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DEVISING A TECHNOLOGY FOR OBTAINING GLUED SAUSAGE CASINGS FROM INTESTINAL RAW MATERIALS USING ELECTROPHORESIS

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The object of research is the technique for obtaining glued sausage casings, in which adhesive related structures and electrophoresis for tanning are used to glue the layers of intestinal raw materials.

Devising a technique for gluing sausage casings from intestinal raw materials with the use of adhesive related structures by stitching by tanning, via intensified electrophoresis, has been substantiated.

The technology of glued sausage casings from intestinal raw materials, which are classified as unclaimed residues and waste, has been proposed. The technology differs from known similar technologies by applying a technique for gluing intestinal membranes using an adhesive related construct and electrophoresis during tanning. The devised gluing technique and the device for its implementation make it possible to avoid violation of the integrity of the raw material, are universal in relation to it, and are easy to operate.

The rational parameters of electrophoresis, which is used to accelerate the tanning process of the place of gluing of the layers of the intestinal membranes using an adhesive related construct, have been determined. The potential difference between the electrodes and the duration of exposure of the gluing site for gluing the original intestinal raw materials: pork belly, lamb belly, beef belly were determined. At a potential difference of 100 V, the duration of exposure of the gluing site for pork and lamb bellies is 17 minutes, and for beef bellies – 20 minutes. It is noted that the results differ in the duration of exposure of the gluing site, which is probably due to the thickness of the layer of the raw material.

The proposed technology would contribute to improving the efficiency of the technology of glued sausage casings from intestinal raw materials and could be used at enterprises for the processing of agricultural products and the meat processing industry

Keywords: glued sausage casings, adhesive related construct, tanning with tannin, breaking load

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1. Introduction

Improving the efficiency of using the resource potential of raw materials for intestinal and sausage production is important for the meat industry [1]. The development and introduction of new technological processes for the processing of unclaimed residues and waste intestinal raw materials correspond to the concept of sustainable development of processing and food enterprises. At the same time, the transformation of secondary resources into a conditioned useful product is carried out. This is promising, in particular, from the standpoint of commitment to lean manufacturing principles [2, 3].

One of the closest ways to return the remains and waste of intestinal raw materials to the food chain, from the point of view of minimizing the depth of processing and, accordingly, the involvement of additional valuable operations and materials, is the production of glued intestinal films and sausage casings. Despite the simplicity of technical solutions related to the natural properties of raw materials and well-known proposals, the main attention is paid to the improvement of measures to increase the strength of the cohesive

seam of various types of intestines. At the same time, significant attention is paid to its stability under technological conditions, as well as rationalization of the amount of spent raw materials for the formation of mechanical properties of the functional-technological capacity [4].

Therefore, the development of innovative resource-efficient technical and technological solutions for improving techniques of obtaining glued shells from various types of intestinal raw materials with high and stable strength characteristics is a relevant task.

2. Literature review and problem statement

Work [5] summarizes the conceptual directions for improving the technology of glued intestinal films, which include targeted modification of their mechanical properties by local thermal coagulation, local and integral tanning with plasticization. These modification techniques provide sufficient strength of glued intestinal membranes in the technology of fried sausages [6].

Along with this, splicing sleeve films with partial defects is much more efficient in terms of maintaining the shell and its strength, without cutting into pieces. In this case, it is more expedient to turn it into a fold, overlapping the damaged area. In addition, the specified proposals are justified for pig intestinal raw materials, in particular, films from pork belly products, in connection with which the parameters of physicochemical modification for other raw materials remain uncertain.

The results of biological splicing of intestines in medical practice by tissue engineering methods with the use of collagen frameworks are reported in [7]. At the same time, the biological unsustainability of the native structure of treated intestines and the desire for irreversible stitching make it expedient to find other ways.

It has been shown that due to the treatment of the cohesive seam of glued intestinal films from pork bellies with vegetable tanner, irreversible stitching occurs, which significantly increases the strength of the bond between the layers [4]. However, the differences in the structure, chemical composition, thickness of different types of intestines [8], the need for a sufficient amount of bound and tanned collagen on the surfaces to ensure strength [9] require additional research.

Overcoming these difficulties is connected with the need to achieve an increase in the availability of collagen, as a protein of the intestinal structure, which plays a positive role in diffusion processes, as well as the efficiency of tanning to ensure the irreversibility of the obtained crosslinking [10, 11] and hydrophobicity [12]. Under these conditions, an option to overcome the relevant difficulties and an effective way to increase the strength of the cohesive seam of glued intestinal membranes may be the use of adhesive structures that are similar in nature to intestines (related). Adhesive constructs are serous films and muscular intestinal films (they remain as ballast layers in the process of technological treatment of the intestines) [8], which are located between the surfaces to be glued. As a result of such a structural and technological operation, on the one hand, additional adhesion conditions are formed, a profiling section and, accordingly, a stiffening rib [13], and on the other, a doubling of layers and a noticeable increase in the thickness of the cohesive layer. The specified factors determine the revision of the parameters of the modification effect. In particular, there is the task of finding and implementing measures to intensify the diffusion of tannin as a cross-linking agent of the glued area of the sleeve intestinal film.

It is known that among a number of measures to intensify diffusion processes, deep penetration into the porous structure of materials of various nature is achieved thanks to the use of electrophoretic methods [14]. However, among available sources there are currently no data on determining the effect of electrophoresis on the rate of diffusion of plant tannins into the structure of intestinal raw materials. Since tannin has a negative charge [15], the application of a potential difference can accelerate the diffusion of these particles into the substance.

Thus, devising a technique for gluing sausage casings from intestinal raw materials using adhesive related structures by means of stitching by tanning, intensified electrophoresis is a relevant area for solving the problem. At the same time, it is necessary to design a device for gluing them together and determine the rational parameters for the process implementation.

3. The aim and objectives of the study

The purpose of our work is to devise the technology for gluing intestinal membranes using tannin solution tanning of the gluing site, adhesive related structures and electrophoresis. This will contribute to increasing the efficiency of the technology of glued sausage casings from intestinal raw materials.

To achieve the goal, the following tasks were solved:

– to devise a technique for gluing different layers of intestinal raw materials to each other using adhesive related structures and a technique for accelerating the process of tanning the place of gluing with tannin solution;

– to determine the rational parameters of the tanning process using electrophoresis: the potential difference applied to the electrodes; processing time.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our research is the technique for obtaining glued sausage casings, in which adhesive related structures and electrophoresis for tanning are used to glue the layers of intestinal raw materials.

The hypothesis of the study is to prove the possibility of using adhesive related structures for gluing layers of intestinal raw materials with subsequent tanning of the gluing site by accelerated electrophoresis.

The initial conditions when devising the technology and technique for gluing intestinal membranes, as well as the device for their implementation, were the following:

– the absence of operations in the gluing technology being developed, which entail a violation of the integrity of the raw material (intestinal membranes), such as cutting, perforating, burning, etc.;

– the versatility of the equipment in relation to the raw material to be glued (type of raw material and its origin) and to the dimensional characteristics of the finished product (sausage casings);

– ease of operation and low energy and material costs.

4. 2. Researched materials and equipment used in the experiment

The raw material for which the research was carried out are pieces of manufactured pork, lamb and beef bellies, processed and prepared according to current technological instructions. That is, the raw material was separated bellies, which were previously defatted and freed from extra layers, washed, salted, and stored in the form of a salty product. The raw material was freed from salt, washed, and kept in water.

Serous films obtained as a result of technological processing of pig intestines were used as an adhesive related construct applied to the place of gluing, that is, placed between the layers of the intestinal membranes.

Since a technique for obtaining glued sausage casings is being developed in the work, obviously, the quality criterion for gluing intestinal casings to each other will be the strength of the connection before tearing or delamination. Further in the text, the place that is the combination of the intestinal membranes with the help of gluing in a developed way is termed a seam. The strength of the seam should be close to the strength of the raw material, i.e. a single layer of the intestinal lining. Lower strength of the seam can lead to a violation of the integrity of the resulting sausage casing. Greater strength of the seam compared to the strength of the raw material is not advisable, as it entails additional material and energy costs for obtaining this seam. Thus, the rational parameters of the process of obtaining a seam between the layers of intestinal raw materials were chosen based on the conditions for achieving the appropriate strength with this seam.

To establish the strength of the seam between the layers of the intestinal membranes, the procedure and device (Fig. 1) given in [5] were used.

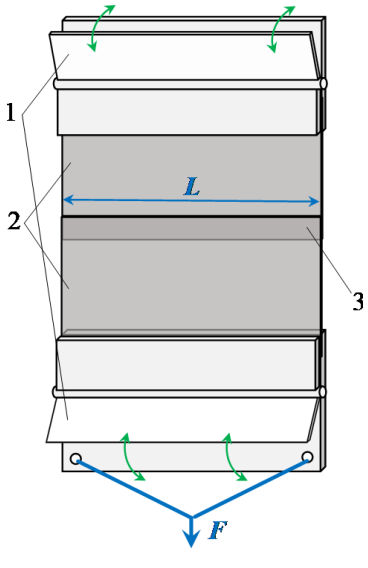

Fig. 1. Schematic diagram of the device for examining the strength of the seam obtained by gluing layers of intestinal membranes using adhesive related structures and electrophoresis during tanning of the gluing site with a tannin solution: 1 — holders-clamps; 2 — layers of intestinal membranes to be glued; 3 — seam

The installation consists of two holders-clamps (1), between which the tested sample (2) is fixed, the strength of the seam (3) of which is examined.

4. 3. The procedure used for investigating the strength of the seam between the layers of the intestinal membranes before rupture or delamination

The procedure for studying the strength of the seam between the layers of the intestinal membranes, obtained using adhesive related structures and electrophoresis, was as follows (Fig. 1). The studied sample 2, which is two layers of intestinal membranes glued together, is fixed between clamp holders (1). Next, one of the clamp holders is rigidly fixed, and a variable force is applied to the second one in the direction of stretching the test sample fixed between them. We fix the test sample so that the applied force is perpendicular to the seam line. The strength is gradually increased. The study is completed if seam 3 between the layers of the intestinal membranes is torn or separated. At the same time, the limit value of the force at which the rupture or delamination of the seam occurred was recorded.

According to this limit value of forces, the breaking load for the seam between the layers of the intestinal membranes was calculated according to the formula:

$$P=F/L, \quad (1)$$

where F is the limit value of the force at which the tear or delamination of the seam occurred, N; L is the length of the seam, m. That is, the breaking load refers to the value of the force per unit length of the seam, during which its rupture or delamination occurred.

The control sample was chosen according to the raw material, the layers of which were to be glued, namely, according to its origin (beef, lamb, pork, etc.) and its type according to the part of the intestine (bellies, circles, bilge, bladder, etc.). That is, the control sample was the naturally glued together two layers of intestinal film (made of intestines) [4] of the origin and type corresponding to the samples of intestinal membranes that were to be glued.

5. Devising a technology for obtaining glued sausage casings from intestinal raw materials using tanning

5. 1. Devising a technique for gluing intestinal membranes using tanning and an apparatus for its implementation

The main node during gluing the layers of the intestinal membranes (Fig. 2) is node 3 for gluing the layers of the intestinal membranes and tanning the place of gluing. Template 1 for the sausage casing is attached to this node. The template for the sausage casing is a hollow cylinder made of dielectric material, the outer surface of which is covered with an inert substance (Teflon). One end of the sausage casing template has a connector to connect to the casing gluing and tanning assembly 2.

The unit for gluing intestinal membranes and tanning the place of gluing (Fig. 3) is two coaxial cylinders 1 and 3, which are made of material with high electrical conductivity. Cylinder 3 is hollow. On the end side of the inner cylinder 1, a connector 2 is made for connecting the template for the sausage casing. A heater 8 is mounted inside the cylinder 1. The outer cylinder 3 consists of two halves in such a way that it can be opened along the diameter and disconnected from the inner cylinder 1. A lock 5 is provided to fasten the parts of the outer cylinder. The entire inner surface of this cylinder is covered with a sponge 4 from a capillary-porous material that has the property of being wet with a tannin solution.

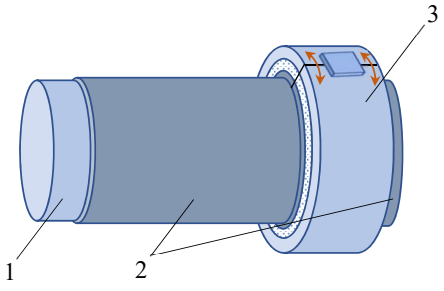

Fig. 2. Schematic diagram of the device for gluing intestinal casings using electrophoresis during tanning with tannin solution: 1 — template for sausage casing; 2 — intestinal membranes to be glued; 3 — a node for gluing layers of intestinal membranes and tanning the place of gluing

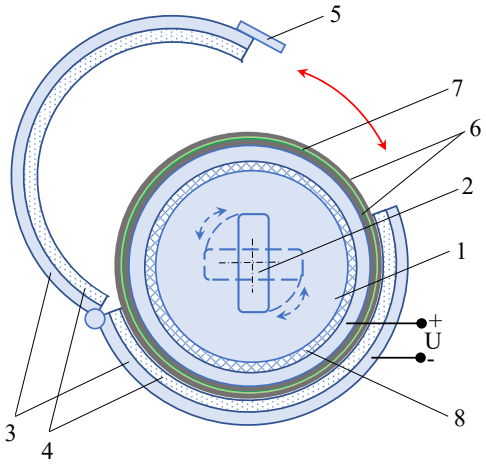

Fig. 3. Cross-section of a node for gluing intestinal membranes using electrophoresis during tanning with a tannin solution: 1 — an internal cylinder to which a positive potential is applied; 2 — a connector for connecting a sausage casing template; 3 — external cylinder to which a negative potential is connected; 4 — a sponge impregnated with tannin solution; 5 — a lock for fastening parts of the outer cylinder; 6 — intestinal membranes to be glued; 7 — adhesive related construct (serous film) applied to the place of gluing; 8 — heating element

The node for gluing intestinal membranes and tanning the place of gluing functions as follows. A template for sausage casings 1 (Fig. 2) is attached to this unit using connector 2 (Fig. 3). At the same time, the outer cylinder is previously disconnected.

The intestinal membrane is pulled from the side of the node for gluing and tanning on the template. The diameters of the template for sausage casings, the inner and outer cylinders of the assembly for gluing intestinal casings and tanning the place of gluing are selected according to the raw materials. This refers to the origin of the raw material (beef, lamb, pork, etc.) and its type by part of the intestine (belly, circles, bilge, bladder, etc.). The free end of the intestinal lining or its damaged part is the area to be glued. We place this section in such a way (Fig. 4) that it is on the surface of the inner cylinder of the unit for gluing and tanning.

Next, the part of the intestinal membrane 6 (from Fig. 3, 4), which is to be glued with another intestinal membrane or part of the same intestinal membrane, is covered with a serous film 7 (from Fig. 3, 4). Bonding with another intestinal membrane is carried out in the case of gluing the free ends of different intestinal membranes. The gluing of parts of the same membrane is carried out in the event of a violation of its integrity. After that, either the free end (in the case of gluing the free ends of different intestinal membranes) or part of the same membrane (in the case of gluing parts of the same shell due to violation of its integrity). Next, we turn on the heater 8 (from Fig. 3, 4), mounted in cylinder 1, and dehydrate the place of gluing.

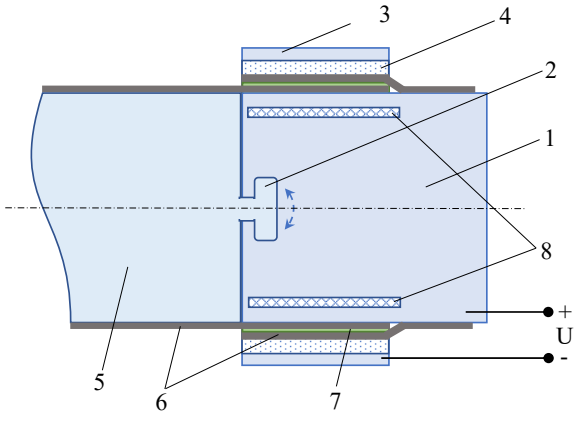

Fig. 4. Longitudinal section of a node for gluing intestinal membranes using electrophoresis during tanning with a tannin solution: 1 — an internal cylinder to which a positive potential is applied; 2 — a connector for connecting a sausage casing template; 3 — external cylinder to which a negative potential is connected; 4 — a sponge impregnated with tannin solution; 5 — template for sausage casing; 6 — intestinal membranes to be glued; 7 — adhesive related construct (serous film) applied to the place of gluing; 8 — heating element

After dewatering the place of gluing, the outer cylinder 3 (from Fig. 3, 4) is fixed above it with the help of lock 5 (from Fig. 3). The sponge 4 (from Fig. 3, 4), which covers the inner surface of the outer cylinder 3, is pre-moistened with a tannin solution of a certain concentration in the range from 1.5 to 3 %. The distance between the inner and outer cylinders of the unit for gluing and tanning is selected in such a way that, provided the parts of the outer cylinder are fixed, the layers of the intestinal membranes are tightly pressed against each other.

The next stage is the tanning of layers of intestinal raw materials with a tannin solution. Tanning is carried out in order to give the place of gluing of intestinal membranes irreversible properties in terms of recovery in liquid. In the absence of this treatment, the properties of the connected intestinal membranes, provided they are moistened, are restored before the weekend. As a result, the strength of the seam does not meet the requirements for functional and technological properties of glued sausage casings. Based on this, tanning is a necessary operation for the devised technique of gluing intestinal membranes.

Since tannin has a negative charge, applying a potential difference will help accelerate the diffusion of these particles into the substance. Based on this, a certain positive potential is applied to the inner cylinder, and a certain negative

potential is applied to the outer cylinder. After a certain duration of exposure, the outer cylinder is removed, and the glued intestinal casings are moved along the template for the sausage casing. The operation of gluing casings is repeated until the template for sausage casings is completely covered with glued intestinal casings. Next, the template is disconnected from the assembly for gluing and tanning, and the resulting sausage casing on the template is sent to a drying cabinet (Fig. 5) for dehydration.

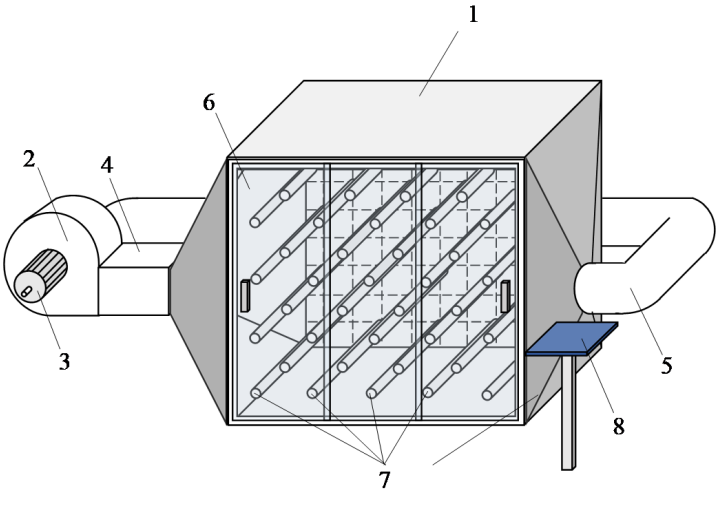

Fig. 5. Schematic diagram of a dryer for dehydrating sausage casings on templates: 1 — drying chamber; 2 — radial centrifugal fan for pumping air into the drying chamber; 3 — electric motor of the auger screw; 4 — duct with a block of electric heaters; 5 — air duct for air recirculation with a condensate trap; 6 — sliding transparent door of the drying chamber; 7 — templates with sausage casings; 8 — control panel tablet

Drying of wet sausage casings on templates is carried out in a drying cabinet by convective technique (Fig. 5). One of the walls of the drying chamber 1 is equipped with connectors for connecting templates 7 with wet sausage casings put on them. After filling the drying chamber with wet raw materials, the sliding door 6 is tightly closed and the electric motor 3 is turned on, which rotates the radial centrifugal fan 2, which pumps air into the drying chamber. In duct 4, a block of electric heaters is placed, with the help of which the drying agent (air in the drying chamber) is heated. Heated air is a heat and mass carrier. Exhausted air enters duct 5 for recirculation with a condensate trap. In the air duct, the exhaust air is partially dried and enters the opening of the radial centrifugal fan for suction. This makes it possible to partially use the spent heat, which helps increase the energy efficiency of the drying process. To control the drying parameters (temperature of the drying agent, its speed), a control panel 8 is provided. To monitor the dehydration process and its visual control, the sliding door 6 of the drying chamber is made of a transparent material with low thermal conductivity.

5. 2. Determining the rational parameters for the tanning process of the place of gluing between the layers of the intestinal membranes

The schematic diagram of the proposed process includes the following operations:

– preparation for gluing of fabricated bellies of various origins and types;

– preparation of the gluing site using an adhesive related structure;

– bringing the layers of intestinal membranes to be glued into direct contact;

– dehydration of the bonding site;

– tanning of the bonding site with tannin solution using electrophoresis to speed up this process;

– drying of the resulting sausage casings.

The process that includes the proposed technique and the presence of which distinguishes it from known techniques for gluing intestinal membranes should be highlighted here. This process is the process of tanning with a tannin solution, accelerated by the use of electrophoresis. In work [4], the process of tanning intestinal raw materials with a tannin solution was studied in detail, the rational values of its concentration and the rational duration of exposure of the gluing site were determined. However, electrophoresis is not used in the proposed technique to speed up the tanning process. Therefore, it is necessary to investigate the influence of the parameters of this process on the tanning process. That is, it is necessary to determine the rational potential difference that is applied to the electrodes, and the rational duration of exposure of the gluing site at the given potential difference.

The criterion used to search for a rational potential difference between the electrodes during electrophoresis and a rational duration of exposure of the gluing site was the breaking load of the seam between the glued intestinal membranes until rupture or delamination. The concentration of tannin in the tanning solution was equal to 3 %.

The breaking load of the seam between the glued intestinal membranes was determined for different potential differences (U) and for different durations of exposure (τ) of the gluing site. At the same time, the potential difference U varied discretely from 50 to 100 V at a constant current of 50 mA, and the duration of exposure τ – from 10 to 30 min. That is, a two-factor experiment was conducted, where the arguments were the potential difference between the electrodes and the duration of the exposure, and the result was the breaking load of the seam between the glued intestinal membranes, obtained at the specified values of the arguments.

Rational values of the potential difference applied to the electrodes and the duration of exposure of the gluing site were determined for samples of intestinal membranes from beef bellies.

The experimental data, which represented the value of the breaking load of the seam between the glued intestinal membranes at different potential differences (U) and at different durations of exposure (τ) of the gluing site, were approximated by a function of the form:

$$P(U,\tau)=a_0+a_1\cdot U+a_2\cdot\tau+a_3\cdot U^2+a_4\cdot\tau^2+a_5\cdot U\cdot\tau, \quad (2)$$

where $a_0=-26.889$, $a_1=0.53$, $a_2=0.967$, $a_3=-3.067\cdot10^{-3}$, $a_4=-0.019$, $a_5=3\cdot10^{-3}$ – approximation coefficients.

The range of values of the obtained approximation function in the form of a surface is shown in Fig. 6.

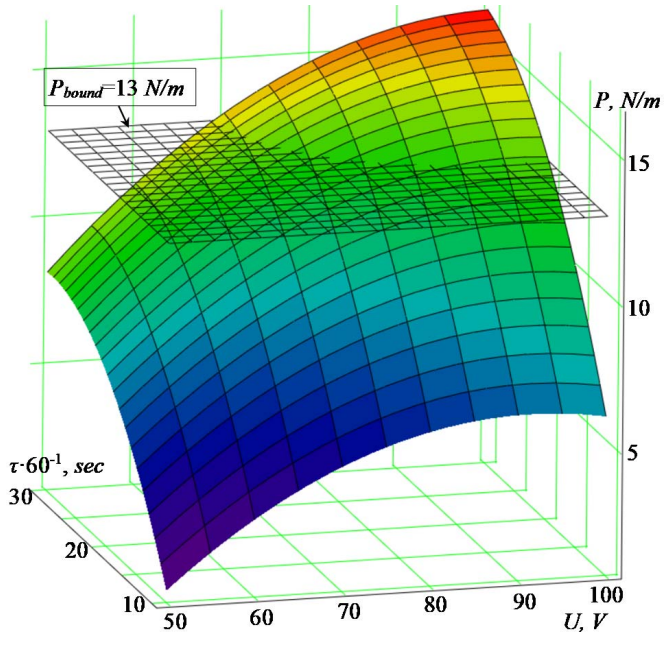

Fig. 6. The range of values of the breaking load of the seam (P) between glued intestinal membranes (on the example of beef bellies) at different potential differences (U) and at different exposure durations (τ) of the bonding site during tanning using electrophoresis

Fig. 6 also shows a plane parallel to the plane $OU\times O\tau$, which corresponds to the ultimate breaking load P_{bound}. The quantity of P_{bound} is the load, the value of which corresponds to the sufficient strength of the seam for glued sausage casings from beef bellies, as noted in paper [4]. That is, for the breaking load value less than P_{bound}=13 N/m, the sausage casing obtained by gluing intestinal raw materials (beef bellies) will be insufficiently strong from the point of view of functional and technological properties. Based on this, one should choose rational electrophoresis parameters during tanning with a tannin solution of the bonding site (potential difference and exposure duration) from the range that corresponds to the values of the breaking load above the plane P_{bound}.

Technological operations in the devised technique for obtaining sausage casings from intestinal raw materials using electrophoresis are not long-term. Based on this, when choosing rational parameters for electrophoresis, we focused on the shortest duration of exposure of the gluing site. The shortest duration of exposure of the gluing site, based on the line of intersection of the planes shown in Fig. 6, corresponds to the largest potential difference between the electrodes, i. e. U=100 V.

Fig. 7 shows the cross-sectional area of values of the breaking load of the seam between the glued intestinal membranes (on the example of beef bellies) at a potential difference of U=100 V.

From Fig. 7, it can be seen that the minimum duration of exposure of the gluing site, which corresponds to the breaking load of the seam between the glued intestinal membranes of at least 13 N/m at a potential difference of U=100 V, is equal to 20 minutes. Thus, the potential difference U=100 V and the duration of exposure of the bonding site τ=20 min should be considered as rational electrophoresis parameters during tanning with a tannin solution of the bonding site between intestinal membranes from beef bellies. In this case, the place of gluing before tanning was covered with an adhesive related structure (serous film).

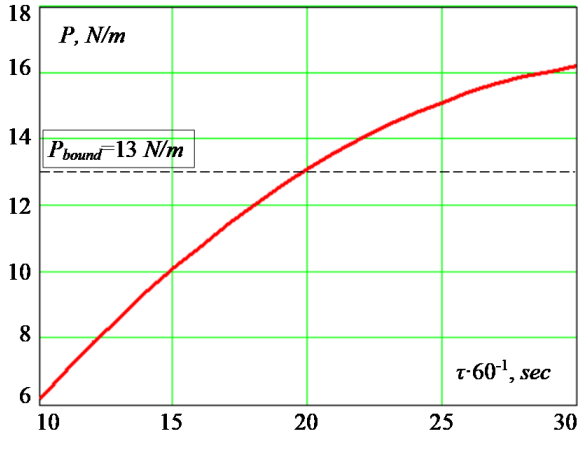

Fig. 7. Change in the breaking load of the seam between glued intestinal membranes (on the example of beef bellies) for different durations of exposure of the place of gluing during tanning using electrophoresis at a potential difference of U=100 V

In the work, the rational parameters for electrophoresis during tanning with a tannin solution of the place of adhesion between the intestinal membranes from lamb and pork bellies using an adhesive related construct (serous film) are similarly determined. Our results are given in Table 1.

Table 1

Rational parameters for electrophoresis during tanning with tannin solution of the places of gluing between the intestinal membranes from raw materials of different origins

Sausage casing from:	Potential difference between electrodes, V	Exposure time of the gluing site, ×60⁻¹ s
Beef bellies	100	20
Lamb bellies	100	17
Pork bellies	100	17

The given results differ for raw materials of different origins in terms of the exposure time of the gluing site.

6. Discussion of results related to devising the technology for glued sausage casings from intestinal raw materials using electrophoresis during tanning

The technology of glued sausage casings from intestinal raw materials of various origins and species has been devised. This technology differs from the known ones in the application of the technique for gluing intestinal membranes using an adhesive related structure and electrophoresis during tanning.

Gluing sausage casings using this technique involves connecting the edges of different intestinal casings or damaged areas of the same intestinal casing. At the same time, an adhesive related structure (serous film) is used between the layers of the glued intestinal membranes as an adhesive, which also promotes better contact between them. To give the obtained seam the appropriate strength, dehydration of the place of gluing and tanning with a solution of tannin (tannin) is used, where electrophoresis is used to speed up this process. It is such technological operations that make the proposed technique one that does not lead to a violation of the integrity of the raw material, and, as a result, contributes to the integrity and, accordingly, to the improvement of the quality of the final product – sausage casing. In addition, such products are similar in appearance to sausage casings from raw materials whose integrity is not violated, that is, raw materials that do not belong to waste.

The proposed gluing technique could be applied to different raw materials, i.e. raw materials of different origin (beef, lamb, pork, etc.) and its type according to part of the intestine (bellies, circles, bruises, bladders, etc.). The type and origin of the raw material determine the overall dimensions of the template (Fig. 2) and the node (Fig. 3, 4) for gluing intestinal membranes using electrophoresis during tanning with a tannin solution, namely their diameter and length. The origin and type of raw materials also determine the rational parameters of electrophoresis during tanning – the potential difference applied to the electrodes and the duration of exposure of the gluing site. However, due to the limited range of raw materials, one should expect a low level of material costs for the technical support of the technique and device for obtaining glued sausage casings.

It should be noted that the operations of preparation of raw materials, gluing, tanning, and drying of glued sausage casings do not require special qualifications from the personnel. This indicates the simplicity of the proposed technique.

Based on this, it should be considered that the devised technique satisfies the initial requirements set for it.

Raw materials for the production of glued sausage casings according to the devised technique of gluing are prepared in accordance with current technological instructions. The size of the sausage casing template is selected according to the raw material, and the casing gluing node is selected according to the size of the sausage casing template.

The place of gluing was covered with a serous film with a layer thickness of no more than 0.5 mm. Control over the thickness of the layer, density and thoroughness of the covering of the gluing site was carried out visually.

During tanning, in the absence of any methods that accelerate this process, the duration of exposure of the gluing site should be at least 10...12 hours [4, 5]. With this duration of exposure, the minimum seam strength of the obtained sausage casings is achieved from the point of view of their functional and technological properties [4]. At the same time, the concentration of the tannin solution, which was used as tannin, was equal to 1.5 %. However, the imposition of a potential difference corresponding to the polarity on the electrodes, between which there is a layer of serous film between the layers of the intestinal membranes to be glued, makes it possible to accelerate the diffusion of the tanning substance in the place of glueing.

As research shows, on the example of pork, lamb, and beef bellies (or, precisely, parts of the small intestine of the cattle), there is an opportunity to shorten the tanning process to 17...20 minutes (Table 1). In this case, a solution of tannin with a concentration of 3 % is used. This duration of the tanning process is achieved, firstly, due to the use of a serous film (an adhesive related structure) as an adhesive substance, which also promotes better contact between them. Second, the technique involves the use of electrophoresis to increase the rate of diffusion of charged tannin into the area to be tanned. At the same time, the concentration of tannin is increased by 2 times in order to increase the number of charge carriers in the solution.

Studies (on the example of beef bellies) show (Fig. 6) that there are values of the potential difference and duration of exposure of the gluing site, at which the appropriate strength of the received seam between the intestinal membranes is achieved. No mechanical damage occurred for the raw material under the influence of the largest potential difference (U=100 V) and the largest current (I=50 mA), which the electrophoresis device can technically provide. Based on this, the rational value of the potential difference was chosen as much as possible. In addition, the selection of the potential difference between the electrodes as much as possible was determined by the desire to reduce the duration of exposure of the bonding site (Fig. 7).

The result of our study on the tanning process of the gluing site between the layers of the intestinal membranes using electrophoresis is the rational values for the potential difference between the electrodes and the duration of exposure of the gluing site (Table 1). Table 1 gives the rational parameters for electrophoresis during tanning with a tannin solution of the place of adhesion between intestinal membranes from the following raw materials (parts of the small intestine): pig bellies, lamb bellies, beef bellies. The results differ in the value of the duration of exposure of the gluing site. For example, the duration of exposure is 17 minutes for venison and lamb bellies, and 20 minutes for beef bellies. Differences in these values are probably due to the thickness of the layer of the raw material: lamb and pork bellies are technologically freed from all ballast layers, leaving only the submucosa, while beef bellies are not, leaving the muscle layer. Along with other factors, this is obviously the reason for the greater thickness of the beef bellies and, as a result, the longer duration of exposure of the tanning site.

Drying of the obtained sausage casings, which is described in various works on the dehydration of collagen-containing raw materials [4], was carried out by the convective technique. The drying temperature was 50–60 °C, and the duration was 15–20 min.

Thus, the technology of glued sausage casings from intestinal raw materials, which are classified as unclaimed residues and waste, has been proposed. The technology differs

from known similar technologies [4, 5] by using a technique of gluing intestinal membranes using an adhesive related construct and electrophoresis during tanning. The proposed technique for gluing and the device for its implementation make it possible to avoid violation of the integrity of the raw material, universal in relation to it and easy to operate.

A limitation of the study is that the rational parameters of electrophoresis, which is used to accelerate the tanning process, have been determined only for pig, lamb, and beef bellies, namely parts of the small intestine of the cattle. That is, the work did not determine the rational parameters of electrophoresis during the tanning of such parts as the blue, bubble, circle, passage, etc. This is a prospect for further research.

The disadvantage of our study is that the equipment for providing electrophoresis has power limitations, that is, a limited range of changes in the potential difference applied to the electrodes (<100 V). Obviously, the increase in the potential difference applied to the electrodes during tanning will contribute to the reduction of the duration of exposure of the bonding site between the layers of the intestinal membranes. However, due to the limited technical capabilities of the equipment used for electrophoresis, there are no experimental data on larger potential difference values. A possible way to overcome this drawback is the use of equipment with wider technical capabilities.

7. Conclusions

1. A technique for gluing together layers of intestinal raw materials using adhesive related structures with subsequent tanning of the gluing place with a tannin solution accelerated by electrophoresis has been proposed. A device for obtaining glued sausage casings has been designed, with the help of which the operations of gluing layers of intestinal raw materials and tanning the place of gluing using electrophoresis are carried out.

2. The rational parameters for electrophoresis, which is used to speed up the tanning process at the place of gluing the layers of the intestinal membranes using an adhesive related construct, have been determined. The potential difference between the electrodes and the duration of exposure of the gluing site for gluing the original intestinal raw materials: pork belly, lamb belly, beef belly was determined. At a potential difference of 100 V, the duration of exposure of the gluing site for pork and lamb bellies is 17 minutes, and for beef bellies – 20 minutes. It is noted that the results differ in the duration of exposure of the gluing site, which is probably due to the thickness of the layer of the raw material.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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