UDC 53.06. 637

DOI: 10.21323/2414–438X-2019–4–1-4-8
Original scientific paper

THE INFLUENCE OF IONIZING RADIATION ON THE THERMOPHYSICAL PROPERTIES OF MEAT FROM THE BROILER CHICKENS WITH DIFFERENT STRESS RESISTANCE

Roza T. Timakova[1], **Sergey L. Tikhonov**[1], **Natal'ya V. Tikhonova**[1], **Sergey V. Shikhalev**[1], **Leonid S. Kudryashov**[2*]
[1]Ural State Economic University, Ekaterinburg, Russia
[2]V.M. Gorbatov Federal Research Center for Food Systems of Russian Academy of Sciences, Moscow, Russia

Keywords: *stress-resistant and stress-sensitive broiler chickens, ionizing radiation, thermophysical properties*

Abstract

The studies on the influence of radiation treatment of carcasses from the stress-resistant and stress-sensitive broiler chickens on the thermophysical properties of raw meat are presented. An increase in thermal diffusivity of meat from the stress-resistant poultry by 24.7 % and 54.7 % after radiation treatment of carcasses with ionizing radiation doses of 9 kGy and 12 kGy, respectively, was established. In meat from the stress-sensitive poultry, this figure increased by 33.3 % and 35.8 % compared to the untreated carcasses.

It is shown that radiation treatment of carcasses by applied doses increased the thermal conductivity coefficient of meat from the stress-resistant poultry by 5.3% and 7.0 %; in meat from the stress-sensitive poultry, this figure increased by 2.0 and 6.2 times compared to meat from the carcasses not exposed to radiation. At the same time, the value of the heat capacity coefficient was reduced.

The irradiated poultry meat samples accumulate energy of ionizing radiation more intensively, which allows the intensification of the thermal processes occurring at various stages of meat product production. Treatment of meat from the stress-resistant poultry with ionizing radiation can reduce the amount of meat with non-traditional autolysis due to changes in its functional-technological properties. The results of the research should be taken into account in technological processes in the production of meat products with non-traditional autolysis.

Introduction

The task of maximum preservation of food raw materials and food products at all stages of their production and storage takes on great significance. Meat and meat products are perishable produce. Therefore, it is necessary to chill them as soon as possible to minimize the growth of bacterial pathogens and store them at a low temperature to ensure microbiological safety.

The methods of poultry carcass chilling (water or air) and thermophysical properties of meat raw materials affect the post mortem changes in meat and, therefore, the quality of manufactured products. High rates of carcass chilling at the initial stage of the technological cycle can cause the so-called cold shortening of muscles; as a consequence, meat becomes tough during the whole period of post mortem storage. Fast chilling of carcasses can facilitate occurrence of meat with non-traditional properties, in particular, DFD meat. To improve the functional-technological properties of meat with DFD and PSE defects, manufacturers use different phosphate containing additives, salts of organic acids, different methods of meat chilling, electrical stimulation and so on [1,2,3,4,5].

According to the data of several authors [6], the physical parameters of meat such as the thermal conductivity coefficient, thermal diffusivity and specific heat are influenced by stress resistance of animals and poultry. It is associated with the fact that animals and poultry with different stress resistance are characterized by the different ratio of the muscle and fatty tissues, ratio of free and bound moisture, which have different thermophysical properties.

It is known that DFD meat is unstable in storage due to the high pH value and possible rapid contamination by microorganisms.

One of the promising methods for increasing shelf-life of meat raw materials, including meat with DFD properties can be its treatment with ionizing radiation according to GOST 33820–2016 "Fresh and frozen red meat. Guidance for irradiation to control parasites, pathogens and other microorganisms" and GOST 33825–2016 "Packed semi-finished meat. Guidance for irradiation to control parasites, pathogens and other microorganisms". The use of radiation treatment can significantly increase meat shelf life at low energy and material expenses compared to traditional methods [7,8,9,10]. Treatment with ionizing radiation of initial meat raw materials ensures microbiological stability and allows increasing shelf life of vacuum-packed meat semi-finished products by more than 3 times [11,12]. Moreover, meat treatment with ionizing radiation has a positive effect on ageing process. The mechanism of action of ionizing radiation on the biochemical processes of meat

FOR CITATION: Timakova R.T., Tikhonov S.L., Tikhonova N.V., Shikhalev S.V., Kudryashov L.S. The influence of ionizing radiation on the thermophysical properties of meat from the broiler chickens with different stress resistance. *Theory and practice of meat processing*. 2019;4(1): 4-8. DOI: 10.21323/2414–438X-2019–4–1-4-8

ageing can be presented as follows. According to the law of conservation of energy "Energy does not disappear and is not created, but transforms from one form into another". The energy of ionizing radiation is absorbed by the muscle tissue, which contains a significant amount of water with dissolved proteins, nucleic acids, enzymes, hormones and other biologically active substances, which leads to its radiolysis (a process of radiation destruction) [13] and correspondingly, to the intensive destruction of protein substances [14] both under the action of radiation per se and by the action of the radiation-activated tissue proteolytic enzymes, to which the energy that was initially absorbed by water is transferred. One of the main conditions for manifestation of the activity of the radiation-activated tissue proteolytic enzymes throughout a product volume is a uniform temperature of the muscle tissue, which determines the thermophysical characteristics of meat. The ionizing radiation is one of the means of heat (energy) transfer, and radiation treatment of meat allows the even distribution of heat obtained by the muscle tissue ensuring the same activity of tissue enzymes in all layers of the muscle tissue, which is important for reducing meat ageing duration and preventing uncharacteristic changes of the muscle tissue in the process of autolysis.

The above-mentioned hypothesis can be explained by the ability of ionizing radiation to activate proteolytic reactions, occurring in the muscle tissue under the effect of cathepsins and calpains, which leads to an increase in the number of free carboxyl and amino groups in the protein molecule, and increases hydration and tenderness of meat. Swelling of connective tissue collagen and muscle tissue proteins increases an amount of bound moisture, correspondingly, influences the thermal conductivity coefficient of meat raw materials [15].

In this connection, the aim of this work is to study an effect of different doses of ionizing radiation on the thermophysical properties of meat from broiler chickens with different stress resistance.

Objects and methods

The objects of the research were the meat samples from broiler chickens, which were chilled to an internal temperature in muscles of -2 °C to 4 °C inclusively (according to GOST 31962–2013 "Chicken meat (carcasses of chickens, broiler-chickens and their parts"). The meat samples were taken from male Arbor Acres broiler chickens (42-day-old) raised in the Bektysh poultry farm and divided into two groups by phenotypical traits using the method of balanced analogous groups: stress-resistant chickens (SRC) and stress-sensitive chickens (SSC). Stress resistance of broiler chickens was determined by the method described in [16]. Poultry keeping and feeding corresponded to the zoohygienic requirements and recommendations of the All-Russian Research and Technological Institute of Poultry upon cage technology of chicken keeping.

For the experiment, six groups of meat were formed: group 1 (control) – the meat samples from the stress-resistant birds (not treated with ionizing radiation); group 2 (experimental) – the meat samples from the stress-resistant birds treated with a dose of 9 kGy; group 3 (experimental) – the meat samples from the stress-resistant birds treated with a dose of 12 kGy; group 4 (control) – the meat samples from the stress-sensitive birds (not treated with ionizing radiation); group 5 (experimental) – the meat samples from the stress-sensitive birds treated with a dose of 9 kGy; group 6 (experimental) – the meat samples from the stress-sensitive birds treated with a dose of 12 kGy.

Ionizing radiation treatment was carried out in the Center of radiation sterilization of the Ural Federal University named after B.N. Yeltsin on the electron linear accelerator (UELR-10-10C2 model) with the energy of up to 10 MeV at doses of 9 and 12 kGy. The experiments were carried out with five replications.

To determine the thermophysical characteristics based on the thermal conductivity coefficient, thermal diffusivity and specific heat coefficient, the method of the regular regime of chilling by G.M. Kondratiev was used [17].

Boneless meat tissue of broiler chickens was sampled by GOST R "Meat and meat products. Methods of primary sampling". During the experiment, poultry meat samples were minced to forcemeat condition according to the requirements of GOST R 55365–2012 "Minced meat. Specifications."

Experimental investigations were carried out on the pilot unit [16] (Figure 1) consisted of the α-calorimeter 7 in a form of a spherical copper jacket with minced poultry meat under investigation, thermostat 1 with a lid 2, agitator with a drive 6, chromel-copel thermocouples 3 to detect a temperature in samples and refrigerating (water/air) media, potentiometer 4 of the precision class 0.25 with incubation of the free ends of the thermocouples and the control thermocouple.

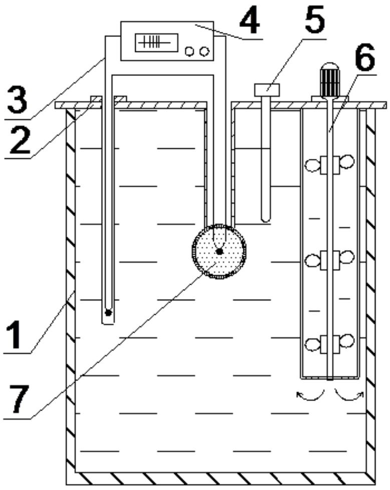

Figure 1. Schematic diagram of the pilot unit: 1 - thermostat; 2 - lid; 3 - differential thermocouple; 4 - potentiometer; 5 - thermometer; 6 - agitator; 7 - calorimeter

Figure 2 presents a schematic layout of the spherical calorimeter used in the pilot unit.

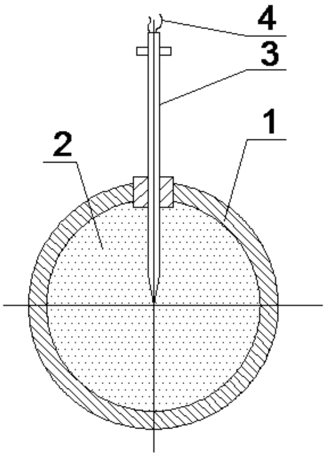

Figure 2. Spherical calorimeter: 1 - calorimeter jacket; 2 – product under investigation; 3 – protective tube; 4 - thermocouple

After heating and incubation of the calorimeter to a temperature that did not exceed the temperature of denaturation of thermally labile meat muscle proteins, it was chilled in a liquid thermostat at an intensive agitation using an agitator; that is, the conditions were created under which thermal diffusivity from the calorimeter surface to the refrigerating medium had high values close to [17]. In this case, thermal diffusivity can be determined from the transcendent equation for a sphere

$$a = m_{\infty}\left(\frac{R}{\pi}\right)^2, \qquad (1)$$

where R – is the radius of the calorimeter (copper sphere); m∞ - the chilling rate.

The m∞ value was determined on the basis of the graphic dependence of the excess temperature in the semi-logarithmic coordinates.

Determination of the thermal conductivity coefficient was carried out on the stand unit (Figure 3) consisted of the λ-calorimeter 5 in a form of a spherical copper jacket with minced poultry meat under investigation, air-bath thermostat 4 with a fan 3, chromel-copel thermocouples 1 and potentiometer 2 of the precision class ±0.25% with incubation of the free ends of the thermocouples.

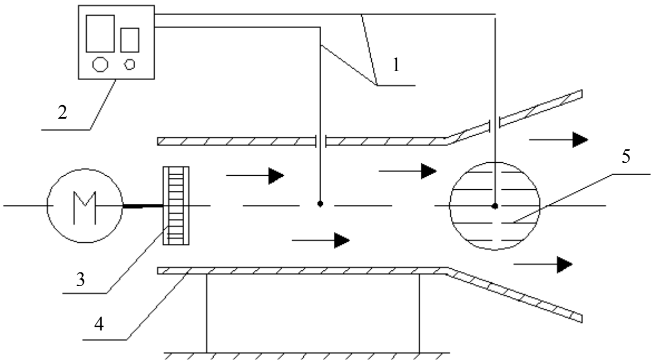

Figure 3. Stand for determination of the coefficient of thermal conductivity: 1-chromel-copel thermocouples; 2- potentiometer; 3- fan; 4- air-bath thermostat; 5-λ- calorimeter

In this case, the thermal conductivity coefficient is determined by the characteristic equation for a sphere:

$$\lambda = \frac{\overline{\alpha} \cdot R}{1 - R \cdot \sqrt{\frac{m}{a}} \cdot ctg\left(R\sqrt{\frac{m}{a}}\right)}, \qquad (2)$$

where m – the chilling rate at these conditions, determined by the above-mentioned method;

$\overline{\alpha}$ - thermal diffusivity, determined on the reference calorimeter by the method of comparison with a sample having the known thermal conductivity coefficient.

To determine the specific heat capacity, the method of the comparative chilling of the control and experimental samples of minced poultry meat was used, where the flour of the higher grade with the known thermal conductivity coefficient was used as a reference by obtaining the chilling curves in a time interval. Calculations were made by the equation:

$$\tilde{n}_m \frac{\partial t_m}{\partial \tau} = \tilde{n}_r \frac{\partial t_r}{\partial \tau}, \qquad (3)$$

where $c_{m,} c_r$ – the coefficients of the specific heat capacity of the sample (poultry meat) and reference (flour);

$t_{m,}$ t_r – a temperature of the sample (poultry meat) and reference.

As the experiments showed, thermal diffusivity of minced poultry meat increased when the temperature decreased, which is consistent with the published data [18].

The statistical processing of the research results was carried out using the standard computer programs Microsoft Excel XP, Statistica 8,0.

Results and discussion

The results of the performed investigations are graphically presented in Figure 4 and Figure 5, and in Table 1.

It was established that upon minced meat chilling in a liquid and air-bath thermostat, the chilling rate of the meat samples from the stress-sensitive birds of the 4th (control), 5th (experimental) and 6th (experimental) groups was lower than in the samples from the stress-resistant birds (1st, 2nd and 3rd groups) (Figure 4 and Figure 5). As the obtained results indicate, minced meat treatment with ionizing radiation at doses of 9 and 12 kGy allows increasing thermal diffusivity of minced meat from the stress-resistant birds by 24.7 % and 54.7 %, and from the stress-sensitive birds by 33.3 % and 35.8 %, respectively.

It is necessary to note that in the irradiated samples from the stress-sensitive birds, the values of thermal diffusivity increased to the levels that corresponded to the non-irradiated minced meat from the stress-resistant birds. For example, in the samples from the stress-sensitive birds of the 5th and 6th experimental groups with the irradiation doses of 9 kGy and 12 kGy, thermal diffusivity reached and exceeded the value of this indicator in the non-irradiated stress-resistant birds from the 1st group.

Table 1. Changes in the thermophysical properties of meat from birds with different stress resistance upon processing with ionized radiation (n=5)

Thermophysical parameter	Stress-resistant poultry			Stress-sensitive poultry		
	Without treatment (group1)	Irradiation dose 9 kGy (group 2)	Irradiation dose 12kGy (group 3)	Without treatment (group 4)	Irradiation dose 9 kGy (group 5)	Irradiation dose 12kGy (group 6)
Thermal diffusivity, m^2/s	$7.3 \bullet 10^{-8}$	$9.1 \bullet 10^{-8}$	$11.29 \bullet 10^{-8}$	$5.89 \bullet 10^{-8}$	$7.85 \bullet 10^{-8}$	$8.0 \bullet 10^{-8}$
Thermal conductivity coefficient, W/(m•K)	0.57	0.60	0.61	0.098	0.20	0.306
Specific heat coefficient, J /(kg•K)	5321	4670	4317	4358	4843	3995

*reference values of minced meat from broiler chickens ā=10.9•10-8m2/s. λ=0.41W/(m•K), cp = 3559 J/(kg•K) [17].

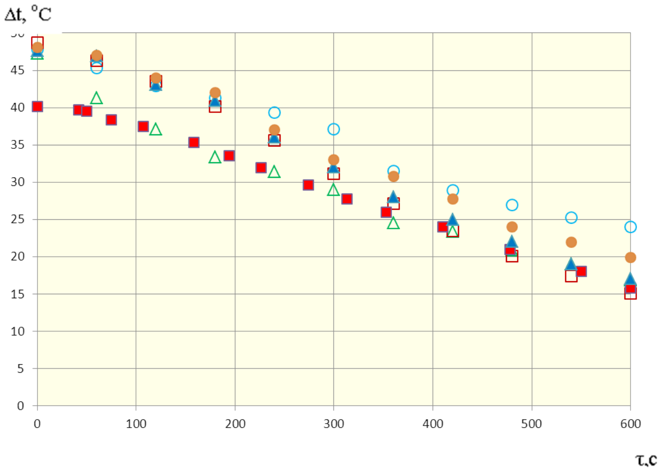

Figure 4. Chilling rate of the poultry minced meat samples in the liquid thermostat : ●– control group 1 (SRC); ▲ – experimental group 2 (SRC) (9 kGy); □– experimental group 3 (SRC) 3 (12 kGy); ○– control group 4 (SSC); Δ – experimental group 5 (SSC) (9 kGy); ■– experimental group 6 (SSC) (12 kGy) Spherical calorimeter: 1 - calorimeter jacket; 2 – product under investigation; 3 – protective tube; 4 - thermocouple

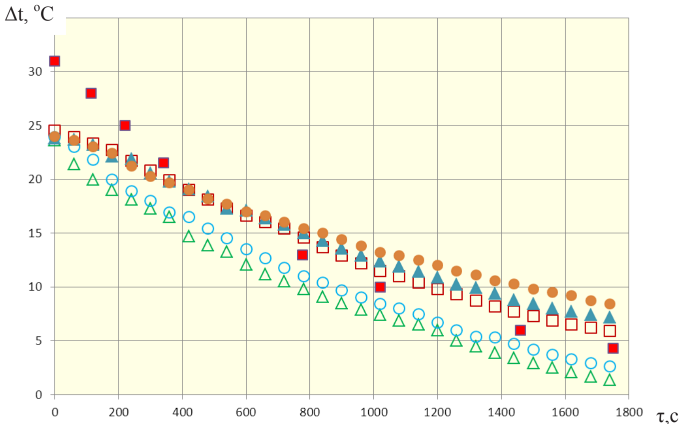

Figure 5. Chilling rate of the poultry minced meat samples in the air-bath thermostat: ●– control group 1 (SRC); ▲ – experimental group 2 (SRC) (9 kGy); □– experimental group 3 (SRC) (12 kGy); ○– control group 4 (SSC); Δ – experimental group 5 (SSC) (9 kGy); ■– experimental group 6 (SSC) (12 kGy)

It is possibly associated with the fact that after exposure of meat to ionizing radiation, the chain reactions of ionization are activated and excitation of atoms occurs with the development of different products of water radiolysis: hydroxyl radicals, hydrated electrons and hydrogen atoms having the high reaction capacity. According to the available information [19,20], the observed change in the moisture binding capacity and moisture content in the studied samples of minced meat is a key factor of the changes in the thermal diffusivity value.

Analysis of the experimental values of the thermal conductivity coefficient showed that meat from the stress-resistant birds was characterized by the high ability to conduct the amount of heat. Moreover, as a result of irradiation of the meat samples from the stress-resistant broiler chickens with a dose of 12 kGy, the value of the thermal conductivity coefficient increased by 7.0 % compared to the non-treated samples, in meat from the stress-sensitive birds by 6.2 times, respectively. As can be seen from table 1, ionizing radiation had the most significant effect on the value of the thermal conductivity coefficient of meat from the stress-sensitive birds. In our opinion, an increase in λ could be influenced by the total fat content in the muscle tissue, which thermal conductivity is three times lower than thermal conductivity of the meat muscle tissue [21]. For example, it was found in [16] that the stress- sensitive broiler chickens had somewhat larger depositions of subcutaneous fat compared to the stress-resistant birds.

The specific heat coefficients of the meat samples from the stress-sensitive birds had lower values compared to the corresponding samples from the stress- resistant birds. The value of the specific heat coefficient of the meat samples from groups 4, 5 and 6 was 22.1 %, 3.7 % and 8.1 % lower compared to the samples of the stress-resistant birds from groups 1, 2 and 3, respectively. With that, a decrease in the specific heat coefficient was observed practically in all six groups of the meat samples depending on a dose of ionizing radiation, which can be explained by a decrease in the humidity and fat content in irradiated poultry meat [21].

After meat treatment with ionizing radiation, a positive effect on the organoleptic indicators was noticed. For example, the consistency of the meat samples from the stress-sensitive broiler chickens became firmer, their moisture content decreased, correspondingly, the signs of meat with uncharacteristic autolysis (PSE) were leveled.

Conclusions

Therefore, as the results of the investigations showed, irradiation differently affected the change in the thermophysical properties of meat from the stress-resistant and stress-sensitive broiler chickens. After treatment with ionizing radiation with doses of 9 kGy and 12 kGy, it was found that thermal diffusivity increased by 24.7 % and 54.7 % in the meat samples from the stress-resistant birds and by 33.3 % and 35.8 % in the meat samples from the stress-sensitive birds, respectively, compared to the untreated poultry meat samples.

An increase in the coefficients of heat conductivity by 5.3 % and 7.0 % was found in meat from the stress-resistant birds and by 2.0 and 6.2 times in meat from the stress-sensitive birds depending on the dose of irradiation upon a decrease in the value of the of heat capacity coefficient.

The irradiated meat samples more intensively accumulate the energy of ionizing radiation, which allows intensification of thermal processes occurred at different technological stages of meat product manufacture. Processing of meat from stress-sensitive birds with ionizing radiation allows decreasing quantity of meat with non-traditional autolysis due to the changes in its functional and technological properties. It is necessary to take into account the obtained results of the investigations in the technological processes when manufacturing products from meat with uncharacteristic autolysis as well as in automation of processes of chilling and thermal processing of minced meat, smoked products and other meat products from irradiated raw materials.

REFERENCES

1. Honikel, K.O. (1989). Biochemie, Biophysikund Analiyticdes Fleisches. *Fleischwirtschaft*, 9, 217-221.
2. Lisitsyn, A.B., Kudryashov, L.S., Motovilina, A.A., Goroshko, G.P., Solodovnikova, G.I., Kuznetsova, T.G., Gorbunova, N.A. (2001). Technological aspects of the use of phosphate additives in the production of sausages from beef. *Vsyo o myase*, 2, 3-5. (In Russian)
3. Potoroko, I. Yu., Fatkullin, R. I., Tsirulnichenko, L. A. (2013). The system approach to water treatment technology for food production. *Bulletin of the South Ural State University. Series: Economics and Management*, 7(3), 153–158. (In Russian)
4. Potoroko, I. Yu., Tsirulnichenko, L. A. (2014). Analysis of kinetic regularities of poultry curing with the use of cavitating active liquid media. *Bulletin of the South Ural State University. Series: Food and Biotechnology*, T. 2(3), 21–28. (In Russian)
5. Potoroko I.Yu., Tsirulnichenko L.A., Krasulya O.N. (2015). Study of factors determining quality of broiler chicken meat processing products produced in the ural region and evaluation of their variability. *Economics & Management Research Journal of Eurasia*, 1(5), 53-59.
6. Nogina, A. A., Tikhonov, S. L., Tikhonova, N. V., Miftakhutdinov, A. V., Shelepov, V. G., Ulitin, E.V. (2017). The application of arabinogalactan in the sausage production using meat raw materials with abnormalities in the process of autolysis. *Agro-Industrial Complex of Russia*, 24(1), 160-164. (In Russian)
7. Chiaravalle, A.E., Mangiacotti, M., Marchesani, G., Vegliante, G. (2010). Electron spin resonance (ESR) detection of irradiated fish containing bone (gilthead sea bream, cod, and swordfish). *Veterinary Research Communications*, 149-152. DOI: 10.1007/s11259-010-9374-5
8. Tikhonov, A.V., Anashkin, R.S., Kryukov A.E. (2013). The use of radiation technologies in agricultural production . *Collection of scientific works of GNU SNIIZhK*, 6, 330-333. (In Russian)
9. Drozdova, N.A., Dydykin, A.S., Gorbunova, N.A., Semenova A.A. (2017). Using ionizing and non-ionizing radiation in food industry. *Vsyo o myase*, 1, 16-20. (In Russian)
10. Isamov, N.N., Sanzharova, N.I., Kobyalko,V.O., Kozmin, G.V., Pavlov, A.N., Gubareva, O.S., Polyakova, I.V., Ursu, N.V., Aleshkina, E.N. (2017). Using radiation technologies to provide safety of foods of animal origin. *Vsyo o myase*, 1, 11-15. (In Russian)
11. Timakova, R.T., Tikhonov, S.L., Tikhonova, N.V., Gorlov, I.F. (2018). Effect of Various Doses of Ionizing Radiation on the Safety of Meat Semi-Finished Products. *Foods and Raw Materials*, 6(1), 120-127. DOI: 10.21603/2308-4057-2018-1-120-127
12. Timakova R., Tikhonov S., Tikhonova N. (2018). Ionizing Irradiation of Chilled Meat Raw Materials as the World's Leading Technology. In: Strielkowski W., Chigisheva O. (eds) Leadership for the Future Sustainable Development of Business and Education. Springer Proceedings in Business and Economics. Springer, Cham. DOI: 10.1007/978-3-319-74216-8_63
13. Povorova, O.V. Radioecology: Textbook. – Mogilev: MGU named after A.A. Kuleshov, 2005. [Electronic resource: https://studfiles.net/preview/3217773/ Access date 02.11.2018] (In Russian)
14. Kudryashov, Yu. B., Berehfeld B.S. (1984). Radiation biophysics. M: MGU. – 302 p. (In Russian)
15. Dolganova, N.V., Mizhueva, S.A. (2006). Technology and equipment for processing of fruit, vegetables, meat and hydrobionts. Astrakhan: Astrakhan State Technical University. – 210 p. (In Russian)
16. Kudryashov, L.S., Vaganov, E.G., Shikhalev, S.V., Tikhonov, S.L., Tikhonova, N.V. (2015). Stress resistance and meat quality of broiler chickens. *Meat Industry*, 7, 44-47. (In Russian)
17. Kondratiev, G.M. (1954). Regular thermal conditions. M: Gostekhizdat. – 408 p. (In Russian)
18. Dulger, N.V., Zaripov R.N., Lysova V.N. (2005). Experimental assessment of thermophysical characteristics of products of animal origin. *Vesnik AGTU*, 2(25). – pp. 284-287. (In Russian)
19. Filippov, V.I. (2015). Application of methods of the regular thermal mode for definition of heatphysical characteristics of foodstuff. *Scientific Journal of ITMO University. Series Processes and Equipment for Food Production*, 3, 22-30. (In Russian)
20. Svetlov Yu.V., Nikiforov Yu. B. (2015). Effective thermal conductivity and inner transfer surface of porous and fibrous materials on the example of foodstuffs. *Fine Chemical Technologies*, 10(6), 71-78. (In Russian)
21. Ginsburg, A.S. (1975). Thermophysical characteristics of food products and materials. M: Food Industry, 1975. - pp. 50-51. (In Russian)

AUTHOR INFORMATION

Roza T. Timakova – candidate of agricultural Sciences, docent, Department of tourism and hospitality, Institute of trade, food technologies and service, Ural state University of Economics, 620144, Ekaterinburg, 8-th Marta Str./Narodnoy voli str., 62/45. Tel.:+7-912-247-99-74. E-mail: trt64@mail.ru

Sergey L. Tikhonov – doctor of technical Sciences, Professor, head of Department "Food engineering", Institute of trade, food technologies and service, Ural state University of Economics, 620144, Ekaterinburg, 8-th Marta str./Narodnoy voli str., 62/45. Tel.:+7-912-227-69-89. E-mail: tihonov75@bk.ru

Natal'ya V. Tikhonova – doctor of technical Sciences, docent, Department "Food engineering", Institute of trade, food technologies and service, Ural state University of Economics, 620144, Ekaterinburg, 8-th Marta str./Narodnoy voli str., 62/45. Tel.:+7-912-227-69-89. E-mail: tihonov75@bk.ru

Sergey V. Shikhalev– candidate of technical sciences, docent, Department "Food engineering", Institute of trade, food technologies and service, Ural state University of Economics, 620144, Ekaterinburg, 8-th Marta str./Narodnoy voli str., 62/45 Tel.:+7-922-613-11-09. E-mail: sershih@rambler.ru

Leonid S. Kudryashov – doctor of technical sciences, professor, chief researcher, V.M. Gorbatov Federal Research Center for Food Systems of Russian Academy of Sciences, 109316, Moscow, Talalikhina str., 26. Tel.: +7-903-627-33-06. E-mail: lskudryashov@yandex.ru. *corresponding author

Contribution

Authors equally contributed to the writing of the manuscript and are equally responsible for plagiarism

Conflict of interest

The authors declare no conflict of interest

Received 14.11.2018 **Accepted in revised 11.01.2019** **Accepted for publication 15.02.2019**