The object of this study is the technology of glued sausage casings from non-grade beef intestinal raw materials. Gluing is achieved through local tanning of the layers of intestinal raw materials to be glued. Tanning is used to give the gluing site irreversible properties, i.e., in the presence of such treatment, there is no delamination or separation of the gluing site. At the same time, due to the local tanning, the original properties of the raw material are preserved, namely, plasticity and elasticity. To accelerate the tanning process, the technique devised proposes using a preliminary local pre-hydrolytic acid treatment of the layers of raw materials to be glued. Local pre-hydrolytic acid treatment helps accelerate the diffusion process between the layers of intestinal casings to be glued and also helps reduce the duration of the operation of local tanning of the gluing sites treated in this way.

The rational parameters for local tanning have been determined, namely, the concentration of the tanning solution and the duration of local tanning provided that the raw material has been pre-hydrolyzed: the rational duration of local tanning is 10 hours at a tannin concentration in the tanning solution of 1.3%, at a tannin concentration of 2.0% – 5...5.5 hours. It has been established that there are certain pairs of values of these factors at which the seam strength (seam breaking load) is not less than the limit value of the seam breaking load, which is a necessary functional and technological condition for glued sausage casings. It has been established that the preliminary local pre-hydrolyzed acid treatment helps reduce the local tanning process by more than two times

Keywords: glued sausage casings, pre-hydrolyzed acid treatment, local tanning, breaking load

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IMPROVING THE TECHNOLOGY OF GLUED SAUSAGE CASINGS FROM SUBGRADE BEEF INTESTINAL RAW MATERIALS

Andrey Pak
Corresponding author
Doctor of Technical Sciences, Professor
Department of Physics and Mathematics**
E-mail: pak.andr1980@btu.kharkov.ua
Vyacheslav Onishchenko
Doctor of Technical Sciences, Associate Professor*
Maryna Yancheva
Doctor of Technical Sciences, Professor,
Dean*
Nataliya Grynchenko
Doctor of Technical Sciences, Associate Professor
Development Director
CAPS FOOD SYSTEMS LLC
Zaliznychnyi lane, 3/4, Derhachy, Ukraine, 62302
Alina Pak
PhD, Associate Professor
Department of Marketing and Trade Entrepreneurship
V. N. Karazin Kharkiv National University
Svobody sq., 4, Kharkiv, Ukraine, 61022
Samvel Inzhyyants
Senior Production Technologist of Uncooked Unsmoked Products
Chuhuyiv Meat Plant LLC
Heroyiv Chornobyl'tsiv str., 50, Chuguyiv, Ukraine, 63503
Artem Onyshchenko
PhD Student*
*Department of Meat Technology**
**State Biotechnological University
Alchevskykh str., 44, Kharkiv, Ukraine, 61002

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1. Introduction

Increasing the volume and degree of processing of meat industry resources, involving secondary animal raw materials, in food technologies to design an additional marketable product [1] corresponds to the modern global paradigm of the purpose and development of the food industry [2, 3].

Among the directions for solving the task of comprehensive processing of intestinal raw materials in the technologies of natural casings and sausage products with their use, the most effective is the return of residues and waste to commercial production, which is implemented with minimal transformations. In this case, the use of natural film form-capacity can be considered a priority given the universal properties and functionality of sausage casings [4, 5].

The fundamental principle of obtaining glued intestinal casings is the natural ability of film layers to form a strong connection as a result of their dehydration. However, along with the technological simplicity of known conventional solutions, both splicing of sleeve films and creating multifunctional films, the task to ensure stability of the strength of bonding seams in an aqueous environment and under the influence of internal stresses remains relevant [6].

2. Literature review and problem statement

In [7], the results of research into methods for connecting natural sausage casings in a wet state using high-frequency current are reported. It is shown that attempts to use this technique, which is successfully implemented in medicine, for pork and lamb intestines in the process of obtaining natural casings for sausage production may prove effective. However, issues related to obtaining dry glued intestinal casings from non-grade beef raw materials, in particular the formation of tubular films from cut strips of residues and waste products, remain unresolved. The reason for this is the fundamental impossibility of implementing the technique for such raw materials in a dry state, as well as the uncertainty of the process parameters for non-grade beef intestines.

A close option for overcoming corresponding difficulties may be to achieve the efficiency of connecting intestines using a laser. This is the approach used in [8]. However, the high cost and technical complexity, limited adaptation (for splicing only parts of the sleeve in a wet state) of this technique predetermine the expediency of searching for other technical and technological solutions.

In work [9], hardware solutions for local tanning, local thermal coagulation technologies, including due to the flow of electric current and using an arc discharge, are proposed. It is shown that irreversible strength indicators of glued shells made from manufactured pig intestines are achieved. However, these solutions are experimentally adapted using the example of exclusively pig intestines. This creates the need to conduct appropriate studies for beef, lamb raw materials, including for individual sections of the animal intestine, which differ in structural-mechanical and physical-chemical properties [10, 11]. As a result, one of the most common in intestinal production, beef intestinal raw materials, must be additionally prepared for the effective implementation of modification of its properties by tanning. Increasing the degree of accessibility of collagen in beef products to effective diffusion and subsequent tanning can be achieved through preliminary pre-hydrolysis acid treatment [12]. In this case, the parameters of both pre-hydrolysis acid treatment and subsequent tanning of beef bellies need to be determined.

An option to overcome these complications may be to improve the technology using adhesive related constructs (serous films, etc.) and electrophoresis as an accelerator of tannin diffusion. This approach was used in [13]. However, a characteristic disadvantage of this technique is the increase and complexity of manual labor, the need for the availability, isolation, and preparation of additional raw materials, which reduces its overall efficiency.

The theory and practical results of surface bonding indicate a significant role in the efficiency of the pressing process [14, 15]. Pressing can mechanically improve the interdiffusion processes of cohesive layers subjected to pre-hydrolysis acid treatment and improve the quality of their bonding. At the same time, there is currently no data on the influence of the pressing action on the strength of the bonding of intestinal films. And the known solutions are unsuitable for use for intestinal material due to the difference in its physical properties.

All this gives grounds to argue that research into improving the technology of glued beef casings using pre-hydrolysis treatment, pressing, and tanning of cohesive seams, as well as the development of structural solutions for relevant devices, is needed.

3. The aim and objectives of the study

The aim of our work is to improve the technology of glued sausage casings from non-graded beef intestinal raw materials by using local preparatory pre-hydrolysis treatment, pressing, and tanning of cohesive seams in the technique of gluing them. The use of this technique could enable the formation of stable (irreversible) mechanical properties of natural films.

To achieve the set goal, the following tasks were solved:

– to devise a technique for obtaining glued sausage casings by pre-hydrolysis treatment of the surfaces of the layers of intestinal raw materials to be glued, followed by pressing them together and local tanning of the gluing site;

– to determine the rational parameters of operations for obtaining glued sausage casings from non-graded intestinal raw materials using the devised technique.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the technology of obtaining glued sausage casings from non-grade beef intestinal raw materials.

The hypothesis of the study is to prove the possibility of using, when gluing non-grade beef intestinal raw materials, preliminary local pre-hydrolysis treatment of the surfaces to be glued, followed by their pressing and local tanning.

It is assumed that preliminary pre-hydrolysis treatment of the layers of intestinal raw materials to be glued helps accelerate the diffusion process between them and also helps reduce the duration of the operation of local tanning of the gluing areas treated in this way.

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

The raw material for which the study was conducted is strips of intestinal films obtained by cutting manufactured beef stomachs, which were processed and prepared in accordance with current regulatory and technological documentation.

Surface treatment was carried out with an aqueous solution of lactic acid ($C = 2.0\%$). Treatment duration – 4 h [16].

4. 3. Methodology for studying the strength of the seam between the layers of intestinal membranes

The methodology for studying the strength of the seam obtained by pressing two layers of intestinal membranes together, their local pre-hydrolysis acid treatment with subsequent local tanning, was as follows (Fig. 1).

The test sample, which was a fragment of a glued sausage casing, through which a seam of a certain length L passes, was tightly fixed in holders. Then, a longitudinal force F was applied for 1...2 min and the seam was visually observed. If, during the observation, the seam did not rupture or delamination occurred, the force was discretely increased. The study was completed in the event of a seam rupture or delamination. The limit value of the load at which the seam ruptured, or delamination occurred was considered to be breaking.

The rupture load P of the seam between the layers of the intestinal casings was determined in a wet state (after soaking in water for 3 min) from the following formula

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

where F is the force at which the seam between the layers of the intestinal membranes ruptures or separates, N; L is the length of the seam, m.

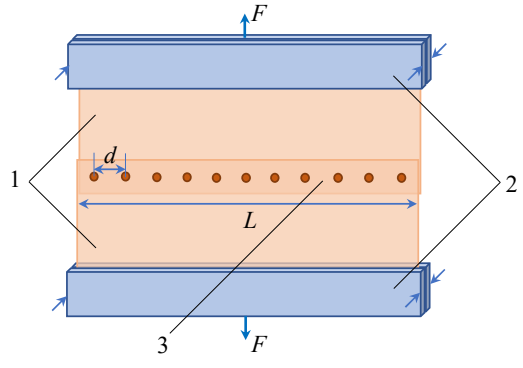

Fig. 1. Scheme for determining the breaking load of the seam between the layers of intestinal membranes: 1 — layers of intestinal membranes; 2 — holders; 3 — seam between the layers of intestinal membranes

5. Devising technology for glued sausage casings from non-graded intestinal raw materials

5. 1. Devising a technique for gluing intestinal casings using pre-hydrolysis treatment, pressing, and tanning

The requirements set during the development of a technique for gluing non-graded intestinal raw materials, which would make it possible to improve the efficiency of the technology for obtaining glued sausage casings, are:

– low material and energy consumption of equipment for ensuring the gluing technique;

– universality of the technique in terms of the dimensional characteristics of the raw material and the dimensional characteristics of the finished product, i.e., the dimensional characteristics of glued sausage casings;

– ease of manufacture and operation of the equipment used.

Given the requirements, a technique for obtaining sausage casings using pre-hydrolysis treatment of parts of the surfaces of the layers of raw materials to be glued, followed by their pressing and tanning of the gluing site, is proposed.

The technique for obtaining glued sausage casings is implemented in the following main stages:

– fabrication of a blank for a sausage casing;

– pressing the surfaces of the layers of intestinal casings to be glued;

– local pre-hydrolysis treatment of parts of the layers of raw materials to be glued;

– local tanning of parts of the layers of raw materials to be glued;

– drying the resulting sausage casing.

The device for fabricating a blank for a sausage casing consists of two main parts: a rubber template for a sausage casing 1 and a hollow metal perforated cylinder 2 (Fig. 2).

The rubber template has a cylindrical shape and is made in such a way that it is possible to fill it with air through valve 3. The size of the template is such that at a pressure inside it, which is equal to atmospheric (p), it fits freely inside a hollow perforated metal cylinder. At the same time, the diameter of the template at atmospheric pressure is less than the internal diameter of the hollow cylinder by 5...7 mm. The rubber template and the perforated cylinder were made in pairs, based on the requirements for the dimensional characteristics of the finished sausage casing (length and diameter).

Before fabricating a blank for a sausage casing, the pressure inside the rubber template was brought to atmospheric. Atmospheric pressure was chosen based on providing the template with sufficient elasticity provided that there are no special requirements for the properties of the rubber template regarding gas permeability.

Next, a sausage casing blank was fabricated from ungraded intestinal raw material. Ungraded raw material is a rectangular strip with characteristic dimensions $a \times b$. In this case, one characteristic dimension, which corresponds to the width of the strip, is significantly smaller than the other, which corresponds to its length, i.e., $a << b$. The characteristic dimension a is determined to a greater extent by the part of the intestine (stomach, round, blue, bladder, etc.) used as raw material, and dimension b is determined by the quality of the raw material (integrity of ungraded raw material).

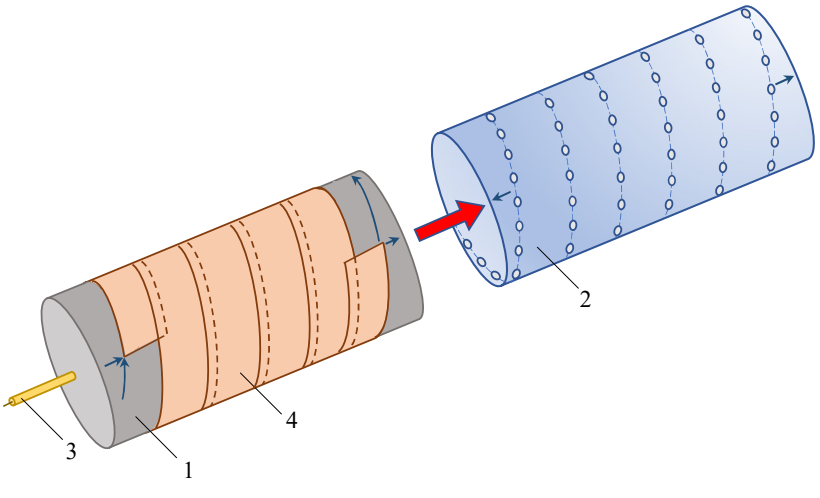

Fig. 2. Device for fabricating a sausage casing blank: 1 — rubber template for sausage casing; 2 — hollow metal perforated cylinder; 3 — valve for filling the rubber template with air; 4 — sausage casing blank from ungraded intestinal raw materials

Strips of raw material were wound in a spiral on template 1 in accordance with the markings applied with paint on the template (blue arrows on template 1 in Fig. 2). The raw material was overlapped. The strip was laid with an overlap on the previous layer. In this case, the width of the overlap is not less than 10...15 mm. In this way, a sausage casing blank 4 of the required length was formed (Fig. 2).

After fabricating the sausage casing blank, the template was inserted into the hollow metal perforated cylinder according to the marks on the cylinder and the template. The perforation on the hollow metal cylinder was made in a spiral with the same pitch as the marking for laying the raw material on rubber template 1. The marks were set in such a way that the sections of the sausage casing blank, which

represent the seam between the layers of intestinal raw material, were located directly opposite the perforation of the hollow cylinder.

Next, through the valve using an air compressor, the pressure inside the rubber template was brought to the value $p + \Delta p$. At the same time, the volume of the template increases and tightly presses the sausage casing blank to the inner surface of the hollow metal perforated cylinder. In places of perforation, the wall of the rubber template bends together with the sausage casing blank, the section of which is located opposite the perforation hole. A schematic view of the cross-section of a fragment of this section is shown in Fig. 3.

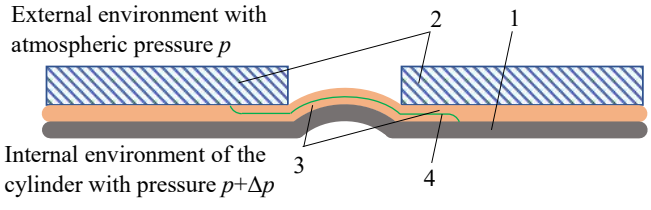

Fig. 3. Scheme of pressing the places of gluing the intestinal membranes between the wall of the rubber template and the wall of the hollow perforated cylinder: 1 — wall of the rubber template; 2 — wall of the metal cylinder; 3 — layers of intestinal membranes to be glued; 4 — contact surfaces of the layers of raw materials to be glued

The sausage casing blank prepared in this way was first sent for local pre-hydrolysis treatment of the gluing sites, and then for local tanning of the treated sites.

Without changing the pressure in the rubber template, the sausage casing blank inside the hollow perforated metal cylinder 1 was immersed in container 2 filled with lactic acid solution 3 of the appropriate concentration (Fig. 4). The blank is in the solution environment for a time $\tau_{treat.}$. Thus, the operation of local pre-hydrolysis treatment of the layers of raw materials to be glued was carried out.

Since the rubber template tightly presses the intestinal raw material blank to the inner surface of the hollow cylinder, the penetration of the solution under the solid part of the hollow cylinder through the perforation is excluded. Based on this, only that part of the sausage casing blank that is opposite the perforation is subjected to treatment. This technique of processing makes it possible to avoid changes in the initial properties of the raw material and to carry out local (point) pre-hydrolysis treatment of the places of gluing of intestinal shells.

After local pre-hydrolysis treatment of the places of gluing, local tanning of these places was carried out by immersing the sausage casing blank inside a hollow perforated metal cylinder into a container with a tanning solution. The blank is in the environment of the tanning solution for a time τ_{tan}. Thus, the operation of local tanning of locally processed layers of raw material to be glued was carried out.

After local tanning of the seams, the sausage casing blank, clamped by a rubber template inside a hollow perforated metal cylinder, was removed from the container with the tanning solution, and its surface was freed from the solution. Next, the air pressure inside the rubber template was reduced to atmospheric pressure (p). As a result, the volume of the template decreases, which allows it to be removed together with the sausage casing blank from the hollow perforated metal cylinder. The inner surface of the hollow perforated metal cylinder has a Teflon coating to prevent the sausage casing blank from sticking to it.

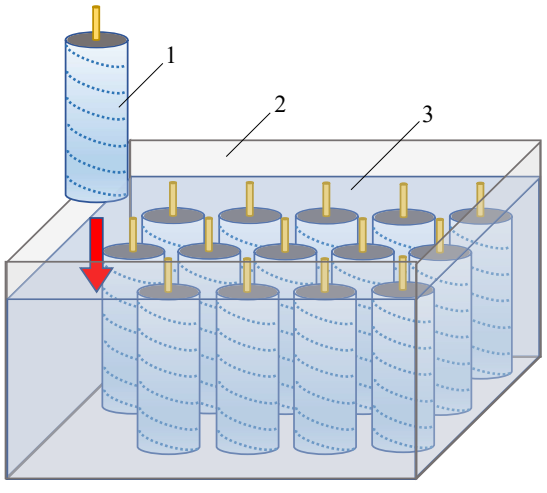

Fig. 4. Schematic showing the technique of local pre-hydrolysis treatment and local tanning of sausage casings: 1 — sausage casing blank, clamped with a rubber template inside a hollow perforated metal cylinder; 2 — processing container; 3 — lactic acid solution or tanning solution, depending on the operation being performed

The rubber template with the spot-tanned sausage casing blank was sent for drying. Drying was carried out in a drying cabinet by convection until the casing reached equilibrium moisture content.

After drying, the pressure in the rubber template through the valve was reduced to a value below atmospheric. Its volume decreases, as a result of which it is possible to remove the sausage casing dried to equilibrium moisture content. The finished product was folded and sent for storage.

5. 2. Determining the rational parameters for the operation of local tanning of layers of raw materials to be glued

The technique of obtaining glued sausage casings from non-grade intestinal raw materials consists of operations for which there are a number of external control parameters, such as:

– design characteristics of the devices (template size, frequency of raw material application, frequency of perforation of the hollow cylinder);

– conditions and parameters of pre-hydrolysis treatment (acid or alkaline treatment, concentration of the solution for pre-hydrolysis treatment, duration of pre-hydrolysis treatment, treatment temperature);

– conditions and parameters of tanning (duration of tanning, concentration of tanning solution, treatment temperature);

– drying parameters (dehydration technique, drying temperature).

These external parameters determine the resource and energy efficiency of the technology for obtaining glued sausage casings and the quality of the finished product. Among them, two external parameters of the local tanning operation of the layers of raw materials to be glued should be distinguished – the duration of tanning and the concentration of the tanning solution.

It should be noted that the proposed technique for obtaining glued sausage casings includes the operation of local pre-hydrolytic acid treatment of the layers of raw materials to be glued. This operation is used, firstly, to accelerate the diffusion between the layers of intestinal raw materials to be glued. Secondly, this operation helps reduce the duration of another operation that gives irreversible properties to the seam of the glued sausage casing in terms of preserving its properties in the wetting liquid – the operation of local tanning.

Based on the fact that gluing sausage casings in this way has not been done before, these selected parameters for the raw material chosen for the study (non-grade beef casings) have not been previously investigated.

We determined rational tanning parameters by a two-factor experiment, where one factor is the concentration of the tanning solution, and the second is the duration of tanning.

The criterion for selecting rational parameters of local tanning is the breaking load of the seam between the glued layers of intestinal raw materials. The breaking load was determined as shown in the diagram in Fig. 1. The limiting value of the criterion was considered to be a breaking load of 13 N/m [9].

The experimental data, which represented the values of the breaking load of the seam between the glued intestinal shells at different concentrations of the tanning solution (C) and at different tanning durations (τ), were approximated by a function of the form

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

where a_0, a_1, a_2, a_3, a_4, a_5 – approximation coefficients.

As a control, a seam sample obtained by local tanning of intestinal raw materials without pre-hydrolysis treatment of the raw materials was used.

The values of the coefficients of the approximation functions are given in Table 1.

Table 1

Coefficients of approximation functions obtained from experimental values of the breaking load of the sausage casing seam

Sample	Coefficient value:					
	a_0	a_1	a_2	a_3	a_4	a_5
Without pre-hydrolysis treatment	–26.528	21.833	1.850	–5.333	–0.053	0.1
With pre-hydrolysis acid treatment	–8.463	9.833	2.176	–1.667	–0.102	$8.0 \cdot 10^{-15}$

As a tanning solution, a solution of tannin was used with a concentration that varied discretely in the range from 1.0% to 2.0%. The duration of local tanning for the control sample (sample without preliminary treatment of raw materials) varied discretely in the range from 10 to 20 hours. The duration of local tanning for the intestinal casing sample with prior local pre-hydrolysis acid treatment varied discretely in the range from 4 to 10 hours. The temperature at which local tanning was performed was 15...25 °C.

The surface, which represents the value of the breaking load at different values of the concentration of the tanning solution and the duration of local tanning of the intestinal casing layers without preliminary treatment, is shown in Fig. 5. A similar dependence for the sausage casing sample, obtained with the use of prior local pre-hydrolysis a

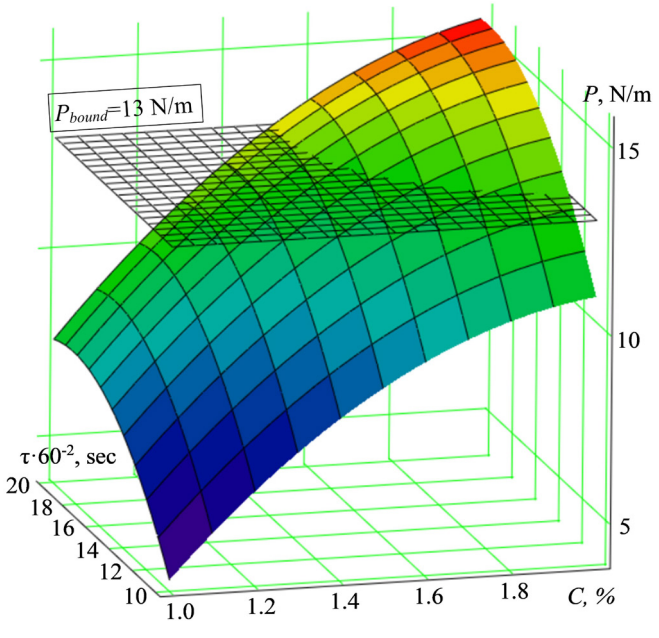

Fig. 5. Value of breaking load (*P*) of the seam between glued intestinal membranes without prior pre-hydrolysis treatment at different concentrations of tanning solution (*C*) and at different tanning durations (τ)

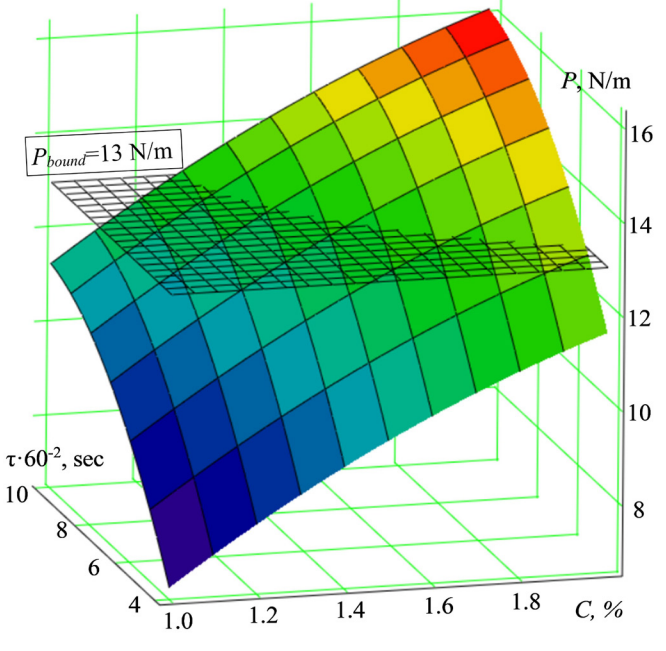

Fig. 6. Value of breaking load (*P*) of the seam between glued intestinal membranes with prior local pre-hydrolytic acid treatment of the gluing sites at different concentrations of tanning solution (*C*) and at different tanning durations (τ)

The surfaces have a similar nature: there is an increase in the breaking load of the seam between the glued intestinal shells with an increase in the concentration of the tanning solution and the duration of the tanning process from the studied ranges of their values. At the same time, there is a part of the surface, both with the pre-hydrolysis treatment of the raw material and without treatment, which is higher relative to the limiting value of the breaking load, i.e., above 13 N/m. These values of the concentration of the tanning solution and the duration of the tanning process should be considered rational.

To determine the region of rational values of these parameters, the equations of the lines along which the plane parallel to the $OC \times O\tau$ plane intersect at the level of 13 N/m and the surface of the breaking load values at different concentrations of the tanning solution and different duration of tanning are derived. The analytical form of the functions corresponding to these intersection lines was determined by equating the approximation functions of form (2) to the level of the limiting load plane (13 N/m). Next, the resulting equation was solved with respect to variable τ, that is, with respect to the tanning duration, and the analytical form of the intersection lines was obtained

$$C_{lim}(\tau_{lim}) = -(a_1 + a_5 \bullet \tau_{lim})/(2 \bullet a_3) - \\ - (((a_1 + a_5 \bullet \tau_{lim})/(2 \bullet a_3))^2 - \\ - (a_0 + a_2 \bullet \tau_{lim} + a_4 \bullet (\tau_{lim})^2 - 13)/a_3)^{0.5}, \quad (3)$$

where τ_{lim} and C_{lim} are the limiting values of the tanning duration and concentration of the tanning solution; a_0, a_1, a_2, a_3, a_4, a_5 are approximation coefficients from Table 1.

The ranges of rational values of the concentration of the tanning solution and the duration of local tanning of the gluing sites for sausage casing samples without pre-treatment and with local pre-hydrolytic acid treatment of the raw material are shown in Fig. 7, 8, respectively. These areas in the figures are highlighted by hatching.

Thus, rational values for the concentration of tanning solution and the corresponding duration of local tanning of intestinal membranes to be glued should be selected from the shaded areas shown in Fig. 7, 8.

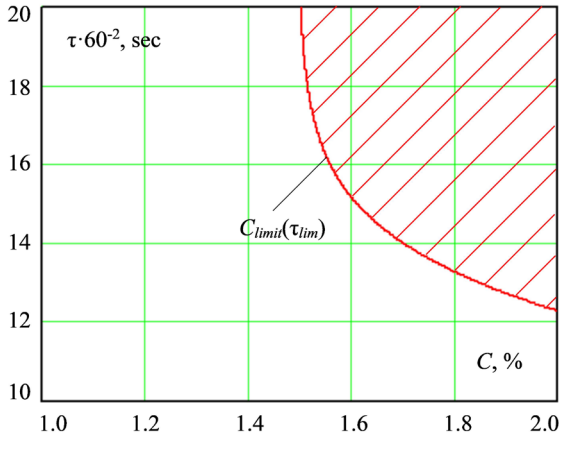

Fig. 7. The range of rational values for the concentration of tanning solution and the duration of local tanning of the gluing sites for sausage casing samples without preliminary processing of the raw materials

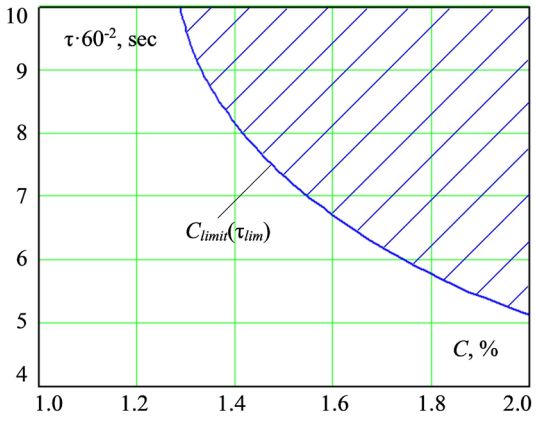

Fig. 8. The range of rational values for the concentration of tanning solution and the duration of local tanning of the gluing sites for sausage casing samples with local pre-hydrolytic acid treatment of the raw materials

6. Discussion of results based on the development of a technology for gluing intestinal casings from non-grade beef raw materials

A technique for obtaining glued sausage casings from non-grade intestinal raw materials has been devised. The technique uses local pre-hydrolysis acid treatment of parts of the surfaces of the layers of raw materials to be glued, followed by their pressing and local tanning of the gluing sites (Fig. 2–4).

The technique is intended for use as a starting material of non-grade intestinal raw materials – intestinal casings with impaired integrity. The use of such raw materials to obtain sausage casings is possible by gluing different layers of raw materials together.

Gluing is achieved due to local tanning of the layers of intestinal raw materials to be glued. Tanning is used to give the gluing site irreversible properties, i.e., with such treatment, delamination or separation of the gluing site does not occur. At the same time, due to the local tanning, the original properties of the raw material are preserved, namely, plasticity and elasticity. It should be noted that the tanning process is quite long and takes at least 10...20 hours. To speed up the execution of this operation, the devised technique proposes using local pre-hydrolysis acid treatment of the layers of raw material to be glued. This operation precedes local tanning.

Local pre-hydrolytic acid treatment helps accelerate the diffusion process between the layers of intestinal casings to be glued and also helps reduce the duration of the operation of local tanning of the glued places treated in this way.

To enable the proposed technique of gluing, it is necessary, based on the results of our study and the findings from previous research, to provide the features of the hardware of the technique and the rational values for control parameters of the operations used.

The dimensional characteristics of the devices (rubber template, perforated hollow metal cylinder) used in the devised technique (Fig. 2) are determined by the dimensional characteristics of the finished product, i.e., the size of the glued sausage casings. Based on the conditions that are put forward for the size of the sausage casing, a rubber template

of appropriate size and a hollow cylinder for this template are selected, which are performed in pairs.

The marking on the rubber template for the raw material that is wound on it is applied in accordance with the characteristic size of the raw material used. The raw material used in the study was beef stomachs. This raw material in the devised technique is used in the form of strips with a shape close to rectangular with characteristic dimensions $a \times b$. The basic characteristic dimension is the width of the strip, which is determined by the properties of beef stomachs. This dimension a lies in the range of 70...100 mm [17]. Based on this, the width of the marking, taking into account the fact that the strips are overlapped (the overlap width is 10...15 mm), is 55...60 mm. Since the strips are laid in a spiral, the spiral pitch is equal to the width of the marking.

The seam on the sausage casing (3 in Fig. 1) is not a solid line but a series of points with a certain distance between them d (Fig. 1), which were subjected to pre-hydrolytic acid treatment and subsequent tanning. The periodicity of these points is determined by the periodicity of perforation on a perforated hollow metal cylinder (2 in Fig. 2). The perforation holes are applied to the hollow cylinder in a spiral, while the rubber template is inserted into the cylinder in such a way that the holes are located above the overlap of the layers of raw material one on one. That is, the pitch of the spiral should correspond to the pitch of the spiral on which the strips of intestinal raw material are wound. Based on this, the pitch of the spiral along which the perforation is applied on the hollow cylinder is equal to 55...60 mm.

The distance d between the perforation holes in the spiral is determined by the properties of the seam to hold the filling for sausage products. The results of study [17] show that for sausage products with a diameter of not more than 100 mm, the acceptable distance between the points forming the seam of the sausage casing is $d = 20$ mm. In this case, the leakage of the liquid fraction of the filling of the sausage product occurs by no more than 7...8% over a period of 20...30 min. In view of this, the recommended distance between the centers of the holes in the perforation is 20 mm, and the diameter of these holes is 5 mm.

When choosing rational conditions and parameters for local pre-hydrolysis treatment of intestinal raw materials to be glued, we were guided by the results reported in work [16]. First, acid treatment was chosen, and a lactic acid solution was chosen as the working solution. The concentration of lactic acid was 2.0%. Secondly, the duration of pre-hydrolysis treatment was chosen, $\tau_{\text{treat.}} = 4$ h, in accordance with earlier studies [12]. At the same time, the temperature of the production room was chosen as the temperature at which local pre-hydrolysis treatment of layers of intestinal raw materials takes place – from 15 to 25 °C.

Rational conditions and parameters for local tanning of the places of gluing between the layers of intestinal casings were selected based on the results obtained in the study. The recommendations are based on the results of a two-factor experiment, where one factor is the concentration of the tanning solution (tannin solution), and the second is the duration of local tanning. These results show (Fig. 5, 6) that there are certain pairs of values of these factors, at which the strength of the seam (seam breaking load) is not less than the limit value of the seam breaking load. This is one of the necessary functional and technological conditions for glued sausage casings [9]. These pairs of values of the concentration of the tanning solution and the duration of the local tanning process form the range of values of the pairs of these factors, which were considered rational (Fig. 7, 8).

Studies show that for a sausage casing seam sample without prior pre-hydrolysis treatment, the rational duration of local tanning is 20 hours at a tannin solution concentration of 1.5%, and for a concentration of 2.0% – 12...12.5 hours. For a sample with prior local pre-hydrolysis treatment of the gluing areas, the rational duration of local tanning is 10 hours at a tannin concentration in the tanning solution of 1.3%, and for a concentration of 2.0% – 5...5.5 hours. The findings indicate that prior local pre-hydrolysis acid treatment helps reduce the process of local tanning by more than two times.

Obviously, the reduction in the duration of local tanning, due to the presence of a preliminary pre-hydrolysis treatment, is not a determining factor in terms of energy efficiency since this operation is not accompanied by significant energy consumption. However, from the point of view of rational use of raw materials, the duration of the tanning process should be chosen as short as possible. The intestinal raw material is in a wet state during tanning and may be microbiologically contaminated. As a result, an increase in the holding time relative to 15...20 hours may be accompanied by irreversible changes in the initial properties and loss of quality due to the growth of microorganisms.

The recommended temperature at which local tanning is carried out is 15...25 °C.

The recommended drying temperature was chosen based on the results reported in [6]. The temperature of the drying agent under the condition of convective drying of sausage casings glued using the devised technique should be chosen from the range from 50 to 60 °C.

Thus, the technology of glued sausage casings from non-grade intestinal raw materials has been improved. The technique underlying this technology differs from existing ones in the presence of operations of local pre-hydrolysis acid treatment, pressing, and local tanning of the gluing site. The technique does not require the use of complex hardware and highly qualified personnel. It does not contain operations with high energy consumption, except for drying, which is a necessary component of known techniques for obtaining glued intestinal casings.

The limitation of the study is that for local pre-hydrolysis treatment only a lactic acid solution was used, and for tanning – only a tannin solution. That is, the recommended parameters are rational only for such a combination of substances that are used for tanning and pre-hydrolysis treatment.

The disadvantage of the study is that in the proposed technique, it is obviously advisable to use only raw materials that can be used as strips with characteristic dimensions, one of which is significantly larger than the other (beef, pork, sheep stomachs). The use of short strips, strips with comparable characteristic dimensions (raw materials – blue, bladder, etc.) is complicated by the need for additional gluing operations.

A possible prospect for further research is the use of other substances for pre-hydrolysis treatment and tanning operations, excluding those used in this study, i.e., besides lactic acid and tannin solutions, respectively.

7. Conclusions

1. Special feature of the proposed technique for obtaining glued sausage casings is that the gluing of the raw material

is achieved through local tanning of the layers of intestinal raw material to be joined. Tanning is used to give the gluing site irreversible properties, i.e., in the presence of such treatment, there is no delamination or separation of the gluing site. At the same time, due to the local tanning, the original properties of the raw material are preserved, namely, plasticity and elasticity. To accelerate the tanning process, the devised technique proposes applying a preliminary local pre-hydrolysis acid treatment of the layers of raw material to be glued. Local pre-hydrolysis acid treatment is aimed at accelerating the diffusion process between the layers of intestinal casings to be glued, as well as at reducing the duration of the local tanning operation of the gluing sites treated in this way.

2. The rational parameters of local tanning were determined by a two-factor experiment, where one factor is the concentration of the tanning solution (tannin solution), and the second is the duration of local tanning. It was established that there are certain pairs of values of these factors, at which the strength of the seam (seam breaking load) is not less than the limit value of the seam breaking load, which is a necessary functional and technological condition for glued sausage casings. For the seam of a sausage casing sample without prior pre-hydrolysis treatment at a tannin solution concentration of 1.5%, the rational duration of local tanning is 20 hours, and for a concentration of 2.0% – 12...12.5 hours. For a sample with prior local pre-hydrolysis treatment of the gluing sites, the rational duration of local tanning is 10 hours at a tannin concentration in the tanning solution – 1.3%, and for a concentration of 2.0% – 5...5.5 hours. This indicates that the prior local pre-hydrolysis acid treatment helps reduce the local tanning process by more than two times.

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, as well as 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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