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Original scientific paper

THAWING PROCESS CALCULATION OF EGG INGREDIENTS PARTICLES IN MINCED MEAT

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Abstract

Sausages from poultry meat are present on the domestic market. In this regard, the problem of improving the competitiveness of these products is urgent. One way to solve this problem is to replace part of the raw meat in the minced meat for sausages with chicken egg products (pasteurized liquid egg, egg white, yolk). Using egg products as ingredients of minced meat will help stabilize minced meat for sausages before and after heat treatment, increase the nutritional value of the finished product, and reduce its cost. However, currently, the mass fraction of egg ingredients in meat and egg products formulations does not exceed 5–10 %. This is due to the appearance of a specific taste, if it is exceeded, and because it is impossible to obtain a pattern of egg fragments in the section of the finished products, if necessary. This fact restricts the use of egg products as ingredients of meat and egg products. A technological method to eliminate these problems is freezing egg ingredients before adding to minced meat. In order to control the application of this method, the mechanism of changes in frozen egg ingredients during the preparation and heat treatment of minced meat for sausages is revealed. It was found that at the stage of minced meat mixing, the liquid part of the egg ingredients resulting from the thawing of frozen particles surface mixes with meat ingredients. Moreover, when unmoved relative to the surrounding minced meat, the frozen particles of egg ingredients are caught by the minced meat, and then locally coagulate in the process of meat and egg product heat treatment. The weight of the liquid phase resulting from the thawing of frozen egg ingredient particle and the weight of its remaining local part depend on the duration of the minced meat mixing process, its temperature and particle weight. Based on the knowledge about this mechanism, analytical equations are obtained using the energy balance method. They describe the duration of egg ingredients thawing in meat and egg products depending on the particle weight and the temperature of minced meat. The experimental data of the authors are used as a basis for calculating the process of egg ingredients thawing. The proposed calculation method will allow purposeful controlling the process of change in frozen egg ingredients aggregative state in minced meat for sausages, under production conditions.

Introduction

Currently, the volume of poultry meat on the Russian market exceeds that of slaughtered animals, which are traditional raw materials for the production of sausages [1].

For this reason, in recent years, various types of sausages from poultry meat, including cooked ones, have been widely represented on the domestic market [2].

In this regard, it should be noted that each change in the technology of sausage production may require the introduction of appropriate additional technological methods.

In particular, some researchers note the need to replace fat in the composition of minced meat based on poultry meat, since chicken fat, due to the low melting point, easily melts during heat treatment forming oily «pockets» in minced meat for sausages, thereby reducing the quality of products [3, 4].

The stabilizing function in an unstable heterogeneous system of minced meat for cooked sausages is performed by emulsifiers and gelling agents that provide binding and retention of water and fat in a single system before and after heat treatment [5].

One of the best natural emulsifiers and gelling agents are products chicken egg processing, i. e. pasteurized liquid egg and yolk (emulsifiers), egg white (gelling agent) [6].

In addition, the introduction of these egg products into minced meat for sausages will significantly increase the nutritional value of the finished product, because, for example, pasteurized liquid egg almost completely corresponds to human milk in terms of essential amino acids content (g/100 g of protein), which is the highest standard of nutritional value [7].

At the same time, the use of egg products as ingredients of minced meat for cooked sausages will reduce their cost because the cost of chicken eggs is lower than the equivalent weight of poultry meat.

Thus, the use of egg products in minced meat for cooked sausages will solve the following important problems: stabilize minced meat for sausages before and after heat treatment, increase the nutritional value of the finished product and reduce its cost.

However, currently, egg products are used in the production of sausages in liquid form. This fact determines their low mass fraction in the formulations of combined meat and egg products (on average 5–10 %) [8], which restricts their use as ingredients of meat and egg products.

In addition, the liquid state of egg ingredients does not allow obtaining a pattern of egg fragments in the section of finished products, if necessary.

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In this regard, the search for technological methods that can eliminate these limitations is urgent.

One of such methods is to freeze egg ingredients before adding to minced meat.

The use of frozen egg ingredients during the mixing of minced meat for sausages will allow to use them in the process of finished product manufacturing for two purposes. The thawed liquid part mixed with meat ingredients of minced meat will act as an emulsifier (pasteurized liquid egg and yolk) or as a gelling agent (egg white). Moreover, the part of egg ingredients remaining in the frozen state will be transformed into pattern in the section of finished products as a result of coagulation at the heat treatment stage.

In general, this technological approach will allow to better stabilize of minced meat for sausages, increase the mass fraction of egg ingredients in combined meat and egg products and the nutritional value of finished products without giving them a specific egg flavor, cool down minced meat in the process of its preparation and reduce the cost of finished products.

The practical implementation of the above technological method requires the possibility of calculating the changes in frozen egg ingredients during the preparation and heat treatment of minced meat for sausages.

The aim of this work was to obtain analytical equations describing the duration of egg ingredients thawing in meat and egg products depending on the particle weights and ambient (minced meat) temperature.

Materials and methods

Objects of study: egg ingredients of meat and egg products, i. e. pasteurized liquid egg, yolk and egg white, cylindrical (D = H), where D is the diameter of the cylinder and H is its height.

Subject of study: egg ingredients thawing process.

The calculation of food products thawing duration is a complex problem, since it requires consideration of many factors, including changes in the thermophysical properties of the product during this process.

There are number of mathematical models developed for this purpose, for example [9,10,11,12, 13,14,15].

These calculation methods may be divided into two groups: relatively simple analytical dependencies based on a number of assumptions, and therefore, the results of calculations using them contain unacceptably large errors; and complex mathematical models that require unreasonably complicated calculations to solve practical problems.

We have chosen an intermediate analytical and empirical model that optimally combines their advantages (simplicity and acceptable accuracy).

In order to obtain engineering equations for calculating the process of egg ingredients thawing convenient for use in production conditions, kinetic indicators (the rate of egg products thawing — pasteurized liquid egg, yolk and egg white, in relative units) obtained empirically by the authors were used as the basis for the calculations [16].

The experiments to obtain the base for calculations were performed as follows.

Egg white, yolk, and pasteurized liquid egg were transferred into cylindrical metal containers with an inner diameter and height of 43 mm. The temperature sensor was fixed in the thermal center of the sample (on the axis of the cylinder, at the same distance from the bottom of the container and the surface of the sample). In order to ensure the identical conditions of the experiment for all objects of study, three containers with prepared samples (protein, yolk and pasteurized liquid egg) were simultaneously placed into freezer and frozen.

After freezing, product samples were removed from the freezer and thawed at room temperature. During freezing and thawing, changes in temperature of the samples over time were recorded.

The temperature was measured using IS203.4 temperature recorder (Russia). The sensor readings were recorded automatically, with an interval of 2 seconds. The absolute measurement error was ± 0.2 °C. Overall, five experiments were performed at the same air temperature in the freezer, i. e. minus (15 ± 0.5) °C.

The coefficient of variation for the set of measurements did not exceed 4 %.

The relationship between the temperature of the study objects and their aggregative state was established qualitatively (visually) and quantitatively (by determining the penetration using KP-3 penetrometer (Russia). The difference between the results of three parallel measurements did not exceed 3 %.

Analytical equations describing the duration of egg ingredients thawing in meat and egg products depending on particle weight and ambient temperature were obtained based on the energy balance of egg ingredients thawing process [17,18]. In such a case, the results were used of studies on the mechanism of change in egg ingredients during mixing and heat treatment of minced meat for sausages.

Comparison of calculated and experimental data confirmed the validity of this assumption, i. e. the relative error of the calculation results with the proposed equations did not exceed 5 %, which is acceptable for technical calculations in sausage production.

Results and discussion

The surface of egg ingredient frozen particle located in minced meat with a positive temperature thaws. During minced meat mixing, the resulting liquid is mixed with meat ingredients. If the frozen particle (or its frozen part remaining after thawing) is unmoved relative to the surrounding minced meat, then it is caught by the minced meat and locally coagulates during the subsequent heat treatment forming the pattern in the section the meat and egg products [16].

The weight of the liquid phase resulting from the thawing of egg ingredient frozen particle and the weight of its remaining local part depend on the duration of the minced meat mixing process, its temperature and the weight of the egg particle.

In the production environment, purposeful control of the mechanism for changing the aggregative state of egg ingredients frozen particles in the minced meat for sausages is possible only with the help of analytical equations that describe the dependence of duration of egg ingredients thawing on particle weight and ambient (minced meat) temperature.

The indicated analytical dependences are as follows.

Calculation of the duration of egg ingredient particle thawing depending on its weight

The energy balance equations for the thawing process of two cylindrical frozen particles of egg ingredient of different weights are as follows. The first particle of egg ingredient (equation members are indicated by index 1):

$$W \times \omega \times M_1 \times r = q \times F_1 \times \tau_1, \quad (1)$$

where:

W is the humidity of egg ingredient, %;
ω is the fraction of frozen water in egg ingredient, %;
M_1 is the weight of egg ingredient, kg;
r is the specific heat of ice thawing, J/kg;
q is the specific heat flux that enters the surface F1, m^2 of frozen egg ingredient, J/m^2s;
τ_1 is the duration of thawing process, s.

By analogy with equation (1), the energy balance equation for the second particle of egg ingredient (equation members are indicated by index 2) is as follows:

$$W \times \omega \times M_2 \times r = q \times F_2 \times \tau_2. \quad (2)$$

As a result of transformations of equations (1) and (2) (i. e. expressing the areas F and weights M of the egg ingredient particles through their radii: $F = 4\pi R^2$; $M = \rho^* \pi^* R^3$, where ρ is the specific gravity of the egg ingredient frozen particle, kg/m^3) the following equations are obtained:

$$\tau_1 = W \times \omega \times r \times \rho \times \pi \times R_1^3 / q \times 4\pi R_1^2. \quad (3)$$

$$\tau_2 = W \times \omega \times r \times \rho \times \pi \times R_2^3 / q \times 4\pi R_2^2. \quad (4)$$

Dividing equation (3) by (4) gives the following equation:

$$\tau_2 = \tau_1 \times R_2/R_1, \quad (5)$$

where:

R_1 and R_2 are the radii of the first and second particles, m.

By expressing the radii of the particles through their weights ($R^3 = M/\rho \times \pi \times$), we obtain the desired equation:

$$\tau_2 = \tau_1 \times \sqrt[3]{M_2/M_1}. \quad (6)$$

Calculation of the duration of egg ingredient particle thawing depending on ambient temperature

The energy balance equations for the thawing process of two frozen particles of egg ingredient of the same weight at different ambient temperatures are as follows.

The particle of egg ingredient at the ambient temperature T1 (equation members are indicated by index 1):

$$W\omega M \times r = q_1 \times F \times \tau_1, \quad (7)$$

where:

M is the weight of egg ingredient;
q_1 is the specific heat flux that is transmitted to the surface F of frozen egg ingredient under the influence of temperature difference between the environment and the frozen product surface ΔT_1;

By analogy with equation (7), the energy balance equation for the particle of egg ingredient at the ambient temperature T_2 (equation members are indicated by index 2) is as follows:

$$W\omega M \times r = q_2 \times F \times \tau_2, \quad (8)$$

where: q_2 is the specific heat flux that is transmitted to the surface F is the specific heat flux that is transmitted to the surface ΔT_2;

From equations (7) and (8), we express τ_1 and τ_2

$$\tau_1 = W\omega M \times r / q_1 \times F, \quad (9)$$

$$\tau_2 = W\omega M \times r / q_2 \times F, \quad (10)$$

Dividing equation (9) by equation (10) gives the following equations:

$$\tau_2 = \tau_1 \times q_1/q_2 \quad (11)$$

Based on the Newton's law of cooling ($q = \alpha^* \Delta T$)), we can write equation (11) in the following form:

$$\tau_2 = \tau_1^* \, \Delta T_1/\Delta T_2 \quad (12)$$

The change in the temperature difference between the environment (minced meat) and the surface of the egg ingredient frozen particle, under the influence of which the heat flux is transferred for thawing, depends only on the changes in the ambient temperature. This is because the surface temperature of the frozen object that receives heat flux from the environment is constant and equal to the cryoscopic temperature of egg ingredient.

For this reason, to perform the calculations with convenience, we replace ΔT in equation (12) with the ambient temperature T.

As a result, the desired equation is as follows:

$$\tau_2 = \tau_1 \times T_1/T_2, \quad (13)$$

where T_1 and T_2 are the ambient temperatures**.**

Here is an example of calculating the parameters of the meat and egg product manufacturing process regarding the use of frozen egg ingredients using equations (6) and (13).

Statement. It is necessary to produce meat and egg product with a total content of egg ingredients equal to 25 %. The part of egg ingredients, which should be turned into a liquid state and mixed with meat ingredients, is 10 % of the whole product weight. The remaining part is 15 % of the whole product weight. It forms a pattern on the product section, i. e. local coagulated inclusions of cylindrical shape $H = D = 1.10$ cm (weight 1.0 g).

Unknown. The initial sizes of the egg ingredients frozen particles ($H = D$) and the duration of minced meat (with a temperature of 12 °C) mixing with added egg ingredients.

Solution. According to the statement, the total weight of the egg ingredients particles forming the pattern on the product section should be 15 % of the whole product weight. The total weight of thawed egg ingredients should be 10 % of the whole product weight, i. e. 1.5 times less than the total weight of the particles forming the pattern. As for one particle, the weight of its thawed part is 1.0 g/1.5 = 0.67 g. Hence, the initial weight of the frozen particle is 1.0 g + 0.67 g = 1.67 g.

To determine the size of the initial frozen particle, the following well-known equation should be used:

$$M = \rho \times V = \rho \times \pi \times H^3/4 \qquad (14)$$

where:

M is the initial weight of the frozen particle;
ρ is the specific gravity of the egg ingredient frozen particle;
V is the volume of the egg ingredient frozen particle;
H is the height of the cylinder equal to its diameter (D).

Expressing H from equation (10):

$$H = \sqrt[3]{4 \times M/\rho \times \pi}. \qquad (15)$$

By substituting the numerical values of the symbols in equation (11) (for the convenience of calculations, we approximate the numerical values of M to 1.70 g, and ρ to 1.0 g/cm^3), we obtain the size of the initial egg ingredient frozen particle: H = D = 1.30 cm.

Next, using equations (6) and (13), we can determine the duration of the minced meat mixing (we consider the temperature of minced meat equal to 12 °C) with added frozen egg ingredients (e. g. pasteurized liquid egg). This duration must provide the specified values of the mass fractions of liquid (10 %) and coagulated (15 %) phases of egg ingredients in the finished product.

First, using equation (6), we determine the duration of thawing for pasteurized liquid egg with weight of 0.7 g at the ambient temperature of T_2 = 23 °C.

For this purpose, by substituting in this equation the numerical values of the symbols: τ_1 = 16 min and M_1 = 60 g (determined experimentally [16]), and the given value M_2 = 0.7 g (according to the statement, this weight should be turned into the liquid state), we obtain:

$$\tau_2 = \tau_1 \times \sqrt[3]{M_2/M_1} = 16 \times \sqrt[3]{0{,}7/60} = 16 \times 0{,}23 = 3{,}7 \text{ min}$$

Then, using equation (13), we determine the duration of thawing for pasteurized liquid egg with weight of 0.7 g at the ambient temperature of T_2 = 12 °C.

By substituting the numerical values of the symbols in equation (13), we obtain the following value:

pasteurized liquid egg:

$$\tau_2 = \tau_1 \times T_1/T_2 = 3{,}7 \times 23/12 = 7{,}1 \text{ min}$$

Using kinetic indicators of the egg ingredients thawing process expressed in relative units (yolk — 1.3; pasteurized liquid egg — 1.1; egg white — 1.0) [16], we calculate the duration of thawing for particles with weight of 0.7 g for yolk and egg white at the ambient temperature of T_2 = 12 °C. We can make it using as a base the obtained value of a similar indicator for pasteurized liquid egg:

yolk: $\tau_2 = 7{,}1 \times 1.1/1{,}3 = 6{,}0$ min

egg white: $\tau_2 = 7{,}1 \times 1.1/1{,}0 = 7{,}8$ min

Result of the solution. As a result of solving this problem, it was established that the fulfillment of the above statement requires the following process parameters:

Initial frozen cylindrical particles of egg ingredients should have the dimensions: D = H = 1.30 cm, and the duration of minced meat mixing with added particles (at the minced meat temperature T_2 = 12 °C) should have the following values for various egg ingredients (min) — pasteurized liquid egg, 7.1; egg white, 7.8; yolk, 6.0.

Conclusion

The obtained analytical equations allow carrying out calculations of changes in the aggregative state and the geometric dimensions of the egg ingredients frozen particles in the minced meat for sausages, when egg ingredients are used to develop the technology of meat and egg products.

The simple structure of the obtained equations, which contains only physical parameters, ensures their convenient application in a production environment.

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