Запропоновано удосконалений експрес-метод дослідження структурно-механічних властивостей м'яса індика, оснований на визначенні релаксаційного зусилля за деформації розтягу та пенертації. Охарактеризовано зміни пружності та релаксаційного зусилля охолодженого філе індика за різного терміну зберігання. Встановлено динаміку релаксаційних змін, швидкості руйнування структури та межи міцності поверхні філе індика, яке зберігалося від 6 до 48 годин. Визначено, що енергія релаксації філе, яке зберігалося протягом 48 годин, зменшилася на 29 %, а межа міцності поверхні – на 15 %

Ключові слова: пенетрація, структурно-механічіні властивості, осьова деформація, деформаційна діаграма, філе індика

Предложен усовершенствованный экспресс-метод исследования структурно-механических свойств мяса индейки, основанный на определении релаксационного усилия по деформации растяжения и пенертации. Охарактеризованы изменения упругости и релаксационного усилия охлажденного филе индейки разного срока хранения. Установлена динамика релаксационных изменений, скорости разрушения структуры и предела прочности поверхности филе индейки, которое сохранялось от 6 до 48 часов. Определено, что энергия релаксации филе, которое сохранялось в течение 48 часов, уменьшилась на 29 %, а предел прочности поверхности – на 15 %

Ключевые слова: пенетрация, структурно-механические свойства, осевая деформация, деформационная диаграмма, филе индейки

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IMPROVED METHOD TO DETERMINE STRUCTURAL-MECHANICAL PROPERTIES OF TURKEY MEAT AT AXIAL DEFORMATION

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1. Introduction

All real bodies can be considered as elastic only at fairly small deformations. When a deformation exceeds a certain limiting magnitude, which varies for various bodies, the properties of bodies are significantly different from the properties of perfectly elastic bodies [1]. For samples of meat, this is traditionally determined organoleptically. After pressing a sample of meat, it is possible to visually determine the recovery time from the previous form [2].

However, this technique has drawbacks: from subjective perception of time by the person and required experience to an unknown sample structure below the surface, which is pressed.

In engineering, elastic properties of real bodies, depending on their deformation, are commonly studied by the schedule of deformation, which reflects a graphical dependence between relative deformation and mechanical stress obtained experimentally [1].

After Ukrainian market was introduced with non-expensive digital recording measuring instruments, there appeared a possibility to adapt materials research methods to determine the food products quality.

Structural-mechanical properties of raw materials define quality of the culinary products made of poultry, but determining them organoleptically is difficult. Mechanical properties of meat depend on the feed, bird's age and gender and are significantly different from one batch to another. Therefore, development of a universal technique and equipment to study structural-mechanical properties of raw meat under conditions of small-scale production is a relevant task.

2. Literature review and problem statement

Among fast methods for determining quality of meat raw materials, the easiest one traditionally is the use of physical methods [1] as there is no need for chemical reagents, as well as a relatively higher rate of defining raw materials parameters.

Thus, studies have been conducted of the stressed-strained state of biopolymers in meat that are exposed to the processes of elastic, residual and high elastic deformation [3] when modeling the processes of cutting and crushing over a wide range of temperatures. Beef was subjected to axial deformation for constructing cyclical diagrams and defining the limits of strength and elasticity. However, the article lacks data about equipment that was used in the research, its mobility and possibility to use it in the production and trade.

There are known results of research into rheological properties and texture of muscle tissue of roe deer of all ages [4]. However, there are no data on changes in the structure of meat in the storage process.

The influence of storage technology on the quality of poultry meat was examined [5]. However, the technology is based on the injection of solutions of polysaccharides, which is difficult to do under conditions of small-scale production; more to the point, the paper did not describe comparison of structural-mechanical properties before and after applying the proposed method of storage.

A lot of research has addressed a problem of establishing the dynamics of structural and mechanical properties of meat. In particular, [6] revealed changes in the rheological properties of beefsteaks in the course of thermal treatment with different techniques [6]. However, studying the structure of meat was conducted only by the penetration method, which is not enough for a comprehensive evaluation of rheological properties.

In Ukraine, solving a task of instrumental determination of structurally-mechanical properties of fish raw materials has been the subject of study by a team of researchers from the National University of Food Technologies (NUFT) and Kyiv National Trade and Economic University (KNTEU).

In particular, a technique for determining consistency by the penetration method was proposed [7]. The proposed method makes it possible to rapidly determine the readiness of fish preserves, but there is no way to determine other structural-mechanical properties. The patent did not take into account the peculiarities of motion of indenter in the muscles of fish; this issue was considered in subsequent articles [8]. This method is fairly simple in execution, and using registering equipment allows simultaneous exploration of the processes related to penetration.

It was proposed to use digital measuring equipment to examine relaxation properties of products made of fish raw materials [9], which allows determining the relaxation rate of fish preserves instrumentally and recommending the appropriate type of packaging.

Thus, the penetration method was employed in the studies of changes in the structure of poultry meat at different temperatures and the effect of protein coagulation on it [10]. An organoleptic method of research into structural-mechanical properties cannot be applied in this case because of low initial temperatures in the experiment – starting at 30 °C. However, a difference in the physical properties of poultry was observed at high temperatures and large protein denaturation. This is due to either low sensitivity of penetrometer or insufficiency of data obtained in the process of penetration, or a combination of the two above-mentioned factors. An overview of biophysical methods that make it possible to define the direction to use meat was carried out [11]. Theoretical substantiation of the complex to study meat quality in the production process is presented, which includes optical, electromagnetic, ultrasonic and mechanical sensors. But the proposed equipment is installed in the production line and it is difficult to use it for an express-diagnosis of mechanical properties of meat.

When examining influence of percentage of meat of mechanical deboning on the organoleptic properties of semi-finished products made of poultry [12], physical methods for determining organoleptic properties were applied with the analogy established between organoleptic and structural-mechanical properties of semi- finished nuggets.

Summing up the aforementioned, we can conclude that the use of digital measuring devices with the capacity to register data makes it possible to improve existing methods of determining dynamics in the structural-mechanical properties and to use under conditions of small-scale production. Development of equipment that will perform a study of meat raw materials with sufficient accuracy, to conduct real-time detection of parameters independent of each other and to present research outputs with relevant recommendations in a short time, is of both practical and theoretical significance.

3. The aim and tasks of the study

The main aim of present research was to devise a methodology for examining structural-mechanical properties of turkey meat raw materials.

To achieve the set aim, the following tasks were to be solved:

– to improve a methodology of research into the structure of poultry meat, which would enable registration of minor changes in the rheological properties that are difficult to determine organoleptically;

– to explore dynamics of change in the structural-mechanical properties of turkey fillet during storage.

4. Materials and methods of experimental research

For the purpose of verification of the method, we conducted a series of experiments in the physics laboratory of Kyiv National Trade and Economic University (KNTEU), Ukraine.

The research was performed in the modules "rheology" and "Penetration" of the installation MIG 1.3 [13], Ukraine, made jointly by TOV "ITM", Kharkiv, Ukraine and KNTEU, Kyiv, Ukraine. A detailed description of methods and equipment is in [14].

5. Results of examining the indicators of properties

After deforming the sample, data of dynamometer, using the software of measuring unit, form a chart of relaxation of muscle tissue. An example of data from one sensor of the designed installation over the course of deformation of turkey fillet's sample No. 2 is shown in Fig. 1.

Next, data were exported to a tabular processor for processing. The initial schedule of deformation is saved for registration or research protocol.

An example of determining tensile strength of muscle fibers by the penetration method is shown in Fig. 2.

Using the method of indicator immersion, strength of the structure is typically assessed by a special indicator – a magnitude that characterizes a degree of penetration of the indenter inside the examined sample material under constant loading. This indicator is expressed by the magnitude of boundary shear stress, which characterizes strength of the structure of material at low deformation velocity. Its use is not expedient for the estimation of structure of such complex systems as meat [8], so it was proposed to use a cylindrical indenter and by plunging it at a constant rate down to a constant depth to capture resistance force of the product [15]. During immersion of the indenter, resistance force rapidly increases (Fig. 2, sector 1), but after the fracture of surface of the sample (and in our case, muscle fibers in the surface layer), resistance of the muscle tissues decreases sharply (Fig. 2, sector 2). A chart of change in the resistance force forms a peak over time (Fig. 2, mark 4), by measuring the magnitude of which it is possible to calculate tensile strength of the surface of product.

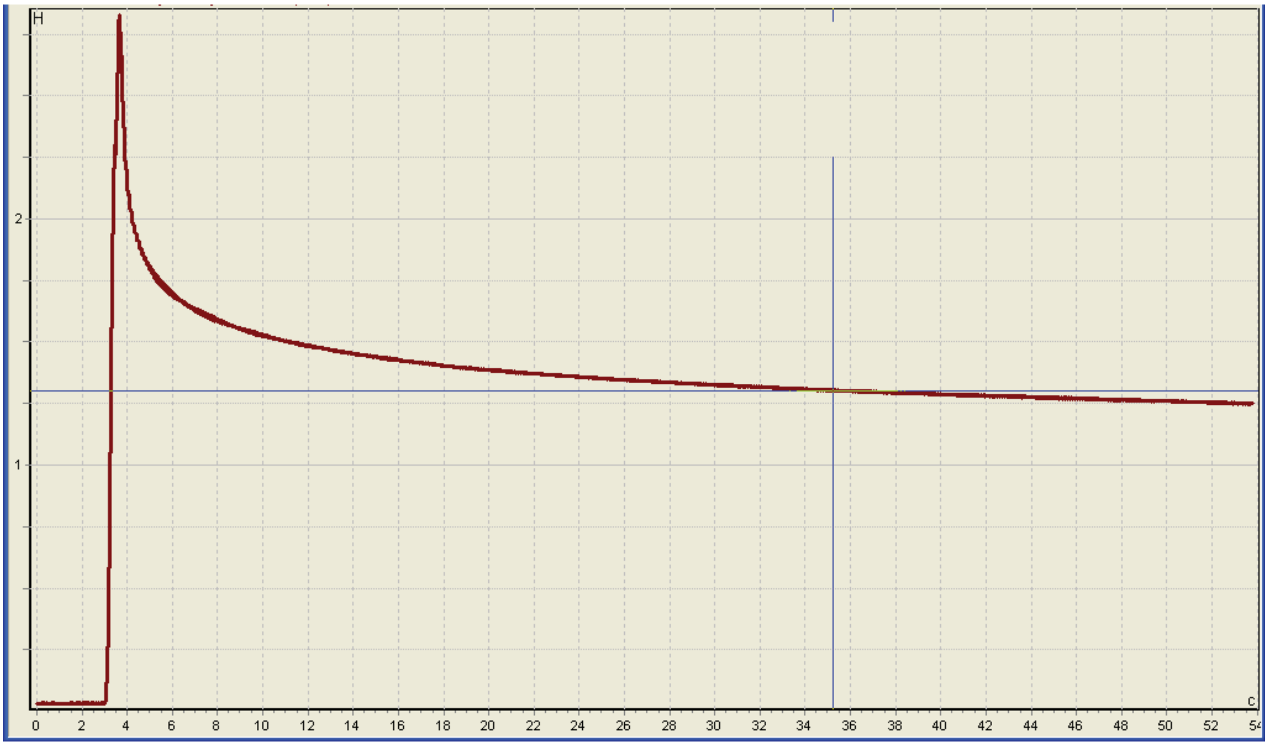

Fig. 1. Program window "Multimedia laboratory MIG 1.3".
Chart of deformation of turkey fillet sample when stretching along fibers

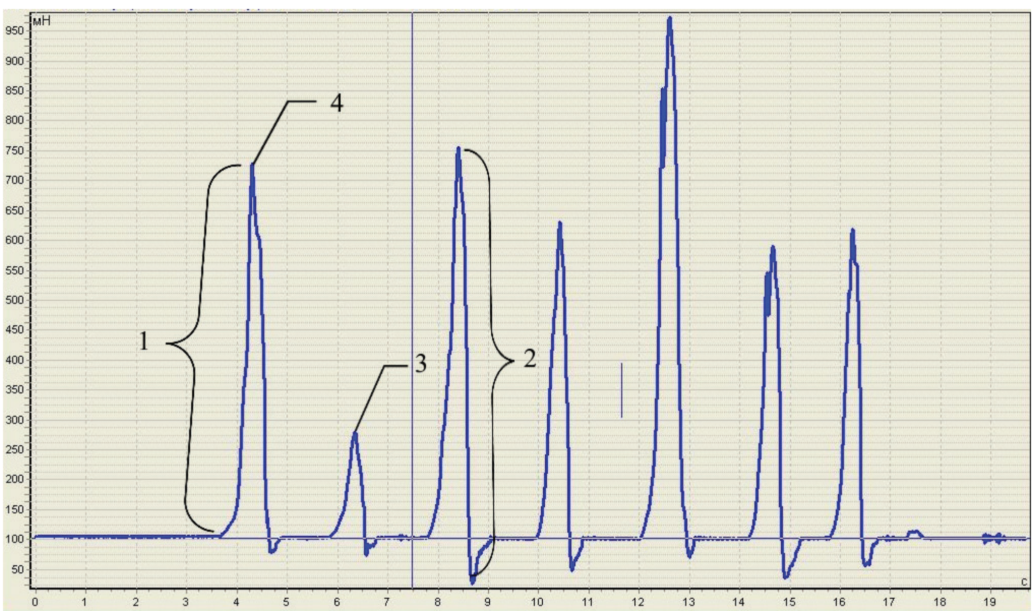

Fig. 2. Program window "Multimedia laboratory MIG 1.3". Determining tensile strength of sample 2 of turkey fillet by the penetration method at angle 85–95° to the fibers: 1 – sector of growth in the resistance force; 2 – sector of fall in the resistance force strengthened by product adhesion, 3 – penetration effort in failed experiment, 4 – penetration effort

7. Discussion of results of examining changes in the structural and mechanical properties of turkey fillet during storage time

In order to compare the properties of samples with different storage time, we constructed turkey fillet relaxation curves (Fig. 3), which completely correlate with the data on relaxation effort for other varieties of meat [16].

Data of graphs in Fig. 3 are built exclusively by points without interpolation.

Fig. 3 shows a zone of the loading (1), which is before the limit of proportionality, that is, one can argue that the load at 17 kPa causes elastic deformation in the fillet's muscle tissues, therefore, it corresponds to the pressing force when using an organoleptic method for determining freshness of turkey meat [9].

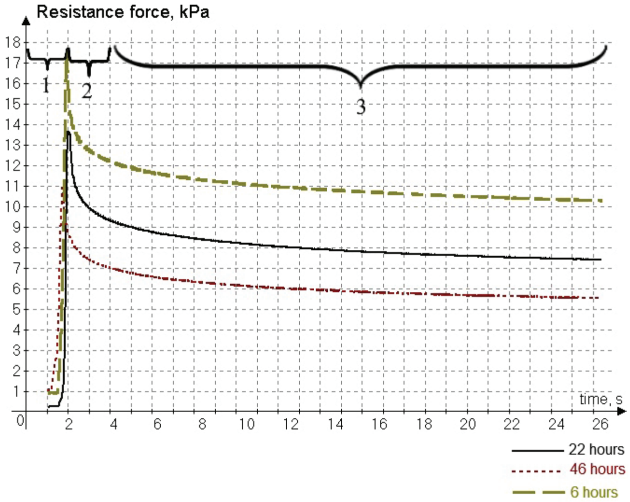

Fig. 3. Relaxation curves of turkey fillet with different storage time at axial deformation, zones: 1 – load, 2 – intensive deformation, 3 – slow deformation

A zone of intensive strain (Fig. 3, zone (2) is specific for each sample, and is characterized by a reduction in resistance force by 50 %. It is the size of the area of intensive deformation (period of partial recovery in the shape of surface) that is determined visually by pressing the surface of meat while checking quality of raw materials. However, when processing the semi-finished poultry products, deformation and recovery of structure usually last longer than the width of zone of intensive deformation (1...2 s).

A zone of slow deformation (Fig. 3, zone (3) is characterized by a gradual change in the structure and displacement of muscle fiber. Zone (3) is difficult to define organoleptically, but in the process of mechanical treatment or shaping products, the velocity of processes that taking place in the zone of gradual deformation, will form the consistency and outer look of culinary products.

At the next step, we built mathematical models of change in the structural-mechanical properties of turkey fillet over the storage time.

One of the commonly applied methods of mathematical modeling, which is used to plan an experiment in food technology, is the method of full factorial experiment and construction of response surfaces by two factors [16]. This method is very effective when determining rational values of the examined factors [16, 17]. However, in the analysis of dependence of parameter on one factor, it is more expedient to use the method of integral analysis [18]. To improve the visualization of data, we performed the following:

– an artificial axis of time is drawn, which does not correspond to the real time of experiment, but maintains obligatory scale and period of taking the data;

– for the resulting resistance force, the weight of the examined samples was calculated;

– the relaxation data were limited in accordance with the time of relaxation in the fastest sample (all charts have the same length of 24.275 s);

– charts of relaxation were shifted relative to each other over time by 1 s.

All of the steps above do not distort original data and are performed solely to improve the perception of difference in the deformation energy of the examined samples.

To facilitate the regression analysis, we rejected the zone of loads in the obtained data (Fig. 3, sector (1)).

At the next stage, we carried out a regression analysis and obtained relaxation equations of the examined samples. Function type was selected so that the confidence level of approximation (R^2) was as large as possible. In all the derived functions, $R^2 \geq 0.98$.

Results of regression analysis are shown in Fig. 4.

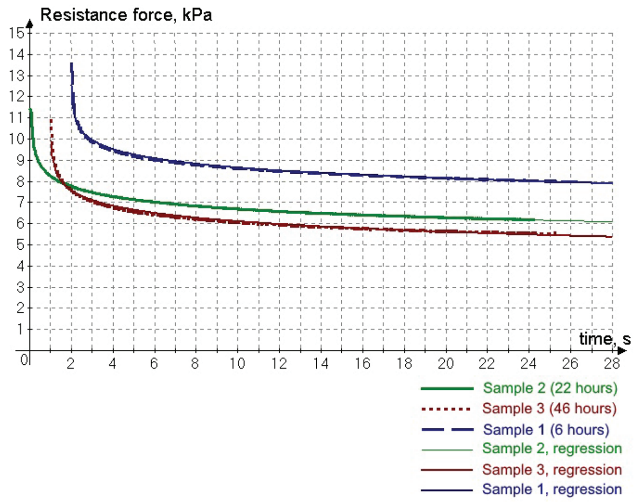

Fig. 4. Results of regression analysis of relaxation equations

The resulting data array makes it possible to apply a method of energy comparisons for the analysis of structural-mechanical properties of meat. The obtained regression equations are analyzed by the graphical method of determining deformation work, which allows us to define the energy used for deformation. To determine the difference in energy, which is spent on the relaxation, the obtained equations were integrated (Fig. 5).

A geometrical method allows us to determine rather simply the energy used on the process of deformation as the area under the chart.

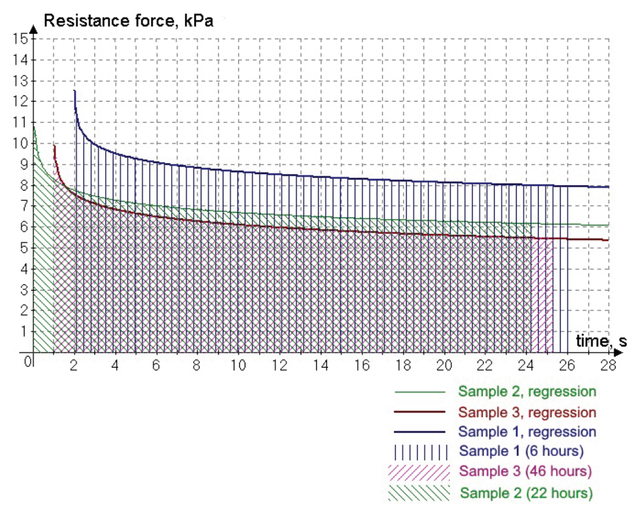

Fig. 5. Integration of relaxation curves of turkey fillet

After obtaining the integrals, we defined their area, which along the x axis is limited by the time of relaxation, and along the y axis – by the x axis and the relaxation equation. The area of integral between the obtained equation of relaxation and y=0 over the time period of examining relaxation effort will determine the energy of sample's resistance to deformation.

Table 1

Integration of relaxation curves of turkey fillet with different storage time

No. of sample (storage time)	Relaxation equation	Inequality for determining the area of figure	Energy of sample's resistance (E), kJ	Absolute error (ΔE), kJ
1 (6 hours)	y=–0.63ln(x)+ +9.95	$\int_{2.005}^{26.205}(-0.63\ln x+9.95)dx\geq 0$	207.297	13.24
2 (22 hours)	y=–0.67ln(x)+ +7.57)	$\int_{1.002}^{25.27}(-0.67\ln x+7.57)dx\geq 0$	164.946	11.06
3 (46 hours)	$y=8.28x^{(-0.0921)}$	$\int_{0.002}^{24.275}(8.28x^{-0.092})dx\geq 0$	148.104	11.20

Results of determining the integration of relaxation curves of turkey fillet with different storage time are shown in Table 1.

By the analysis of Table 1 it can be argued that the largest resistance energy during axial tensile deformation was displayed by the first sample, stored for 6 hours. A difference in the relaxation energy of the samples that were stored for 22 and 46 hours, in comparison, is small and is about 11 %, indicating a sharp softening in turkey fillet during first 22 hours and slowing down of this process in the 2 day of storing. In practice, this means that the difference in the consistency of half-finished products made of turkey fillet, which was stored for 22 and 46 hours, is almost impossible to detect organoleptically.

During manufacturing, natural raw materials are subjected to deformation while at the same time they must keep the set shape. This property is, in many ways, defined by the time of irreversible change in the structure of sample, that is, at a constant loading over certain time, the deformation of the sample becomes more plastic.

The time of irreversible change in the structure under load is determined by the shape of relaxation chart. In order to determine the curvature of relaxation charts, we applied a method for constructing tangents [18]. The angle of tangent to the curve of relaxation indicates how fast the structure of the product is destroyed in a specified time when deforming force is applied.

To improve the visualization, the charts are combined along the x and y axes without changing data arrays. The tangents were built for all samples from the first to the tenth second of relaxation with an interval of 1 second. An example of constructing tangents at the first and fourth second of relaxation is shown in Fig. 6.

By analyzing Fig. 6, it is possible to obtain the equations, inclination angles and points of intersection of tangents with the x axis (Table 2). The largest difference in inclination angles of the tangents was observed at the fourth second of relaxation, which is why we present these data for analysis of the curves.

The difference between samples 1 and 2 is within statistical error, the angular difference between model 3 and other samples is credible. This indicates a significantly slower recovery of the structure of turkey fillet after applying deforming force for 4 seconds. Organoleptically, this difference will be unrecognizable, but after 46 hours of storing autolytic processes significantly affect the elastic properties of turkey fillet.

From a technological standpoint, the fillet that was stored longer than 46 hours is expedient to use in the special types for products – rolls or roulettes.

When processing results of the penetration, we rejected those results of penetration, in which it was impossible to isolate a clear strength maximum [14]. In the process of mathematical-statistical processing, we discarded unreliable results (slips), which is why the number of credible results (n_d) for each sample was individual. Relative penetration stress (Θ_p) and tensile strength of the surface of muscle tissue (Θ_{og}) were calculated by procedure [19]. Results on the penetration of turkey fillet samples are given in Table 3.

Table 2

Analysis of tangents to the relaxation chart of turkey fillet samples at the 4th second of relaxation

No. of sample (storage time)	Relaxation equation derivative	Equation of the tangent	Inclination angle of the tangent, ⁰
1 (6 hours)	$y'(x)=-0.63x^{-1}$	–0.158x+7.205	–8.970
2 (22 hours)	$y'(x)=-0.67x^{-1}$	–0.147x+6.996	–8.388
3 (46 hours)	$y'(x)=8.28x^{-0.0921}-$ $-0.0921x^{-1}$	–0.167x+7.308	–9.477

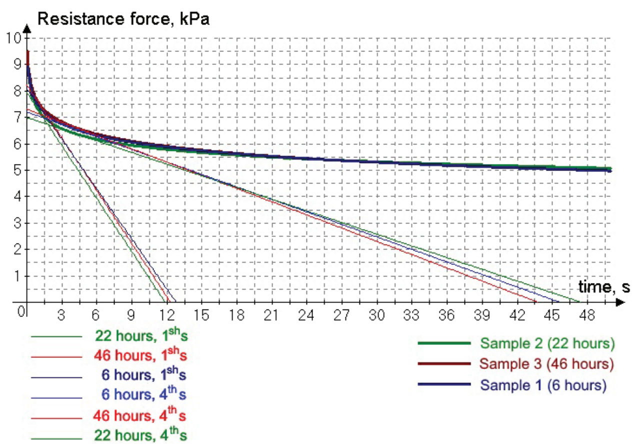

Fig. 6. Determining the curvature of relaxation chart of turkey fillet samples with different storage periods

Table 3

Results on the penetration of turkey fillet samples with different storage time

Sample No.	Number of experiments, n	Penetration effort, mN			Number of credible results, nd	Relative penetration stress (Θ_p), Pa	Tensile strength of the surface (Θ_{og}), Pa
		P_{max}	P_{min}	$\overline{P}$			
1	12	955	534	734	8	3262.22	3849.42±137.12
2	12	948	432	692	11	3146.64	3713.07±87.18
3	12	946	352	627	9	2786.67	3288.27±116.05

Note: P_{max} is the maximum resistance force, P_{min} is the minimal resistance force; $\overline{P}$ is the arithmetic mean of resistance force

When analyzing Table 3, it is possible to note that in 22 hours of storage, there were no significant changes in the strength of fibers observed. However, after 46 hours of storing turkey fillet, tensile strength at the surface, at pinching with a cylindrical indenter across the fibers, decreased by 15 %. Therefore, when using sample No. 3 in the technological processes, we may recommended reducing the intensity of mechanical culinary treatment (such as beating) or using a turkey fillet, which was stored longer than 46 hours, for manufacturing culinary products that should have delicate consistency.

7. Conclusions

1. We improved a methodology that makes it possible to explore and analyze structural and mechanical properties of poultry meat, in particular, time and relaxation energy at tensile deformation, tensile strength of the surface and the speed of structure destruction. Sensitivity of the designed equipment is 0.002 N, measurement period is 0.005 s, which allows us to determine changes in the rheological properties of poultry meat that organoleptically are not detectable.

2. While examining dynamics of changes in the structural and mechanical properties of turkey fillet, we employed the installation MIG 1.3 of original design. It was found that over 22 hours of storage, significant changes in the structural-mechanical properties occurred, for example, relaxation time increased by 18.4 %, while tensile strength of the surface decreased by 0.9 %. In the next 24 hours of storing a turkey fillet, relaxation energy decreases by 11 % (by 29 % from the onset of research) and the limit of elasticity is reduced, which, in the combination with the lower tensile strength of the fibers (by 15 %), allows us to recommend it for the formation of natural culinary products with a required shape.

References

1. Kuznecov, O. A. Reologija pishhevyh mass [Text] / O. A. Kuznecov, E. V. Voloshin, R. F. Sagitov. – Orenburg: GOU UGO, 2005. – 106 p.
2. Alehina, L. T. Tehnologija mjasa i mjasoproduktov [Text] / L. T. Alehina, A. S. Bol'shakov, V. G. Boreskov et. al.; I. A. Rogov (Ed.). – Moscow: Agropromizdat, 1988. – 576 p.
3. Suhenko, V. Ju. Mehanika biopolimeriv m'jasa [Text] / V. Ju. Suhenko // Naukovyj visnyk Nacional'nogo universytetu bioresursiv i pryrodokorystuvannja Ukrai'ny. Serija: Tehnika ta energetyka APK. – 2012. – Issue 170 (1). – P. 292–304.
4. Zochowska, J. Effects of Carcass Weight and Muscle on Texture, Structure, Rheological Properties and Myofibre Characteristics of Roe Deer [Text] / J. Zochowska, K. Lachowicz, M. Sobczak, L. Gajowiecki // American Journal of Animal and Veterinary Sciences. – 2007. – Vol. 2, Issue 4. – P. 114–120. doi: 10.3844/ajavsp.2007.114.120
5. Onishhenko, V. Improvement of frozen poultry storage technology [Text] / V. Onishhenko, N. Grinchenko, V. Bol'shakova // Eastern-European Journal of Enterprise Technologies. – 2015. – Vol. 6, Issue 10 (78). – P. 37–41. doi: 10.15587/1729-4061.2015.54656
6. Garcia-Segovia, P. Effect of cooking method on mechanical properties, color and structure of beef muscle (M. pectoralis) [Text] / P. Garcia-Segovia, A. Andres-Bello, J. Martinez-Monzo // Journal of Food Engineering. – 2007. – Vol. 80, Issue 3. – P. 813–821. doi: 10.1016/j.jfoodeng.2006.07.010
7. Pat. No. 14496. Sposib vyznachennja konsystencii' harchovyh produktiv. MPK (2006) G01N 33/02 [Text] / Guc' V. S., Koval' O. A., Sydorenko O. V., Tymofjejeva O. V.; zajavnyk i patentovlasnyk KNTEU. – No. 200511305; declareted: 29.11.2005; published: 15.05.2006, Bul. No. 5.

8. Pobedash, N. Formuvannja jakosti rybnyh preserviv iz dribnyh oseledcevyh ryb [Text] / N. Pobedash, E. Sydorenko, R. Romanenko // Tovary i rynky. – 2015. – Issue 1. – P. 112–120.
9. Romanenko, O. Metod vyznachennja strukturno-mehanichnyh vlastyvostej rybnyh preserviv [Text] / O. Romanenko // Tovary i rynky. – 2013. – Issue 2. – P. 58–65.
10. Perlo, F. Physicochemical and sensory properties of chicken nuggets with washed mechanically deboned chicken meat: Research note [Text] / F. Perlo, P. Bonato, G. Teira, R. Fabre, S. Kueider // Meat science. – 2006. – Vol. 72, Issue 4. – P. 785–788. doi: 10.1016/j.meatsci.2005.09.007
11. Damez, J.-L. Meat quality assessment using biophysical methods related to meat structure [Text] / J.-L. Damez, S. Clerjon // Meat Science. – 2008. – Vol. 80, Issue 1. – P. 132–149. doi: 10.1016/j.meatsci.2008.05.039
12. Tornberg, E. Effects of heat on meat proteins – Implications on structure and quality of meat products [Text] / E. Tornberg // Meat science. – 2005. – Vol. 70, Issue 3. – P. 493–508. doi: 10.1016/j.meatsci.2004.11.021
13. Shapoval, S. L. Rekomendacii' do vykonannja naukovo-doslidnyh robit na UVKP [Text] / S. L. Shapoval, N. P. Forostjana, Ju. V. Lytvynov, R. P. Romanenko. – Kyiv: Kyi'v. nac. torg.-ekon. un-t, 2013. – 96 p.
14. Shapoval, S. The Study of Changes in the Structural and Mechanical Properties of Turkey Fillet During Storage [Text] / S. Shapoval // EUREKA: Life Sciences. – 2017. – Issue 1. – P. 3–11. doi: 10.21303/2504-5695.2017.00284
15. Pererabotka mjasa pticy [Text] / A. R. Sjems (Ed.). – Sankt-Peterburg: Professija, 2007. – 432 p.
16. Dudenko, N. Modeling of the proteolysis process of fish collagen raw materials [Text] / N. Dudenko, O. D'jakov, B. Panikarova // Eastern-European Journal of Enterprise Technologies. – 2014. – Vol. 2, Issue 12 (68). – P. 8–13. – Available at: http://journals.uran.ua/eejet/article/view/23144/21388
17. Zelkowitz, M. V. Experimental models for validating technology [Text] / M. V. Zelkowitz, D. R. Wallace // Computer. – 1998. – Vol. 31, Issue 5. – P. 23–31. doi: 10.1109/2.675630
18. Barker, T. B. Quality by Experimental Design [Text] / T. B. Barker, A. Milivojevich. – CRC Press, 2016. – 724 p.
19. Savinok, O. N. Vybor racional'nyh parametrov izmerenija reologicheskih harakteristik cel'nomyshechnoj tkani govjadiny metodom penetracii [Text] / O. N. Savinok, V. D. Kosoj, V. G. Garbuz // Naukovi praci ONAHT. – 2014. – Issue 46 (2). – P. 160–163.