UDC 637.5’62-027.242:005.52(0.034.2:084.12A/Z)

DETERMINATION OF FUNCTIONAL AND TECHNOLOGICAL PROPERTIES OF BEEF BASED ON THE ANALYSIS OF COLOR DIGITAL IMAGES OF MUSCULAR TISSUE SAMPLES

O. Savinok, Candidate of Technical Sciences, associate Professor*, *E-mail*: savoksamit12@gmail.com
N. Azarova, Candidate of Technical Sciences, associate Professor*, *E-mail*: savoksamit12@gmail.com
O. Arsiriy, Doctor of Technical Sciences, professor, head of a chair**, *E-mail*: e.arsiriy@gmail.com
A. Nikolenko, Candidate of Technical Sciences, associate Professor**, *E-mail*: anatolyn@ukr.net
*Department of technology of meat, fish and seafood
Odessa National Academy of Food Technologies, 112, Kanatna str., city of Odessa, Ukraine, 65039
**Department of Information Systems
Odessa National Polytechnic University, 1, Shevchenko avenue, Odessa, Ukraine, 65044

Abstract. The paper considers the kinetics of changes in the values of pH and temperature of beef of slaughtered Holstein bull calfs aged 15 months during cold storage. It has been established that the rate of pH decrease during autolytic maturation is greatly influenced by the rate of temperature decrease. This was observed in the two muscles taken as an example – *m. Longissimus dorsi* and *m. Semimembranosus*.

A method is suggested of analysing digital images of beef muscular tissue samples in the color coordinate space to study the beef’s color characteristics during cold storage. It has been found out that using this method, with second order polynomial fitting, provides a mean-square approximation error of 5.6% on average from the minimum coordinate of the maximum level of the red component of color. This suggests the objectivity of its use to assess the color of the meat.

An analytical dependence has been established between the beef color and the term of refrigeration with the use of information technologies. In accordance with it, it has been determined that due to biochemical processes, there takes place intense oxidation of myoglobin, which results in a dark color of the muscle tissue. In the course of time (up to 120 hours of storage), the red color intensity increases. This is accompanied with decomposition of myoglobin forms that have appeared, and with appearance of MbO_2. When beef is stored for more than 140 hours, deeper iron oxidation begins, with formation of methyoglobin, and the brightness of the meat decreases.

The developed method allows automating registration and processing of images of muscle tissue in real time, increases the productivity of the assessment, and gives an opportunity to obtain reliable objective results about the meat properties during its storage.

Keywords: beef, functional properties, color characteristics, color image processing.

ВИЗНАЧЕННЯ ФУНКЦІОНАЛЬНО-ТЕХНОЛОГІЧНИХ ВЛАСТИВОСТЕЙ ЯЛОВИЧИНИ НА ОСНОВІ АНАЛІЗУ ЦИФРОВИХ КОЛЬОРОВИХ ЗОБРАЖЕНЬ ЗРАЗКІВ М’ЯЗОВОЇ ТКАНИНИ

О.М. Савінок, кандидат технічних наук, доцент*, *E-mail*: savoksamit12@gmail.com
Н.Г. Азарова, кандидат технічних наук, доцент*, *E-mail*: savoksamit12@gmail.com
О.О. Арсірій, доктор технічних наук, професор**, *E-mail*: e.arsiriy@gmail.com
А.О. Ніколенко, кандидат технічних наук, доцент**, *E-mail*: anatolyn@ukr.net
*Кафедра технології м’яса, риби та морепродуктів
Одеська національна академія харчових технологій, вул. Канатна, 112, м. Одеса, Україна, 65039
**Кафедра інформаційних систем
Одеський національний політехнічний університет, пр-т Шевченка, 1, м. Одеса, Україна, 65044

Анотація. У роботі досліджено кінетику змін показника pH і температури яловичини, отриманої від забою бичків Голштинської породи віком 15 місяців при холодильному зберіганні. Встановлено, що на швидкість зменшення pH при автолітичному дозріванні, значною мірою впливає швидкість зниження температури, що відслідковано на прикладі двох м’язів – *m. Longissimus dorsi* та *m. Semimembranosus*.

Запропоновано методику аналізу цифрових зображень зразків м’язової тканини яловичини в колірному координатному просторі для дослідження кольорових характеристик яловичини при холодильному зберіганні. Встановлено, що використання запропонованої методики, при згладжуванні поліномом другого порядку, забезпечує середньоквадратичну помилку апроксимації в середньому 5,6% від мінімального значення координати рівня максимуму червоної складової кольору, що дозволяє стверджувати про об’ктивність її використання для оцінки кольору м’яса.

Встановлено аналітичну залежність між кольором яловичини та терміном холодильного зберігання з використанням інформаційних технологій. Відповідно до неї визначено, що за рахунок протікання біохімічних процесів відбувається інтенсивне окиснення міоглобіну, що забезпечуює темне забарвлення м’язової тканини. З часом, інтенсивність червоного кольору зростає (до 120 годин зберігання), що супроводжується розкладанням утворених форм міоглобіну і появою MbO_2. При зберіганні більше 140 годин починається більш глибоке окиснення заліза з утворенням метміоглобіну, яскравість м’яса зменшується.

Розроблена методика дозволяє автоматизувати процеси реєстрації та обробки зображень м’язової тканини в реальному часі, збільшує продуктивність оцінки і дає можливість отримувати об’єктивні достовірні результати про властивості м’яса при зберіганні.

Ключові слова: яловичина, функціональні властивості, кольорові характеристики, обробка кольорових зображень.

DOI: http://dx.doi.org/10.15673/fst.v12i3.1044

Introduction. Formulation of the problem

The effectiveness of systems of monitoring the technological process at food enterprises depends on the timeliness of receiving information. This system isparticularly important for technological operations that are critical control points (CCP). For CCP, the promptness and accuracy of assessing the controlled parameters determine the quality and safety of manufactured products. Initial CCP at any food enterprise is receiving raw materials, because the properties of food raw materials are labile and depend on many factors. That is why, at this stage, it is so important to have online assessment of the initial functional and technological characteristics of raw materials.

It is known that, when received at an enterprise, the quality of meat raw material, especially in carcasses or half-carcasses, is usually assessed on the basis of temperature, pH, and sensory parameters. The temperature and pH level are controlled with measuring instruments. And determining complex sensory parameters requires workers of a certain qualification. That is why, the sensory characteristics obtained are subjective and contradictory. The situation is still more complicated because of the fact that the sensory parameters are the basis for determining the sanitary condition of the surface, veterinary safety, and functional properties of the meat – and the latter determine its further use.

At the same time, it is known that one of the most informative sensory parameters that characterizes meat as a complex biochemical system and is directly related to technological properties is the color of fat and muscle tissue. The color characteristics of muscle tissue depend on the amount and state of meat's basic chromoproteins – myoglobin (Mb) (90% of the total number of pigments) and hemoglobin (10%) [1]. These proteins determine the intensity of the color of the raw material. The biochemical state of meat chromoproteins is influenced by pH, the presence of oxygen in the tissues, the level of autolytic changes. These factors are decisive not only for pigments, but for all other muscle tissue proteins that determine the functional and technological properties of meat. This is especially true for beef, which has an intense red color. That is why determining the color indicators of beef during cold storage on the basis of a method for analyzing digital images of beef muscle tissue samples is a topical scientific and practical problem. Its solution will eliminate experts' subjectivity and allow obtaining mathematically grounded dependences between the functional and technological properties of meat and its color.

Analysis of recent research and publications

The problem of operational control of the quality indicators of meat raw materials has been relevant for a long time. Scientists of different countries are looking for effective express methods to assessment meat. The possible methods fall into instrumental and organoleptic ones. By their underlying principles, they are classified into chemical, physico-chemical, physical, and biological. By means of special devices and reagents, one can determine the qualitative and quantitative composition, the state of proteins, lipids, moisture, structural and mechanical properties, color characteristics, and other parameters of raw materials and finished products. Almost all control methods require sampling and take time to conduct an analysis. For operational control, express methods are needed allowing online monitoring of the process. The most popular with scientists is the spectral method of analyzing the quality of meat products using different wavelengths.

According to Yu.G. Sazonov and K.G. Pankratov, spectroscopy in the near infrared spectrum allows us to determine a significant number of parameters in products of complex chemical composition [2]. With the help of infrared analyzers, solid, liquid, and paste-like products can be analyzed. This was proved experimentally, and the results were compared with those of other types of control. The authors developed methods for processing the results of analyses with modern computer programs. The same was the direction of V.V. Zinchenko and V.A. Bogomolov's studies [3,4] that proved that near-infrared spectroscopy can be used to determine the composition and properties of food products. This determination was based on the previously accumulated data of the samples the composition and properties of which was already known. The idea of the infrared spectroscopy method consists in determining the composition of a sample by its spectrum without separating the components. Different components of the sample selectively absorb light at different wavelengths, it means that they have unique spectra. Thus, by the spectrum of an unknown sample, the concentration of components can be determined.

Bruce W. Mossa and others [5] studied whether Raman-spectroscopy could be used to assess the marbling of meat. The essence of the method was in irradiating the sample with a laser beam with a wavelength of 785 nm and measuring the light scattered by the surface. In this case, a certain number of molecules on the surface of the product become excited, and it is this energy that changes in diffused light (Stokes Scattering) measured with the device. The suggested method was used to assess the fatty acid composition of marbling fats and to determine the quality of meat when stored for up to 3 days. This method can be recommended for on-line meat quality assessment after additional research.

N. Prieto and others used the method of near-infrared spectroscopy [6] and computer tomography of X-rays [7] to predict the chemical composition of meat and to classify it according to the quality classes, and to determine the fatty acid composition of intramuscular fat. The suggested methods are potentially promising for using in meat processing industry, but require establishing additional functional and sensory parameters.

Fabıola Manhas and others studied the qualitative characteristics of beef by means of nuclear magnetic resonance spectroscopy [8]. In selected samples, sensory (aroma, juiciness, tenderness) and physico-chemical (moisture content, fat, instrumental tenderness, shear force) parameters were analyzed with standard methods and with NMRS. In this work, Carr-Purcell-Meiboom-Gill (CPMG) and Continuous Wave-Free Precession (CWFP) sequences were used. The regression models were described and calculated with the partial least squares (PLS) method using CPMG. The results obtained allowed the authors to conclude that the qualitative indicators assessed by standard methods and by the prediction ones did not show significant differences, with the confidence interval being 95%.

C. C. Correa and others [9] studied the intramuscular fat content by means of high-performance and non-destructive nuclear magnetic resonance. The method is based on data on the time of spatial and transverse relaxation obtained with continuous wave-free precession (CWFP). This method makes it possible to estimate the fat content of beef quickly and conveniently.

The wavelengths in the visible and near-infrared range were used to estimate the moisture content, native protein, and intramuscular fat in lambs and chickens [10]. The objects of the research were both whole muscle products and minced meat. The samples were scanned in reflexion in NIRSystems 6500 (NIRSystems, Silver Spring, MD, USA). By means of modified partial least squares (MPLS) with internal cross validation, the regression equations were calculated. The least error was observed when dealing with minced meat. It was concluded that analysis of spectral characteristics ensures high reliability of the data on the chemical composition of raw materials.

D. Dow and others [11] analyzed various methods for determining the fat content of beef. The methods to be compared included extraction performed with chloroform: methanol – 2:1, microwave drying followed by ether extraction, and nuclear magnetic resonance. All regression equations for determining the percentage of fat, regardless of the method of extraction, were linear. The highest accuracy was obtained with extraction using ether. But the difference in the coefficients of the equation between ethereal extraction and the use of NMR is insignificant. So, NMR can be recommended for enterprises as a quick way to assess the total fat content in muscle tissue.

A.G. Shleikin [12] suggested a method of non-destructive control of meat raw materials and unification of the assessment of the color characteristics of pork and beef muscle tissue as an integral indicator of quality and safety of meat and meat products. The objects of his study were meat of various anatomical locations (bacon, undercut, thigh, cutlet, fillets, scapula, etc.) at different refrigeration and storage stages (cooled and defrosted meat after 1, 7, and 120 days of storage at a temperature of –18°C) [13]. The experiments were carried out using spectrophotometers: SF-26 (destructive method), which records the absorbing capacity of extracts (by the method of determining myoglobin), and СФ-18 (remote method), which records the ability of reflection from the cut surface of a muscle. At the same time, functional and technological characteristics, such as pH, and moisture retaining and wetting ability of meat, were determined. The research was conducted at wavelengths of 488 and 640 nm. The results obtained revealed the superiority of the remote color estimation method, which is much faster and thus eliminates the contamination of the test sample.

In recent years, researchers have found applications of computer vision technology for the automatic detection of meat marbling [13]. Image processing typically includes such operations as segmentation of *m. Longissimus dorsi* with a picture of steak, segmentation of marbling from the soft part, and the extraction of marbling meat. The advantage of computer assessment is the speed and simplicity of the method, which allows automating the process of sorting meat raw material.

The use of spectrophotometers of various designs does not always allow us to assess objectively the quality of meat. That is why, in recent years, digital cameras and scanners have become popular with scientists. A.A. Kulakov [14] suggested a method for assessment scanned color images where the concentration of the dye was accurately determined. The dye (malachite green) was spread on filter paper, dried, and scanned with an Epson Stylus CX3900 multifunctional scanner. The resulting digital images were processed according to a program developed by the “Blot-1” authors and based on Borland ImageProcessForm. The relative error of the color intensity was no more than 0.4%. Taking into account the results obtained, the authors recommend using scanning devices, not expensive spectrophotometers, to assess the color intensity.

A general analysis of literature allows noting a lack of universal methods of assessing the color of meat. Existing devices have advantages and disadvantages. So, developing an objective express method for assessing the quality of meat, in particular beef, is necessary and timely, taking into account the dynamic development of food industry.

The purpose of the research is determining of functional-technological and color parameters of beef during refrigeration on the basis of the development of a method for analyzing digital images of beef muscle tissue samples. To achieve this goal, the following **tasks** have been solved:

giving reasons for the selection and obtaining of samples to be studied;

studying the changes in the pH and temperature parameters of beef during refrigeration;

developing a method for analyzing digital images of beef muscle tissue samples in the color coordinate space RGB for the study of color characteristics of beef during cold storage;

establishing analytical dependence between the color of beef and the term of refrigeration using information technologies.

Research Materials and Methods

When solving the first problem, as an object to obtain the research samples from, chilled half-carcass beef of Holstein bulls slaughtered at the age of 15 months was taken. The Holstein breed complies with all the main characteristics of bovine cattle productivity. But its main unique quality is the fact that cows and bulls gain weight quickly and can be freely used in the production of meat. The slaughtered animals under study were 480–500 kg of live weight, 265–280 kg of slaughtering weight. Cooling the half-carcasses was carried out by the single-stage method, with the following conditions: temperature +4ºC; air speed 0.5–1.0 m/s; relative humidity 90%; total duration 36 hours till the temperature achieved in the center of the pelvis was not higher than +4 ºC; storage: temperature +4 ºC; air speed 0.5 m/s; relative humidity 95%; total duration 172 hours from the moment of slaughter. The character of autolytic changes was determined by the pH [15], by the temperature in the thickness of the muscles, and by the change in the meat color. The points of control of functional indicators were *m. Longissimus dorsi* and *m. Semimembranosus*. The color characteristics were assessed on the slices of *m. Semimembranosus*. The samples were taken from half-carcasses at certain time intervals (see Table 1).

Table 1 – Input data on the time of the experiment

Number of the point studied	Time after the slaughter of animals, h	Number of the point studied	Time after the slaughter of animals, h
1 point	1	9 point	44
2 point	6	10 point	53
3 point	9	11 point	71
4 point	12	12 point	99
5 point	21	13 point	121
6 point	26	14 point	148
7 point	31	15 point	172
8 point	35	-	-

The change in the meat color was determined by analyzing the digital color images obtained by scanning the samples of the muscle sections with an HP ScanJet 5590P (L1912A) scanner (the CCD matrix, the color depth 48 bits). Each image contained 3 to 9 beef cuts. What the image of a cut looked like at the second point (see Table 1) is shown in Figure 1. The algorithm for analyzing images of meat cuts is described as follows:

Obtaining output images for processing.

– Construction of a red color distribution histogram in the RGB color system.
– Construction of the spatial distribution of the red component on the basis of an average of all histograms, depending on the time of obtaining the samples.
– Determination of the maximum intensity coordinates for each average histogram.
– Construction of the point dependence (data) of the coordinates of the red color maximum intensity on the time of obtaining samples. Smoothing the obtained experimental data by first and second order polynomials.

Results of the research and their discussion

The quality of the finished product is determined by the initial properties of the main raw material. The main raw material for meat products is beef, pork, poultry meat, and fat derived from processing slaughtered animals. Leaving aside the in-life factors, the functional characteristics of meat are largely influenced by primary processing and refrigeration. In the production of cooled raw materials, refrigeration has two stages – cooling and storage in a cooled state. When cooled, complex biochemical changes take place in meat. According to the stage of autolysis, they allow classifying it roughly into steamed meat, meat in a rigor mortis state, and meat at the stage of maturation. Products made from carcass meat and matured meat have excellent sensory characteristics. Posthumously numb meat is not suitable for industrial processing, since it is characterized by low pH, moisture-retaining ability, rigidity, darker color. Some of these parameters can be determined directly, in the work area, without complex physical or chemical research. During this series of studies, pH and temperature changes in the longest muscle of the back and in the internal muscle of the pelvis were studied.

Analysis of the dependencies presented in Fig. 2 shows that the pH level for *m. Longissimus dorsi* throughout the trial period is higher than that for *m. Semimembranosus*. An explanation for this is the difference in the initial content of the glycogen. The muscles of the pelvis carry a significant dynamic load; that is why, they contain 1.5 times more glycogen than the muscles of the back [16,17]. Accordingly, in amylolysis and subsequent phosphorylation of glycogen, more lactic acid is formed, which shifts the pH of the meat into acidic side. Rigor mortis for *m. Longissimus dorsi* is observed in the interval of time 35 to 44 hours from the moment of slaughter, for *m. Semimembranosus* – 21 to 31 hours. Previous studies [18,19] have found that rigor mortis for *m.*

Longissimus dorsi, which is a standardized pH measurement point, typically takes place after 40 hours from the time of slaughter. The completion of the rigor mortis process, when functional indicators are stabilized, is observed in the interval of time 50 to 55 hours. That is why, it is practical to send beef for processing not earlier than after two days from the moment of slaughter.

A close relationship is observed between the kinetics of change in pH and temperature. The highest biochemical activity in muscle tissue after slaughter occurs within the first 12 hours. The pH reduction rate in this period for *m. Longissimus dorsi* is 0.085 units/h, for *m. Semimembranosus* 0.094 units/h. The rate of decrease in temperature in the thickness of the corresponding muscles: for *m. Longissimus dorsi* 1.99 degrees/h, for *m. Semimembranosus* – 1.79 degrees/h. A higher temperature changes rate in *m. Longissimus dorsi* (Fig. 3) contributes to the slowing of the activity of the enzyme system of muscle tissue, and, accordingly, the level of reduction of pH is smaller and vice versa, in the pelvis, the temperature decreases more slowly, respectively, the activity of enzymes contributes to the intensive reduction of pH.

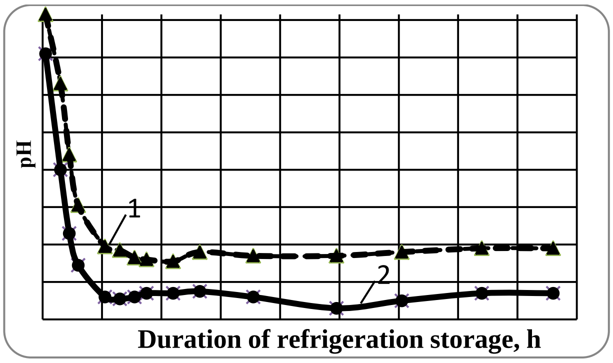


Fig. 2 Change in pH in *m. Longissimus dorsi* (1) and *m. Semimembranosus* (2) during cold storage

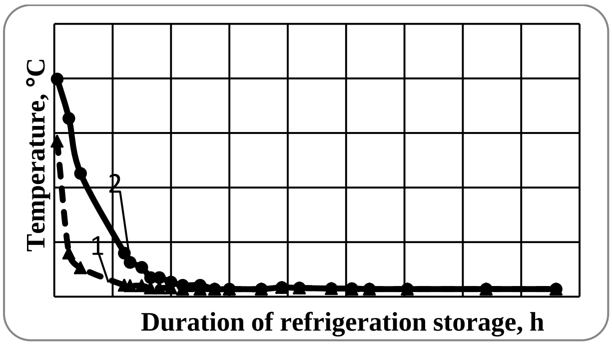


Fig. 3 Temperature change in *m. Longissimus dorsi* (1) and *m. Semimembranosus* (2) during cold storage

When developing a technique for analyzing digital images of beef muscle tissue samples in the color coordinate space RGB during cold storage, the fact was taken into account that the pH indicator characterizes the biochemical state of the meat and determines the color of the raw material. The natural color of meat is due to myoglobin and hemoglobin. The non-protein portion of myoglobin, a heme, consists of iron and four heterocyclic pyrrole rings connected with methylene bridges. The iron atom can easily be oxidized by giving up an electron and determines the forms of myoglobin: proper myoglobin (Mb), oxymioglin (MbO_2), and methymogonin (MetMb). In the presence of oxygen in the air, Mb oxidizes with the formation of oxymoglobin – MbO_2 that gives meat a pleasant, bright red color. MbO_2 is an unstable compound and under the influence of light and air, in acidic medium, it is converted into MetMb, while the heme of iron passes from bivalent to trivalent. Meat becomes brownish-gray [1]. It acquires this color when it contains more than 70% of MetMb of the total proportion of muscle pigments, which is characteristic of the raw material of the deep stage of autolysis. At the same time, in the post-slaughter period, due to the destruction of the bicarbonate system in the cells, free carbon dioxide is released [16]. Most intensively this process goes on in the first hours of autolysis. The carboniferous component decomposes into water and carbon dioxide. Carbon dioxide together with myoglobin forms red-cherry-colored carbomisoglobin, which explains the dark color of the muscles at the stage of rigir mortis. The peculiarities of changing the color of the meat during cold maturation are shown in Table 2.

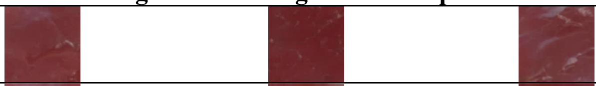
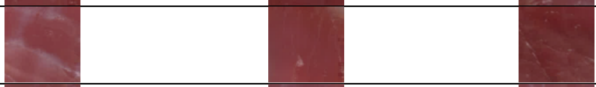
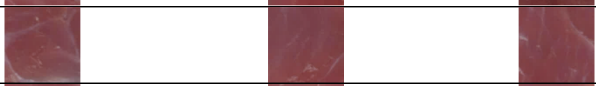
The obtained fragments of images (Table 2), besides the intensity of coloring of muscle tissues, allow us to estimate the texture of fibers. It should be noted that these images confirm other scientists' results about the connective tissue density in the initial period of maturation and in the hydrated period, at the stage of completion of rigor mortis. Obtaining scanned images of meat cuts makes it unnecessary to carry out histological studies using a microscope. It can, at the controller's request, provide information about the degree of cell destruction, which determines the direction of further use of raw materials.

Thus, the received fragments of meat cuts make it possible not only to characterize the correlation between the main forms of myoglobin and the color of meat, but also to determine the degree of destruction of muscle tissues.

Typically, an automated process of determining the color characteristics of meat raw material includes the preparation of a sample; receiving and registering its color digital image in the RGB format; transforming it into another digital format and further computer processing the information by algorithms that distinguish color characteristics. In the review of existing methods for the assessment (instrumental and organoleptic) of meat by color index [20, 21], it is noted that changes in the meat color are associated with such a color characteristic as light. That is why, in many systems, there is additional transition from the original color RGB space to others, such as HSI, Lab [22], etc.

Fig. 1. Example of an image of muscle tissue cuts obtained after 6 hours from the moment of slaughter.

Table 2 - Fragments of images of muscle tissue cuts in different periods of cold storage

Duration of cold storage, h	Fragments of images 256×256 pixel
1	
12	
21	
53	
121	
172	

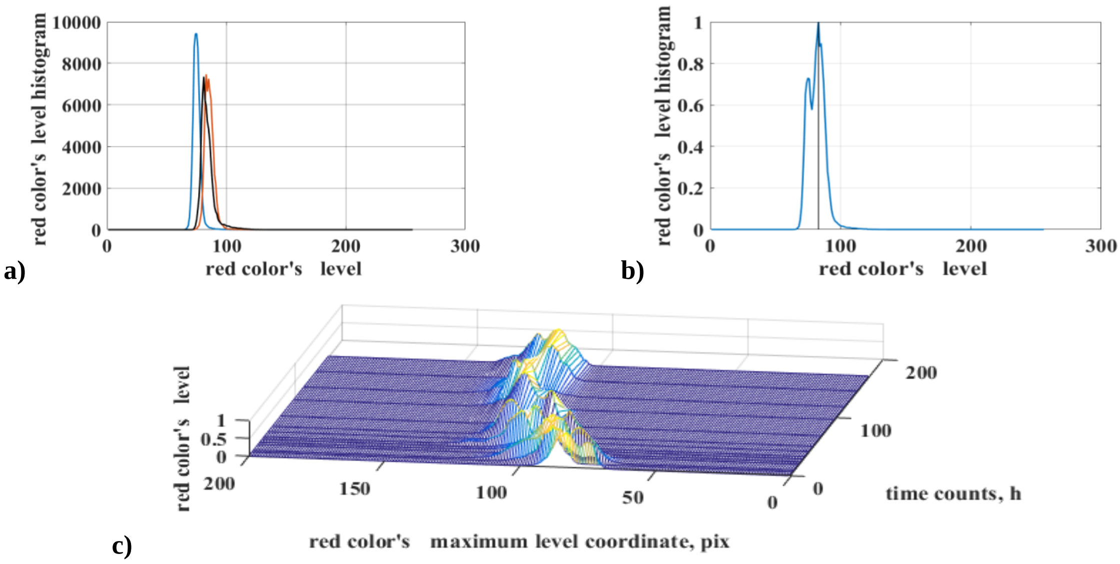


Fig. 4 Red color distribution histograms in the RGB color system for three cuts of meat after 12 hours of cold storage: a) for each cut; b) averaged (coordinate of the red color maximum level 84); c) visual representation

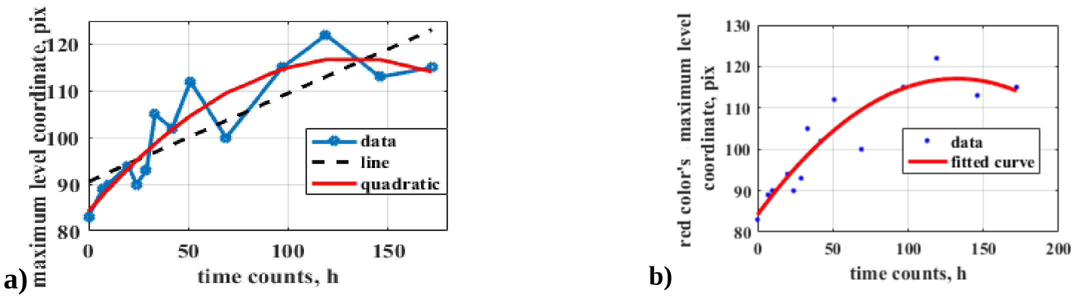


Fig.5 Point dependence (a) and analytical dependence (data) (b) of values of the coordinates of the red color maximum intensity from the time of obtaining samples

When creating a method for analyzing color digital images, scanned cuts of chilled flesh of beef (see Figure 1) were used as inputs. They were being made in certain (irregular) intervals of time for eight days (see Table 1). The developed method for analyzing digital images of muscle tissue beef samples in the color coordinate space RGB consists of three stages. Modeling of the stages of the methodology was carried out using the Matlab software environment.

Stage 1. Receiving fixed-size input images for further analysis. At each one of the presented images of meat cut samples (Fig. 1), 256×256 pixels were selected in an arbitrary manner (in Table 2, the samples of the incoming images were magnified by 4 times). The complete input set consisted of 74 output images

Stage 2. Construction of red color distribution histograms in the RGB color system. For all fragments corresponding to a certain time of storage, red color distribution histograms were constructed in the color system RGB (Fig. 4a). Further, the histogram values were averaged and normalized, resulting in the maximum value of the component R not exceeding 1. For each averaged histogram, the coordinate of the maximum intensity is determined (Fig. 4b). Figure 4c shows the spatial distribution of the maximum intensity of the red color component, depending on the time of receipt, built on the basis of all averaged histograms.

Stage 3. *Construction of the point and analytical dependence (data) of values of the coordinates of the red color maximum intensity from the time of obtaining the samples* (table 1). During a computer experiment based on the results of processing a test sample of 74 images of meat cuts and the analysis of the spatial distribution of the red color component, the point graphic dependence was constructed of the values of the coordinates of the red color maximum intensity from the time of obtaining the samples. The experimental data obtained were smoothed by the first and second order polynomials. The smoothing by the second order polynomial secured a lower mean square error of approximation as compared with the linear approximation. It was an average of 5.6% of the minimum value of the coordinate of the maximum level of the red color component in the color coordinate space RGB (Fig. 5).

In accordance with the received dependence – the spatial distribution of the red color component depending on the time of obtaining the samples (Fig. 4 and Fig. 5), we can assume that during 120 hours of being stored in meat, as a result of biochemical processes, not only oxygen is released, but other gases as well (including carbon dioxide) that oxidize myoglobin and are responsible for a dark color of muscle tissue [1,16]. Most intensively these processes go on before the onset of rigor mortis. Over time, the intensity of red color increases, which is accompanied by the decomposition of the formed forms of myoglobin and the appearance of MbO_2. When stored for more than 140 hours, there is a deeper oxidation of iron with the formation of methyoglobin, the brightness of the meat decreases. It can be assumed that, after 120 hours of cold storage in the muscle tissue, glycolytic transformations are almost fully completed by the influence of enzymes. With prolonged storage, hydrolytic enzymes are activated, and highly reactive compounds are formed – hydrogen sulfide, ammonia and others that are capable of oxidizing myoglobin to methymogon, with a change in the red color intensity.

Using the method of scanning muscle tissue cuts in the production environment with further information processing of images will allow obtaining data on the degree of development of autolytic changes in meat and determining the direction of its use. This method can be recommended for differentiated sorting of beef as to the defects of DFD, RSE at a certain time point.

However, to obtain objective results using this method of assessing the quality of meat by color characteristics, it is necessary to have regional databases on the color of raw materials, depending on age, on methods of fattening, slaughter, refrigeration.

Conclusions

1. Selected muscle tissue samples were taken from half-carcasses of Holstein bulls, aged 15 months. The kinetics of the changes in the pH and temperature of beef during cold storage has been studied. It has been found that a higher rate of temperature change in *m. Longissimus dorsi* contributes to the slowdown in the activity of the enzyme system of muscle tissue, and, accordingly, provides less intense reduction of pH. And vice versa, in the pelvis, temperature decreases more slowly, so the activity of enzymes contributes to the intense reduction of pH.

2. The method of analysis has been developed for digital images of specimens of beef muscle tissue in the color coordinate space RGB so as to study beef's color characteristics during cold storage. It has been established that the use of the suggested method, when smoothing with a second order polynomial, provides a mean square error approximation of 5.6 % on the average, from the minimum value of the coordinate of the red color component maximum level, which confirms its objectivity when used to assess the color of the meat. An analytical dependence has been established between the color of beef and the term of refrigerated storage with the use of information technologies, according to which it is determined that due to biochemical processes, there is an intense oxidation of myoglobin, which provides a dark color of the muscle tissue. Over time, the intensity of red increases up to 120 hours of storage, which is accompanied by the decomposition of the formed forms of myoglobin and the appearance of MbO_2. When stored for more than 140 hours, a deeper oxidation of iron be-

gins with the formation of methyoglobin, the brightness of the meat decreases.

3. The developed method allows automating the processes of registration and processing of images of muscle tissue in real time, increases the productivity of the assessment, and gives an opportunity to obtain objective reliable results about the properties of meat during storage. It is recommended for application in systems of automated processing of digital images of cuts of meat while conducting an assessment of its quality, as well as the development of colorimetric analyzers.

List of references:

1. Жаринов А.И. Основы современных технологий переработки мяса: Краткий курс. Часть 1: Эмульгированные и грубоизмельченные мясопродукты. Фирма «Протеин Технолоджиз Интернэшнл» (США) /Под ред. Воякина М.П. – Москва: «Протеин Технолоджиз Интернэшнл» (США), 1994. 154 с.
2. Сазонов Ю.Г., Панкратов К.Г. Перспективы метода спектроскопии в ближней инфракрасной области для анализа сельскохозяйственных объектов // Мясные технологии. 2012. №10. С.20-24.
3. Зінченко В.В. БИК-анализ в определении качества // Мясное дело. 2012. №5. С.12-14.
4. Богомолов М.П. Спектральный анализ качества // Мясное дело. 2012. №6. С.4-5.
5. Bruce W. et al. Prediction of Meat Quality: application of hyperspectral imaging and Raman spectroscopy // Quality Report No. CMS/REP/114446/1, V. 2. P 1-57
6. Prieto N., Roehe R., Lav´ın P., Batten G., Andr´es S. Application of near infrared reflectance spectroscopy to predict meat and meat products quality: a review // J Meat Sci. 2009. Vol. 83(2). P.175-86. DOI:10.1016/j.meatsci.2009.04.016
7. Prieto N., Navajas E., Richardson R., Ross D., Hyslop J., Simm G., Roehe R. Predicting beef cuts composition, fatty acids and meat quality characteristics by spiral computed tomography // J Meat Sci. 2010. Vol. 86(3). P. 770-9. DOI: 10.1016/j.meatsci.2010.06.020.
8. Fabıola Manhas Verbi Pereira, Sergio Bertelli Pflanzer, Thaısa Gomig, Carolina Lugnani Gomes, Pedro Eduardo de Felıcio, Luiz Alberto Colnago. Fast determination of beef quality parameters with time-domain nuclear magnetic resonance spectroscopy and chemometrics // J Talanta. 2013. Vol. 108. P. 88-91. https://doi.org/10.1016/j.talanta.2013.02.070
9. Correa C.C., Forato L.A., Colnago L.A. 2009. High-throughput non-destructive nuclear magnetic resonance method to measure intramuscular fat content in beef // J Anal Bioanal Chem. 2009. Vol. 393(4). P.1357-60. DOI: 10.1007/s00216-008-2526-6.
10. Cozzolino D., Murray I. Effect of sample presentation and animal muscle species on the analysis of meat by near infrared reflectance spectroscopy // J Near Infrared Spectrosc. 2002. Vol. 10(1). P.37-44. https://doi.org/10.1255/jnirs.319
11. Dow D., Wiegand B., Ellersieck M., Lorenzen C. Prediction of fat percentage within marbling score on beef longissimus muscle using 3 different fat determination methods // J Anim Sci. 2011. Vol. 89(4), P. 1173-9. doi: 10.2527/jas.2010-3382.
12. Шлейкин А.Г. Внедрение новых методов контроля на отечественных предприятиях // Мясной бизнес. 2013. №10. С. 10-11.
13. Weiwei Cheng, Jun-Hu Cheng, Da-Wen Sun, Hongbin Pu. Marbling Analysis for Evaluating Meat Quality: Methods and Techniques // J Comprehensive Reviews in Food Science and Food Safety. 2015. Vol. 14., P. 523-535 doi: 10.1111/1541-4337.12149
14. Кулаков А.А., Кулакова С.А. О возможности использования сканеров в химическом и биохимическом анализе // Материалы докладов III международной научно-практической конференции «Фундаментальная наука и технологии - перспективные разработки». North Cgarleston, USA, 2014. С. 88-95.
15. Антипова Л.В., Глотова И.А, Рогов И.А. Методы исследования мяса и мясных продуктов. Москва: Колос, 2001. 571 с.
16. Кудряшов Л.С. Физико-химические и биохимические основы производства мяса и мясных продуктов. СПб: ДеЛи принт, 2008. 160 с.
17. Фейнер Г. Мясные продукты. Научные основы, технологии, практические рекомендации. СПб: Профессия, 2010. 720 с.
18. Савінок О.М. Термогравіметричні дослідження яловичини при дозріванні // Харчова наука і технологія. 2011. № 2(15). Р. 113-115
19. Савинок О.Н., Рыжов С.А., Косой В.Д., Пудов М.А. Кинетика зависимости функциональных показателей мяса от продолжительности его выдержки после убоя животного // Хранение и переработка сельхозсырья. 2014. № 4. С. 35-41
20. Алейников А.Ф., Пальчикова И.Г., Смирнов Е.С. Оценка качества мяса птицы по результатам анализа его цветовых характеристик // Вычислительные технологи. 2016. Том 21(1). С. 27-40.
21. Lisitsyn A.B., Kozyrev I.V. Researching of meat and fat colour and marbling in beef // Теория и практика переработки мяса. 2016. № 4, С. 51-56. DOI 10.21323/2414-438X-2016-1-4-51-56
22. Фисенко В.Т., Фисенко Т.Ю. Компьютерная обработка и распознавание изображений. СПб: СПбГУ ИТМО; 2008. 256с.

References:

1. Zharinov AI. Osnovyi sovremennyih tehnologiy pererabotki myasa: Kratkiy kurs. Chast 1: Emulgirovannyie i gruboizmelchennyie myasoproduktyi. Firma «Protein Tehnolodzhiz Interneshnl» (SShA); 1994
2. Sazonov YuG, Pankratov KG. Perspektivyi metoda spektroskopii v blizhney infrakrasnoy oblasti dlya analiza selskohozyaystvennyih ob'ektov. Myasnyie tehnologii. 2012; 10:20-24
3. Zinchenko VV. Bik-analiz v opredelenii kachestva. Myasnoe delo. 2012; 5:12-14.
4. Bogomolov MP. Spektralnyiy analiz kachestva. Myasnoe delo. 2012; 6: 4-5.
5. Bruce W. Mossa et al. Prediction of Meat Quality: application of hyperspectral imaging and Raman spectroscopy.Quality Report No. CMS/REP/114446/1; 2: 1-57.
6. Prieto N, Roehe R, Lav´ın P, Batten G, Andr´es S. Application of near infrared reflectance spectroscopy to predict meat and meat products quality: a review. J Meat Sci. 2009; 83(2):175–86. DOI: 10.1016/j.meatsci.2009.04.016.
7. Prieto N, Navajas E, Richardson R, Ross D, Hyslop J, Simm G, Roehe R. Predicting beef cuts composition, fatty acids and meat quality characteristics by spiral computed tomography. J Meat Sci. 2010; 86(3):770-9. DOI: 10.1016/j.meatsci.2010.06.020.
8. Fabıola Manhas Verbi Pereira, Sergio Bertelli Pflanzer, Thaısa Gomig, Carolina Lugnani Gomes, Pedro Eduardo de Felıcio, Luiz Alberto Colnago. Fast determination of beef quality parameters with time-domain nuclear magnetic resonance spectroscopy and chemometrics. J Talanta. 2013; 108: 88-91 https://doi.org/10.1016/j.talanta.2013.02.070 .
9. Correa CC, Forato LA, Colnago LA. High-throughput non-destructive nuclear magnetic resonance method to measure intramuscular fat content in beef. J Anal Bioanal Chem. 2009; 393(4):1357-60. DOI: 10.1007/s00216-008-2526-6. Epub 2008 Nov 30.
10. Cozzolino D, Murray I. Effect of sample presentation and animal muscle species on the analysis of meat by near infrared reflectance spectroscopy. J Near Infrared Spectrosc. 2002; 10(1):37-44. https://doi.org/10.1255/jnirs.319.

11. Dow D, Wiegand B, Ellersieck M, Lorenzen C. Prediction of fat percentage within marbling score on beef longissimus muscle using 3 different fat determination methods. J Anim Sci. 2011; 89(4):1173-9. doi: 10.2527/jas.2010-3382. Epub 2010 Nov 26.
12. Shleykin AG. Vnedrenie novyih metodov kontrolya na otechestvennyih predpriyatiyah. Myasnoy biznes. 2013; 10:10-11.
13. Weiwei Cheng, Jun-Hu Cheng, Da-Wen Sun, Hongbin Pu Marbling. Analysis for Evaluating Meat Quality: Methods and Techniques J Comprehensive Reviews in Food Science and Food Safety. 2015; Vol.14:523-535. DOI: 10.1111/1541-4337.12149.
14. Kulakov AA, Kulakova SA. O vozmozhnosti ispolzovaniya skanerov v himicheskom i biohimicheskom analize. Materialyi dokladov III mezhdunarodnoy nauchno-prakticheskoy konferentsii «Fundamentalnaya nauka i tehnologii - perspektivnyie razrabotki». North Cgarleston, USA. 2014: 88-95.
15. Antipova LV, Glotova IA, Rogov IA. Metodyi issledovaniya myasa i myasnyih produktov. Kolos; 2001.
16. Kudryashov LS. Fiziko-himicheskie i biohimicheskie osnovyi proizvodstva myasa i myasnyih produktov. DeLi print; 2008.
17. Feyner G. Myasnyie produktyi. Nauchnyie osnovyi, tehnologii, prakticheskie rekomendatsii. Professiya; 2010.
18. Savinok OM. Termohravimetrychni doslidzhennia yalovychyny pry dozrivanni. J. Kharchova nauka i tekhnolohiia. 2011; 2(15):113-115.
19. Savinok ON, Ryizhov SA, Kosoy VD, Pudov MA. Kinetika zavisimosti funktsionalnyih pokazateley myasa ot prodolzhitelnosti ego vyiderzhki posle uboya zhivotnogo. J. Hranenie i pererabotka selhozsyirya. 2014; 4:35-41
20. Aleynikov AF, Palchikova IG, Smirnov ES. Otsenka kachestva myasa ptitsyi po rezultatam analiza ego tsvetovyih harakteristik. J Vyichislitelnyie tehnologii. 2016; 21 (1): 27-40.
21. Lisitsyn AB, Kozyrev IV. Researching of meat and fat colour and marbling in beef. J. Teoria I praktika pererabotki myasa. 2016; 4:51-56. DOI 10.21323/2414-438X-2016-1-4-51-56.
22. Fisenko VT, Fisenko TYu. Kompyuternaya obrabotka i raspoznavanie izobrazheniy. SPb: SPbGU ITMO; 2008.

Отримано в редакцію 14.05.2018 Received 14.05.2018
Прийнято до друку 04.09.2018 Approved 04.09.2018

Цитування згідно ДСТУ 8302:2015
Savinok O., Azarova N., Arsiriy O., Nikolenko A. Determination of functional and technological properties of beef based on the analysis of color digital images of muscular tissue samples // Food science and technology. 2018. Vol. 12, Issue 3. P. 88-96. DOI: http://dx.doi.org/10.15673/fst.v12i3.1044

Cite as Vancuver ctyle citation
Savinok O, Azarova N, Arsiriy O, Nikolenko A. Determination of functional and technological properties of beef based on the analysis of color digital images of muscular tissue samples. Food science and technology. 2018; 12(3): 88-96. DOI: http://dx.doi.org/10.15673/fst.v12i3.1044