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Justification Of The Technology Of Cavitation Massage Meat Delicates From Pork

Keywords: meat processing; pork; ultrasound; massaging meat; cavitation massaging

1. Abstract

The article discusses the methodology and results of experimental studies to determine the optimal modes of cavitation massaging of pork meat delicacies. It has been established that the use of this technology will significantly improve the technological and consumer properties of the finished product: looseness of meat fibers, improved juiciness and tenderness of meat, greater moisture-binding and water-holding capacity and, as a result, a greater yield of finished products (84% versus 75% provided by the standards). According to the results of the study, the optimal parameters of cavitation massaging were: ultrasound frequency 22 kHz, power 150 W. In the process of processing experimental data, a functional dependence of the cavitation massaging duration on the thickness of a piece of meat and the ultrasound power was obtained, which showed that the duration of the operation with the above parameters will be 4-5 minutes when using one-sided ultrasonic meat massagers or 2–2.5 minutes when using bilateral ultrasonic meat masseurs for a separate piece of pork with a thickness of 50-70 mm (carbonade, neck, loin). It was found that the thickness of the meat and the power of ultrasound have the strongest influence on the duration of the massaging operation.

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2. Introduction

Cavitation massaging is a new technology for processing meat delicacies, in which the massaging effect is achieved by the mechanical impact on the meat fibers of shock waves that occur during cavitation when ultrasonic waves pass through the medium.

Ultrasound - elastic mechanical vibrations of ultrasonic frequency, excited and propagated in the medium and representing a periodically alternating compression and rarefaction of the particles of this medium. The range of ultrasonic frequencies extends from 16 kHz and above [5]. The ultrasonic wave graph is shown in Figure 1.

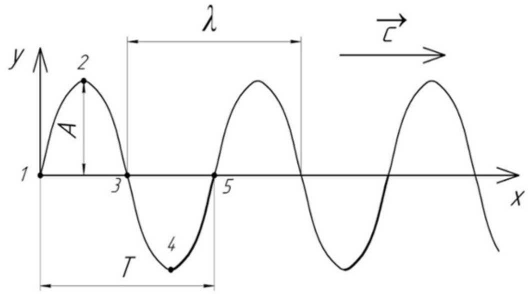

Figure 1. Graph of an ultrasonic wave: A - oscillation amplitude (m), λ - wavelength (m), T - oscillation period (s), s - ultrasonic wave propagation speed (m / s); thickened lines mark areas of cavitation.

Ultrasonic waves can cause significant changes in the physical and chemical state of the medium. The effects caused by the energy of ultrasonic waves can be very diverse, and often unexpected. Radiation and alternating sound pressure (voltage) arise in the medium. This may result in the development of cavitation, the occurrence of acoustic deformation flows, thermal, mechanical, and electrochemical effects.

The active impact of ultrasonic energy causes a number of effects in the working environment – liquids, gases, solid materials (Abramov et al., 1984):

1. Generation and transfer of heat. When ultrasound propagates in any medium, energy losses are inevitable, which are converted into heat.
2. Cavitation. From fig. 1 shows that:

   - on segment 1-2, the medium is compressed, the peak value of compression is reached at point 2, corresponding to the amplitude of the positive half-cycle;

   - on segment 2-3, the medium is stretched, returning to its original state at point 3, corresponding to the half-cycle of the oscillation;

   - on segment 3-4, the medium continues to stretch, while micro-ruptures of the medium (cavitational bubbles) appear, which reach their maximum size and maximum number at point 4, corresponding to the amplitude of the negative half-cycle;

   - in the segment 4-5, the medium is again compressed, while the cavitation bubbles collapse, forming shock waves with a pressure of up to 100 MPa. This process is called cavitation. At point 5, corresponding to the oscillation period, the medium returns to its original state.

   Cavitation leads to erosion of materials, and in combination with other effects causes dispersion, homogenization, emulsification, and intensifies diffusion, and other physical and chemical processes. It is this which causes the massaging effect in the processing of meat: under the influence of shock waves, the meat fibres are loosened, acquiring a microcellular structure. The consequence of such a change in the structure of meat fibres is the manifestation of the so-called "sponge effect", in which water is perfectly retained in the formed pores, thereby increasing the water-holding capacity.
3. Acoustic currents. This concept refers to a stationary vortex with micro- and macro-flows that occurs in an ultrasonic field.
4. Chemical effects. Ultrasonic energy affects chemical reactions, speeding them up. In particular, under the action of ultrasound, myofibrillar proteins break down with the formation of smaller molecular residues, which leads to a higher moisture-binding capacity of meat. Such decay is accompanied by a loss of enzymatic activity, which prolongs the storage of raw meat for further processing [9].

5. Mechanical effects. A high level of alternating stresses created during ultrasonic vibrations in solids can lead to the development of fatigue phenomena and destruction. In liquids, pressure arising from the collapse of cavitation bubbles causes intense mechanical erosion of the surface of materials.
6. Diffusion effects. Ultrasonic energy intensifies and accelerates diffusion processes through cell walls, porous membranes, and filters.
7. Capillary effects. These effects contribute to faster and more perfect penetration of liquids into porous and other inhomogeneous materials.

Currently, the meat processing industry uses the technology of mechanical massaging of meat delicacies (intensive mixing, tumbling, tenderization), which is characterised by a number of disadvantages (Bogdanov et al., 2020; Kurochkin 2010; Poznyakovsky 2014):

- low productivity (6-10 hours of continuous massaging in accordance with the standards);
- damage to meat fibres of varying degrees;
- the impact on the meat is superficial as the centre of the meat is often not massaged;
- the complex design of the equipment used and its high cost.

At present, ultrasound has not been used in the meat processing industry, however, studies carried out in the middle of the 20th century and the beginning of the 21st century by Russian and foreign scientists showed that the processing of meat by ultrasound significantly improves technological and consumer qualities of meat such as moisture-holding capacity, juiciness, and tenderness; in addition, the yield of finished products increases (Dunaev 2006, Zayas 1970, Ultrasonic... 2020).

Conducted laboratory studies on the basis of FGBOU VO SURSAU confirmed the feasibility of using ultrasound in the meat processing industry. It has been established that ultrasound significantly intensifies the process of massaging meat, improving its quality and not destroying the meat fibres, while the impact on raw meat materials occurs not only from the outside, but also the inside, which is achieved due to the penetration of ultrasonic waves into the thickness of the meat. In laboratory studies, the optimal ultrasound parameters for cavitation massaging were determined: frequency 22 kHz, power 150 W; in addition, it was found that the yield of the finished product using this technology will be at least 83% instead of the 75% specified in the standards. Based on the results of the research, a graph was drawn up of the dependence of cavitation massaging duration on the thickness of the meat (Figure 2) (Ganenko et al. 2022, Ganenko et al. 2020).

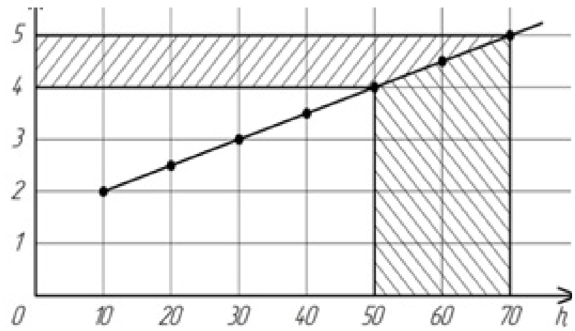

Figure 2. Graph of the dependence of cavitation massaging duration on the thickness of the meat

From the graph, the following conclusion was made: the duration of massaging meat pieces with a thickness of 50-70 mm (neck, loin, chop) at an ultrasound frequency of 22 kHz and a power of 150 W will be 4-5 minutes [4].

2. Materials and methods

The purpose of the research is to establish the optimal modes of cavitation massaging, to establish a functional relationship between the duration of cavitation massaging and the parameters of ultrasound and meat, as well as to evaluate the quality of the product prepared using improved technology.

Research methodology. First of all, the factors influencing the duration of cavitation massaging were determined:

1. The thickness of the meat. When passing through the meat thickness, ultrasonic waves inevitably scatter, losing their intensity. Obviously, the greater the thickness of the meat, the greater the scattering of ultrasound.

2. Power. This parameter directly affects the oscillation amplitude (A~N). With an increase in power, the amplitude increases, therefore, the areas of cavitation increase (Figure 3). It can be said that the medium will experience greater tension, therefore, there will be a greater number of cavitation bubbles and with larger sizes, and, as a result, the shock waves formed during their collapse will have a greater force. Thus, an increase in power intensifies massaging, however, it should be taken into account that too large an amplitude of oscillations will inevitably lead to the destruction of meat fibres.

3. Frequency. This parameter directly affects the oscillation period (T~1/ν). By definition, frequency is the number of oscillations per unit time, therefore, with an increase in the frequency of oscillations per unit time, a greater number of cavitation processes will occur (Figure 4).

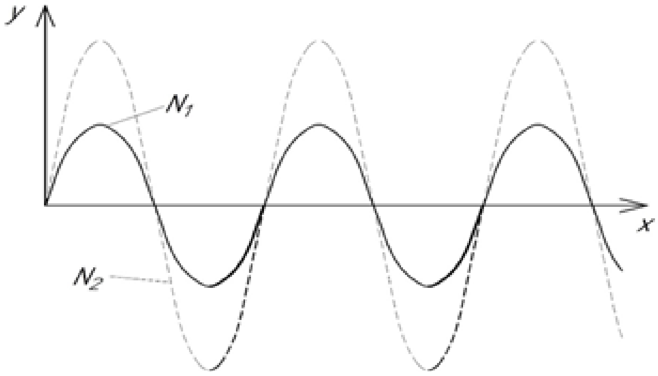

Figure 3. Graph of an ultrasonic wave at different powers of ultrasound N 1 and N 2; N 1 < N 2. Thickened lines show areas of cavitation

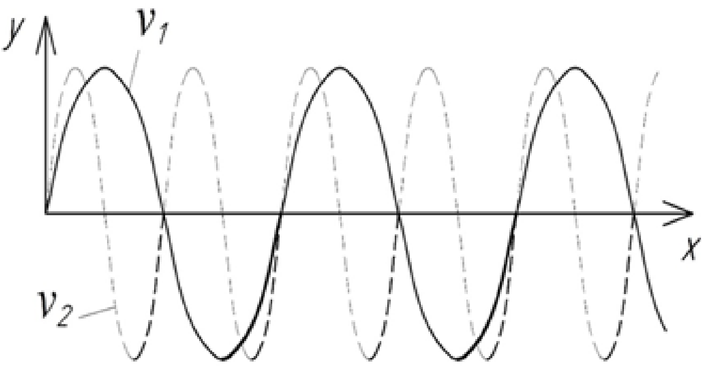

Figure 4. Graph of an ultrasonic wave at different frequencies ν 1 and ν 2; ν 1 < ν 2. Thickened lines show areas of cavitation

Due to the lack of the equipment necessary to operate with different frequencies of ultrasound, it was decided to conduct a two-factor experiment. Meat thickness and power were taken as factors, and the duration of massaging was taken as an effective feature.

The research was carried out according to the following methodology:

1. Preparation of raw meat materials:

- pieces of chilled pork (carbonade) were purchased;

- the brine was kneaded in accordance with the recipe for smoked-boiled carbonade [11];

- pieces of carbonade with a knife and a ruler were cut into samples of a certain thickness. Each of the samples was assigned a serial number of the form nh, where n is the number of the experiment corresponding to a certain set ultrasound power, h is the thickness of the sample in mm. Each of the samples was weighed on an electronic balance;

- to determine the yield of the finished product, samples No. 1.50, 2.50 and 3.50 were taken, their masses are shown in table 2;

- each of the samples was sprinkled with brine in accordance with the recipe.

2. Conducting the experiment. The ultrasonic bath UZV-7/100-MP-RELTEK was chosen as the equipment for the research. This bath is designed to remove grease and oil from small parts of various configurations, as well

as for homogenization and extraction of raw vegetable materials; it is also capable of generating ultrasonic waves at a fixed frequency of 22 kHz, adjusting the ultrasonic power to 50%, 75% and 100% of the nominal. When translating these percentages into power units, we obtain 75, 112.5 and 150 W, respectively). The control system has a built-in timer that shuts down the bath after a predetermined period of time (Ultrasonic bath UZV-7/100-MP-RELTEK).

3. Result and discussion

Progress of research:

- set the parameters of the bath. The power, depending on the serial number of the experiment, was set equal to: 150 W (100%) for the first experiment, 112.5 W (75%) for the second, 75 W (50%) for the third;

- samples sprinkled with brine were alternately placed in the bath tank and filled with brine to half their thickness (Figure 5);

Figure 5. Sample in a tank

- the lid of the tank was closed and the bath was started. For uniform exposure to ultrasound, the samples were turned over every minute, and at the same time their condition was assessed. When there were noticeable signs of impact on the meat (softening, release of myofibrillar proteins), the processing periods were reduced to 30 seconds. When the samples were destroyed, the experiment was stopped, and the total duration of processing until the last period corresponding to the destruction of the samples was recorded in the experiment log. Figure 6 shows an image of meat before cavitation treatment (left) and after cavitation treatment (right). Figure 7 shows an image of a brine before (left) and after (right) treatment.

Figure 6. Image of meat before cavitation treatment (left) and after cavitation treatment (right)

Figure 7. Brine before (left) and after (right) treatment

- according to the data obtained, a table was built in which the rows correspond to the serial number of the experiment at a given power, and the columns correspond to a given thickness of the samples (table 1). The cells formed by the intersection of rows and columns contain numerical values of the duration of cavitation massaging in minutes with the given parameters.

Table 1: *Experiment results*

experience number	Power N , W	Meat thickness h, mm							
		0	10	20	30	40	50	60	70
1	150	0	2	2.5	3	3.5	4	4.5	5
2	112.5	0	3	4	5	6	7	8	9
3	75	0	4	6	8	10	12	14	16

At the end, softened, brightened samples were obtained with traces of multiple released proteins, which, mixed with blood, gave the brine a white-pink colour (Figure 6-7). The stickiness of samples and the luster, characteristic of massed meat, were noted. The loosened structure of the meat fibres was observed with the naked eye.

Thus, the results of previous studies have been confirmed. From Table 1, you can determine the optimal parameters of cavitation massaging: ultrasound frequency 22 kHz, power 150 watts. With these parameters, the duration of the operation will be minimal, while it is possible to ensure the safety of meat fibres.

3. Preparation of the finished product. Roasting raw meat materials, after the stage of cavitation massaging, was carried out according to the standard method. The baked carbonade samples were weighed. Based on the weighing results, the yield of finished products was calculated (Table 2).

Table 2: *Determining the yield of finished products*

Index	Sample No.		
	1.50	2.50	3.50
Initial weight, g	293	297	296
Final weight, g	246	258	251
Exit, %	84	87	85

Thus, the minimum yield was 84%;

- the quality of the finished product was assessed (Figure 8).

Figure 8. Appearance of the finished product (left) and in section (right)

The grey colour of the product is due to the absence of colour-forming additives in the composition, as well as the heat treatment technology (baking instead of boiling). The surface of the product shines in the light, which is a sign of massed meat. The consistency is dense, elastic and very tender. The smell is characteristic of baked meat. The taste is pleasant, salty, and the juiciness of the product is noted. It is chewed very easily, requiring minimal chewing effort.

Table 1 shows that the relationship between the factors h (meat thickness, mm) and N (power, W) and the resulting sign t (massaging time, min) has a nonlinear relationship, because there are jumps in the values of the resulting feature that cannot be described by an arithmetic progression. Based on this consideration, to assess the closeness of the relationship between these quantities, the calculation of the correlation ratio was applied, carried out according to the following method:

1. The resulting general sample of values of the resulting feature Y was divided into a certain number of intervals k, determined by formula (1):,

$$k = 1 + 3{,}322\lg(n), \quad (1)$$

where n is the volume of the general population.

The resulting value of k was rounded up to an integer.

2. According to formula (2), the interval step was determined:

$$b = \frac{Y_{max} - Y_{min}}{k}, \qquad (2)$$

where Y_{max} and Y_{min} are the maximum and minimum values of the resulting feature Y in the sample, respectively.

3. The data of the general sample were grouped by intervals in such a way that:

$$n = \sum_{j=1}^{k} m_j, \qquad (3)$$

where m j is the number of sample elements in the j -th grouping interval.

4. The average value of the resulting feature Y was calculated in the j -th interval according to the formula (4):

$$\bar{y_J} = \sum_{l}^{m_j} \frac{y_{jl}}{m_j}. \qquad (4)$$

5. The overall average of the resulting feature Y was calculated using the formula (5):

$$\bar{y} = \frac{1}{n} \sum_{j=1}^{k} m_j \bar{y_J}. \qquad (5)$$

6. The intergroup dispersion was determined by the formula (6):

$$S_{y_j}^2 = \frac{1}{n} \sum_{j=1}^{k} m_j \left(\bar{y_J} - \bar{y}\right)^2. \qquad (6)$$

7. The total dispersion was determined by the formula (7):

$$S_y^2 = \frac{1}{n} \sum_{i=1}^{n} (y_i - \bar{y})^2. \qquad (7)$$

8. The correlation ratio of the dependent variable Y for the independent variable X was obtained from the ratio of the intergroup variance to the total variance (formula 8):

$$\eta = \sqrt{\frac{S_{y_j}^2}{S_y^2}} = \frac{S_{y_j}}{S_y}. \qquad (8)$$

The strength of the connection between X and Y was determined by the value of the correlation ratio (table 3).

Table 3: *The strength of the relationship depending on the value of the correlation ratio*

Strength of connection	The value of the correlation ratio
Complete	1
Strong	from 0.7 to 1
Medium	from 0.3 to 0.7
Weak	0 to 0.3
No connection	0

Cavitation massaging was estimated at different ultrasound powers. Thus, the calculation of the correlation ratio for experiment No. 1 had the following form:

- table 4 contains the initial data for the calculation;

Table 4: *Initial data for experiment No. 1*

Meat thickness X, mm	0	10	20	30	40	50	60	70
Duration Y , min	0	2	2.5	3	3.5	4	4.5	5

- the number of intervals was determined by the formula (1):

$$k = 1 + 3{,}322\,\lg(8) = 5$$

- the interval step was determined by the formula (2):

$$b = \frac{5 - 0}{5} = 1$$

- Y values were grouped by intervals. Table 5 contains the numbers of intervals and their boundaries, the elements of the intervals and their number, and the average value of Y in each interval as determined by the formula (4). The grouping was based on the factor X;

Table 5: *Grouping Y values by intervals*

Interval boundaries	Y values in the j-th interval	m_j	y_J
0-1	0	1	0
1-2	2	1	2
2-3	2.5; 3	2	2.75
3-4	3.5; 4	2	3.75
4-5	4.5; 5	2	4.75

- the total average was calculated according to the formula (5):

$$\bar{y} = \frac{1}{8} \times (0 \times 1 + 2 \times 1 + 3{,}75 \times 2 + 3{,}75 \times 2 + 4{,}75 \times 2) = 3{,}0625$$

- the intergroup dispersion was determined by the formula (6):

$$S_{y_j}^2 = \frac{1}{8} \times (1 \times (0 - 3{,}0625)^2 + 1 \times (2 - 3{,}0625)^2 + 2 \times (2{,}75 - 3{,}0625)^2 + 2 \times (3{,}75 - 3{,}0625)^2 + 2 \times (4{,}75 - 3{,}0625)^2) = 2{,}17$$

- the total variance was calculated according to the formula (7):

$$S_y^2 = \frac{1}{8} \times ((0 - 3{,}0625)^2 + (2 - 3{,}0625)^2 + (2{,}5 - 3{,}0625)^2 + (3 - 3{,}0625)^2 + (3{,}5 - 3{,}0625)^2 + (4 - 3{,}0625)^2 + (4{,}5 - 3{,}0625)^2 + (5 - 3{,}0625)^2) = 2{,}21$$

- the correlation ratio was determined by the formula (8):

$$\eta = \sqrt{\frac{2{,}17}{2{,}21}} = 0{,}991$$

Similarly, the correlation ratio for experiments No. 2 and No. 3 was determined, which turned out to be equal to 0.987 and 0.87, respectively. The following conclusion was made: the thickness of the massaged meat has a strong influence on the duration of massaging, however, with a decrease in the ultrasound power, the influence of the thickness also decreases. This can be explained as follows. With softer modes of massaging, as can be seen from Table 1, the duration of massaging increases, therefore, the physicochemical processes in the meat will take longer, affecting the thickness of the meat to a greater extent than with more severe modes, therefore, the duration of massaging the meat will depend on its thickness to a lesser extent.

Similarly, the strength of the relationship between the power of ultrasound and the duration of massaging was evaluated for different thicknesses of meat. The calculations performed have established that the value of the correlation ratio is the same in all cases and equals 1, i.e. power has a complete effect on the duration of the operation.

Since the strong influence of meat thickness and ultrasound power on the duration of massaging was established, it can be said that these two factors are functionally related to the resulting trait:

$$t = f(h; N), \qquad (9)$$

where:

- t – duration of cavitation massaging, min;

- h - thickness of raw meat, mm;

- N – ultrasound power, W.

This dependence was determined by the following method:

1. The two-factor experiment resulted in three single-factor experiments, in which the duration of massaging was determined at different thicknesses of the meat (see table 1).

2. For each of the experiments, the functional relationship between the thickness of the meat and the duration of massaging was determined. To do this, using the Microsoft Office software product Excel 2016, graphs were built showing the relationship between the thickness of the meat and the duration of the operation. Next, the "trend line" function was used, which is used to identify trends in the resulting feature. From the proposed options for the trend line, the one that most fully corresponds to the experimental data was chosen (Figure 9).

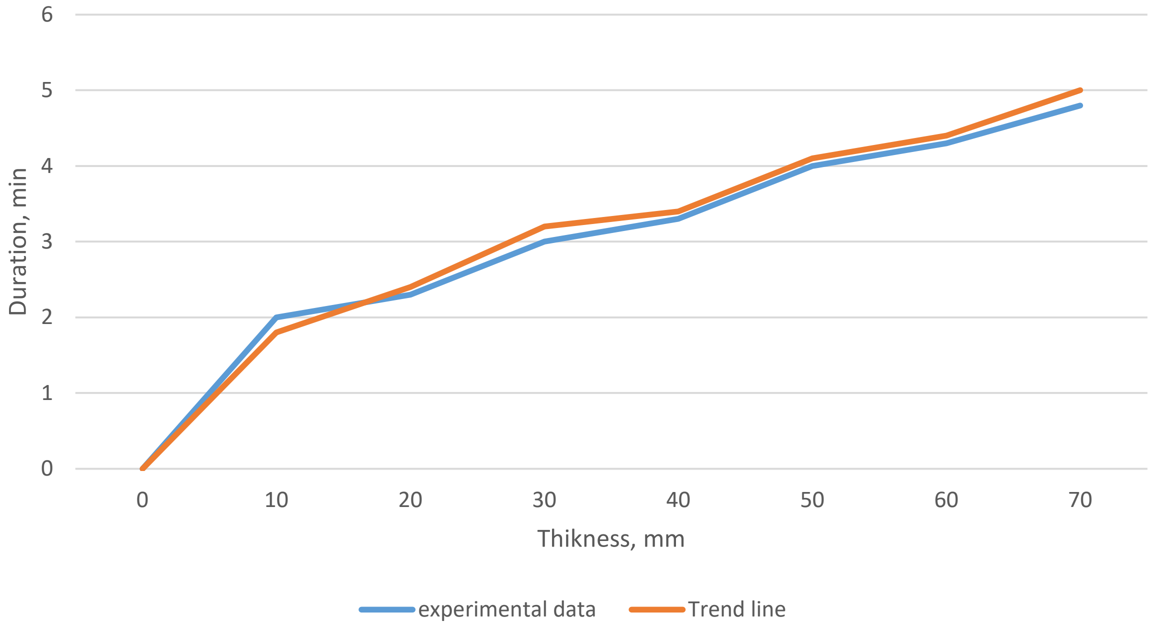

Figure 9. Graph of massaging duration and trend line for experiment No. 1

The trend lines in experiments No. 1, No. 2, and No. 3 are set by the following functional dependences of the duration of cavitation massaging on the thickness of the meat (functions (10), (11), and (12), respectively):

$$t = 2{,}2432 \ln(0{,}1h + 1) + 0{,}089; \quad (10)$$

$$t = 4{,}1037 \ln(0{,}1h + 1) - 0{,}1897; \quad (11)$$

$$t = 7{,}4418 \ln(0{,}1h + 1) - 1{,}1147. \quad (12)$$

3. The obtained dependences (10) - (12) were reduced to the general form:

$$t = a \ln(0{,}1h + 1) + b, \quad (13)$$

where a and b are the coefficient and free term of the function, respectively.

As can be seen from the functions (10) - (12), when the ultrasound power changes, both the coefficient and the free term change, therefore, they are functionally related to the power:

$$a = f(N); \quad (14)$$

$$b = f(N). \quad (15)$$

These functions were determined in a similar way using a trend line:

$$a = 24{,}724e^{-0{,}016N}. \quad (16)$$

$$b = 1{,}7723 \ln N - 8{,}7062. \quad (17)$$

The resulting functions (16) and (17) were substituted into function (13) instead of the coefficient a and the free term b, respectively:

$$t = 24{,}724e^{-0{,}016N} \ln(0{,}1h + 1) + 1{,}7723 \ln N - 8{,}7062. \quad (18)$$

Formula (18) will be valid only for one-sided ultrasonic meat massagers, in which ultrasound penetrates the meat from one side. To be able to apply formula (18) to two-sided ultrasonic meat massagers, the coefficient k was introduced to take into account the type of ultrasonic meat massager: k = 1 for one-sided, and k = 0.5 for two-sided. From here, the desired function took the form:

$$t = k(24{,}724e^{-0{,}016N} \ln(0{,}1h + 1) + 1{,}7723 \ln N - 8{,}7062) \quad (19)$$

4. Conclusions

Cavitation is one of the emerging technologies being used in the meat processing industry and as a food processing technology is improving both the tenderness and the biophysical properties of the meat (Saleem 2016). The ultrasonic oscillation causes periodic compressions and expansions in the liquid, which creates cavitation bubbles, resulting in changes in physicochemical properties (Al-Hilphy et al., 2016).

Hu et al. (2013) declared that ultrasonic pulses are capable of increasing the solubility and surface hydrophobicity of soy protein, which leads to altering the protein's rheological properties (Hu et al., 2013). Guzey, Gulseren, Bruce, and Weiss (2006) clarified that the molecular structure altered by pulsed cavitation treatment leads to improved surface activity and intramolecular mobility with the increase in the secondary structure proteins and free sulfhydryl groups (Guzey et al., 2006). Wang, Yang et al. (2017) examined the effect of treating chicken with ultrasonic pulses with a power of 240 W at 0, 3, 6, 9, 12, and 15 min on the structural and rheological characteristics of chicken myofibrillar protein. The findings revealed that the viscosity coefficients decreased significantly through pulsed cavitation treatment (Wang et al., 2017).

As a result of the research, the expediency of using cavitation massaging of meat instead of mechanical means has been shown. The optimal parameters of this operation were established: ultrasound frequency 22 kHz, power 150 W.

It has been established that the product prepared using this technology will have the best technological and consumer qualities: looseness of meat fibres, improved juiciness and tenderness of meat, greater moisture-binding and water-holding capacity and, as a result, a greater yield for the finished product (84% versus 75% provided for by the standards).

A significant reduction in the time required for the massaging operation was established: 4-5 minutes for a separate piece of pork with a thickness of 50-70 mm (carbonade, loin, neck) when using one-sided ultrasonic meat massagers, or 2-2.5 minutes when using bilateral meat massagers that can provide the presented higher ultrasound parameters.

It has been established that the power of the ultrasound and the thickness of the meat significantly affect the duration of massaging; the functional relationship between these factors and duration is determined.

Conflicts of interest

We declare that we have no financial or personal relationships with people or organisations that could inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service, and/or company that could be construed as influencing the content of this paper.

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