UDC 664.8/.9

FORMATION OF FUNCTIONAL AND TECHNOLOGICAL PROPERTIES OF THE FILM FROM INTESTINAL RAW MATERIALS DURING THE DRYING PROCESS

A. Pak[1], Doctor of Technical Sciences, Associate Professor
V. Onishchenko[2], Doctor of Technical Sciences, Associate Professor
M. Yancheva[2], Doctor of Technical Sciences, Professor
A. Onyshchenko[2], Postgraduate student
N. Grynchenko[3], Doctor of Technical Sciences, Associate Professor, Development Director
A. Pak[4], PhD, Associate Professor
S. Inzhyyants[5], Senior production technologist of uncooked unsmoked products
[1] Department of Physics and Mathematics
[2] Department of Meat Technology
State Biotechnological University
Alchevskih str., 44, Kharkiv, Ukraine, 61002
[3]CAPS FOOD SYSTEMS LLC
Zaliznychnyi lane, 3/4, Derhachy, Kharkiv region, Ukraine, 62302
[4] Department of Marketing and Trade Entrepreneurship
Ukrainian Engineering Pedagogics Academy
Universitetskaya st., 16, Kharkiv, Ukraine, 610035
[5]Ltd “Chuhuyivskyy myasokombinat”
Heroyiv Chornobyl’tsiv str., 50, Kharkiv region, Chuguyiv, Ukraine, 63503

https://doi.org/10.15673/fst.v18i1.2850

Correspondence:

A. Pak
E-mail: pak.andr1980@btu.kharkov.ua

Cite as Vancouver style citation

Pak A, Onishchenko V, Yancheva M, Onyshchenko A. et al. Formation of functional and technological properties of the film from intestinal raw materials during the drying process. Food science and technology. 2024;18(1):73-83. https://doi.org/10.15673/fst.v18i1.2850

Цитування згідно ДСТУ 8302:2015

Formation of functional and technological properties of the film from intestinal raw materials during the drying process / Pak A. et al. // Food science and technology. 2024. Vol. 18, Issue 1. P. 73-83. https://10.15673/fst.v18i1.2850

Abstract. The purpose of the research is formation of the functional and technological properties of a multi-purpose film from intestinal raw materials during drying. Its hygroscopic properties after drying at temperatures ranging from 40 to 70°C were studied. It was established that the increase of the drying temperature leads to the decrease in the amount of moisture that the sample absorbs from the environment. Ranges of relative air humidity at which it is possible to store dried products in vapor-permeable packaging have been determined. It is noted that the storage of the multifunctional film is possible in a vapor-tight package with an increase in air humidity relative to the recommended ranges. The operations of packing dried film and making sausage casings from it, which follow after drying operation, are described. It was noted, that during these operations there are mechanical deformations of the film bending at angles up to 180°. It was established, that there is no violation of the integrity of the film, provided that it is bent to an angle of 180° during the packaging of finished products and the production of sausage casings from it. The integrity of the manufactured casings after their recovery during the production of sausage products has been proven. The elastic-plastic properties of the intestinal raw material film obtained at different drying temperatures were investigated. It was found, that strength of the film increases and its plasticity decreases in case of increasing the drying temperature. It is noted that, from the point of view of strength, the highest drying temperature from the range of 40–70°C. From the point of view of plastic properties, the minimum temperature should be chosen from the specified range. Studies of the drying process of a wet multifunctional film from intestinal raw materials have determined the rational values of the temperature and duration of the its drying. It is noted that during the selection of the drying temperature in the technology of obtaining a multifunctional film from intestinal raw materials, the determining factor is the functional and technological properties of the obtained semi-finished product, which depend on the drying temperature.

Key words: film from intestinal raw materials, drying process, hygroscopic properties, elastic-plastic properties.

Introduction. Formulation of the problem

Modern technological processes in the production of meat products are inextricably linked with the efficiency of using both traditional and modern solutions. A consistently relevant direction, among others, in order to achieve increased efficiency is the introduction of lean production innovations, which cover a wide range of issues at different stages of the product life cycle. In particular, these innovations should correspond to the concept of reducing the share of resources that do not have additional value, as well as the rationalization of other costs in the technological process [1-3]. Saving resources is one of the main tasks of the modern world food system, simultaneously regulating not only the issue of food security, but also preventing the influence of dangerous factors due to the growing consumption of natural raw materials [4]. Along with this, the task of involving secondary, non-standard, non-traditional raw materials in the food flow must be justified from the point of view of functional and technological compliance, which is determined by certain properties.

Analysis of recent research and publications

The primary packaging of sausage products, as well as some other meat products, according to the terminological definition, are casings and food films, the functional and technological properties of which determine both consumer benefits and economic profitability of production [5]. Recently, the high cost of meat raw materials has been compensated by manufacturers due to the use of effective technologies, thanks to which an increase in the yield of finished products is achieved due to an increase in the mass fraction of moisture in minced meat [6-8]. On the one hand, this allows to get an additional amount of ready-made food products, and on the other hand, it puts forward additional requirements for the functional and technological properties of the container in which the minced meat is located. After all, an increase in the amount of water inevitably leads to a change in the nature and values of the stress directed to the side of the casing during heat treatment of minced meat [9-12]. Based on this, it is necessary to distinguish between the assortment of casings and food films glued intestinal casings, which have a relatively low cost.

The raw material for the production of glued intestinal membranes is the residues formed in the processes of intestinal and sausage production, while their amount (up to 30%) cannot be ignored [13]. The specificity of the formation of a connecting cohesive seam between the layers of glued intestinal membranes is determined by the properties of the native, mostly collagen-elastin, structure of the films [9, 10] to form a fairly strong adhesion as a result of their drying. However, the main disadvantage of the films obtained by this method is their delamination under conditions of prolonged contact with the aqueous environment and tension due to recovery [13].

The elimination of this drawback is achieved by improving the technology of glued intestinal sausage casings by means of local thermal coagulation, local and integral vegetable tanning [14]. Another method of strengthening the cohesive seam to obtain a multifunctional intestinal film is the thermocoagulation and structural-mechanical methods of stitching the layers of intestinal raw materials [15]. Research on the formation of sleeve intestinal membranes using a laser and high-frequency current is also known [16, 17]. Operations to strengthen the cohesive seam are carried out both under the condition of using wet and under the condition of pre-dried intestinal raw materials. The condition of the raw material is determined by the method of strengthening the cohesive seam. However, for any method of stitching the layers of raw materials in the film production technology, there is an operation to dehydrate it.

Obviously, the formation of the functional and technological properties of a multi-purpose film from intestinal raw materials, like any other product, occurs during each of the technological operations that make up its production. At the same time, it should be noted that one of the operations that significantly determine the functional and technological properties of a multifunctional film is its drying. During drying, wet raw materials are subjected to hydrothermal treatment, which entails corresponding changes in the structure of wet raw materials.

All types of intestinal films are suitable for drying and have certain peculiarities of the implementation of the process due to the different chemical composition and morphological structure of the tissue [9-13]. The mass fraction of moisture after drying in dry intestinal raw materials can range from 8 to 15%, which determines the storage conditions and mechanical characteristics of dried products [18]. At the same time, the recommended temperature range for drying intestinal films is 35–50°C, and for glued intestinal films – 35–60°C, which is due to the possibility of denaturation of the protein component and, as a result, deterioration of elasticity [19,20]. Based on this, the drying process of glued intestinal films should be justified from the point of view of their functional and technological properties, among which the preservation of the primary native structure is important in order to ensure the characteristic elastic-elastic properties, and from the point of view of ensuring the strength of the cohesive seam.

Sufficient attention has been paid to the study of the drying processes of intestinal films and glued intestinal films, but today there are practically no systematic research results on rational modes and parameters of drying in the technology of intestinal films with a reinforced cohesive seam and the effect of drying parameters on the functional and technological properties of these products. This is what determines the relevance of the research.

The purpose of research is to form the functional and technological properties of a multi-purpose film from intestinal raw materials during drying by varying the temperature effect of this technological operation on the raw materials.

To achieve the aim, the following **objectives** were set:

1. to investigate the hygroscopic properties of a multifunctional film made from intestinal raw materials obtained at different drying temperatures;
2. to investigate the effect of the packaging method of the multifunctional film, obtained by drying at different temperatures, and the method of making sausage casings from it on the integrity of the finished product;
3. to investigate the elastic-plastic properties of a multifunctional film made of intestinal raw materials, which was dried at different temperatures;
4. to investigate the kinetics of dehydration of a multi-purpose film made of intestinal raw materials by the conductive method of drying at different temperatures of the process organization.

Research materials and methods

The object of research is the process of drying raw materials of animal origin. The subject of the study is the functional and technological properties of a multi-purpose film made of intestinal raw materials and the influence on them of the technological parameters of the drying process of the raw materials.

The raw material for which the research was conducted is a multi-purpose wet film obtained by cross-linking by the method of thermal coagulation of manufactured beef stomachs. Fabricates of beef bellies were previously processed and prepared according to current technological instructions. That is, the raw material was separated beef bellies, which were previously defatted and cleaned from the mucous membrane, washed, salted and stored in the form of a salty product. Raw materials are freed from salt, washed and kept in water. Before stitching, segments of manufactured goods, which are bodies close to hollow cylinders, are cut in the longitudinal direction. In this way, samples (strips) with a geometric shape close to a rectangle are obtained. Next, the strips of manufactured beef stomachs are stitched together by the method of thermal coagulation, as described in [15], and thus a multi-functional wet film is obtained.

The study of the process of drying the film from intestinal raw materials was carried out using the experimental stand, which is shown in Fig. 1.

The kinetics of the moisture content of the raw material and the kinetics of the drying speed were determined as follows. The wet film sample 2 was placed between the heating surfaces 1, located on the scales 3. By changing the voltage on the power source of the heating surfaces, the determined drying temperature was selected. Control over the value of the drying temperature was carried out using thermocouples 4. Then, the mass of the sample was fixed at certain time intervals and the current moisture content was calculated. Measurements were carried out until the sample reached a constant moisture content.

Longitudinal deformation and normal stress for the construction of the elasticity diagram of the multifunctional film obtained by drying at different temperatures were determined experimentally using the setup shown in Fig. 2.

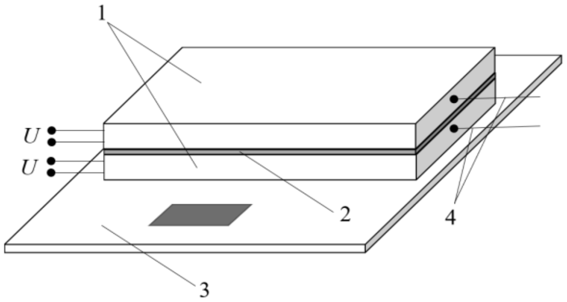

Fig. 1. Experimental stand for researching the process of conductive drying of film from intestinal raw materials: 1 – heating surfaces; 2 – wet film; 3 – scales; 4 – thermocouple

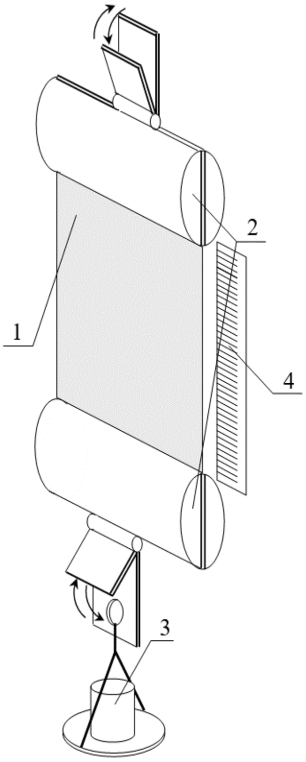

Fig. 2. Scheme of the unit for the study of elastic-plastic properties of a multifunctional film made of intestinal raw materials: 1 – studied sample; 2 – holder-clamp; 3 – variable load; 4 - ruler

The studied sample was placed between the holder clamps, to one of which a bowl with a load is attached. The load was discretely increased and the increase in the length of the sample was recorded along the ruler. The exposure duration was 2–3 minutes. A gradual increase in the load was carried out until the test sample was destroyed, that is, before it broke.

Mathematical processing of the obtained experimental data was carried out using the MathCad program package using built-in and author's procedures. The type of approximation functions is given directly when describing the results of the experiment.

Results of the research and their discussion

The functional and technological properties of the multi-purpose film from intestinal raw materials, which are significantly formed during drying, are the properties of the dried raw materials to absorb moisture from the surrounding environment during storage, the elasticity of the dried product during its packaging, elasticity during the production of sausage casings from it, elasticity after recovery. The formation during drying of these functional and technological properties of the film was studied in the work.

The raw material (stitched wet film of intestinal raw material) to be dried is, from the point of view of its physical properties, a colloidal capillary-porous body. Such raw materials have a capillary structure, but the walls of the capillaries have the property of significantly changing their dimensions due to changes in the moisture content.

To dehydrate such colloidal capillary-porous bodies, various drying methods are used, among which convective and conductive methods are most common.

The paper considers the process of dehydration of intestinal raw materials to the final moisture content by the method of conductive drying [15]. This is due to the method of obtaining a wet film from intestinal raw materials, namely, the method of stitching stomach products, which are the raw material. It is the use of the conductive method of drying that makes it possible to use the device for cross-linking intestinal raw materials and for drying the film obtained after cross-linking.

At the first stage of the work, research was carried out on the hygroscopic properties of a multifunctional film made from intestinal raw materials obtained at different drying temperatures

Hygroscopic properties, that is, the ability of dried products to release or absorb water vapor from the environment, largely depend on the conditions under which dehydration was carried out. Since the conductive method of drying was chosen in the work, the main factor affecting the hygroscopic properties of dried products is the temperature of the heating surfaces. These properties can change due to irreversible changes in the composition of the raw material to be dried, due to different temperature effects on it from the heating surfaces [21].

It is important here that hygroscopic properties determine the conditions and terms of storage of dried products. If the partial pressure of the water vapor near the surface of the product is greater than the partial pressure of the vapor in the air, then evaporation (desorption) occurs. At the same time, the mass and moisture content of the sample decrease. If the ratio of partial pressures is reversed, the sample is moistened (sorption) - its mass and moisture content increase.

Since the dried product has a low moisture content, namely, 0.09...0.10 relative units, it is obvious that the sorption process will prevail during its stay in the atmosphere. The final moisture content of multifunctional film samples obtained at different drying temperatures from the range of 40...70°C is the same, but the ability to absorb moisture from the atmosphere may differ.

The tensometric method was used to study the sorption of samples of dried products. The studied samples were placed in desiccators with a fixed value of relative air humidity φ in the range from 10 to 90%. All desiccators were kept at a constant ambient temperature during the measurements (20...25 °C). The duration of the product's stay in the desiccator was determined by the sample reaching a constant mass. The result of the study is the value of the moisture content of the sample (w) at the corresponding relative humidity of the air in the desiccator (φ). Experimental points were approximated by polynomial functions of the form:

$$w(\varphi)=b_0+b_1\cdot\varphi+b_2\cdot\varphi^2+\ldots+b_n\cdot\varphi^n, \qquad (1)$$

where w – the current moisture content, kg/kg of dry matter;

n – the degree of the polynomial; b_0, b_1, b_2, … b_n – approximation coefficients.

The sorption isotherms of the studied samples of the multifunctional film meant exactly these approximation functions (Fig. 3).

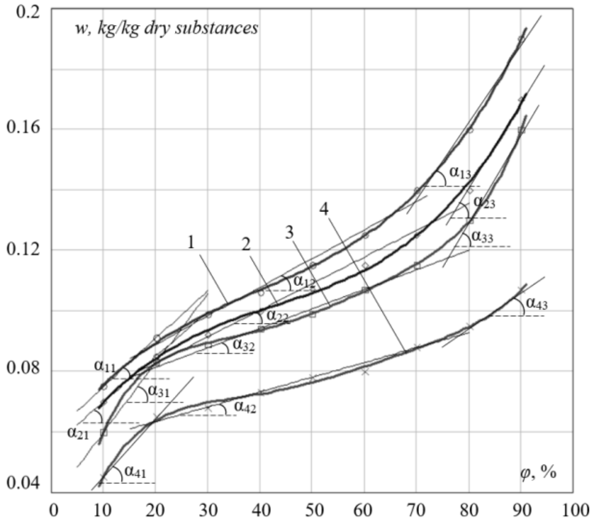

Fig. 3. Sorption isotherms of samples of multifunctional film from intestinal raw materials, which were dried at temperatures, °C: 1 – 40; 2 – 50; 3 – 60; 4 – 70

The obtained sorption isotherms of the samples of the multifunctional film from intestinal raw materials, which were dried at temperatures ranging from 40 to 70°C, have the same character (Fig. 3). There are three characteristic areas that correspond to different types of connection of system water with dry substances of the studied samples. These sections correspond to different inclinations of the parts of the sorption isotherms to the axis on which the relative humidity of the air is deposited.

Graphically, these three sections can be separated by approximating the experimental data with a linear function of the form:

$$w(\varphi)=c_0+c_1\cdot\varphi, \qquad (2)$$

where c_0, c_1 – approximation coefficients. At the same time, the coefficient c_1 represents the tangent of the inclination angle (α) of the sorption isotherm section to the axis on which the relative humidity is deposited. The value of the tangent of the inclination angles of different sections of the sorption isotherms of the samples of the multifunctional film, which was dried at temperatures ranging from 40 to 70°C, are given in Table 1.

Table 1 – The value of the tangent of the inclination angles of different sections of the sorption isotherms of the multifunctional film samples

Drying temperature of the multifunctional film sample	The tangent of the inclination angle of the sorption isotherm section		
	α_{i1}	α_{i2}	α_{i3}
40°C (*i*=1)	0.159	0.095	0.245
50°C (*i*=2)	0.149	0.088	0.291
60°C (*i*=3)	0.226	0.065	0.293
70°C (*i*=4)	0.221	0.049	0.119

The highlighted parts of the sorption isotherms correspond to monomolecular sorption of system water (angle αi_1), its polymolecular sorption (angle α_{i2}) and filling of microcapillaries with system water (angle α_{i3}).

In the area of monomolecular sorption, all samples are at a relative humidity of 10 to 20%. In the field of polymolecular sorption, samples dried at temperatures of 40, 50, and 60°C are at a relative humidity of 20 to 70%. As for the sample, the drying of which was carried out at a temperature of 70°C, in the area of polymolecular sorption, it is located at a relative humidity of 20 to 75–80%. This difference indicates the possibility of its storage at a relative humidity of 75–80%. As for the other three samples (drying temperature 40, 50 and 60°C), their storage is possible only at a relative humidity of no more than 70%.

With a further increase in humidity, moisture is absorbed by microcapillaries. At the same time, the tangents of the inclination angle of the sorption isotherms for samples dried at temperatures of 40, 50, and 60°C are more than 2 times higher than the tangents of the inclination angle of the sorption isotherm of the sample dried at 70°C. This indicates a less developed system of microcapillaries in the last sample (drying temperature 70°C).

It should be noted that the sample dried at a temperature of 40°C absorbs the largest amount of moisture from the air. The samples dried at temperatures of 50 and 60°C are followed by the amount of absorbed moisture. The sample dried at a temperature of 70°C absorbs the least amount of moisture from the air. Since the starting raw material for the studied samples was the same intestinal raw material, this obviously indicates a change in its structure during drying due to different temperature effects. That is, an increase in the drying temperature contributes to a decrease in the degree of porosity development of the obtained dried products.

Thus, studies of the hygroscopic properties of samples dried at temperatures ranging from 40 to 70°C show that an increase in the drying temperature contributes to a decrease in the amount of moisture that the sample absorbs from the surrounding environment. Ranges of relative air humidity at which it is possible to store dried products in vapor-permeable packaging have been established. Thus, dried products, which were dried at temperatures of 40, 50 and 60°C, can be stored without loss of quality in vapor-permeable packaging at a relative humidity of no more than 70%. Storage of the multifunctional film, which was dried at a temperature of 70°C, is possible at a relative humidity of no more than 75–80%. With an increase in air humidity relative to the specified ranges, storage of the multifunctional film is possible in vapor-tight packaging.

It should be noted that from the point of view of preserving the multifunctional film, its drying temperature should be chosen the highest from the range considered.

At the second stage of the work, the mechanical effect on the multi-purpose film from intestinal raw materials after drying such operations as packing this product and making sausage casings from it was investigated.

The finished product, which is obtained according to the developed technology [15], is an endless tape of a certain width. According to the method of obtaining this tape (multifunctional film), it is wound on a cardboard sleeve 2, which is put on the shaft 1 (Fig. 4). After the specified amount of film is wound on the sleeve, its free end 3 is cut off. The resulting roll 4 is removed from the shaft and sent to storage.

Production of cylindrical sausage casings is carried out on the device, the general view of which is shown in Fig. 5.

The device is a template of a cylindrical shape 4 of a certain diameter put on a shaft 3. A roll of multifunctional film 2 is placed on the shaft 1, which is parallel to the shaft 3. The free end of the film is fixed in the groove 5 on the template. Next, the sausage casing is made according to the following stages. At the first stage, the template is rotated using shaft 3 to an angle of 360°. On the second – with the help of plate 7, heated to the appropriate temperature, a seam is created between the layers of the film that are in contact with each other by the method of thermal coagulation. At the third stage, the stitched sausage casing is cut from the free end of the film roll with the help of a knife 8 and the working surface 6, and the resulting casing is removed from the template. To make the next casing, the free end of the film is fixed on the template and the described operations are repeated.

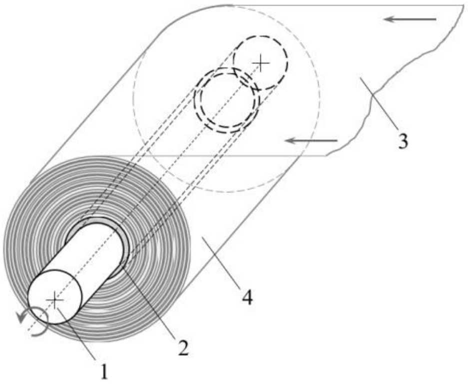

Fig. 4. The method of packing the multifunctional film obtained by the developed technology: 1 – shaft; 2 – cardboard sleeve; 3 – free end of the multifunctional film; 4 – roll of multifunctional film

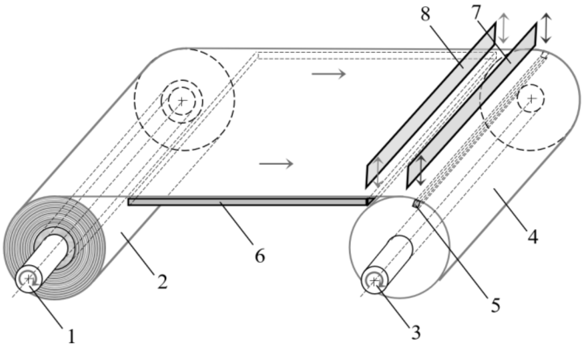

Fig. 5. General view of the device for the production of cylindrical sausage casings from multifunctional film

The sausage casing removed from the template is folded lengthwise and sent to storage or to the production of the sausage product.

Based on the description of the operations that follow the operation of drying the multifunctional film, the following mechanical actions on the dried products should be highlighted. Both during the packaging of the dried film and during the production of sausage casings from it, the film is wound on a cylindrical body of different diameters. When assembling the finished sausage casing, the film is bent at an angle of 180°. That is, for the film there are bending deformations during the specified mechanical actions at angles up to 180°.

Obviously, in order for the film not to crack or have other integrity violations during these bending deformations, it must have the appropriate elasticity. The elasticity of the dried product is determined by its final moisture content, namely the properties of the raw material and irreversible changes in the structure of the raw material caused by the influence of the temperature of the heating surfaces on the raw material.

During the packaging of the multifunctional film and during the production of sausage casings from it, bushings were used for winding the tape with a diameter of at least 50 mm. A multifunctional film dried at a drying temperature of 40, 50, 60, 70°C was wound on such sleeves. The result of visual observation is the absence of cracking or other violations of the integrity of the films obtained at different drying temperatures from the range of 40–70°C, during winding on bushings with a diameter of at least 50 mm.

A similar result was obtained during the observation of the assembly operation of finished casings. It was visually established that there was no violation of the integrity of the film, provided that it was bent to an angle of 180° during the assembly of sausage casings. The presence of the integrity of the manufactured casings was also proven after their restoration during the production of sausage products.

That is, it should be assumed that the finished dried products, obtained at different drying temperatures in the range of 40–70°C, meet the requirements of such packaging methods as multifunctional film and sausage casings from it in terms of their elastic properties.

One of the defining functional-technological characteristics of sausage casings, and, accordingly, the raw material for their production – multifunctional film, is their elastic-plastic properties. It is this characteristic that is investigated at the third stage of the work.

Obviously, the elasticity diagram should be considered an objective characteristic of the elastic-plastic properties of such a material as a multifunctional film made of intestinal raw materials.

The elasticity diagram is a change in the relative longitudinal deformation with a change in the force acting on a unit cross-sectional area of the material sample (normal stress).

Longitudinal strain ε is calculated by the formula:

$$\varepsilon = \frac{\Delta l}{l}, \qquad (3)$$

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

The normal stress is calculated as the force F acting on a unit cross-sectional area of the sample S:

$$\sigma = \frac{F}{S} = \frac{m \cdot g}{d \cdot h}, \qquad (4)$$

where m – the load weight, kg; g – acceleration of free fall, m/s^2; d – the thickness of the investigated multifunctional film, m; h – the width of the investigated sample of multifunctional film, m.

Samples of multifunctional films, which were dried at different drying temperatures from the range of 40–70°C, were studied using the installation from Fig. 2. The samples were pre-soaked in cold water for 15–20 minutes. to restore their elastic-plastic properties.

Next, the normal stress corresponding to the applied load was calculated according to formula (4) and the corresponding longitudinal strain according to formula (3). Further, the obtained experimental data were approximated for clarity by a polynomial function of the form:

$$\varepsilon(\sigma)=a_0+a_1\cdot\sigma+a_2\cdot\sigma^2+\ldots+a_n\cdot\sigma^n, \qquad (5)$$

where ε – the current longitudinal strain, m/m; n – the degree of the polynomial; a_0, a_1, a_2, $\ldots a_n$ – approximation coefficients.

Approximation functions obtained in this way are elasticity diagrams, which are shown in Fig. 6.

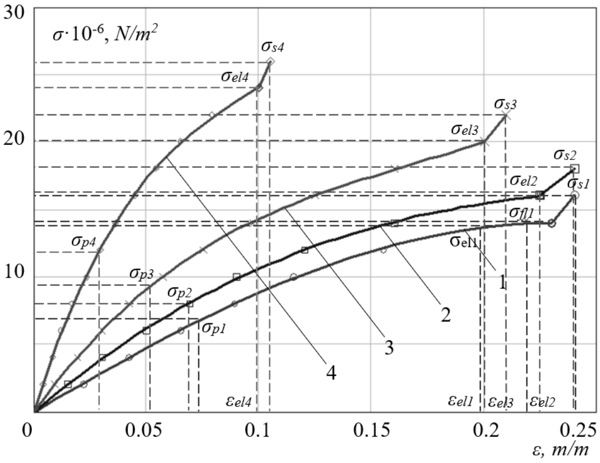

Fig. 6. Elasticity diagrams of samples of multifunctional film from intestinal raw materials, which were dried at temperatures, °C: 1 – 40; 2 – 50; 3 – 60; 4 - 70

The elasticity diagrams of the obtained samples have the same character. There is a linear increase in longitudinal strain with increasing normal stress, i.e. there is a section where the strain can be described by Hooke's law. This section is limited by the limit of proportionality – σ_p.

With a further increase in the normal stress relative to σ_p, the dependence of the longitudinal strain becomes nonlinear. At the same time, up to the limit of elasticity σ_{el}, the final deformations are not significant.

For the sample, which was dried at a temperature of 40°C, there is a section corresponding to the fluidity of the sample (σ_{fl1}). At the same time, the longitudinal deformation increases at a constant value of the normal load, that is, the material "flows". There is no such section on the elasticity diagrams of other samples.

With a further increase in the normal load, the destruction of the samples occurs. The strength limit σ_s is the characteristic of the maximum stress that occurs in the tested sample before failure.

Thus, the elasticity diagrams for different samples differ in the values of the normal load and the corresponding longitudinal deformation within the limits of proportionality (σ_p), elasticity (σ_{el}), fluidity (σ_{fl}) and strength (σ_s). The corresponding values for the studied samples are given in Table 2.

From the point of view of the functional and technological properties of the multifunctional film, which is a raw material for the production of sausage casings, the values of the elastic limit and the strength limit are the most important.

The given results show that the greatest limits of elasticity and strength are for the sample dried at 70°C, they are, respectively, $24.11\cdot10^6$ and $26.02\cdot10^6$ N/m^2. The smallest limits of elasticity and strength are available for the sample, which was dried at a temperature of 40°C, they are, respectively, equal to – $13.78\cdot106$ and $16.15\cdot106$ N/m^2. The samples, which were dried at temperatures of 50 and 60°C, occupy the values of the elastic limit and the strength limit occupy an intermediate value. Based on this, to increase the strength of the multifunctional film, the temperature at which it is dried should be increased.

However, with regard to longitudinal deformations, the largest deformations, which correspond to the limits of elasticity and strength, are observed for the film sample dried at 40°C (0.19 and 0.24 m/m, respectively), and the smallest - for the sample dried at temperature of 70°C (0.10 and 0.11 m/m, respectively). That is, from the point of view of the plastic properties of sausage casings, the raw material for which is a multifunctional film, during its drying, the minimum temperature should be chosen from those under investigation.

Table 2 – Characteristic points of elasticity diagrams of multifunctional film samples, which were dried at temperatures from 40 to 70°C

Sample drying temperature	Longitudinal deformation (m/m) and normal load (×10-6 N/m^2) of the corresponding boundary							
	ε_{pi}	σ_{pi}	ε_{eli}	σ_{eli}	ε_{fli}	σ_{fli}	ε_{si}	σ_{si}
40°C (*i*=1)	0.07	6.37	0.19	13.78	0.22	14.16	0.24	16.15
50°C (*i*=2)	0.07	8.04	0.22	16.07	–	–	0.24	18.06
60°C (*i*=3)	0.05	9.49	0.20	20.13	–	–	0.21	22.12
70°C (*i*=4)	0.03	12.17	0.10	24.11	–	–	0.11	26.02

The obvious increase in strength and decrease in plasticity of the multifunctional film due to an increase in its drying temperature is explained by irreversible changes in the composition of the intestinal raw material from which the film is obtained under the influence of temperature.

Thus, studies show that from the point of view of strength, the highest drying temperature should be chosen from the range of 40–70°C. From the point of view of plastic properties – the minimum temperature from the specified range. At the same time, taking into account the fact that the more important property of sausage casings is their elasticity, the recommended temperature for drying the film, from the point of view of its elastic-plastic properties, should be considered a temperature of 40°C.

The last stage of the work was the study of the process of drying a wet multifunctional film from intestinal raw materials, since the choice of temperature of this process significantly affects the energy costs for its implementation. It should be noted that drying is one of the most energy-intensive operations in the production of a multifunctional film from intestinal raw materials, according to the proposed technology. The profitability of the production of this film significantly depends on the costs of the process of dehydration of the raw material.

The study of the drying process consisted in obtaining and analyzing the drying kinetics of wet raw materials. The kinetics of the moisture content of the raw materials and the kinetics of the drying speed were determined according to the experimental data obtained using the experimental stand from Fig. 1. At the same time, the current moisture content was calculated according to the formula:

$$w=m_{d.s.}/m_{w.}, \tag{6}$$

where $m_{d.s.}$ – mass of dry substances of raw materials, kg; $m_{w.}$ – mass of system water that the raw material retains, kg.

Next, based on the obtained experimental points, an approximation function was constructed, i.e., the kinetics of drying the wet film. Polynomial functions of the form were used as approximation functions:

$$w(\tau)=a_0+a_1\cdot\tau+a_2\cdot\tau^2+\ldots+a_n\cdot\tau^n, \tag{7}$$

where τ – the current time, s; n – the degree of the polynomial; a_0, a_1, a_2, $\ldots a_n$ – approximation coefficients.

The research was conducted at different temperatures of the heating surfaces, which varied discretely from 40 to 70°C.

Fig. 7 shows the drying kinetics of a multifunctional film at different drying temperatures. The drying temperature is the temperature of the heating surfaces.

The given drying kinetics at different temperatures of the heating surfaces have a typical appearance for the conductive method of dehydration. The moisture content tends monotonically to the final moisture content as the duration of the drying process increases. The differences between the given kinetics consist in the different inclination of the kinetics to the axis on which the moisture content is deposited. That is, the speed of approaching the final moisture content of the given dependencies is different. The physical meaning of the rate of drying kinetics approaching the final moisture content is the rate of dehydration of wet raw materials. Obviously, the result of this is the different duration of the process of removing system water from the raw material.

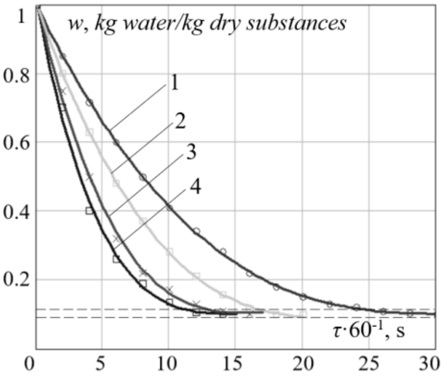

Fig. 7. Drying kinetics of a multifunctional film at different temperatures of heating surfaces, °C: 1 – 40; 2 – 50; 3 – 60; 4 – 70

Based on the kinetics of film drying at different drying temperatures, it can be seen that all samples reach the final moisture content, which is in the range of 0.1–0.09 relative units. This range of moisture content, separated in Fig. 7 on two sides by a dotted line, is balanced for dry stomach products [18]. Thus, provided that the raw material reaches this moisture content, it should be considered that the dehydration process for this raw material is complete. The drying speed is equal to zero.

Determination of the rational duration of drying of a multifunctional film was determined by the moment when the drying speed reached a value equal to zero. The drying rate kinetics was obtained as the first derivative of the drying kinetics:

$$\omega(\tau)=dw(\tau)/d\tau. \tag{8}$$

Fig. 8 shows the kinetics of the drying rate of the raw material obtained at different temperatures of the heating surfaces.

The nature of the change in the rate of drying of wet raw materials with the change of time for different temperatures of the heating surfaces is the same. The drying speed monotonically decreases with a decrease in the amount of system water, which is obviously related to the removal of moisture with different connections to the dry substances of the raw materials. The differences in the given dependences are in the value of the drying speed and in the values of the duration for which the zero drying speed is reached (dashed lines in Fig. 8).

The rational duration of drying a wet film at different dehydration temperatures, determined according to Fig. 3, is given in Table 3.

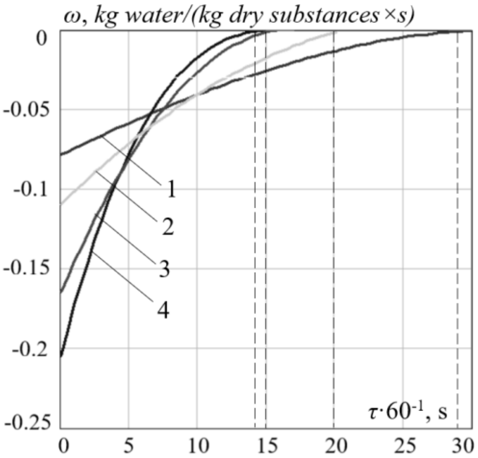

Fig. 8. Kinetics of drying speed of multifunctional film at different temperatures of heating surfaces, °C: 1 – 40; 2 – 50; 3 – 60; 4 – 70

Table 3 – Duration of drying of wet multifunctional film from intestinal raw materials at different temperatures of heating surfaces

Temperature, °C	40	50	60	70
Duration of drying, min.	29–30	20–21	15–16	14–15

The obtained results show that when the temperature increases from 40°C to 50°C, i.e. by 25%, the duration of dehydration decreases by 31%, i.e. from 29 min up to 20 min. With a further increase in temperature from 50°C to 60°C (with an increase of 21%), the drying time decreased by 25% (decreased from 20 min to 15 min). When the temperature increased from 60°C to 70°C, i.e. by 17%, the drying time decreased by only 7%, i.e. it decreased from 15 min up to 14 min.

Based on the obtained result, it can be seen that with an increase in the temperature of the heating surfaces to 60°C, there is a significant decrease in the duration of drying. This contributes to the increase in the efficiency of the production technology of the multi-purpose film, since the technological operations for its production are of a periodic nature with an order of duration of 10–20 minutes. However, a further increase in temperature relative to 60°C does not significantly reduce the duration of dehydration. At the same time, it should be taken into account that an increase in temperature above the value of the coagulation temperature of the proteins contained in the raw material can lead to a significant decrease in the quality of the final product due to irreversible changes in its elastic properties.

According to the results of this stage of the research, it is possible to determine the recommended rational values of the temperature and duration of drying the wet film. The rational values of the temperature of the heating surfaces, from the point of view of the efficiency of the dehydration process, is a temperature of 60°C, while the duration of drying will be 15–16 minutes. However, when choosing the drying temperature in the technology of obtaining a multifunctional film from intestinal raw materials, one should take into account the functional and technological properties of the obtained semi-finished product, which depend on the temperature of the heating surfaces.

Thus, taking into account the results obtained at the stages of the research, the temperature and duration of drying of the multifunctional film from intestinal raw materials should be chosen based on the direction of its further use. That is, in accordance with what functional and technological properties must be available for its use in the production of the specified sausage product.

Approbation of research results. The implementation of technical and technological solutions for the creation of sheet films from intestinal raw materials provides the possibility of using such an edible natural material for a wide range of products in food technology. Taking into account the affinity of raw materials, it is preferable to introduce them into the production cycle of the meat and fish industry, in particular, in the technologies of sausage and ham products, semi-finished products and finished products wrapped in edible films (rolls, pate, fryers, etc.), of various shapes and sizes.

Conclusions

1. Studies of the hygroscopic properties of the multi-purpose film made of intestinal raw materials, which were dried at temperatures ranging from 40 to 70°C, established that an increase in the drying temperature contributes to a decrease in the amount of moisture that the sample absorbs from the surrounding gas environment. Ranges of relative air humidity at which it is possible to store dried products in vapor-permeable packaging were determined. It was established that the multi-purpose film, which was dried at temperatures of 40, 50 and 60°C, can be stored without loss of quality in vapor-permeable packaging at a relative humidity of no more than 70%. Storage of the multifunctional film, which was dried at a temperature of 70°C, is possible at a relative humidity of no more than 75–80%. It is noted that with an increase in air humidity relative to the specified ranges, storage of the multifunctional film is possible in vapor-tight packaging.

2. The operations of packing dried multifunctional film and making sausage casings from it, which follow the drying operation, are described. It is noted that during these operations, which include mechanical deformations of bending the multi-purpose film at angles up to 180°, so that cracking or other violations of its integrity do not occur, the film must have appropriate elasticity. By visual observation, it was established that during the winding of the

multifunctional film from intestinal raw materials, obtained at different drying temperatures from the range of 40–70°C, on sleeves with a diameter of at least 50 mm, there are no cracks or other violations of the integrity of the film. It was established that there is no violation of the integrity of the film, provided that it is bent to an angle of 180° during the assembly of sausage casings. The integrity of the manufactured casings after their restoration during the production of sausage products is proven.

3. Studies of the elastic-plastic properties of the multi-purpose film made of intestinal raw materials determined that the maximum limits of elasticity and strength are for the sample dried at a temperature of 70°C, which are, respectively, $24.11\cdot10^6$ and $26.02\cdot10^6$ N/m^2. The smallest limits of elasticity and strength are available for the sample, which was dried at a temperature of 40°C, they are, respectively, equal to – 23.78·106 and $16.15\cdot10^6$ N/m^2. The samples, which were dried at temperatures of 50 and 60°C, occupy the values of the elastic limit and the strength limit occupy an intermediate value. It was established that the largest longitudinal deformations, which correspond to the limits of elasticity and strength, are observed for the film sample dried at a temperature of 40°C (0.19 and 0.24 m/m, respectively), and the smallest – for the sample dried at a temperature of 70 °C (0.10 and 0.11 m/m, respectively). It is noted that the increase in strength and decrease in plasticity of the multifunctional film due to an increase in its drying temperature is due to irreversible changes in the composition of the intestinal raw material from which the film is obtained under the influence of temperature. It is noted that, from the point of view of strength, the highest drying temperature should be chosen from the range of 40–70°C. From the point of view of plastic properties – the minimum temperature from the specified range. At the same time, taking into account the fact that the more important property of sausage casings is their elasticity, the recommended temperature for drying the film, from the point of view of its elastic-plastic properties, should be considered a temperature of 40°C.

4. Studies of the process of drying a wet multifunctional film from intestinal raw materials have determined the rational values of the temperature and duration of drying the wet film. It is noted that the rational values of the temperature of the heating surfaces, from the point of view of the efficiency of the dehydration process, is a temperature of 60°C, while the duration of drying will be 15...16 minutes. It is noted that during the selection of the drying temperature in the technology of obtaining a multifunctional film from intestinal raw materials, the determining factor is the functional and technological properties of the obtained semi-finished product, which depend on the temperature of the heating surfaces.

It is noted that, taking into account the results obtained at the stages of the research, the temperature and duration of drying of the multifunctional film from intestinal raw materials should be chosen based on the functional and technological properties that must be available for its use in the production of the specified sausage product.

References

1. Mrugalska B, Wyrwicka MK. Towards Lean Production in Industry 4.0. Procedia Engineering. 2017;182:466-473. https://doi.org/10.1016/j.proeng.2017.03.135
2. Nicholas J. Lean production for competitive advantage: a comprehensive guide to lean methodologies and management practices. Boca Raton, New York, London: CRC Press; 2015. https://books.google.com.ua/books?id=23a9CgAAQBAJ&printsec=frontcover&hl=ru&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false
3. Kleshchov A, Hugi C, Hengevoss D, Maslikov M. Resource efficient and cleaner production for meat sector. Kyiv: Center for resource efficient and cleaner production, 2018. https://www.researchgate.net/publication/330442289_Resursoefektivne_ta_ciste_virobnictvo_u_m'asnij_promislovosti_Resource_efficient_and_cleaner_production_for_meat_sector/citations (in Ukrainian).
4. Westhoek H, Ingram J, Van Berkum S, Özay L, Hajer M. Food Systems and Natural Resources. A Report of the Working Group on Food Systems of the International Resource Panel. UNEP, 2016. https://www.resourcepanel.org/sites/default/files/documents/document/media/food_systems_summary_report_english.pdf
5. Savic Z, Savic I. Sausage Casings. Wien: Victus International GmbH, 2016. https://www.linkedin.com/pulse/new-publication-book-sausage-casings-zoran-savic?trk=portfolio_article-card_title
6. Glorieux S, Goemaere O, Steen L, Fraeye I. Phosphate reduction in emulsified meat products: impact of phosphate type and dosage on quality characteristics. Food Technol Biotechnol. 2017;55(3):390-397. https://doi.org/10.17113/ftb.55.03.17.5089
7. Goemaere O, Glorieux S, Govaert M, Steen L, Fraeye I. Phosphate elimination in emulsified meat products: impact of protein-based ingredients on quality characteristics. Foods. 2021;10(4):882. https://doi.org/10.3390/foods10040882
8. Thangavelu KP, Kerry JP, Tiwari B, McDonnell CK. Novel processing technologies and ingredient strategies for the reduction of phosphate additives in processed meat. Trends in Food Science & Technology, 2019;94:43-53. https://doi.org/10.1016/j.tifs.2019.10.001
9. Mykhailov VM, Onishchenko VM, Yancheva MO, Shubina LY. Study of protective properties and safety of intestinal sausage casings. Kharkiv: KhSUFT; 2021. https://repo.btu.kharkov.ua/bitstream/123456789/21615/1/Mon_zakhysni%20obolonky_2021.pdf (in Ukrainian).
10. Gunn S, Sizeland KH, Wells HC, Haverkamp RG. Collagen arrangement and strength in sausage casings produced from natural intestines. Food Hydrocolloids, 2022;129:107612. https://doi.org/10.1016/j.foodhyd.2022.107612
11. Liu W, Chen X, Tsutsuura S, Nishiumi T. Toughness Variations among natural casings: an exploration on their biochemical and histological characteristics. Foods, 2022;11(23):3815. https://doi.org/10.3390/foods11233815
12. Suurs P, Barbut S. Collagen use for co-extruded sausage casings – a review. Trends in Food Science & Technology, 2020;102:91-101. https://doi.org/10.1016/j.tifs.2020.06.011.

13. Mykhailov VM, Onishchenko VM, Pak AO, Inzhyyants ST. Substantiation of the technology of glued intestinal sausage casings reinforced with thermal coagulation and tanning. Kharkiv: KhSUFT; 2022. https://repo.btu.kharkov.ua/bitstream/123456789/22535/1/Monohr_OTSKKOATKD_2_2022.pdf (in Ukrainian).
14. Onishchenko V, Pak AO, Goralchuk A, Shubina L, Bolshakova V, Inzhyyants S, Pak AV, Domanova O. Devising techniques for reinforcing glued sausage casings by using different physical methods. Eastern-European Journal of Enterprise Technologies, 2021;1/11(109):6-13. http://journals.uran.ua/eejet/article/view/224981/225469 (in Ukrainian).
15. Pak A, Onishchenko V, Yancheva M, Grynchenko N, Dromenko O, Pak A, Inzhyyants S, Onyshchenko A. Devising a technique and designing an apparatus for obtaining a multifunctional purpose film from intestinal raw materials. Eastern-European Journal of Enterprise Technologies, 2023;3/11(123):6-15. https://doi.org/10.15587/1729-4061.2023.279008 (in Ukrainian).
16. Bartel S, Domin J, Pilch Z, Karczewski J. Joining methods of natural sausage casing with using of high frequency current. Proceeding of 26th International Conference Engineering mechanics, 2020:149-152. https://doi.org/10.21495/5896-3-070
17. Domin J, Karczewski J, Kciuk M, Kozielski L, Pilch Z, Wyciślok P. Testing the strength of laser-bonded animal intestines. Proceeding of 26th International Conference Engineering mechanics, 2020:166-170. https://www.engmech.cz/im/proceedings/show_p/2020/66
18. Onishchenko V, Pak A, Goralchuk A, Shubina L, Bolshakova V, Inzhyyants S, Pak A, Domanova O. Investigation of hygroscopic properties and porosity of glued reinforced sausage casings. EUREKA: Life Sciences, 2021;1:31-36 https://doi.org/10.21303/2504-5695.2021.001632
19. Fratzl P. Collagen: structure and mechanics. New York: Springer Science+Business Media, LLC, 2008. https://doi.org/10.1007/978-0-387-73906-9
20. Zhang X, Xu S, Shen L, Li G. Factors affecting thermal stability of collagen from the aspects of extraction, processing and modification. Journal of Leather Science and Engineering, 2020;2:19. https://doi.org/10.1186/s42825-020-00033-0
21. Milanović MP, Komatina, MS, Zlatanović, IJ, Manić, NG, Antonijević, DL. Kinetic Parameters Identification of Conductive Enhanced Hot Air Drying Process of Food Waste. Thermal Science, 2021, 25: 1785-1807. https://doi.org/10.2298/TSCI200312223M

ФОРМУВАННЯ ФУНКЦІОНАЛЬНО-ТЕХНОЛОГІЧНИХ ВЛАСТИВОСТЕЙ ПЛІВКИ ІЗ КИШКОВОЇ СИРОВИНИ В ПРОЦЕСІ СУШІННЯ

А. Пак[1], доктор технічних наук, доцент, *E-mail*: pak.andr1980@btu.kharkov.ua
В. Онищенко[2], доктор технічних наук, доцент, *E-mail*: onvm70@gmail.com
М. Янчева[2], доктор технічних наук, професор, E-mail: ya.marina11@gmail.com
А. Онищенко[2], аспірант, *E-mail*: 16Neverhood1994@gmail.com
Н. Гринченко[3], доктор технічних наук, доцент, директор з розвитку, E-mail: tatagrin1201@gmail.com
А. Пак[4], кандидат технічних наук, доцент, E-mail: pak.alina1984@gmail.com
С. Інжиянц[5], старший технолог виробництва сиров'ялених виробів, E-mail: samvel123@gmail.com
[1]Кафедра фізики та математики
[2]Кафедра технології м'яса
Державний біотехнологічний університет, вул. Алчевських, 44, м. Харків, Україна, 61002
[3]ТОВ «КАПС ФУД СІСТЕМС», Пров. Залізничний, 3/4, м. Дергачі, Харківска обл., Україна, 62302
[4]Кафедра маркетингу та торговельного підприємництва
Українська інженерно-педагогічна академія, вул. Університетська, 16, м. Харків, Україна, 61003
[5]ТОВ «Чугуївський м'ясокомбінат», вул. Героїв Чорнобильців, 50, Харківська обл., м. Чугуїв, Україна, 63503

Анотація. Метою дослідження є формування функціонально-технологічних властивостей плівки багатофункціонального призначення із кишкової сировини під час сушіння. Досліджено її гігроскопічні властивості після сушіння у діапазоні температур 40–70°C. Встановлено, що збільшення температури сушіння сприяє зменшенню кількості вологи, яку зразок поглинає із оточуючого газового середовища. Визначено діапазони відносної вологості повітря, за якої можливе зберігання сушеної продукції у паропроникному пакуванні. Відзначено, що зберігання багатофункціональної плівки можливе в паронепроникному пакуванні за збільшення вологості повітря відносно рекомендованих діапазонів. Описано операції фасування сушеної плівки та виготовлення ковбасних оболонок із неї, які слідують після операції сушіння. Встановлено, що під час цих операцій наявні механічні деформації згину плівки на кути до 180°. Має місце відсутність порушення цілісності плівки за умови її згинання на кут 180° під час фасування готової продукції та виготовлення ковбасних оболонок із неї. Доведено, що виготовлені оболонки після їхнього відновлення під час виробництва ковбасних виробів є цілісними. Досліджені пружно-пластичні властивості плівки із кишкової сировини отриманої за різної температури сушіння. Встановлено, що за збільшення температури сушіння плівки, збільшується її міцність та зменшується її пластичність. Відзначено, з точки зору міцності, слід обирати найвищу температуру сушіння із діапазону 40–70°C. З точки зору пластичних властивостей – мінімальну температуру із означеного діапазону. Дослідженнями процесу сушіння вологої багатофункціональної плівки із кишкової сировини визначено раціональні значення температури та тривалості сушіння вологої плівки. Під час вибору температури сушіння в технології отримання багатофункціональної плівки із кишкової сировини, визначальним чинником є функціонально-технологічні властивості отримуваного напівфабрикату, які залежать від температури сушіння.

Ключові слова: плівка із кишкової сировини, процес сушіння, гігроскопічні властивості, пружно-пластичні властивості.