Investigation of frying process of meat sausages in glued casings from intestinal raw materials

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Abstract

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Introduction. The purpose of the work is to specify the peculiarities of heat and mass transfer processes during the frying of meat sausages in glued shells obtained in different ways from intestinal raw materials.

Materials and methods. Samples of meat sausages in different intestinal casings were studied: pork bellies; glued intestinal sausage casings from pork bellies with local thermal coagulation reinforcement, with local tanning reinforcement, with continuous tanning and plasticization.

Results and discussion. The temperature kinetics of different layers of meat sausages in glued intestinal casings during their frying were studied. The temperature of raw material inside the sample is uniformly distributed in the range from 80 to 90 °C in the investigated frying modes. This eliminates the negative impact of high temperatures on product quality due to the formation of substances of pyrogenetic fat breakdown with an unpleasant taste and odor.

The kinetics of the mass of meat sausages in glued intestinal casings during their frying is studied. The maximum rate of weight loss is obtained for the control sample – sausage in the traditional intestinal shell. The smallest value of the rate of weight loss has a sample which uses a sausage casing glued by continuous tanning followed by plasticization with glycerin. This is due to the lower permeability of the developed shells to the transmission of fat and water vapor in relation to the control sample. Glued intestinal membranes have less permeability in relation to the transmission of fat and vapor of system water than the traditional intestinal membrane, which is a more acceptable functional and technological property.

Thermophysical properties of the studied samples are determined to a greater extent by thermophysical properties of minced meat, the mass fraction of which is much larger compared to the mass fraction of the sausage casing.

Conclusions. Regularities of the course of heat and mass transfer process during frying of sausages in casings from intestinal raw materials are revealed.

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Introduction

The main technological peculiarities of fried meat sausages are frying on the surface at a temperature of 140–200 °C (Sukhareva et al., 2021) and use of mostly natural casings (Heinz et al., 2007). This is the cause of significant losses during the technological production process, which is about 40% (Toldrà et al., 2007).

The peculiarities of the process of meat products' frying compared to other methods of heat treatment are that the product is heated not in water or steam, but on the special surface for frying with the addition of vegetable oil or fat at a temperature of 140–200 °C. During the use of this method of heating a specific crust is formed on the surface of the product. The heating of minced meat during frying is characterized by temperature changes at different points and at different time, i.e. the temperature is a function of coordinates and time. It is worth noting that the heat and moisture transfer in this process are determined by the heating regime and the forms of system moisture connection with the material (Zayas, 1981).

On the other side, special attention should be paid to the formation of the protective properties of casings, as their level determines the degree of technological losses and economic efficiency of fried meat sausages production (Sidorova et al., 2011).

From the standpoint of resource conservation, an effective way to rationalize the technological process of preparing fried meat sausages is to use glued casings from intestinal raw materials remaining after obtaining gut products.

Literature analysis indicates the presence of scientific reports on improving the technology of glued casings (Domin et al., 2020), known regularities of heat and mass transfer during meat frying (Skrypnyk, 2015). Quantitative and qualitative indicators of fried sausages technology in modified shells (Shubina et al., 2015) are determined.

In order to increase the strength and reduce the degree of reversibility of the gluing-delamination process during the contact with minced meat containing a significant amount of water, methods of their additional reinforcement using thermal coagulation, tanning and plasticization have been proposed. It is shown that thermal coagulation, tanning and plasticization change physical and mechanical properties of shells (Onishchenko et al., 2021). At the same time, the regularities of heat and mass transfer processes during frying of meat sausages in glued intestinal casings, obtained in different ways, remain uncertain, which is a necessary scientific basis for comparing the efficiency of their use. These data are currently absent in the scientific and practical literature.

Thus, the study of the kinetics of temperature and mass of meat sausages in the intestinal casings glued in different ways during their frying is crucial. Their results will scientifically substantiate the feasibility of using the proposed technical and technological solutions and increase the resource efficiency of the technology.

The aim of the work is to establish the peculiarities of heat and mass transfer processes during the frying of meat sausages in the traditional intestinal shell and in the glued shells obtained in different ways from intestinal raw materials.

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

- To study the temperature kinetics of meat sausages layers in glued intestinal casings during their frying;
- To study the kinetics of meat sausages mass in the glued intestinal casings during their frying;
- To compare the processes of heat and mass transfer and to determine regularities of their passing during the frying of meat sausages in the traditional intestinal shell and in the glued shells obtained in different ways from intestinal raw materials.

Materials and methods

Materials

Samples of meat sausages in different intestinal casings were studied:

control: pork bellies with a diameter of 35–37 mm;

experiment: glued intestinal sausage casings (in one row) with a diameter of 35–37 mm, made of pork bellies:

- With a local reinforcing seam using thermal coagulation;
- With a local reinforcing seam using tannage;
- Reinforced with continuous tannage and plasticized with glycerin.

Separated pork bellies, which were previously cleaned of serous, muscular and mucous membranes, washed, sorted by quality, salted and stored as a salty product were used as outward raw material. The outward raw material was freed from salt, then washed and kept in water. Methods of obtaining glued sausage casings are described in detail in [9].

As a control, intestinal casings – pork belly products used in traditional technologies of making fried sausages – were used. That is, the raw material was the separated pork bellies, which were cleaned in advance from serous, muscle, and mucous membranes, washed, sorted by quality, salted, and stored in the form of salted products. The raw materials were desalted, washed, and aged in water (Hyro et al., 2007).

Preparation of semi-finished meat sausages in glued casings

Meat sausages were prepared by the following recipe (Rohov et al., 1993), kg/100 kg: lean pork semi-fat – 100; table salt – 1,8; white sugar – 0,2; ground black pepper – 0,25; fresh peeled crushed garlic – 1,0. In order to bring the moisture state of the minced meat to modern technological conditions, 30% water was added to the minced meat composition that is mixed. In order to form a monolithic structure of the finished product, 1/2 of the semi-fat skimmed pork was crushed on a meat comminutor with a lattice hole diameter of 14–20 mm, and the other 1/2 with a lattice hole diameter of 3–4 mm. The obtained minced meat was mixed with spices in a mixer, water was added, mixed again and left for pickling for 8–10 h at a temperature of 6–10 °C.

After loose filling and knitting, the sausage loaves were blanched in water at a temperature of 85–90 °C for 5 minutes, then placed on a greased surface and fried at a temperature of 140–150 °C for 20 minutes on each side. Cooling was carried out to a temperature in the loaf thickness of 8°C.

Samples of sausages, for which the frying process was studied (Božiková et al., 2017), were made using a parallelepiped frame (Figure 1). The framework is made of a steel wire with plastic isolation. The dimensions of the frame $a \times b \times c$, respectively, were 30×30×100 mm. 5 thermocouples were placed between the frame guides at a distance of 7,5 mm from each other, as shown in Figure 1.

Next, a sausage casing, tied on one side, stuffed with minced meat and tied on the other end, was stretched on the frame along the guides.

The test sample was placed on a frying surface preheated to a temperature of 140–150 °C and lubricated with vegetable oil (Naghavi et al., 2018). The sample was placed on the surface for frying with the plane $a \times b$ (Figure 1).

Figure 1. Parallelepiped frame for making samples of sausages used in the study of the frying process, and the layout of thermocouples in them

Methods of research of heat and mass transfer processes during the frying of sausages in glued intestinal casings and in control sample

Thermograms obtained during the frying of the control sample are shown in Figure 2. They are signals from thermocouples placed as shown in Figure 1. Thermocouple number VI is fixed on the surface for frying.

Frying from side 1 was performed until the temperature inside the sample (thermocouple III) reached the value of 70 °C. Duration of frying side 1, as can be seen from Figure 2 (first dotted line), is 20 minutes.

The sample was then inverted and fried for 1, i.e. 20 minutes.

After frying the sample for 40 minutes, heating of the frying surface was stopped (second dotted line). The product was cooled to room temperature. The cooling process to room temperature took 44 minutes. During the frying and cooling of the samples, their current weight and time were recorded.

Extensive evidence of various parameters obtained in the course of research. Their mathematical processing was carried out in order to check the degree of probability of the obtained data, to establish certain relationships between them, to present the results of processing in graphical form. Processing was performed using the Mathcad software package, which contains a wide range of procedures for solving problems of statistical analysis, interpolation, data smoothing, regression and correlation analysis (Snezhkin et al., 2019).

Figure 2. Thermograms obtained during frying and cooling of the control sample:
I, II, III, IV, V – thermocouples (from Figure 1);
VI – thermocouple mounted on the surface for frying.

Results and discussion

Temperature kinetics of different layers of meat sausages in glued intestinal casings during their frying

At the time of flipping, the temperature at evenly distributed points of thermocouples I, II, III, IV, V is 98 °C, 86 °C, 70 °C, 56 °C and 48 °C, respectively, due to their distance from the frying surface. Flipping and additional frying, on the other hand, mostly gives opposite results concerning peripheral thermocouples. There is a slight increase in temperature (by 2–3 °C), associated with an increase in the duration of thermal contact. The direction and the nature of temperature changes in the cooling phase are close to all thermocouples. The curves are finally smoothed in the interval (70–74)·60 s, with the temperature values of about 20 °C.

The nature of thermograms for the samples of meat sausages in glued intestinal casings is similar to the thermograms for the control sample (Figure 2). It is assumed that the analysis of thermograms by characteristic points for the control sample is valid for thermograms for other test samples. The differences are in the position of these characteristic points, which is reflected in the nature of the dependence of the moisture content of the studied samples in the process of frying and cooling.

Obviously, the nature of thermograms is determined by how close a certain layer of the test sample is to the heat source, the function of which is performed by the surface for frying. The most sensitive are the layers with thermocouples: I – before turning the sample on the surface for frying; V – after inversion of the sample on the surface for frying. These layers are heated the fastest, respectively, the first before inversion of the sample, and the second – after. After inversion of the sample, the layer with thermocouple I is cooled, as it is found the furthest from the heat source and borders on the environment. As for the layer with

thermocouple V, its heating is the slowest for the same reasons before inverting the sample. Accordingly, after turning – the layer heats up at the highest speed.

The layer for which the distance from the heat source is constant and which is a kind of «indicator» of the product's readiness, is the central layer of raw materials (thermocouple III). It heats up at an intermediate rate before turning over. After inversion, its temperature rises to 75–80°C and is kept constant due to the heat accumulated by the layers with thermocouples I and II and due to heat supply from the heat source through the layers with thermocouples IV and V.

Let us consider the characteristic points of the obtained thermograms.

As noted above, the most sensitive to changes in surface temperature for frying (thermogram VI) is the surface layer (layers with thermocouples: I – before inversion of the sample on the surface for frying; V – after inversion of the sample on the surface for frying), i.e. the layer in direct contact with heat source. The thermograms of these layers have characteristic inflection points A and A', which correspond to the beginning of intense evaporation from the surface of the sample. At these points begins intensive loss of the sample mass to be fried.

The thermogram of the central layer (thermocouple III) has an inflection point B. The presence of this point indicates that at a temperature of 35–40 °C internal endothermic processes are completed and more intense heat accumulation begins by the inner layers of the sample.

To analyze the temperature distribution over the volume of the sample, the created temperature fields are shown in Figure 3.

Figure 3. Temperature fields inside the control sample during frying and cooling at different times, min.:
1 – 10; 2 – 20; 3 – 30; 4 – 40; 5 – 50; 6 – 60.

Temperature fields were constructed according to the data obtained from thermocouples placed inside the sample, as shown in Figure 1, at intervals of 10 minutes. The start time and end time (last 14 minutes) are not given, because the temperature values from all thermocouples are close to room temperature at these time points.

Figure 3 shows that the largest temperature gradient occurs in the first 10 minutes (1) because thermocouple I is the closest to the heating surface. As a result, a convective heat transfers to the sample through the shell. Next, the temperature gradient decreases (2) due to the heating of the inner layers of the raw material. After inversion of the sample, the temperature gradient changes its sign, but its value is insignificant. It should be noted that 30 minutes after the beginning of the frying process at a surface temperature for frying 140–150 °C, the temperature of the raw material inside the sample is uniformly distributed in the range from 80 to 90 °C. This, firstly, indicates the readiness of the product (Vujadinović et al., 2014), and, secondly, eliminates negative influence of high temperatures on product quality due to the formation of pyrogenetic cleavage of fat with an unpleasant taste and odor (Grujić et al., 2014).

The differences between the temperature fields during frying for the test samples and for the control sample are within the error. The temperature values between the respective layers of raw materials inside the samples differ by no more than 3–7%. The mass fraction of sausages, i.e., minced meat, is much higher (more than 98%) compared to the mass fraction of sausage casings (Marcus et al., 2013). Thus, thermophysical properties of the studied samples are determined mostly by thermophysical properties of minced meat, that is the same for all samples (Akpan et al., 2017). The indicated allows to use glued intestinal casings in the technology of making meat sausages without any changes in the relevant technological schemes.

Kinetics of the meat sausages mass in glued intestinal casings during their frying

Kinetics of the mass of the studied samples of sausages during frying and cooling is shown in Figure 4. On the y-axis of the graph the mass of the sample is plotted and normalized to its original value.

These dependences were determined by approximating the obtained experimental data by a polynomial function of the form:

$$m(\tau) = \sum_{n=0}^P a_n \cdot \tau^n,$$

where m is the current relative weight, kg/kg; τ – current time, s; P – the degree of the polynomial.

The optimal degree of the polynomial was determined by the minimum ratio

$$\sigma_{\min}^2 = \frac{\sum_{i=1}^N \left(m_i - \sum_{n=0}^P a_n \cdot \tau^n \right)}{N - P - 1}$$

The values of the approximation coefficients for different samples are given in the Table 1.

Kinetics of the studied samples mass are of the same nature: the mass decreases monotonically during the process of frying and subsequent cooling. Obviously, the decrease in mass is due to the evaporation of system water and the leakage of fat through the used shells (Behailu et al., 2020).

Figure 4. Kinetics of the control sample (1) mass and samples in the shells:
2 – glued sausage casings, reinforced with the use of local thermal coagulation;
3 – glued sausage casings, reinforced with the use of local tannage with a solution of tannin;
4 – sausage casings glued by continuous tannage followed by plasticization with glycerin.

Table 1

Values of approximation coefficients for different samples

Samples in the shells	a_0	$a_1, \times 10^3$	$a_2, \times 10^4$	$a_3, \times 10^6$	$a_4, \times 10^8$
Control sample	1.210	-2.091	-3.020	5.142	-2.344
Glued sausage casings, reinforced with the use of local thermal coagulation	1.213	-1.044	-2.500	3.621	-1.331
Glued sausage casings, reinforced with the use of local tannage with a solution of tannin	1.210	-1.670	-2.261	4.310	-1.838
Sausage casings glued by continuous tannage followed by plasticization with glycerin	1.212	-9.975	-2.381	3.617	-1.429

However, the given kinetics of mass differ in the different angle of inclination to the abscissa axis, on which time is set, and in the different final mass. The angle of inclination to the axis on which time is set, is determined by the rate of weight loss by the samples under research. It is possible to determine kinetics of the rate of mass loss by finding the time derivative of the approximation function. Kinetics of the rate of weight loss obtained in this way for the studied samples are shown in Figure 5.

The nature of these dependences is similar, i.e., there is a monotonic increase in the rate of weight loss, reaching the maximum speed and a monotonic decrease in this characteristic. Obviously, due to the heating of the sample, the evaporation rate of system water increases, respectively, reaching the maximum value at the investigated temperatures. The same concerns the leakage of fat, which melts at temperatures above 39–42 °C (Kameník et al., 2018).

Figure 5. Kinetics of the rate of weight loss of the control sample (1) and samples in the shells:
 2 – glued sausage shells, reinforced with the use of local thermal coagulation;
 3 – glued sausage casings, reinforced with the use of local tannage with a solution of tannin;
 4 – sausage casings glued by continuous tannage followed by plasticization with glycerin.

Due to the reduction in the amount of system water that can evaporate at the temperatures under study and the amount of fat that leaks out, the rate begins to decrease in the process of frying (Hwang et al., 2020). And during cooling, the rate of weight loss tends to zero, due to a decrease in the intensity of these processes (meaning the evaporation of system water, melting and leakage of fat) and their gradual cessation (Huebner-Keese et al., 2016).

It should be noted that the maximum rate of weight loss was obtained for the control sample (curve 1 in Figure 5). For samples of glued reinforced sausage casings, it has an intermediate value among the studied samples (Mellema et al., 2003). The smallest value of the rate of weight loss has a sample that uses a sausage casing glued by continuous tanning followed by plasticization with glycerin.

This happens due to lower permeability of the developed shells to the transmission of fat and water vapor in relation to the control sample. It should be assumed that this is the reason for different final mass of the samples under research.

Thus, the study proves that the developed shells have less permeability to the transmission of fat and vapor of systemic water compared to the traditional intestinal membrane, which is a more acceptable functional and technological property.

Conclusions

Based on the analysis and comparison of the obtained results, the regularities of heat and mass transfer processes during frying of meat sausages in the traditional intestinal shell (pork belly) and in glued shells obtained in different ways from intestinal raw materials were specified.

1. Research of the temperature kinetics of different layers of meat sausages in glued intestinal casings during their frying showed that the temperature of raw materials inside the sample for the studied frying modes is uniformly distributed in the range from 80 °C to 90 °C. It is noted that this eliminates the negative impact of high temperatures on product quality due to the formation of substances of pyrogenetic breakdown of fat with an unpleasant taste and odor.
2. Research of the kinetics of meat sausages mass in the glued intestinal casings during their frying showed that the maximum rate of weight loss was obtained for the control sample – sausage in the traditional intestinal shell (pork belly). It was found that the lowest value of the rate of weight loss has a sample that uses sausage casing glued by continuous tanning followed by plasticization with glycerol, due to lower permeability relatively to the control sample of the developed casings to the transmission of fat and water vapor. The weight loss in the glued intestinal membranes was reduced by 6–11% compared to the control sample made in pork bellies.
3. It is proved that thermophysical properties of the studied samples are determined to a greater extent by thermophysical properties of minced meat, the mass fraction of which is much larger (exceeds 98%) compared to the mass fraction of the sausage casing. It is proved that thermophysical properties of sausages in the intestinal membrane differ from sausages in glued intestinal casings by no more than 3–7%, i.e., within the error. It was found that glued intestinal membranes have less permeability to the transmission of fat and steam of systemic water in relation to the traditional intestinal membrane, which is a more acceptable functional and technological property.

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