted in the liquid phase. Naturally, the freezing and subsequent thawing processes should be reflected in the electric properties of the tissues. This cycle was conducted twice. The resulting polarization indices are shown in Table 1.

Table 1. Dependence of the polarization indices of broiler chicken muscles and liver on the number of freezing–thawing cycles.

Number of cycles	Body part		Liver
	Thigh	Brest	
0	3.8±0.1	3.9±0,1	5.2±0.3
1	5.7±0.1	4.2±0.2	1.1±0.1
2	17.6±0.6	11.6±0.4	–

After the first freezing, the polarization indices of leg and pectoral muscles increased by 50 and 8%, respectively. Repeated freezing increased the indices by 4.5 and 3 times. Again, another behavior was observed in the liver: even after the first cycle the polarization index of liver was 1.1±0.1, indicating complete destruction of cellular structures. Similar results were obtained after warming up the liver at 90^{0}C for 15 min.

The obtained research results have shown that the variance curves of the resistance, capacitance and impedance in fresh muscles and liver of broiler chickens as well as those obtained after 7-day storage, are of similar nature: the measured parameters monotonically decrease within the frequency range 0.1-1000 kHz. The corresponding measurements in liver at 100 Hz gave the values, twice less than those obtained for muscles. This was apparently due to the differences in cellular structure of these tissues. Thus, the muscle cell contains large amounts of contractile structures – myofibrils, composed of proteins, myosin and actin. Water makes up about 75% of the muscles weight and by binding to the protein of myofibrils, increases the electrical resistance. During storage the amount of electrolytes in cytoplasm decreases; magnesium, potassium and calcium bind to proteins, thereby lowering the conductivity of the cytoplasm.

The polarization indices of the muscles and the liver, characterizing the steepness of variance curves, obtained immediately after the slaughter, differ slightly. During a 7-day storage, the steepness of the variance curves of the muscles increases, at that their polarization indices increase about twice by the seventh day that is consistent with the results obtained during storage of beef [Ghatass Z. F., 2008]. In liver, during the first day of storage, the resistance at a frequency of 0.1 kHz increases about five times, though decreases at subsequent storage in the cold. The polarization indices in this case slowly decrease after minor growth.

Freezing and thawing cycles of poultry meat and liver change cellular structure of the tissues due to the destruction of lipid membranes. This leads to a change in bio-physical quantities such as the electric resistance and capacitance that allows determining not only storage life for food, but also storage modes. Straight-through freezing process of the liver leads to the decrease of the polarization index almost to unity. The measurement of this parameter is performed in a shorter time than obtaining the variance curve.

CONCLUSION

The data provided in the present article allow concluding that the used analysis-of-variance method is quite prospective in terms of rapid quality assessment of chicken meat and by-products.

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