Визначено вплив способів і режимів подрібнення м'ясних фаршів для забезпечення високого виходу і якості ковбасних виробів. Показано, що кратність подрібнення складових сировини визначає реологічні, структурно-механічні та якісні показники. Спосіб різання впливає на стан м'язових, жирових, сполучних тканин, розчинність білкової фракції і є вирішальним фактором при створенні приладів для контролю фаршеприготування

Ключові слова: різання, м'ясний фарш, реологічні показники фаршу, структура м'язів, контроль фаршеприготування, вихід ковбасних виробів, якість

Определено влияние способов и режимов измельчения мясных фаршей для обеспечения высокого выхода и качества колбасных изделий. Показано, что кратность измельчения составляющих сырья определяет реологические, структурно-механические и качественные показатели. Способ резания влияет на состояние мышечных, жировых, соединительных тканей, растворимость белковой фракции и является решающим фактором при создании приборов для контроля фаршеприготовления

Ключевые слова: резание, мясной фарш, реологические показатели фарша, структура мышц, контроль фаршеприготовление, выход колбасных изделий, качество

UDC 621.927.044.3/532.135
DOI: 10.15587/1729-4061.2017.108876

CHANGING THE QUALITY OF GROUND MEAT FOR SAUSAGE PRODUCTS IN THE PROCESS OF GRINDING

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1. Introduction

Grinding is the process of separation of raw meat under the mechanical action of cutting tools with the formation of new surfaces. Cutting is accompanied by plastic deformation, friction between the contacting surfaces of meat and cutting tools and increase in their temperature.

As a result of the dimensional analysis of raw meat before and after grinding on different food grinding machines [1, 2], a classification of grinding is proposed (Table 1).

In sausage making, fine and thin grinding, characterized by chopping of raw meat to transform it into a homogeneous mass is predominantly used. Raw meat, which has the same chemical composition but different degrees of grinding, is characterized by different values of structural and mechanical characteristics (SMC), which directly affect the yield and quality of finished products.

Numerous studies have shown that the quality and yield of finished sausage products greatly depend on SMC and rheological properties (RP) of ground meat and compliance with recipes [2, 3].

Table 1

Size classification of grinding [1]

Type of grinding	Average size of a piece (particle), mm	
	before grinding	after grinding
Coarse	up to 300	up to 100
Medium	up to 200	60...10
Fine	200.. .100	10...2
Thin	10...2	2...0.4
Colloidal	10...0.4	0.075...0.001

The physicochemical mechanics of thin meat grinding and the dependence of SMC and rheological properties (RP) of ground meat on the composition of raw materials and modes of grinding with cutters are studied.

SMC and RP of ground meat directly affect its elasticity and moisture-binding capacity, protein solubility and state, mass loss of sausage products during heat treatment and their qualitative indices. Therefore, research and optimization of the degree of grinding of varieties of raw meat are relevant for producing high-quality ground meat and creating control equipment.

2. Literature review and problem statement

Thin grinding provides the formation of such pieces of ground meat, the surface of which binds the maximum amount of moisture, forming a homogeneous mass with certain SMC and RP [3, 4]. The ground meat quality depends on the kind of grinding machine – cutter, cutter-and-mixer, colloid mill, emulsifier, continuous unit and the like. In all these machines, grinding processes are similar [1]. At the same time, the optimum grinding duration, which provides extremely necessary values of physicochemical properties and process characteristics of the product, varies and depends on kinematic characteristics of machines and designs of cutting tools [2].

Cutting in the processes of thin grinding of raw meat is performed at high speeds. Friction of cutting tools is accompanied by the release of a large amount of heat, which can lead to protein denaturation, a change in the water-binding capacity and SMC of ground meat [5]. These circumstances necessitate the development of a methodology for determining the optimum grinding duration, taking into account the characteristics of the cutting parts of machines [2, 6, 10].

In the vast majority of grinding machines, there are no tools and devices that control the RP and SMC of ground meat, which determine the end of the process [1, 7]. On most of the meat-processing enterprises, these operations are performed by production managers, and the quality of finished products depends on their qualifications [1, 9]. Therefore, there is a need to create automatic devices for determining the readiness of ground meat. To do this, it is necessary to determine the objective criteria of the grinding process completion, taking into account the SMC and RP of a disperse system, which can be taken as a basis when designing control tools and devices [8, 12, 13].

3. The aim and objectives of the study

The aim of the research is to improve the methodology for determining the optimum meat grinding modes to produce disperse systems from raw meat with the specified SMC and RP on different equipment for subsequent use in the development of automated control systems and devices of grinding processes.

To achieve the research aim, the following objectives were formulated:

– to investigate the physicochemical properties of raw meat proteins and to determine the relationship between the physicochemical characteristics of ground meat and their influence on SMC, RP of ground meat on ready-made sausage products;

– to investigate the production conditions of ground meat for boiled sausages with a strong structure, the greatest water-binding capacity, which provide minimum weight loss of finished products;

– to determine the optimum grinding duration and moisture content of various ground meats for boiled sausages;

– using histological studies, to assess the effect of the grinding degree on the microstructure of ground meat from various raw meat tissues and their combinations for the creation of meat grinding control devices.

4. Research methodology, materials and devices

To study the effect of cutting on SMC and RP of raw meat and to determine the optimum meat grinding regimes, a laboratory cutter (LC) with a bowl capacity of 8 liters and a rotational speed of two knives of 1000 min^{-1}; a small cutter (SC) with a bowl capacity of 80 liters and a rotational speed of three knives of 1450 min^{-1}; a large cutter (LC) with a bowl capacity of 200 liters of grade L5-FKN with two rotational speeds of 3, 6, 9 and 12 knives equal to 1328 and 2650 min^{-1} were used.

A commercially available homogenizer RT-2 was also used. In more detail, the research methodology is described in [14].

5. Results of studying the meat grinding process

Changes in SMC of ground meat depending on grinding duration (τ_K, min) and moisture content (U_H, kg of moisture/kg of dry product) will be considered on the example of the ground meat for Russian sausages (50 % beef and 50 % pork), ground by small and large cutters. The characteristics of ground meat are given in Table 2.

Table 2

Characteristics of ground meat and raw materials

Sample No.	Characteristics of ground meat			Amount of added water, m_B	Characteristics of meat	
	Moisture content, U_H	Humidity, W_H	Fat content, φ_H		Moisture content, U_M	Humidity, W_M
SC cutter						
1	2.21	0.689	0.166	0.20	1.683	0.627
2	2.44	0.710	0.146	0.30	1.653	0.623
3	2.70	0.730	0.127	0.40	1.650	0.622
4	3.01	0.753	0.111	0.50	1.677	0.627
LC cutter						
5	2.06	0.676	0.183	0.25	1.440	0.590
6	2.30	0.697	0.158	0.30	1.540	0.606
7	2.55	0.718	0.154	0.45	1.453	0.592
8	2.98	0.740	0.113	0.40	1.850	0.649

During the meat cutting in the preparatory period, when the added moisture forms thick layers that facilitate deformation, the value of the ultimate shear stress θ_0 (USS) decreases, and mass loss during heat treatment (m_G, kg/kg of product) increases. With an increase in the cutting duration (the first period), there is further grinding of meat particles, their total surface increases, moisture passes from free into a surface-bound state. In this period, the value of USS and effective viscosity (V) at a single value of the shear rate grow and reach a maximum value, and m_G decreases as much as possible and the number of small particles increases. The formation of the primary structure of ground meat is completed. In the second period of grinding (re-cutting), loosening of muscle fibers of meat continues and the ground meat temperature continues to increase. The process is accompanied by saturation of ground meat with air and emulsification of fat, which leads to a secondary structure formation, as well as to a decrease in USS, an increase in plastic viscosity (PV) and m_G. At the same time, there are colloidal-chemical changes in ground meat.

Fig. 1, *a* shows the change in USS of the undisturbed structure of ground meat, determined using a rotational viscometer and a conical plastometer.

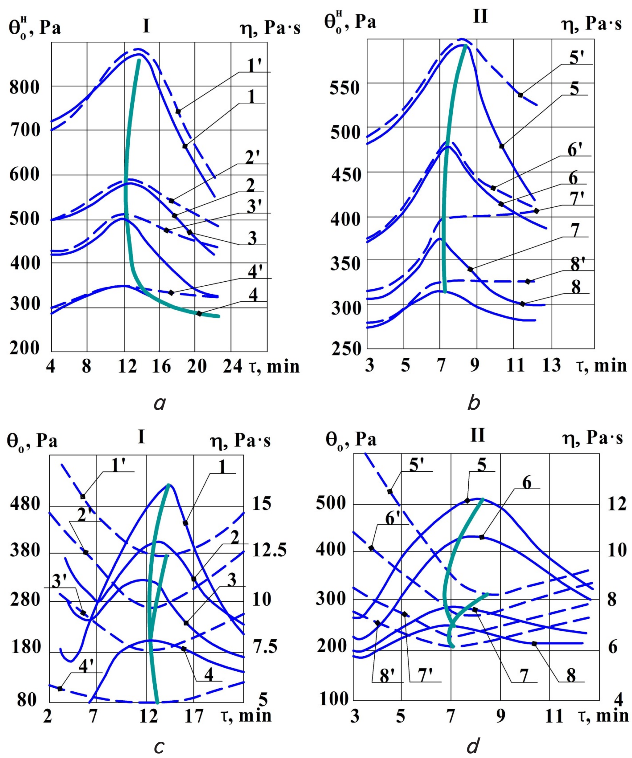


Fig. 1. The change in plastic viscosity (dashed curve) and ultimate shear stress (solid curve): *a, c* — for the undisturbed structure of ground meat; *b, d* — for the disturbed structure of ground meat; 1-8 — the curves obtained on a rotational viscometer; 1'–8' — the curves obtained on a conical plastometer: I — small cutter; II — large cutter. The curve numbers correspond to the process parameters given in Table 2

Table 3 shows the data that characterize ground meat by moisture content, humidity and extreme rheological properties.

Raw materials in each series of experiments had different humidity: pork – 0.35–0.45, beef – 0.68–0.75 parts of the unit. The yield of finished products depends on the humidity of the raw materials, therefore, the yield in relation to the absolutely dry matter of the product was determined in the experiments.

According to the rheological dependencies (Fig. 1), the optimum moisture content U_H^{opt}, which provides the maximum yield and the best quality of finished products, is defined as the inflection point of the curves in the SMC extreme value – moisture content coordinates.

Thus, a large number of extreme points contain one characteristic point, which corresponds to the optimum mode, that is, with U_H^{opt} $\tau_{C.E}$ is minimum. The $\tau_{C.E}$ value with U_H^{opt} is the optimum duration U_H^{opt} of meat grinding. With increasing moisture content, $\tau_{C.E}$ decreases, and with $U_H > U_H^{opt}$ – increases, which is explained by an increase in the thickness of water-protein layers between the ground meat parts and, consequently, a decrease in the cohesion forces between the coagulation structure elements. The particles are as if floating. Their relative shift is facilitated, and the stress relaxation period in ground meat decreases with increasing U_H. The best conditions for grinding are created when the duration of the knife action on a product is equal to or less than the relaxation period of elastic deformations, that is, the product can be considered as an elastic-solid body. When watered, ground meat becomes less elastic, approaching the plastic state [7].

Consequently, due to the rheological dependencies, it is possible to determine the optimum values for grinding duration and moisture content of ground meat.

To characterize the degree of meat grinding, clarify the nature of this process and causes of SMC changes, histological studies were carried out and the effective diameter of ground meat particles was determined:

$$d_e = \sqrt{\sum_{i=1}^{n} N_i d_i^2 \Big/ \sum_{i=1}^{n} N_i},$$

where n is the total number of dimension classes; N_i is the number of particles of ground raw materials; d_i is the diameter of the product particles.

Typical curves for the particle size distribution are shown in Fig. 2.

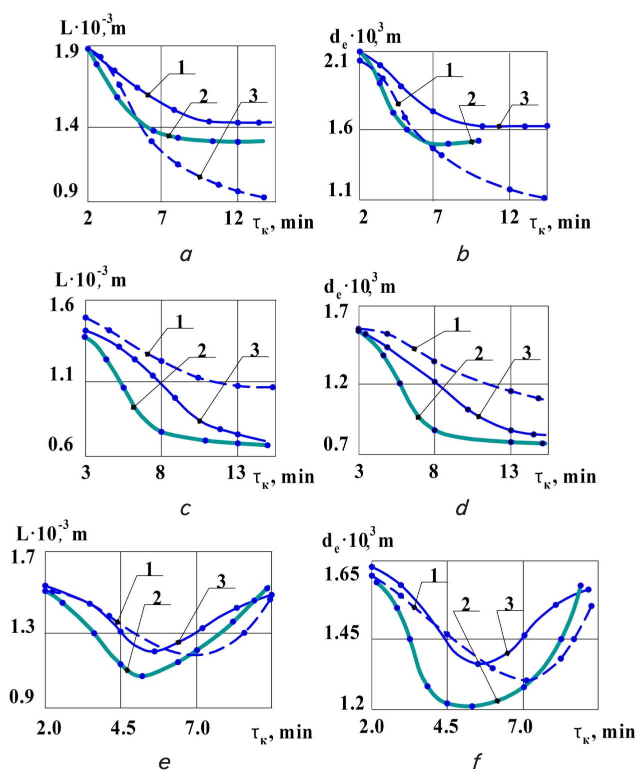


Fig. 2. Linear dimensions of ground meat particles, depending on cutting duration and humidity: *a, b* — beef sausages — 1 — 0.796; 2 — 0.803; 3 — 0.827; *c, d* — doctor's sausage — 1 — 0.596; 2 — 0.673; 3 — 0.696; *e, f* — pork sausages — 1 — 0.591; 2 — 0.567; 3 — 0.554

Table 3

Physicochemical and rheological characteristics

Ground meat	Experi-ment No.	Moisture content, U_H	Humidity, W_H	Fat content, φ_H	Amount of added water, m_B	Rheological characteristics of ground meat (in the ISS system)			
						θ_0	η	θ_0^H	η^H
Beef sausages	1	2.750	0.733	0.140	0.300	400	7.70	–	7.82
	2	3.410	0.733	0.115	0.400	340	5.20	515	5.40
	3	3.905	0.796	0.105	0.500	300	3.88	430	4.32
	4	4.075	0.803	0.103	0.600	280	3.40	380	3.70
	5	4.785	0.827	0.097	0.700	200	2.00	295	2.16
Russian sausages	1	2.086	0.676	0.169	0.250	520	8.30	580	–
	2	2.215	0.689	0.170	0.290	440	7.65	500	–
	3	2.400	0.706	0.178	0.350	320	6.96	425	7.30
	4	2.546	0.718	0.178	0.400	300	6.80	380	–
	5	2.984	0.749	0.154	0.450	260	6.25	325	–
Doctor's sausage	1	1.480	0.596	0.225	0.100	600	6.35	880	7.63
	2	1.650	0.623	0.226	0.200	430	5.40	700	6.12
	3	1.800	0.643	0.234	0.250	310	4.86	450	4.70
	4	2.060	0.673	0.220	0.300	250	4.40	366	3.43
	5	2.290	0.696	0.213	0.450	200	4.00	300	2.33
Pork sausages	1	1.094	0.522	0.377	0.200	235	3.70	295	2.85
	2	1.240	0.554	0.351	0.400	195	3.20	240	2.45
	3	1.335	0.572	0.342	0.400	160	3.02	200	2.00
	4	1.311	0.567	0.347	0.300	165	3.01	200	2.00
	5	1.449	0.591	0.275	0.500	345	–	455	1.98

Note: The characteristics of ground meat in the experiment No. 3 are the reference

The curves in Fig. 2 allow determining the dependence of the ground meat particle size on moisture content and cutting duration.

The inflection point of the curves corresponds to $\tau_{C.E}$. In constructing the dependence of d_e on U_H with τ_C, the extrema on the curves indicate the optimum moisture content of ground meat. Changes in the geometric parameters of particles of the majority of ground meat are similar. The exception is ground meat with a maximum fat content (more than 30 %), the particle size of which reaches a minimum value with $\tau_{K.E}$, and then increases due to the formation of fat.

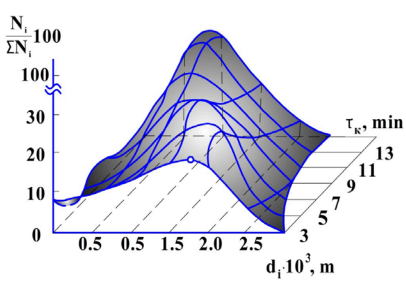


Fig. 3. The quantitative content of particles of ground meat of doctor's sausage depending on their size and cutting duration

Histological studies allow obtaining a criterion for an overall assessment of the grinding degree. The histological sections of the muscular tissues of modeled ground beef of the highest quality at different frequency rates of transmission through the top show that the increase in the grinding degree leads to the disappearance of the transverse mesh of fibers (Fig. 4), which pass from the cell structure into an amorphous state.

With one-time meat grinding, in the field of view of the microscope there are pieces that have a typical structure of meat. After a fivefold grinding, in the field of view, meat particles and voids can be seen, because ground meat is loose. After a 15-fold grinding, voids disappear, ground meat is condensed, and the particles are difficult to distinguish, although individual muscle fibers still retain their shape. After a 25-fold grinding, the diameter of muscle fibers is even more reduced. The structure of muscle fibers does not remain unchanged. These changes depend on the degree of grinding. The shape and proportions of muscle fibers are different. With a one-time grinding of beef, ground meat mainly consists of pieces of muscle fibers. With increasing the frequency of grinding, the proportions change, and the muscle fibers pass into an amorphous structure. If in the original structure the muscle tissue has well-defined and properly located nuclei, in the amorphous state the longitudinal and transverse boundaries of the fibers disappear.

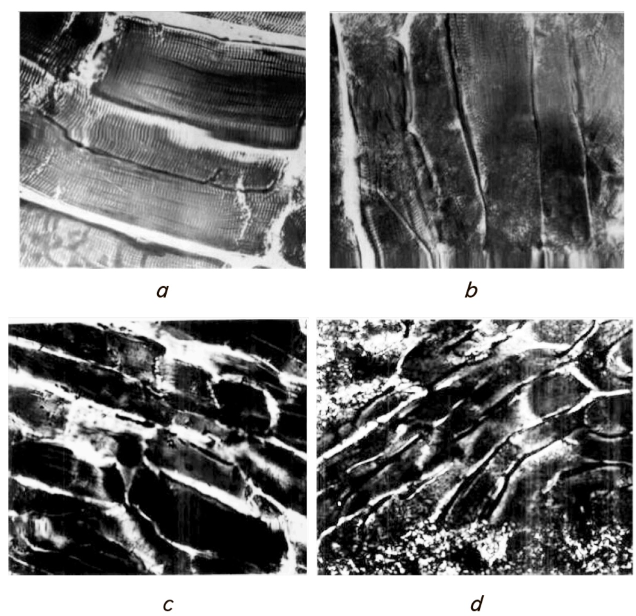
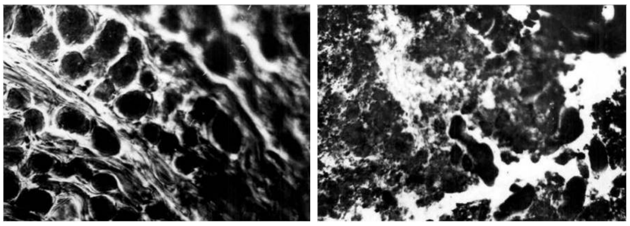


Fig. 4. Histological sections of the muscular fibers of modeled ground beef of the highest quality at different frequency rates of grinding: *a* — the initial sample of raw materials; *b* — 5-fold grinding; *c* — 10-fold grinding; *d* — 15-fold grinding, ·4 — four-fold magnification under a microscope

One-time grinding has almost no effect on the structure of fat tissues (Fig. 5, *a*). With further grinding (Fig. 5, *b*), fat tissues are split, forming agglomerates of different sizes – from the cell size to the drop size of $25 \cdot 10^{-9}$ m^2. Fat tissues that retain the structure after, for example, 25-fold grinding are rare.



a *b*

Fig. 5. Histological sections of the fat tissue at different frequency rates of grinding: *a* – one-time; *b* – 15-fold ·4 – four-fold magnification under a microscope

Connective tissue best preserves the structure when passing through the screw shredders (Fig. 6). Fibers and nuclei in the initial sample are especially expressively outlined (Fig. 6, *a*). When the frequency of grinding increases (Fig. 6, *b*, *c*), the structureless and non-nuclear state is characteristic of the connective tissue. In some cases, a part of nuclei is preserved, but their arrangement is very chaotic. Connective tissue does not undergo significant changes and has the appearance of loose inclusions in the amorphous structure of ground meat. Thus, histological studies revealed structural changes in meat during mechanical processing.

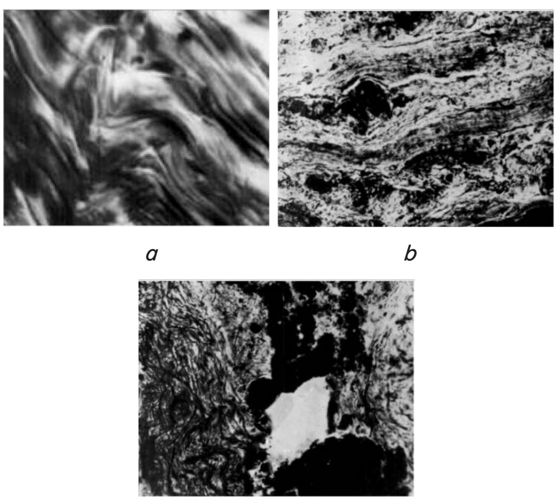


Fig. 6. Micro sections of connective tissue at different frequency rates of grinding: *a* – the initial sample of raw materials; *b* – 3-fold grinding; *c* – 15-fold grinding ·4 – four-fold magnification under a microscope

The patterns of changes in the structure of ground meat of Russian sausages during grinding for 1 to 12 min on the LC cutter are shown in Fig. 7.

In the initial period of grinding for 1–3 min, the SMC level for the ground meat decreases. During intensive grinding, muscle fibers decrease 4–5 times, and their free surface sharply increases. Water or ice added when cutting do not manage to bind to the raw material and are in a free state. This leads to a decrease in the SMC level of ground meat. Conglomerates of muscle tissue break up into smaller particles. There are small areas where muscle fibers pass into an amorphous state, and ground meat is saturated with sufficiently large air bubbles of oval or irregular shape.

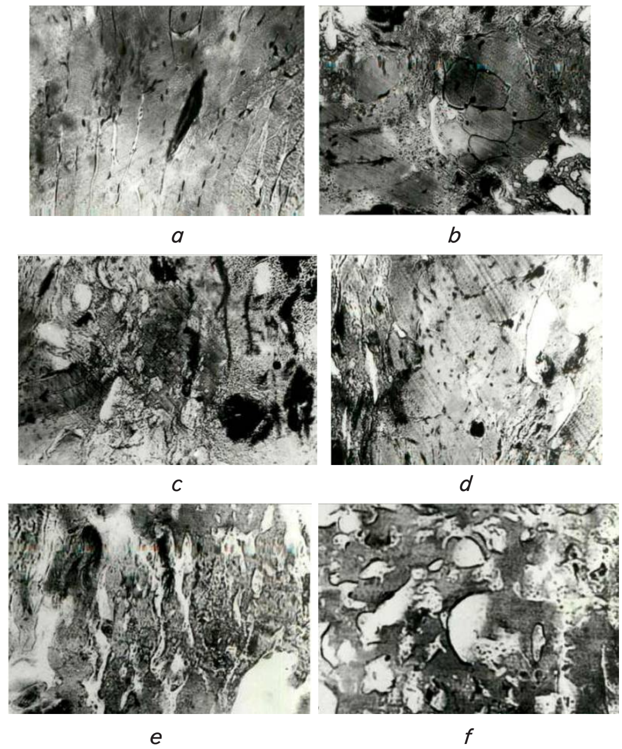


Fig. 7. Histological sections of the samples of ground meat of Russian sausages with different durations of meat grinding: *a* – 1 min; *b* – 3 min; *c* – 5 min; *d* – 6 min; *e* – 9 min; *f* – 12 min, ·6 – six-fold magnification under a microscope

The connective tissue, basically, is not destroyed, but its maximum dimensions in the first 5 minutes of cutting are reduced. On the section at τ_C=1 min, connecting elements that reach a size of 0.5·3.5 mm are identified, and at τ_C=3 min their maximum size is only 0.3·2.0 mm.

In the first grinding period with a duration of 3–5 min, the SMC value of ground meat increases. The size of the connective tissue changes slightly. The particle size of muscle fibers decreases by a factor of 1.5–2. In this period, there are also colloid-chemical changes in ground meat. Moisture completely saturates muscle fibers, which swell and transform into a shapeless amorphous state. On histological sections, the transition of muscle fibers to an amorphous state can be observed. Muscle fibers are evenly distributed in the main amorphous mass of ground meat. Air bubbles decrease and are more evenly distributed in ground meat. All this ensures strengthening of the structure and, respectively, an increase in the SMC level of ground meat. Finished ground meat with extreme SMC values after cutting for τ_C=5–6 min mainly consists of a destroyed tissue. Muscle fibers pass into an amorphous state of pink color, in which individual muscle fibers and their pieces, as well as connective and fatty tissues, are dispersed.

In the second grinding period (from 6 to 12 min), the SMC level decreases. The remaining muscle fibers are ground and almost completely transformed into a shapeless amorphous substance.

To determine the influence of duration of grinding of sausage meat on its physicochemical properties, model ground meat prepared from long back muscles of beef (50 %) and pork (50 %) was examined. Pork in the following studies was replaced by fatback at the rate of 10, 20, 50 %. The amount of water added to ground meat was 15–40 % (with an interval of 5 %). Ground meat was prepared from unfrozen raw materials on a laboratory cutter (LC).

To reveal the nature of structure formation of sausage meat, complex physical and chemical studies, which included the determination of protein solubility in low and high ionic strength solvents, water-binding capacity, and rheological characteristics of the product, were carried out [8].

Protein solubility was determined after a four-fold extraction. First, the proteins were extracted with phosphate-buffered saline with an ionic strength of μ=0.15 and pH 7.4, then phosphate-buffered saline with an ionic strength of μ=1.0 and pH 7.4, stirring the contents for 5 min.

According to the authors of [8, 10], the strength of the structure of sausage meat is determined mainly by the number of dissolved proteins and their physicochemical transformations during processing, the size and quantity of fat particles and droplets formed in fat emulsification. It is known that proteins under the influence of different physical and chemical reagents easily change the structure of macromolecules, losing a number of properties, in particular, solubility [10]. Fig. 8 shows the results of measuring the solubility of protein fractions in three series of experiments.

Curves 1, 3, 5, and 7 suggest that the process of mechanical grinding has a significant effect on the solubility of muscle proteins in salt solutions. Two macroscopic effects were observed during cutting. Initially, the isolation of soluble proteins (meoplasm, myofibril) from the cell structures to the maximum value increased, and then a slight decrease in solubility was observed. Probably, in the first stage, the process of isolation of muscle proteins predominates over denaturation, and in the second stage, the selective heating process predominates. The consequence of these processes is the occurrence or destruction of bonds between protein particles or between proteins and a solvent. In the second stage of grinding, the solubility decreases due to the heating of proteins with their further aggregation and coagulation, which develop more the longer the grinding process.

The nature of change in curves 2, 4, 6, 8 when using the homogenizer RT-2 (Fig. 8) shows that with increasing grinding time, the solubility of protein fractions is uniformly reduced due to local overheating of individual meat particles and protein denaturation. Obviously, such ultrafine meat grinding affects molecular and supramolecular formations much stronger.

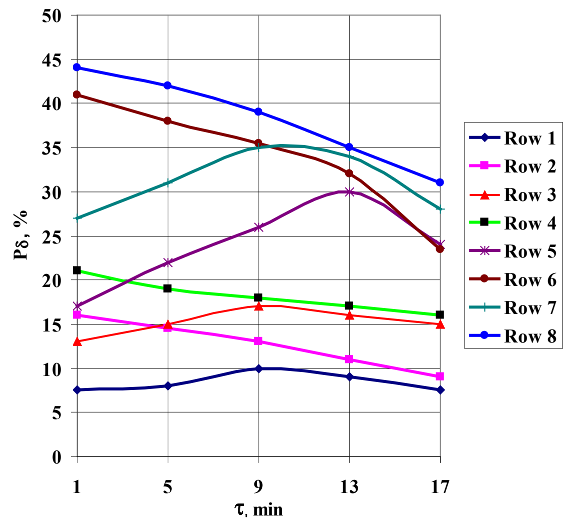


Fig. 8. Transformation of proteins extracted with low (curves 1–4) and high (curves 5–8) ionic strength buffer solutions during meat grinding: 1, 5 — curves showing the change in ground meat proteins (50 % beef, 30 % pork, 20 % fatback with 20 % water added) during grinding on a cutter; 2, 6 — proteins of the same ground meat, but with additional grinding on a homogenizer RT-2; 3, 7 — curves illustrating the change in ground meat proteins (100 % beef with 20 % water added) during grinding on a cutter; 4, 8 — curves illustrating the change in proteins of the same ground meat, but with additional grinding on RT-2

Moisture-binding capacity (MBC), as an objective force of binding water with ground meat, was determined by the ratio of the water, not separated during pressing, to a dry residue. Changes in USS, PV and MBC of ground meat, depending on grinding duration and moisture content, are shown in Fig. 9.

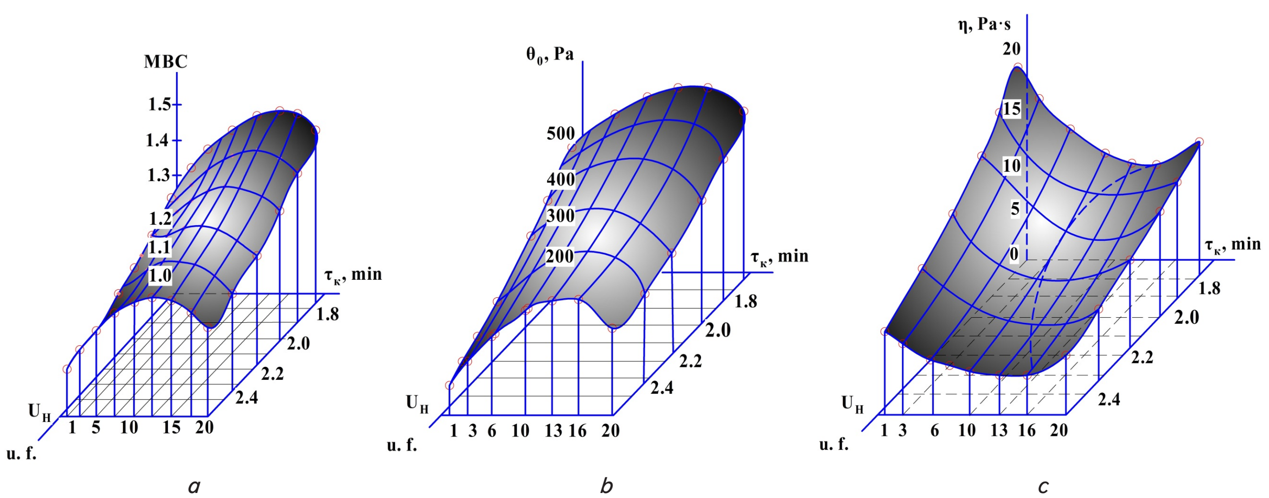


Fig. 9. Change in the moisture-binding capacity and rheological properties of ground meat, depending on the moisture content and cutting duration: *a* — moisture-binding capacity; *b* — ultimate shear stress of the destroyed structure; *c* — plastic viscosity

It is obvious (Fig. 9) that MBC and USS increase during grinding, reach a maximum value and then decrease. Plastic viscosity (PV) first decreases to the lowest value, and then increases. Thus, the analogy of change in rheological properties, moisture-binding capacity and solubility of proteins suggests that the structural strength of ground meat depends on the number of proteins that can pass from cellular structures to the continuous phase.

The strength of the structural lattice of ground meat depends on the number of polar groups, primarily acidic and alkaline ones, which are located on the surface of protein molecules in the continuous phase. The greater the number of these groups on the surface of proteins, the more actively protein molecules interact, binding better water and fat, the more solid the structural lattice of ground meat, the less liquid is released when it is heated.

6. Discussion of the research results

The analysis of the results shows (Fig. 1) that the USS values determined on different devices have almost identical values. The exception is ground meat with a high water-holding capacity. This is due to the fact that when measuring the USS of ground meat of liquid consistency, the depth of immersion of the plastometer cone increased. As a result, the USS values turned out somewhat overestimated. After adjustment for edge effects, the USS values determined on different instruments coincided. In contrast to the change in USS, the PV value in the first period of cutting decreased, reaching a minimum value, and in the second – increased (Fig. 1, *b*). Like USS, stickiness of ground meat (P_0, Pa) increased during cutting and, having reached the maximum value, decreased.

When analyzing the results of the experiments, it is possible to draw a clear conclusion that all the parameters studied (USS, PV, V, P_0) have extrema that are characteristic of a certain duration of grinding. At the end of the first cutting period, the structure of ground meat with the true moisture content is the most homogeneous and the majority of its indicators reach extreme values. Ready-made sausage products from this ground meat have the best quality in terms of consistency, with the extreme duration of grinding ($\tau_{C.E}$). However, $\tau_{C.E}$ determined by adhesion properties is somewhat underestimated compared to the shear ones and is 85–95 % of the latter, as confirmed by the authors' studies [4, 6]. This can be explained by considering the physical nature of shear properties and stickiness of ground meat. Shear properties of ground meat characterize the energy of interaction between the elements of the structure, that is, the properties of the entire volume of the system under stressful conditions, and stickiness characterizes the energy of the free surface of the system. Therefore, shear properties and stickiness are not exactly the same. In the process of cutting, the maximum value of the properties on the ground meat surface (stickiness) is reached faster than in the volume. Therefore, without taking into account the generality of shear and surface properties of ground meat during grinding, the preference should be given to the first because they estimate the entire volume of the product [6]. In view of the fact that the purpose of cutting is the production of ground meat with strong structure and the greatest water-binding capacity, the main characteristic of the process among the shear properties is USS, not PV or effective viscosity (EV). When the moisture content of ground meat increases, the numerical values of all its shear characteristics decrease exponentially.

The histological studies of ground meat (Fig. 4–7) explain the reason for the SMC change in the process of grinding. The grinding degree is characterized by the effective particle diameter (d_e). The curves of changes in d_e depending on τ_C have an inflection point, the location of which coincides with $\tau_{C.E}$, determined with the help of SMC.

The analysis of the results of studies of the transformation of proteins extracted by low and high ionic strength buffer solutions during meat grinding confirms (Fig. 8) that the maximum number of proteins capable of passing to a continuous phase of ground meat depends on grinding duration and composition of raw materials. Indeed, the maximum number of proteins of ground beef passes from cellular structures to the continuous phase 3 min earlier than those of multicomponent ground meat, which consists of 50 % beef, 30 % pork and 20 % fatback, which is in good agreement with the data of changes in water-binding capacity, particle size of raw materials and rheological characteristics.

The structure of ground meat is significantly affected by water. Studies of changes in the solubility of protein fractions of ground meat (50 % beef, 30 % pork and 20 % fatback) at different moisture content showed that the maximum number of proteins that passed from cellular structures to the continuous phase (81 % meoplasm proteins, or 78 % myofibril proteins of the total content) was in ground meat with a moisture content of 2.0.

It is evident (Fig. 8) that the number of proteins extracted with a high ionic strength solvent is approximately 3 times greater than that of proteins extracted with phosphate-buffered saline. It can be assumed that strength and water-binding capacity of ground meat depend on the state of proteins, mainly myofibrillar ones, their ability to pass into a solution and form a coagulation structure.

Studies of changes in the moisture-binding capacity and rheological properties of ground meat, depending on the moisture content and cutting duration (Fig. 9) showed that the maximum number of acidic, alkaline and sulfibril groups that react with parachloromercuribenzoate is observed with extreme grinding time and critical moisture content (for this ground meat 2.0). Consequently, under such conditions, the most stable structural lattice of sausage meat is formed. Meoplasm proteins emulsify fat and promote the formation of the most stable emulsion [2, 11, 12]. The data presented indicate that the nature of changes in USS, MBC and number of proteins that pass to the liquid phase is similar. Therefore, these indicators can be used to objectively characterize the ground meat and they need to be measured using special instruments that will be described in the following publications.

7. Conclusions

1. Ultimate shear stress, plastic and effective viscosity and stickiness of disperse ground meat systems of different composition have extrema that are characteristic of a certain duration of grinding. Continuation of cutting, in which the structure of ground meat is the most homogeneous and the above indicators with the true moisture content are extreme, will be optimum and provides the best quality of ground meat for boiled sausage products.

2. Strong structure, optimum moisture content and the highest water-binding capacity of ground meat, which ensures the greatest sausage yield, are achieved with an extreme grinding duration, which depends on the cutting ability and performance of the grinding machine.

3. The optimum grinding duration for a doctor's sausage is 13 min at a humidity of W_H=0.673 and depends on the chemical composition of raw materials, formulation of sausage products, and type of grinding equipment.

4. Histological studies explained the reason for the change in structural and mechanical characteristics of ground meat in the process of grinding. The degree of grinding is characterized by the effective diameter of the raw material particles and depends on cutting duration. The inflection on the curve of the effective diameter of the particles "has" an inflection point, the location of which coincides with the extreme grinding duration, determined using structural-mechanical characteristics.

5. The research results confirmed that the maximum number of proteins capable of passing to a continuous phase of ground meat depends on grinding duration and composition of raw materials. Strength and water-binding capacity of ground meat depend on the state of myofibrillar proteins, capable of passing into a solution and forming a coagulation structure. The analogy of change in rheological properties, water-binding capacity, and solubility of proteins suggests that the structural strength of ground meat depends on the number of proteins that can pass from the cellular structures to the continuous phase.

6. The given data confirm that the nature of change in rheological characteristics, water-binding capacity and number of proteins passing into the liquid phase of ground meat is similar. This means that these characteristics can be the basis for creating devices that can automatically control the SMC and, accordingly, the quality in ground meat preparation for the automation of the production process.

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