CHAPTER 23

STUDY OF THE ELASTIC-PLASTIC PROPERTIES OF GLUED PIG INTESTINAL FILMS SUBJECTED TO TANNING AND PLASTICIZATION

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INTRODUCTION

Modern global problems of resource conservation[1] and lean production[2], the use of effective tools and methodologies of the closed-loop economy[3] indicate the expediency of constant searches for reducing losses and residues of unused food raw materials. Effective technologies for creating added value as a result of resource-saving solutions should provide not only profit to a specific manufacturing enterprise. The relevance of solving the above problems is also inextricably linked to the environmental consequences of the formation and disposal of unclaimed waste, which should be considered from the social aspects of waste management[4]. At the same time, innovations in livestock and the meat industry inevitably lead to the need to improve and change technological approaches to raw material processing, to develop technical solutions for the implementation of substantiated proposals for the controlled modification of its physicochemical properties.

[1] Клещов А. Й., Хюгі К., Хенгевосс Д., Масліков М. М. Ресурсоефективне та чисте виробництво у м’ясній промисловості. К.: Центр ресурсоефективного та чистого виробництва, 2018. 68 с. URL: https://www.researchgate.net/publication/330442289_Resursoefektivne_ta_ciste_virobnictvo_u_m'asnij_promislovosti_Resource_efficient_and_cleaner_production_for_meat_sector/citations

[2] Palomino A., Carhuamaca N., Mota L. Systematic review on lean manufacturing in the productivity of the food industry // Creating solutions for a sustainable future: technology-based entrepreneurship: 4th LACCEI International Multiconference on Entrepreneurship, Innovation and Regional Development. July 17-19, 2024. Costa Rica. Paper 325. URL: http://dx.doi.org/10.18687/LEIRD2024.1.1.325

[3] Ciccullo F., Cagliano R., Bartezzaghi G., Perego A. Implementing the circular economy paradigm in the agri-food supply chain: The role of food waste prevention technologies // Resources, Conservation and Recycling. 2021. Vol. 164. 105114. URL: https://doi.org/10.1016/j.resconrec.2020.105114

[4] Система управління відходами в циркулярній економіці: фінансові, соціальні, екологічні та енергетичні детермінанти: монографія / За заг. ред. А. С. Росохатої, М. Г. Мінченко. Суми: Сумський державний університет, 2023. 313 с. URL: https://suem.edu.ua/storage/doc/aspirantura/naukova-aktyvnist/tsyrkuliarna-ekonomika.pdf

As for intestinal products, its main consumer remains sausage production, which uses natural casings for the manufacture of sausage products of all types. The universal properties of these natural containers allow for various technological effects (both thermal and mechanical), which ensure the formation of identification features of a wide range of sausage products in casings. Due to their natural properties, technical characteristics and consumer benefits associated with a stable trend towards naturalness, intestinal casings not only withstand competition with artificial analogues – polymers of various origins, but also effectively bring minced meat products with their use to the elite ranks, increasing the competitiveness of meat industry enterprises[5].

Along with this, the intensification of farming, increasing the moisture content of minced meat, the need to mechanize technological processes for the production of sausage products have significantly increased the amount of waste of natural casings in intestinal and sausage production in recent years[6], which in total reaches 30%. The solution to the problem of rational use of casing residues is the active introduction of glued film technologies. Today, a number of solutions have been proposed to eliminate the main drawback of such shells – the reversibility of the natural cohesive bond, which is formed as a result of drying the connected films, in a humid environment. These solutions consist in changing the physicochemical properties of the intestinal raw materials and achieving a state of irreversibility as a result of measures for their physical and chemical crosslinking[7].

Among the wide variety of intestinal products (both by species and anatomical-production names), given the distribution, the predominant share in the set of intestines, technological aspects of processing and mechanical characteristics of the final product, pork intestines, as a raw material that forms significant residues at all technological stages (from processing to use in sausage production), can potentially be involved in the manufacture of conditioned products and requires special attention.

The effectiveness of tanning in order to obtain high and stable mechanical characteristics in the technology of glued intestinal films from pork intestines, on the one hand, and significant losses of elasticity, characterized by the degree

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[5] Онищенко В. М., Шубіна Л. Ю., Янчева М. О. Наукові та практичні аспекти виробництва і застосування натуральних ковбасних оболонок: монографія. Харків: ХДУХТ, 2009. 149 с.

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of stretching, pose the task of studying the ways of forming their elastic-plastic properties that will correspond to the regimes of sausage technology. It is known that such tasks in the technology of film materials are traditionally solved by plasticization[8].

Obviously, under the action of load, film materials are deformed. This is due to the fact that the load causes the particles of this material to move relative to each other. Types of deformation are divided into reversible and irreversible, respectively, reversible deformations disappear after the end of the applied forces, and irreversible ones remain. For sausage casings, which are sleeve-shaped films, such elastic-plastic properties are one of the defining functional and technological properties that characterize this product.

Thus, the study of the elastic-plastic properties of glued pork intestinal films made from pork intestines and subjected to tanning and plasticization is relevant.

1. The aim, objects, subject, materials and methods of the study

The aim of the study is research of the elastic-plastic properties of glued pork intestinal films subjected to tanning and plasticization, and to establish the stress values corresponding to the destruction of the studied films, i.e. their rupture.

The study used samples of the following glued pork intestinal films from manufactured stomachs (sleeve-shaped):

– manufactured using traditional technology;

– additionally strengthened by cross-linking using continuous tanning with an aqueous tannin solution;

– additionally strengthened by cross-linking using continuous tanning with an aqueous tannin solution and plasticization with glycerin.

The control in the conducted studies was the first sample. Glued intestinal films of a sleeve shape were obtained by traditional technology by superimposing strips of intestinal films on a cylindrical shape one on top of the other with a partial overlap of the edge sections of 10–20 mm, after which they were dried, as a result of which the primary natural adhesion was formed.

The regularities of changes in the elastic-plastic properties of glued pork intestinal films were studied by modifying their properties in reasonable rational ranges of tannin concentration from 1.0% to 2.0% and glycerin 5%[9].

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8 Said M. I., Erwanto Y., Abustam E. Properties of Edible Film Produced using Combination of Collagen Extracts of Bligon Goatskin with Glycerol // American Journal of Animal and Veterinary Sciences. 2016. Vol. 11, No 4. P. 151-159. URL: https://doi.org/10.3844/ajavsp.2016.151.159

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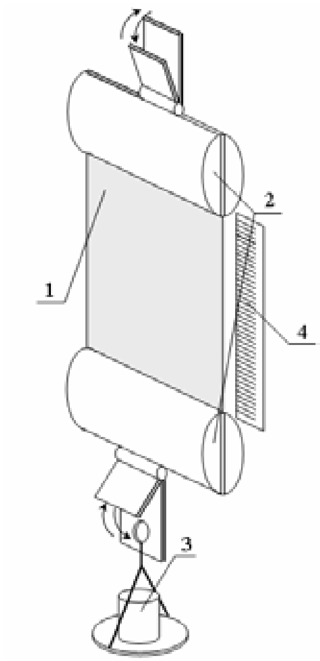

Fig. 1. Scheme of the unit for studying the elastic-plastic properties of glued pig intestinal films: 1 – test sample; 2 – holder-clamp; 3 – variable load; 4 – ruler for measuring the change in length during loading

It should be noted that the main task was to identify the influence of continuous tanning, which is obviously technically simpler from the point of view of implementing the process of modification transformations. Local processing allows avoiding significant irreversible changes in elastic-plastic properties, however, it requires the introduction of additional structural and hardware solutions, which cannot but affect the cost of the resulting finished product. developments. In the presented study, intestinal films stitched by local thermal coagulation and local tanning were not studied. This is due to the fact that additional stitching, both by the first and second methods, is carried out on limited areas determined by the area of their overlap. As a result of such an effect, the change in the elastic properties of the specified film material is not significant and does not significantly affect the overall compliance with the characteristics of traditional natural casings[10]. Based on this, it is assumed that the elastic-plastic properties of glued intestinal films stitched by local thermal coagulation and local tanning differ slightly from the similar characteristics of the sample chosen as the control in this study.

Fig. 1 shows a diagram of the unit for studying the elastic-plastic properties of the studied samples.

In general, the essence of determining the elastic-plastic properties of glued pork intestinal films is as follows. The sample under study is placed between the clamps-holders, to one of which a bowl with a load is attached. The load is increased discretely, while recording the increase in the length of the sample along the ruler. The gradual increase in the load is carried out until the destruction of the sample under study, that is, until it breaks.

According to the obtained experimental data, a stress diagram was constructed, which represents the relationship between longitudinal deformation and normal stress.

Longitudinal deformation ε was calculated by the formula:

$$\varepsilon = \frac{\Delta l}{l}, \tag{1}$$

where l – the initial length of the sample, m; Δl – the change in the length of the sample, m.

Normal stress was calculated as the force F acting per unit cross-sectional area of the sample S of the sample:

$$\sigma = \frac{F}{S} = \frac{m \cdot g}{d \cdot h}, \tag{2}$$

where m – the mass of the variable load, kg; g – the acceleration of gravity, m/s^2; d –the thickness of the intestinal film under study, m; h – the width of the intestinal film under study, m.

2. Results of the study and their discussion

The obtained stress diagram for the studied samples is shown in Fig. 2.

The diagrams of the samples have a similar character, they differ in different values of the normal stress of the characteristic points and the magnitude of the longitudinal deformation that correspond to them.

[10] Pak A., Onishchenko V., Yancheva M., Onyshchenko A., Grynchenko N., Pak A., Inzhyyants S. Formation of functional and technological properties of the film from intestinal raw materials during the drying process // Food Science and Technology. 2024. Vol. 18, Issue 1. P. 73-83. URL: https://doi.org/10.15673/fst.v18i1.2850

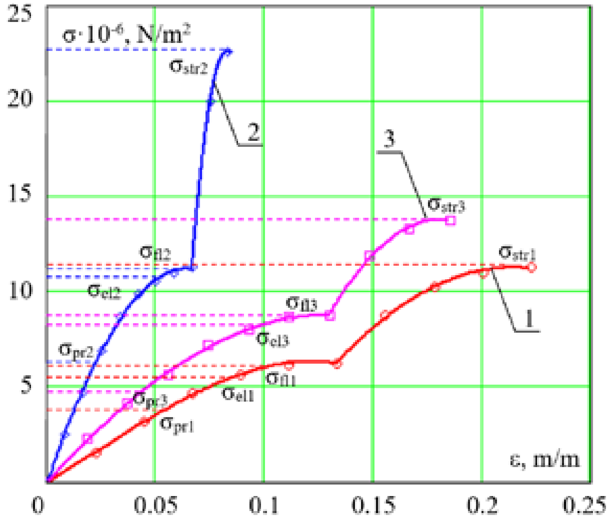

Fig. 2. Stress diagram of samples: 1 – glued pig intestinal films; 2 – pig intestinal films glued by the method of continuous tanning with a solution with a tannin concentration of 1.5%; 3 – pig intestinal films glued by the method of continuous tanning with a solution with a tannin concentration of 1.5%, with plasticization with a 5% aqueous solution of glycerin

A linear section can be distinguished on the diagram, which corresponds to the linear dependence of the longitudinal deformation on the shear stress, where the deformation is subject to Hooke's law. The boundaries of this section, the proportionality boundary, correspond to the stress σ_{pr}.

With a further increase in the normal stress, the deformation is still elastic, although the dependence of the longitudinal deformation on the stress is nonlinear. In this case, up to the elastic limit σ_{el}, final deformations do not occur.

Beyond the elastic limit, final deformations occur in the samples. Significant final deformations occur when the yield point σ_{fl} is reached.

With further stretching of the sample, the body is destroyed. The characteristic of the maximum stress that occurs in the tested sample before failure is the ultimate strength σ_{str}.

The values of normal stress corresponding to the proportionality limit σ_{pr}, the elastic limit σ_{el}, the yield limit σ_{fl} and the tensile strength limit σ_{str} are given in Table 1.

From the data given in Table 1 and the elasticity diagrams presented in Fig. 1, it is clear that the control glued intestinal films have the greatest

Table 1

Normal stress values for characteristic points of the elasticity diagrams of the studied glued intestinal films

Samples of glued pork intestinal films	$\sigma_{pr}\cdot10^{-6}$, N/m^2	$\sigma_{el}\cdot10^{-6}$, N/m^2	$\sigma_{fl}\cdot10^{-6}$, N/m^2	$\sigma_{str}\cdot10^{-6}$, N/m^2
Made using traditional technology	3,86	5,44	6,04	11,25
Additionally strengthened by crosslinking using continuous tanning with 1.5% aqueous tannin solution	6,42	10,77	11,14	22,77
Additionally strengthened by crosslinking using continuous tanning with 1.5% aqueous tannin solution and plasticization with 5% aqueous glycerin solution	4,76	8,41	8,85	13,91

elasticity among the studied samples, and the glued intestinal films subjected to tanning have the least. The maximum longitudinal deformation for the control sample is 2.68 times greater than that of the glued tanned intestinal films and 1.21 times greater than that of the glued tanned intestinal films with glycerin plasticization.

At the same time, the glued intestinal films subjected to tanning with a solution with a tannin concentration of 1.5% have the greatest strength among the studied samples, and the control samples of glued intestinal films have the least. The maximum shear stress for the sample of glued tanned intestinal films is 2 times higher compared to the control sample and 1.64 times higher compared to the sample of glued intestinal films subjected to tanning with a solution with a tannin concentration of 1.5% and plasticized with 5% glycerin.

Thus, tanning of glued intestinal films contributes to an increase in their strength and a decrease in their elasticity. However, experimental studies have shown that plasticization of such films with glycerin contributes to an increase in their elasticity by 1.33 times, provided that the strength decreases by 39%. That is, it is possible to bring glued tanned films closer to the control sample in terms of elasticity by plasticizing them with glycerin, while maintaining their strength characteristics.

However, it should be noted that the elasticity and strength of glued tanned intestinal films significantly depend on the concentration of tannin in the tanning solution. Therefore, studies of the elastic-plastic properties of intestinal films glued by tanning were carried out depending on the concentration of the tannin.

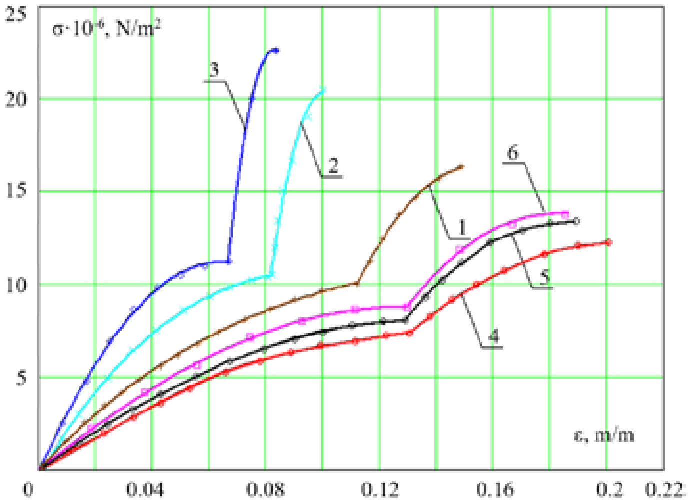

Fig. 3. Stress diagram of intestinal film samples: additionally cross-linked by the method of continuous tanning with a solution with a tannin concentration, %: 1 – 1.0; 2 – 1.5; 3 – 2.0; additionally cross-linked by the method of continuous tanning with a solution with a tannin concentration, %: 4 – 1.0; 5 – 1.5; 6 – 2.0 with glycerol plasticization

In this case, the concentration of the tannin, namely tannin, varied discretely in the range from 1.0% to 2.0%.

Stress diagrams for intestinal films additionally cross-linked by tanning with tannin concentrations in the tanning solution of 1.0%, 1.5%, 2.0%, as well as for the same samples plasticized with glycerin, are shown in Fig. 3.

From the given stress diagrams, it is clear that they have the same character. At the same time, with a decrease in the tannin concentration in the tanning solution, the strength of intestinal films additionally cross-linked by tanning, namely, their breaking load, decreases. At the same time, a decrease in the concentration of tannin in the tanning solution contributes to an increase in the elastic properties of this product. A similar trend is observed for the same tanned intestinal films provided that they are plasticized, which is obvious.

It should be noted that with a uniform change in the tannin concentration in the tanning solution (by 0.5%), the maximum stress, and, accordingly, the breaking load, does not change uniformly, as evidenced by the different distance between the stress diagrams of the studied samples.

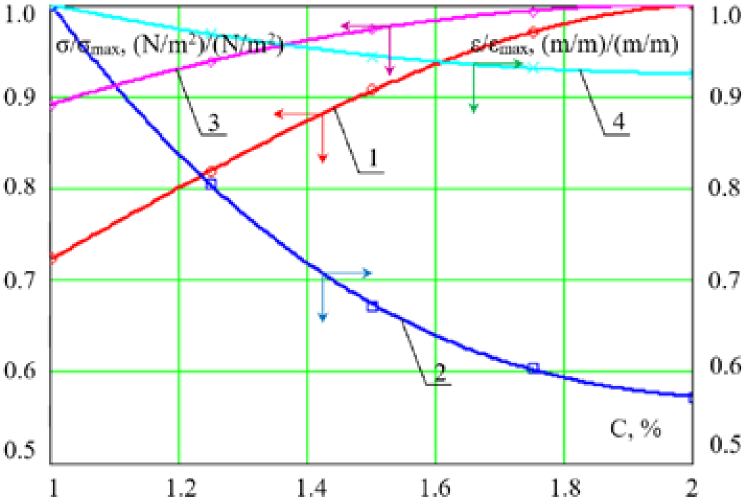

Fig. 4. Dependences of maximum stress and maximum longitudinal deformation on tannin concentration for intestinal films additionally cross-linked by tanning (1 and 2, respectively), and for the same samples plasticized with glycerin (3 and 4, respectively)

Fig. 4 shows the dependences of the maximum stress and maximum longitudinal deformation on the tannin concentration for intestinal films additionally cross-linked by tanning, as well as for the same samples plasticized with glycerin.

The indicated dependences are nonlinear, both for only tanned samples and for tanned and plasticized with glycerin. At the same time, an increase in the tannin concentration in the tanning solution entails an increase in the strength of intestinal films additionally cross-linked by tanning, and a decrease in their elasticity, both for plasticized with glycerin and for tanned intestinal films without this treatment.

The obtained experimental dependences of maximum stress on tannin concentration for glycerin-plasticized samples and samples without plasticization were approximated by a second-order polynomial function, i.e. a function of the form:

$$\sigma(C) = a_0 + a_1 \cdot \mathrm{C} + a_2 \cdot C^2, \tag{3}$$

where C – the concentration of tannin in the tanning solution, %; a_i – approximation coefficients.

Approximation coefficients for the obtained empirical dependences are equal to:

– for the dependence of the maximum tension on the concentration of tannin for intestinal films additionally cross-linked by tanning, N/m^2: a_0 = 1.742; a_1 = 18.615; a_2 = 4.085;

– for the dependence of the maximum tension on the concentration of tannin for intestinal films additionally cross-linked by tanning and plasticized with glycerin, N/m^2: a_0 = 7.73; a_1 = 6.044; a_2 = –1.518;

The experimental dependences of the maximum longitudinal strain on tannin concentration for samples plasticized with glycerol and samples without plasticization were also approximated by a second-order polynomial function, that is, a function of the form:

$$\varepsilon(C) = b_0 + b_1 \cdot \mathrm{C} + b_2 \cdot C^2, \quad (4)$$

where C – tannin concentration in the tanning solution, %; b_i – approximation coefficients.

Approximation coefficients for the obtained empirical dependences are equal to:

– for the dependence of the maximum longitudinal deformation on the tannin concentration for intestinal films, additionally cross-linked by tanning, m/m: b_0 = 0.035; b_1 = –0.264; b_2 = 0.067;

– for the dependence of the maximum longitudinal deformation on the tannin concentration for intestinal films, additionally cross-linked by tanning and plasticized with glycerin, m/m: b_0 = 0.24; b_1 = –0.058; b_2 = 0.014.

The obtained approximation functions are empirical dependences, respectively, of the maximum stress and the maximum longitudinal deformation on the tannin concentration in the tanning solution in the range from 1.0 to 2.0 % for intestinal films, additionally cross-linked by tanning, and for intestinal shells, additionally cross-linked by tanning and plasticized with glycerin.

Thus, it was established that the elastic-plastic properties of glued intestinal films made from pig intestines, additionally cross-linked by the continuous tanning method, and films additionally cross-linked by the continuous tanning method with subsequent plasticization with glycerin, nonlinearly depend on the tannin concentration in the tanning solution in the concentration range from 1.0% to 2.0%. Empirical regularities for these dependencies, which are second-order polynomial functions, have been established.

CONCLUSIONS

1. Among the wide variety of intestinal products, given the distribution, the predominant share in the set of intestines, technological aspects of processing and mechanical characteristics of the final product, pork intestines, as a raw material that forms significant residues at all technological stages (from processing to use in sausage production), can potentially be involved in the manufacture of conditioned products – natural edible films of a wide purpose and requires special attention. This approach is consistent with the modern global policy in the field of food resource conservation, lean production and the use of effective tools and methodologies of the closed-loop economy.

2. The feasibility of the tasks set is substantiated, which consists in the relevance of identifying the impact of continuous tanning of glued pork intestinal films. This approach is obviously technically simpler from the point of view of implementing the process of modification transformations compared to local processing, which allows to avoid significant irreversible changes in the elastic-plastic properties of intestinal films, however, requires the introduction of additional structural and hardware solutions, which cannot but affect the cost of the resulting finished product. development.

3. It was established that greater elasticity is characteristic of control films, the smallest – for samples subjected to tanning. The maximum longitudinal deformation for the control sample is 2.68 times greater compared to the sample of glued tanned intestinal films and 1.21 times greater compared to the sample of glued tanned intestinal films with glycerol plasticization. At the same time, the films subjected to tanning have the greatest strength, and the control samples have the smallest. The maximum shear stress for samples of tanned intestinal films is 2 times higher compared to the control sample and 1.64 times higher compared to the tanned and plasticized sample. Along with this, plasticization of such films with glycerin helps to increase their elasticity by 1.33 times, provided that the strength decreases by 39%. That is, there is a possibility, by plasticizing glued tanned films with glycerin, to bring them closer to the control sample in terms of elasticity, while maintaining their strength characteristics.

SUMMARY

The relevance of introducing resource-saving solutions in the meat industry is substantiated. The results of controlled modification of the physicochemical properties and improvement of the technology of glued intestinal films from pig intestines subjected to tanning and plasticization are obtained.

The study used samples of glued pork intestinal films from manufactured products of sleeve-shaped intestines, manufactured using traditional technology,

additionally strengthened by cross-linking using continuous tannin tanning and using continuous tannin tanning and plasticization with glycerin.

The elastic-plastic properties of glued pork intestinal films subjected to tanning and plasticization are studied. The stress value corresponding to the destruction of the studied film samples is established. It is shown that plasticization of films with glycerin contributes to an increase in their elasticity by 1.33 times, provided that the strength decreases by 39%. That is, it is possible to plasticize glued tanned films with glycerin to bring them closer to the control sample in terms of elasticity, while maintaining their strength characteristics.

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