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Study of the Influence of the Electrohydraulic Effect on the Structure and Mechanical Properties of Muscular Tissue Using Atomic-Force Microscopy.

Andrey Ashotovich Nagdalian*, Natalya Pavlovna Oboturova, Roman Olegovich Budkevich, Magomed Aslanovich Selimov, and Egor Leonidovich Demchenkov.

North Caucasus Federal University, 355000, Russia, Stavropol, st.Pushkin 1.

ABSTRACT

In this paper, by the atomic force microscopy was study the structure, mechanical properties, the morphology and strength characteristics of raw meat, which was processed bypulsed discharge technology high-voltage energy. There were steadying characteristics of the relief, made the graphs of power curves and calculated the stiffness coefficient of area of surfaces, intact, the control and test samples of muscle tissue by the atomic force microscopy, after processing by the pulsed discharge technology. The research results have revealed a direct correlation intensity pulsed discharge technology on the structure and mechanical properties of the muscle fibers, the speed of their destructive changes and separation of fibers. Measuring the stiffness of the muscle fibers before and after the pulsed discharge technology treatment, are evidenced about decrease in rigid with an increase in the number of pulsed discharge technology, and on the general changes in the internal structure of the fibers.

Keywords: electro-hydraulic effect, the muscle fiber, the pulsed discharge technology, atomic-force microscopy.

***Corresponding author**

INTRODUCTION

One of the most effective ways to intensify the process of processing of meat raw materials and improve the quality of products can be pulsed energy effects, in particular pulsed discharge technology. These technologies are based on a pulsed discharge that occurs when you create a short circuit in an electromagnetic pulse. At the time of the breakdown of the electrode gap is formed discharge channel, where a ten-thousandths of a second are converted tens of kilojoules of electrical energy. The process of conversion of electrical energy into other forms has called electrohydraulic effect. Himself electrohydraulic effect is accompanied by a set of physico-chemical phenomena that can, in turn, provide useful work to improve the structural, mechanical and functional and technological characteristics of the meat, as well as contributing to the intensification of the process of salting [4,5,7].

The instantaneous attack of high energy on liquid system contributes to appearance of high and very high hydraulic pressure, which is able to exert a destructive mechanical effect, ie, the pulsed discharge treatment for meat in brine is potentially very highly effective way to intensify the production cycle of meat products [1,6].

Local destruction of muscle fibers and their components under intense swelling of the fibers in the environment of brine filled the interfiber space, resulting in the pulsed discharge treatment, can greatly affect the mechanical properties of the muscle tissue and its main components, as well as the impact on the change of surface topography muscle fibers. Histological studies conducted previously [6,7] confirmed that the pulsed discharge treatment of loosening of muscle tissue due to the rupture of fibers, filling micro cracks and increase interfiber spaces brine. Deformation properties of muscle tissue are largely dependent on the local mechanical properties of the muscle fibers. For instance, it is known that the thickness of fibers in the feedstock is proportional to their hardness, as the sarcolemma thicker fibers developed stronger and more durable. With an increase in fiber diameter to 10% the cutting resistance increases by 20-30% [10].

Currently, one of the most advanced methods for determining the local stiffness of biological objects is the atomic force microscope (AFM) [2,3,8]. AFM is one of the types of scanning probe microscopy. AFM allows obtaining information on both the relief and morphological characteristics of the surface of the object, and their local physical properties [9].

MATERIALSANDMETHODS

In the work used the meat is chilled beef from the silverside, the traditional course of autolysis (pH 5.6-6.2). Weight pieces were approximately 400 ± 50 grams. Processing of meat was carried out at the same level of stored energy - 5 kJ. Research objects placed in the brine (7% salt, 1.5% sugar, 0.0015% sodium nitrite) were exposed to 100, 200 and 300 pulses, which was a variable factor of the experiment, i.e. in the experiment it was supposed study of three prototypes. Control and test samples were kept in the brine of the same composition for 24 hours, also investigated and intact samples of meat, without any process of exposure.

To perform atomic-force microscopy of the samples of meat with a surgical scalpel and tweezers were allocated small bundles of fibers that are placed on a solid substrate - mica. Prepared samples were fixed on the substrate an aliquot of water as an adhesive agent.

Atomic force microscopy fibers were conducted by AFM Ntegra-Spectra / NT-MDT in tapping mode using a cantilever NSG01.

Stiffness coefficient muscle fibers and the elastic modulus of muscle fibers were determined using an atomic force microscope by take a reading the power curves using cantilever.

To study the mechanical properties of the muscle fibers, control and test samples from each piece stands out for 3 bundle of fiber. With the help of an optical system of prior search in each beam selects one fiber, on the surface which in the 18 points were measured the stiffness characteristics by the probe and construct a graph of force's curves.

During the processing of the force's curves and the calculations by the model Sneddon [2,9] were determined the stiffness and modulus of elasticity of the muscle fibers.

RESULTS AND DISCUSSION

In the presented images of the relief surface of the fibers and the roughness height on the central axis of the scanned range, the intact specimen (Fig. 1) was characterized by a relatively smooth surface of the fibers. Constructing a profile the height the intact sample, there is characterize the fraction of the fiber, the roughness which range within several tens of nanometers.

The study of samples control (Fig. 2) show the surface roughness of the fibers with a significant gradient which reaching about 200 nm. Test samples were characterized more unevenness of the surface, which is likely to be due to local irregularities in the structure of the fiber caused by the mass exchange processes between the feedstock and brine.

The results of the study the test sample which exposed by pulsed discharge(100 pulses) (Fig. 3) shows that the level of roughness as compared to the control sample has a more pronounced, which is confirmed by the graph a profile of sectional.The test samples processed pulsed discharge(200 and 300 pulses) (Fig. 4 and 5), are confirmed the trend of destructive changes in the structure of the fibers. The test sample (fig. 4) has a higher level of roughness and the heightened striation of sample in the figure 5 demonstrates the greatest degree loosening muscle tissue, probably this is due by the increase of fiber breakage and microcracks, which are establish during histological examination of samples.

The images obtained by atomic force microscopy, the test, control, and intact samples can be observed freely disposed fragment of particles, which are likely to represent the protein agglomerates "thrown out" on the surface as a result of the diffusion exchange between the brine and meat. With the purpose of systematizing the particles that were detecting by scans, were constructing the histograms, which reflect their average size and quantity (Fig. 6).

A histogram of characterizing the control sample (Fig. 6, A) indicates a sufficiently large size (compared to the size included in the agglomerate core proteins of muscle tissue) the particles from 1.5 to 3.5 microns located on the surface. The test №1 (Fig. 6, B) has the greatest number of particles of about 1.5 microns. The samples №2 and №3 has a more number of particles with a smaller average size. Most of the particles of sample №2 has size about 1 micron and the particles of sample №3 about 0.5 micron respectively.

The results of calculation of stiffness and modulus fibers of the samples are present in the table 1.

According to these data, the stiffness coefficient of the fibers muscle of the control sample were significantly lower than in the intact samples. Rather, the increase in stiffness of the fibers of meat, soaked in brine for 24 h., are due to dehydration, which most intensively flowing just the first day of salting. Dehydration muscle fibers during the salting was caused higher osmotic pressure of the brine compared to the osmotic pressure of the tissue fluid [10]. When aligning the osmotic pressure, the diffusion is increases of the brine into the muscle tissue.When the brine to process by pulsed discharge, it under the influence of hydrodynamic shock force, the brine penetrates into muscle tissue. Due to the partial destruction of the fibers, which are identify in histological sections of samples, the brine will penetrate into the fibers, it is their hydration and swelling, consequently, the change in mechanical properties. It is note that an increase in fiber diameter to 10%, is increase the resistance of cutting by 20-30%. When salting occurs bucking the trend - the increase in the diameter of the fibers due to swelling is reduces the strength characteristics. Thus, the stiffness the test samples were lower than the control by12,2-13,4% and by 10,9-12,1% than in intact. The sample with the lowest rigidity of the fibers has been treated 300 pulsed discharge. The value of elastic module is consistent with the values of the stiffness of the fibers, moreover, it is worth noting, that the most rigid sample is control sample.

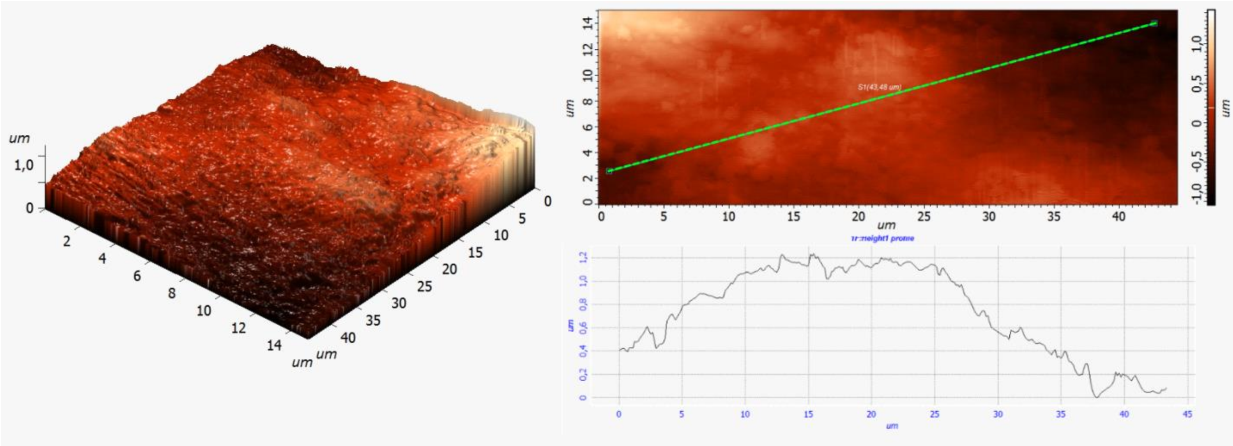

Figure 1: Atomic-force microscopy of intact specimen

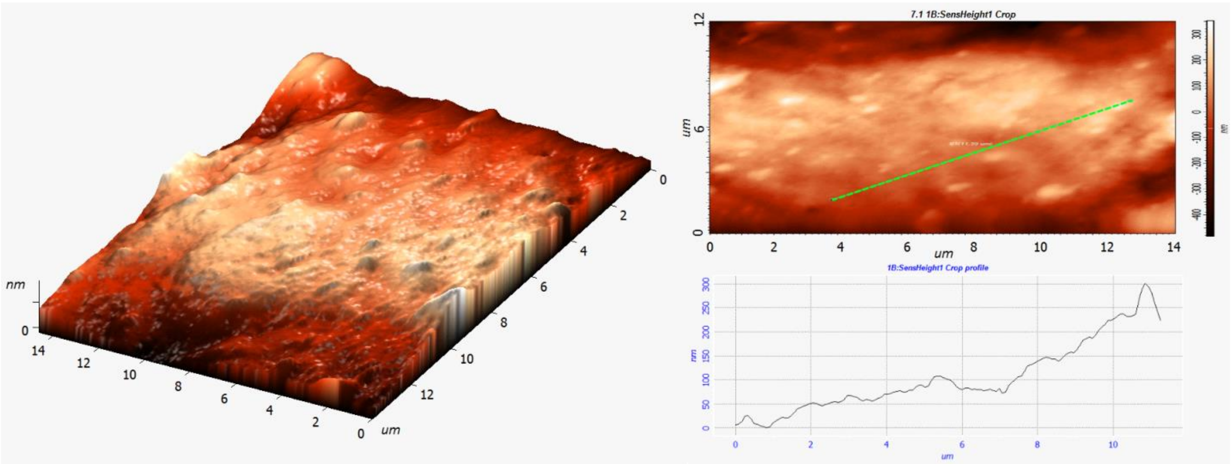

Figure 2: Atomic-force microscopy of the control sample

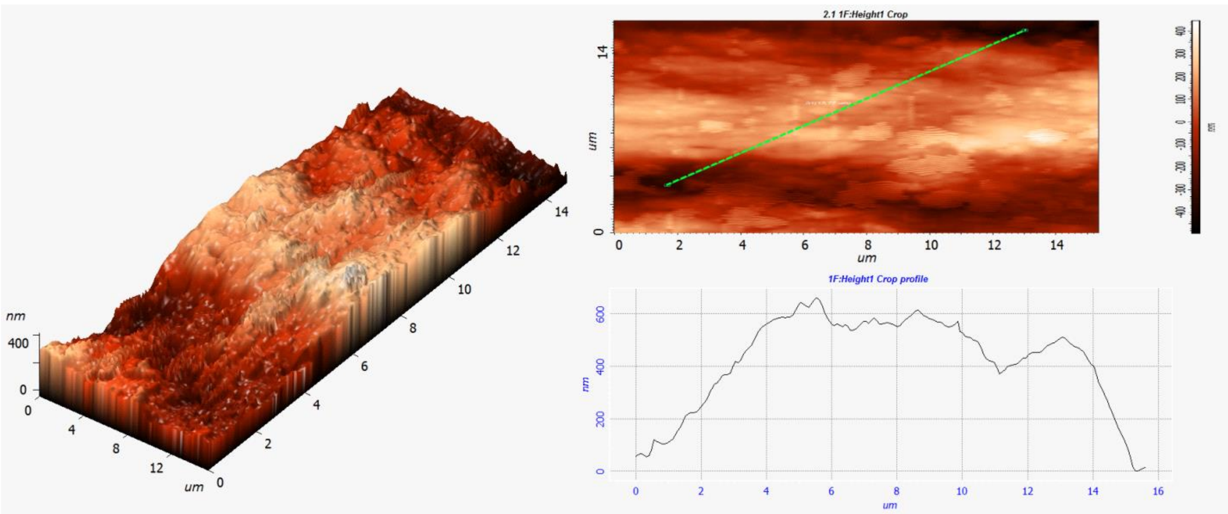

Figure 3: Atomic-force microscopy of the test sample (100 pulses)

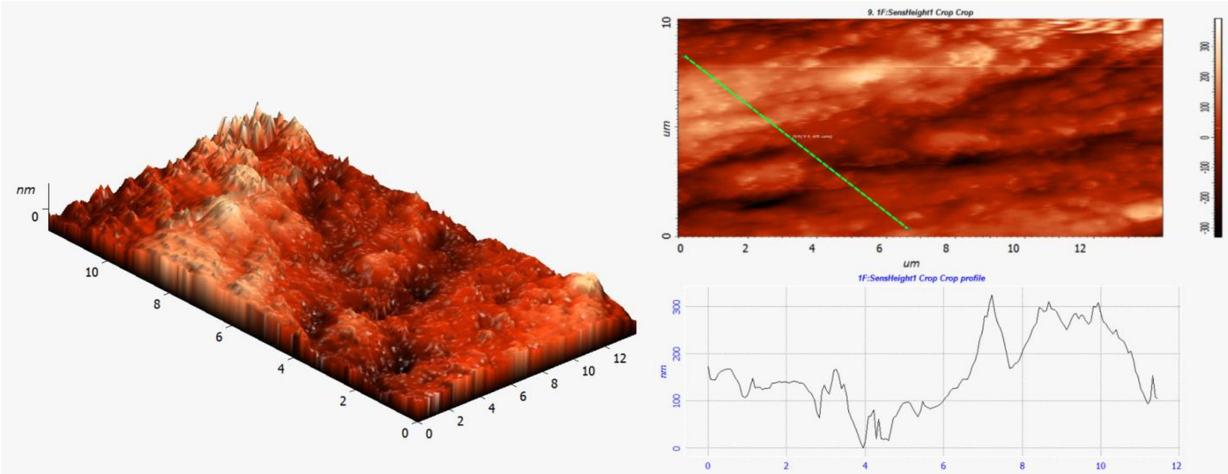

Figure 4: Atomic-force microscopy of the test sample (200 pulses)

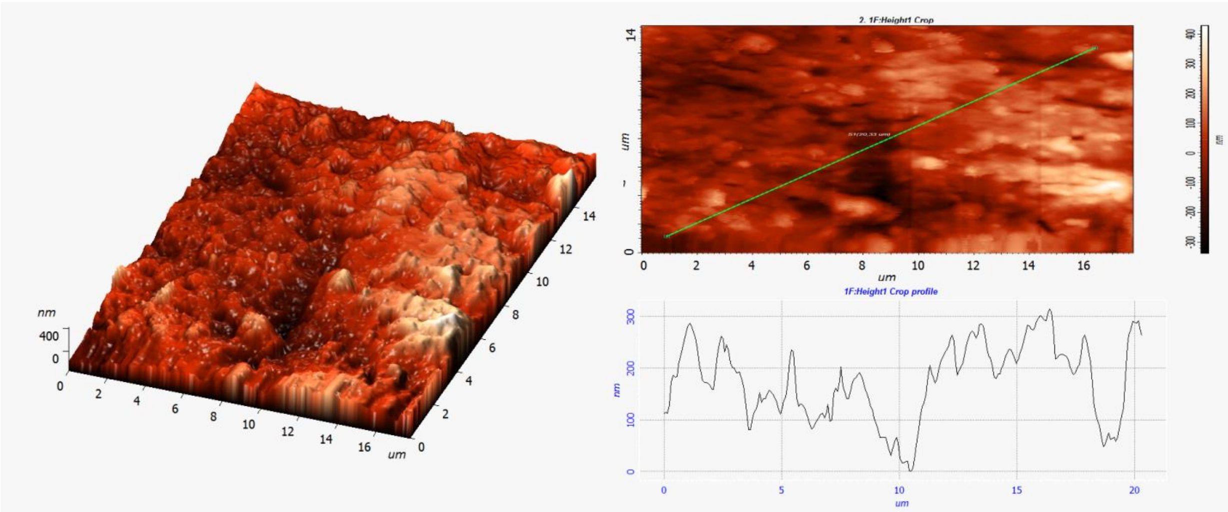

Figure 5: Atomic-force microscopy of the test sample (300 pulses)

Table 1: Results of calculation of stiffness and elastic module of fibers in the samples

Indicators	Intact sample	Control sample	Test sample		
			100 pulses	200 pulses	300 pulses
The stiffness of the fibers, pN / nm	10,5±0,3	11,7±0,4	9,6±0,3	9,4±0,2	8,7±0,4
Standard deviation	0,16	0,25	0,15	0,12	0,22
Young's modulus, kPa	52,4±1,4	68,7±2,2	43,8±1,3	41,6±1,7	33,5±2,1
Standard deviation	0,91	1,22	0,78	0,95	1,31

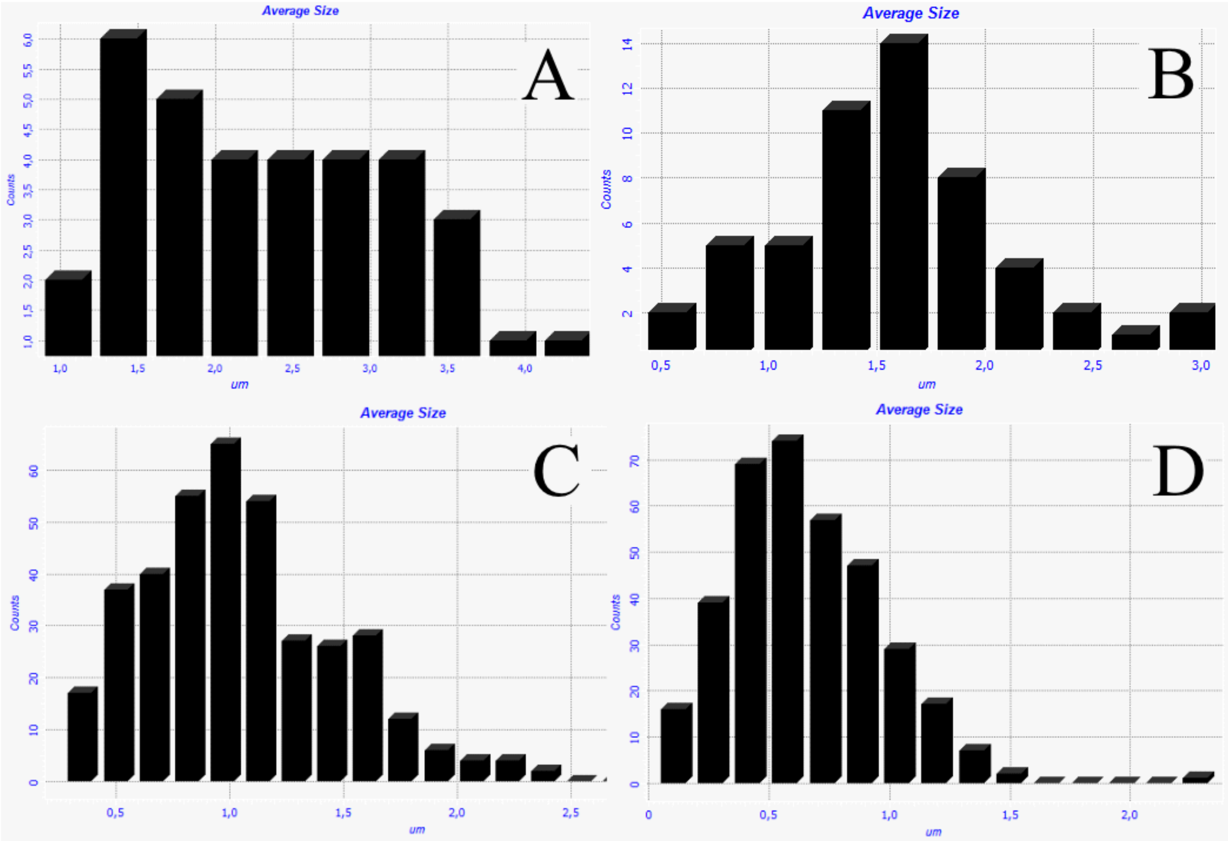

Figure 6: The histogram of particle size distribution: A) a control sample; B) The test sample №1 (100 pulses); C) prototype №2 (200 pulses); D) prototype №3 (300 pulses)

CONCLUSION

Thus, the probe microscopy fibers in the samples showed that the electrohydraulic effect occurring in brine by pulsed discharge technology influences the structure of muscle tissue, reducing their strength characteristics, which leads to a softening of the muscle tissue in general.

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