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THE INFLUENCE OF LOW-TEMPERATURE LONG-TIME PROCESSING ON STRUCTURAL, MECHANICAL AND ORGANOLEPTIC CHARACTERISTICS OF PORK PRODUCTS

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Abstract. A promising area for improving the technological process of meat product manufacturing is the use of moderate temperature treatment regimes to bring them to a state of culinary readiness. For the successful industrial implementation of low-temperature long-time processing, it is necessary to develop regimes based on the scientific justification of the temperature-duration ratio to achieve all the desired quality characteristics of the finished product. The article presents the results of experimental studies of the influence of temperature processing parameters of pork meat in the production of cooked and smoked-cooked pork balyk on the microstructure, structural, mechanical, organoleptic and technological properties of finished meat products. The results show that the use of low-temperature processing has a significant positive effect on product characteristics. In particular, the baliks prepared at low temperatures are characterised by mass losses: cooked 7,3%, smoked-cooked 15,7%, baliks made according to traditional methods have losses of 12,5% and 12,7% more. The experimental samples are characterised by lower shear stresses and higher plasticity values than the control samples, which indicates a more delicate consistency. The analysis of the microstructural study results showed that the control cooked samples have more compact and thinner muscle fibers, with microcracks and tears observed. The muscle fibers of the experimental products are more swollen and intact. The baliks produced using the developed thermal treatment regimes had better organoleptic indicators, taste, and sensory characteristics. The results suggest that low-temperature long-time processing is quite promising and has a positive impact on the characteristics of finished meat products. The implementation of the developed regimes in the meat industry will enable the production of whole-muscle meat products with high quality, compared to products made using traditional methods, as well as reduce production costs.

Keywords: thermal treatment, meat products, structural and mechanical properties, microstructure.

Introduction. Formulation of the problem

During the thermal processing of meat and poultry, a series of biochemical, physicochemical, and microbiological processes take place, ensuring product safety, culinary readiness, the formation of organoleptic properties, and in-creased stability during storage [1].

Changes in meat structure during cooking are caused by structural modifications induced by heat, combined with enzymatic protein breakdown. The effect of the time/temperature factor and the temperature at the product's core depends on the meat composition. Meat with a high connective tissue content becomes more tender when heated slow-ly compared to meat with low connective tissue content. Heating at a low temperature in an airy environment increases the tenderness of meat compared to medium and high temperatures. When selecting the optimum temperature, the part of the carcass and the type of meat used must be taken into account, as well as the cooking method. Different cooking methods, temperature regimes, and muscle types result in products of varying quality [2, 3].

As a result of moderate temperature processing, the bioavailability of meat increases, whereas high heating tem-peratures lead to reduced digestibility and absorption of meat proteins by the human body [4].

In recent years, ready-to-eat meals without intensive heat treatment have been gaining increasing popularity. As a result, the food industry could adapt the LT-LT (low temperature-long time) technique to meet this demand. In the LT-LT technology, products undergo minimal thermal processing, preserving their freshness, taste, texture, and even color while ensuring their microbiological safety [5].

Analysis of recent research and publications

Structural changes in meat during thermal processing result from complex physicochemical transformations that have been studied by many researchers [6-8].

As a result of thermal denaturation of proteins, structural changes occur in the meat, such as the breakdown of cell membranes, shrinkage of muscle fibers, aggregation and gel formation of myofibrillar and sarcoplasmic proteins, as well as shrinkage and dissolution of connective tissue [9].

As a result of the shrinkage or swelling of myofibrils, moisture is lost, which evaporates from the surface as exu-date during muscle contraction [7]. In the studies [10], it was shown that with an increase in temperature, the water con-tent in meat decreases, while the fat and protein content increases, indicating that the primary loss is water.

Thermal denaturation of collagen causes the breaking of bonds, leading to shrinkage as hydroxyl groups stabilize the collagen structure and water forms hydrogen bonds between the hydroxyl groups and hydroxyproline. The com-pression of the collagen surrounding the myofibrils creates physical constraints on these structures, resulting in the dis-placement of water [11].

The study [12] of pork samples treated at heating environment temperatures of 45, 51, 60, and 74°C showed that the greatest mass losses occurred between 60°C and 74°C, with similar results observed in works [3, 13-14]. The authors suggest that this is related to the denaturation and shrinkage of actin fibers and collagen. The most noticeable compres-sion of the sample was observed at 74°C.

Studies on the thermal treatment of duck meat at 100°C until various final internal product temperatures are reached also demonstrate that as the internal temperature increases, mass losses grow. Specifically, at a final internal temperature of 40°C, the loss is 3,34%, at 50°C – 3,86%, at 60°C – 3,33%, at 70°C – 3,65%, at 80°C – 4,07%, at 90°C – 5,68%, and at 95°C, the mass loss is 5,74% [15].

Other studies [18] conducted with beef meat showed that samples processed at 62°C had a yield of 89%, and at 59°C - 93%.

As the proportion of connective tissue in the product increases, the mass losses during thermal treatment also in-crease. However, the higher the internal temperature of the product, the smaller the difference in mass losses between tissue types. At temperatures of 80°C and above, there is only a slight difference in mass loss between the method of thermal treatment and the amount of connective tissue [16].

Mass losses also depend on the method of thermal treatment, as demonstrated by the study on thermal processing of chicken steak [17]. Marinated chicken steak was brought to an internal temperature of 75°C using the following treatment methods: boiling in a water bath at 100°C for 22 minutes; baking in a convection oven for 20 minutes at 120°C; grilling with a surface temperature of 150°C for 14 minutes, turning every 2 minutes; microwaving for 10 minutes; and steaming with superheated steam at 250-380°C for 5 minutes. The greatest mass losses were observed during boiling and baking. Mass losses increased with higher temperatures and longer processing times. Products pre-pared using superheated steam had the lowest mass losses.

Similar studies were conducted on the temperature treatment of foal steaks using different methods. The highest mass losses in the product heated to an internal temperature of 70°C were observed during microwave treatment, with losses of 32.49±6.41%. The lowest losses occurred during grilling at 22.45±5.51% and frying at 23.73±2.87%. During baking, the losses were 26.71±3.51% [18].

It is important to note that when analyzing different research results, several variable factors must be considered that influence the kinetics of water loss: differences in sample size, pH, and the history of the raw material (e.g., prior freezing-thawing).

Thermal treatment is one of the factors that determines the tenderness and juiciness of the finished meat product.

Factors influencing meat tenderness during thermal processing have been studied by many scientists [19]. It is known that high temperatures lead to the softening of connective tissue caused by the transformation of collagen into gelatin, which results in the tenderization of meat, while the coagulation of myofibrillar proteins leads to its toughness. These changes depend on the time, temperature, and cooking conditions. Protein changes, especially collagen denatur-ation, along with proteolytic activity, are often considered the main reasons for increased meat tenderness.

In the opinion of scientists, cooking meat using the LT-LT technology leads to an increase in its tenderness. The structural or molecular mechanisms underlying the improvement in meat tenderness when prepared with LT-LT are not yet fully understood. Recent studies have concluded that there is a complex combination of both degradation and pro-teolysis of the intramuscular connective tissue and possibly myofibrillar proteins [20].

Prolonged heating time also affects the juiciness of meat. According to some studies, the perception of juiciness improves the perception of tenderness and may also influence other parameters [21].

Currently, low-temperature long-time processing is not used in the industrial production of meat products. For the successful industrial implementation of the LT-LT technology, it is necessary to develop processing regimes based on scientific justification of the temperature-duration ratio to achieve all desired quality characteristics and safety of the finished product.

Our preliminary studies [22] on the influence of temperature and cooking time on model pork meat samples showed that heating the meat to 60°C and exposure it for 1 hour are optimal parameters for achieving sufficient mus-cle protein denaturation and ensuring microbiological safety.

The purpose of the study –investigate the effect of thermal treatment on the structural-mechanical properties, mi-crostructure, and organoleptic characteristics of pork products. To achieve this goal, the following tasks were set:

- to investigate the influence of temperature processing parameters on the structural-mechanical properties of cooked and smoked-cooked baliks;
- to determine the effect of thermal processing regimes on the microstructure of finished products;
- to conduct a comparative analysis of the organoleptic characteristics of pork products made using different tem-perature treatment regimes.

Materials and methods.

As the research material, the dorsal and lumbar muscles of pork without skin (DSTU 7158:2010) produced at LLC "Globinsky Meat Processing Plant" were used. The production technology of the "Balyk" product was based on DSTU 4668:2006.

The dorsal and lumbar pork muscles were weighed and injected with a brine solution with a density of 1,100 g/cm³, containing 0,05% sodium nitrite and 0,5% sugar, in an amount of 4,5% of the raw material mass. The meat was then rubbed with table salt at a rate of 2% of the raw material mass and massaged at a rotation frequency of 16 rpm, alternating 15 minutes of rotation with 40 minutes of rest. Afterward, it was washed with water (temperature not exceeding 20°C), left to drain for 3 hours, then tied and subjected to heat treatment.

The heat treatment process was carried out in an electric cooking kettle SVC-14, manufactured by Sammic S.L. (Spain), and in an electric smoking chamber SMOK-4, manufactured by Promtorg (Ukraine).

The control samples were produced using standard processing regimes [23]. They were subjected to roasting at a temperature of 50-110°C for cooked products or hot smoking at 38-55°C for smoked-cooked products, followed by cooking in a heating medium at 75-85°C until the internal temperature of the product reached 72°C.

The experimental samples of cooked balyks were dried in two stages: at a heating medium temperature of 28-32°C and 45-50°C, followed by cooking at 60°C until the same temperature was reached inside the product, with an exposure time of 60 minutes.

For the experimental smoked-cooked balyks, the meat was heated at a heating medium temperature of 28-32°C until the internal product temperature reached 18-22°C, followed by an increase in the air temperature to 45-50°C and holding for 30-40 minutes. Then, smoking was carried out at a temperature of 48-52°C for 60-80 minutes, followed by cooking at the same temperature regime as for the experimental cooked balyks.

For all samples, cooling was carried out with cold water (10-12°C) for 20 minutes, followed by cooling with cold air until the internal temperature of the products reached 4°C.

In the course of the work, structural-mechanical properties were studied, specifically shear stress using the Structurometer ST-1 device and plasticity.

To determine the shear stress, the 'Struna' indenter was used [24]. Shear stress was determined by dividing the force acting on the product by the area of the string that passes over the product's surface, according to the formula.

$$\sigma = \frac{F}{A} \quad (1)$$

where: F – shear stress, H; A – cut surface area, cm^2.

Plasticity was determined using the pressing method [25]. A sample weighing 0,3 g was placed on an ash-free filter between glass plates, and then a 1 kg weight was placed on the plates with the sample for 10 minutes. After that, the contour of the stain around the compressed sample was outlined. Plasticity was determined using the formula:

$$P = \frac{S}{m} \quad (2)$$

where: S – the area of the stain from the pressed sample, cm²/g; m – the weight of the sample, g.

For microstructural studies, the experimental samples were fixed in a 10% neutral aqueous formalin solution and immersed in gelatin. Sections with a thickness of 10-12 μm were obtained using a freezing sliding microtome. The obtained sections were placed under a coverslip in glycerin-gelatin and examined using a Biolam P-12 light microscope. Photographs were taken using a 10× objective lens.

During the study, the weight loss of the meat after heat treatment was determined using a calculation method (weighing the samples before and after heat treatment) [25].

After production, all samples were subjected to organoleptic testing. The tasters assessed the samples based on the following parameters: appearance, texture, appearance on the cross-section, smell, taste, and tenderness using a five-point rating scale. Based on the obtained scores, the overall score for each sample was calculated.

Results of the research and their discussion

The changes in muscle and connective tissue proteins during heating lead to shrinkage and a reduction in the volume of meat and meat products with an intact structure, which is associated with water release. The extent of moisture loss in the product affects not only the toughness but also determines the yield of the product.

An important characteristic of a meat product is its consistency and texture, which are directly related to changes in the meat's water-holding capacity and the loss of free moisture.

Many factors influence the change in water-holding capacity of meat during its heat treatment: the temperature to which it is heated, the duration of holding at that temperature, the temperature of the medium, the method of heat treatment, the heating rate, the pH of the raw material being processed, rheological characteristics, chemical composition of the product, the amount of added table salt, water, the type of meat, anatomical origin of the muscles, age of the animals, etc. [26]. Most researchers associate the decrease in water-binding capacity and moisture loss during meat heating only with changes in the conformational structure of the protein. Changes in muscle and connective tissue proteins during heating lead to shrinkage and a decrease in the volume of meat and meat products with an intact structure, which is associated with the release of water. The amount of moisture loss by the product affects not only its toughness but also determines the yield of the product.

The results of the study on the mass loss of control and experimental balyk samples, shown in Fig. 1, demonstrate a significant impact of heat treatment regimes on the change in the mass of the final product.

The results prove that balyks made using standard heat treatment regimes have significantly higher mass losses compared to samples heated at temperatures not exceeding 60°C. This is consistent with the findings of several similar studies [14, 27-28].

The lowest mass loss was observed in the experimental cooked balyk sample, which amounted to 7,3%, while the control sample lost 19,8% of its mass. Products that underwent smoking had greater mass losses compared to cooked balyks. The difference between the experimental and control smoked-cooked balyk samples was nearly twice as large, at 12,7%.

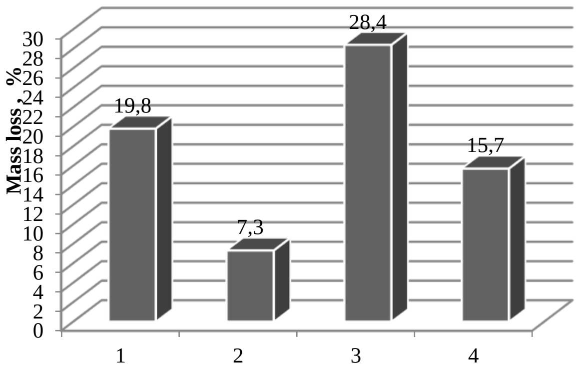


Fig.1. Mass loss of meat after heat treatment: control cooked balyk (1); experimental cooked balyk (2); control smoked- cooked balyk (3); experimental smoked- cooked balyk(4)

The lowest mass loss was observed in the experimental cooked balyk sample, which amounted to 7,3%, while the control sample lost 19,8% of its mass. Products that underwent smoking had greater mass losses compared to cooked balyks. The difference between the experimental and control smoked-cooked balyk samples was nearly twice as large, at 12,7%.

One of the important indicators of the structural-mechanical characteristics of muscle tissue is the plasticity of meat, which, along with shear stress, provides an instrumental characteristic of the tenderness of the meat product. Fig. 2 presents the results of structural-mechanical studies of experimental and control pork balyk samples.

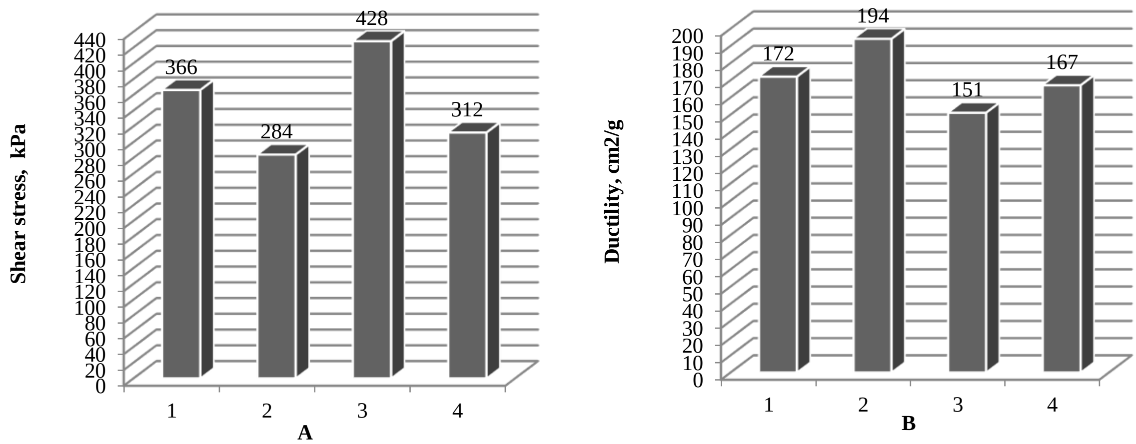


Fig.2. Structural and mechanical properties: (A) shear stress, (B) ductility: control cooked balyk (1); experimental cooked balyk (2); control smoked- cooked balyk (3); experimental smoked- cooked balyk(4)

It was established that the samples produced according to the developed heat treatment regimes are characterized by lower shear stress values and higher plasticity values compared to the control samples.

The difference in shear stress in the experimental cooked samples is 22% lower than in the control samples, while in the smoked-cooked balyk, the difference reaches 27,1%. The products subjected to smoking have a higher shear stress compared to the cooked ones, with a value of 28 kPa in the experimental sample and 62 kPa in the control. This is explained by the lower moisture content in the product and a denser texture. Thus, the control samples are characterized by a tougher texture.

The plasticity index also serves as evidence of the softer texture of the experimental samples. At the same time, in the experimental cooked samples, the plasticity index is 11.3% higher than that of the control, while in the smoked-cooked samples, it is 9,5% higher.

To determine the depth of the impact of heat treatment regimes on the structure of the finished meat product and to justify the functional-technological and structural-mechanical properties, histological studies were conducted. Fig. 3 shows the microstructure of cooked pork products.

The analysis of the results of histological studies indicates changes in the components of muscle and connective tissues in all samples. An increase in the processing temperature leads to an increase in destructive processes, resulting in changes to the functional and technological potential of the product.

The studies showed that an increase in thermal load leads to the intensification of destructive changes, expressed in the rupturing and fragmentation of muscle fibers. The control cooked samples have more compact and thinner muscle fibers, and microcracks and ruptures are also observed. The muscle fibers of the experimental products are more swollen and intact.

These changes can be explained by the reduction of the interfiber distance due to the denaturation of myofibrillar proteins and, subsequently, the strong contraction of collagen fibers. An increase in holding time has a relatively smaller effect on changes in diameter compared to an increase in temperature, which is consistent with studies on different types of meat [29-31].

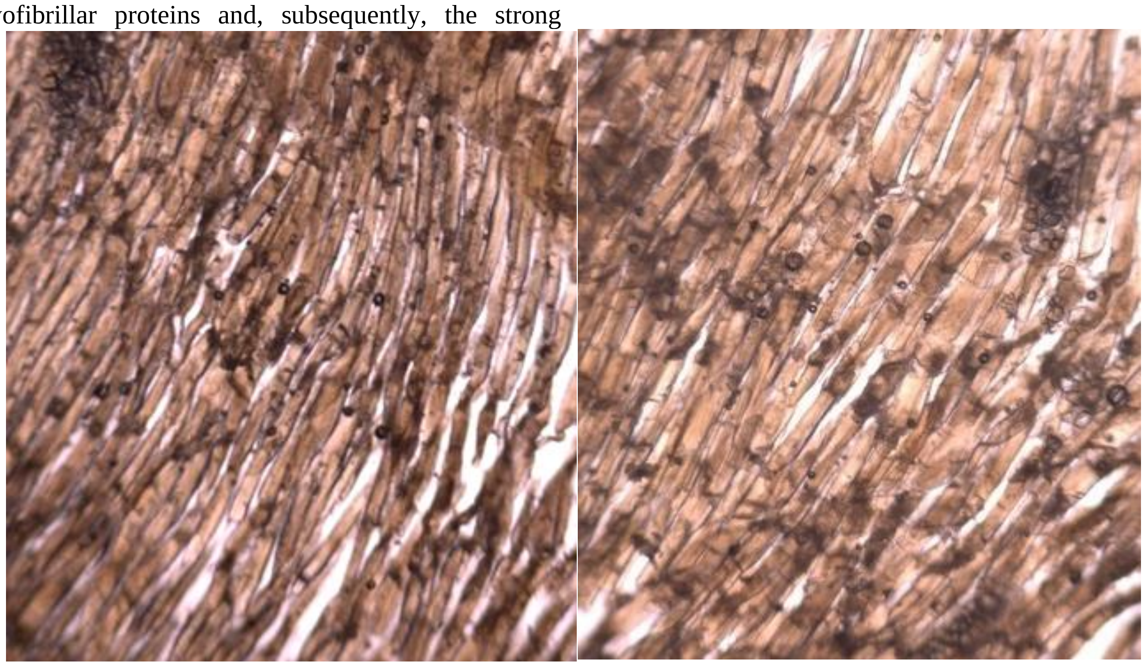
Juiciness, tenderness, and taste are the most important organoleptic characteristics of cooked meat. Tenderness is considered one of the quality characteristics [5, 7] and an important factor determining the acceptability of meat for consumers [24]. Some authors [9, 11] have noted that the perception of juiciness enhances the perception of tenderness, even when shear force values were correspondingly low in the studies.

The data from the organoleptic analysis presented in Table 1 showed that the experimental samples of cooked and smoked-cooked balyk had a more attractive appearance and better taste.

The results of the organoleptic studies showed that the experimental samples were more tender and juicier in taste, which explains the higher scores for taste. In terms of juiciness, the smoked samples had slightly lower ratings compared to the cooked ones, which is related to the lower moisture content in the product.

The results of the consistency study of pork products showed that the control samples had a tougher consistency compared to the experimental products, which is consistent with the results of the structural and mechanical properties study.

There were no significant differences in the intensity of the aroma of the products. Both experimental and control smoked-cooked products had a pronounced smoked aroma.



(A) **(B)**

Fig.3. Microstructure of control cooked balyk (A) and experimental cooked balyk (B) (longitudinal section, magnification ×100)

Table 1 – Organoleptic characteristics

	Control cooked balyk	Experimental cooked balyk	Control smoked-cooked balyk	Experimental smoked- cooked balyk
Appearance	4	4,8	4,5	4,9
Consistency	4	4,9	4,2	5
Cut appearance	3,8	4,8	4,1	5
Smell	5	5	5	5
Taste	4,1	5	4,4	5
Tenderness of the meat	3,7	5	3,5	4,8
Overall evaluation	4,10	4,91	4,28	4,95

Conclusion

It was established that the use of low-temperature processing for the production of cooked and smoked-cooked pork balyk positively affects the taste characteristics and yield of the finished product.

2. A comparative evaluation of control and experimental samples revealed an increase in plasticity in cooked products made using the LT-LT technology by 22 cm²/g and a decrease in shear stress by 82 kPa, while for smoked-cooked products, the increase was 16 cm²/g and 116 kPa, respectively; the mass loss decreased by 12.5% for cooked and by 12.7% for smoked-cooked balyk.

3. The summarized results of the microstructure, structural-mechanical properties, and organoleptic analysis showed that the best taste and sensory characteristics were found in products made using the developed regimes with the LT-LT technology.

4. Further work will focus on studying the effect of the developed thermal treatment regimes using LT-LT technology on the nutritional and biological value of finished pork products and establishing their shelf life.

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ВПЛИВ НИЗЬКОТЕМПЕРАТУРНОГО ТРИВАЛОГО ОБРОБЛЕННЯ НА СТРУКТУРНО-МЕХАНІЧНІ ТА ОРГАНОЛЕПТИЧНІ ПОКАЗНИ-КИ ПРОДУКТІВ ЗІ СВИНИНИ

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Анотація. Перспективним напрямом удосконалення технологічного процесу виготовлення м'ясних продуктів є використання помірних режимів температурного оброблення при доведені їх до стану кулінарної готовності. Для успішного промислового впровадження низькотемпературного тривалого оброблення необхідно розробити режими з точки зору наукового обґрунтування співвідношення температури та тривалості для утворення усіх бажаних якісних характеристик готового продукту. У статті представлені результати експериментальних досліджень впливу параметрів температурного оброблення м'яса свинини при виготовлені варених та копчено-варених баликів на мікроструктуру, структурно-механічні, органолептичні та технологічні властивості готових м'ясопродуктів. Наведені результати свідчать про те, що застосування низькотемпературної обробки істотно позитивно впливає на характеристики продукції. Зокрема, балики, приготовані за низьких температур, характеризуються величиною втрат маси: варені 7,3%, копчено-варені 15,7%, балики виготовлені за традиційними режимами мають втрати на 12,5% і 12,7% більші. Дослідні зразки характеризуються меншими показниками напруги зрізу і більшим значеннями пластичності ніж контрольні, що вказує на більш ніжну їх консистенцію. Аналіз результатів мікроструктурних досліджень показав, що контрольні варені зразки мають більш ущільнені та тонші м'язові волокна, крім цього спостерігаються мікротріщини і розриви. М'язові волокна дослідних продуктів мають більш набряклі та цілісні волокна. Балики, виготовлені за розроблених режимів температурного оброблення мали кращі органолептичні показники, смакові та сенсорні характеристики. Результати дають змогу стверджувати про те, що низькотемпературне тривале оброблення є досить перспективним і має позитивний вплив на характеристики готових м'ясних продуктів. Впровадження розроблених режимів у м'ясній галузі дасть змогу виробляти цільном'язові м'ясні вироби, що мають високу якість, порівняно з продукцією, виготовленою за традиційними методами, а також скоротити витрати на виробництво.

Ключові слова: температурне оброблення, м'ясні продукти, структурно-механічні властивості, мікроструктура.