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IMPROVEMENT OF WHIPPED FLOUR SEMI-FINISHED PRODUCT TECHNOLOGY WITH THE USE OF GELATIN AND TRANSGLUTAMINASE ENZYME

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The monograph contains concentrated and systematized scientific information on the use of gelatin and the enzyme transglutaminase for the production of confectionery products in the restaurant industry, presented in text form, technological calculations, figures, diagrams, tables and intended for teachers, students of higher education, postgraduate students who are engaged in scientific work.

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CONTENT

LIST OF ABBREVIATIONS AND TERMS

TE – transglutaminase enzyme;

NSP - non-starch polysaccharides;

FS - foam stability;

FA – foaming ability;

ARS- amount of residual solution;

MRC- moisture-retaining capacity;

WFSFP- whipped flour semi-finished product;

MBR– medical and biological requirements;

SN – sanitary norms;

TS U – technical conditions of Ukraine;

TI – technological instruction;

FAO/WHO –World Health Organization

INTRODUCTION

In recent years, the process of European integration of Ukraine as a factor in the socio-economic development of the state significantly affects all types of activity in the production sphere and trade, including the food industry and restaurant business. This affects, first of all, the requirements for food products, the indicators of which must meet Ukrainian and European standards, and the production technologies must be attractive for investment and competitive.

The above-mentioned fully applies to the production of structured food products (whipped frozen/whipped semi-finished products such as biscuits), the production and consumption of which has been growing significantly recently. The use of food additives in whipped semi-finished products such as biscuits, which do not take into account the requirements of the final product, namely high foaming ability and long-term stability of the foam, which later (when baking the semi-finished product) leads to deterioration of the structure and appearance of the ready-to-use product, became a restraining factor , which does not meet the requirements of manufacturers.

Structured food products are gaining more and more popularity every year. The implementation of scientific principles of enzymatic modification of the properties of gelatin, as well as its combination with structure formers of a different nature, will allow the creation of fundamentally new non-traditional types of food products (whipped frozen/whipped semi-finished products such as biscuit).

The creation of high-quality food products is based on the selection of various types of raw materials in such proportions that ensure excellent quality of the finished product, high organoleptic indicators, consumer and technological characteristics. The generalization of the scientific and practical principles of the production of whipped semi-finished products allows us to assert the need to improve the existing technology in view of the lack of resilience and stability of the system. The implementation of scientific principles of enzymatic modification of gelatin properties through the use of the transglutaminase enzyme will allow to obtain a thermostable foam-like structure that can withstand heat treatment, characteristic of classic biscuit semi-finished products. The combination of gelatin in a composition with xanthan and the enzyme transglutaminase in the recipe composition of the whipped semi-finished product will give the products uniform porosity, lightness and fluffiness, and will ensure the preservation of taste properties during storage. Baked flour whipped semi-finished product with replacement of egg products with gelatin as an ingredient that will provide a foam structure of the system, will allow to create fundamentally new non-traditional types of food products.

Therefore, the scientific substantiation and development of the technology of whipped semi-finished products of the biscuit type, with high indicators of foaming ability, will allow to expand sales markets and the range of new products, which is an urgent and timely task.

The monograph contains materials that include a description and overview of modern methods of using dry mixes, significantly simplifying the production technology of many types of confectionery and culinary products, because it allows to obtain semi-finished products with specified physico-chemical and rheological properties by mixing. This technology makes it possible to expand the directions of intensification of the production of confectionery and culinary products.

The monograph presents the results of scientific research on the development of a new technology for obtaining a whipped flour semi-finished product using the transglutaminase enzyme:

- the choice and concentration of the content of foaming substances was justified and their complex influence on changes in the organoleptic, rheological and physico-chemical properties of the food system was analyzed;
- the main technological parameters of the whipped flour semi-finished product are substantiated;

- the recipe and production technologies of whipped flour semi-finished product were developed, the organoleptic, rheological, physico-chemical properties were studied;
- the regularity and mechanism of the influence of the concentration of foaming agents on the quality of the finished product have been established;
- comprehensive indicators of the quality of the developed product during storage were investigated;
- recommendations on the use of a dry mixture for obtaining a whipped flour semi-finished product of the biscuit type and ways of forming a range of products are proposed.

The first chapter provides an analysis of the current state and prospects for the development of whipped flour semi-finished products, the functional and technological properties of gelatin in a composition with xanthan, the theoretical basis of foam formation and foam stabilization in protein flour systems, the synergism of the action of structural elements in flour mixtures with the addition of gelatin and the possibility of the use of transglutaminase enzyme in the technology of the whipped flour semi-finished product were studied.

The second chapter is devoted to the scientific substantiation of the technological parameters of obtaining whipped flour semi-finished product, namely:

- selection of recipe components using gelatin in composition with xanthan and transglutaminase enzyme;

- the effect of temperature on the foaming process of the "water-gelatin-xanthan" system with modification by the transglutaminase enzyme;

- the effect of the synergistic interaction of xanthan with gelatin and the catalytic effect of the transglutaminase enzyme in the gelatin-xanthan system on the weight loss of the semi-finished product;

- the influence of the recipe components of the semi-finished product on the mechanism of moisture removal and the study of the forms of moisture connection in the model systems of the semi-finished product;

- the influence of recipe components on the structural and mechanical characteristics of the semi-finished dough blank;

- optimization of the influence of the structuring components concentrations of the model systems of the whipped flour semi-finished product on the parameters of the viscosity and moisture-retaining capacity of the dough.

The third section is devoted to the development of the recipe composition and technology of whipped flour semi-finished product and the technology of confectionery products with its use, physicochemical characteristics of baked whipped flour semi-finished product during storage. The nutritional and biological value of the semi-finished product, consumption safety indicators, storage terms and conditions were studied; a comprehensive quality indicator has been developed.

On the basis of theoretical and experimental studies, the technology of whipped flour semi-finished product using gelatin as a foaming element and transglutaminase enzyme without the use of egg products was scientifically substantiated and developed. This technology makes it possible to produce semi-finished whipped baked goods with fundamentally new properties.

The team of authors hopes that this work will be useful to technologists working in the confectionary branch of the food industry, higher education graduates, students of the degree of doctor of philosophy,, as well as teachers who want to deepen their knowledge of this scientific direction.

CHAPTER 1. SCIENTIFIC BASIS OF THE CREATION OF A WHIPPED FLOUR SEMI-FINISHED PRODUCTS

1.1 Analysis of the current state and prospects for the development of whipped flour semi-finished products

Flour confectionery products occupy a large segment of the domestic confectionery market in terms of sales volume, due to their high consumption qualities, nutritional and biological value. Whipped baked semi-finished products occupy an important place among confectionery products. They can include semi-finished products such as biscuits, air, air-nut.

According to statistical data, the number of biscuit products is from 15 to 17% of the total production volume of flour confectionery products. It should be noted that the current trends in the development of the flour confectionery market indicate an increase in the population's demand for biscuit products [1].

In recent years, in the modern food industry, there has been a trend of increasing demand for new types of food products, which are the result of the introduction of highly efficient technologies in production and are characterized by high nutritional and biological value, which meet to the modern requirements of nutritionology.

The significant consumption of flour confectionery by the population makes it possible to consider them as important food products. Therefore, the issue of improving the quality, nutritional value, and expanding the range of functional flour confectionery products becomes important. All this makes research aimed at expanding and improving the recipes and technology of flour confectionery products relevant. The energy value of flour confectionery is significantly higher than many other food products [2]. They are essential sources of easily digestible carbohydrates, which with excessive consumption, especially with a sedentary lifestyle, can become a factor contributing to the development of a number of diseases associated with metabolic disorders in the body. Therefore, the development of new types of flour confectionery products with a reduced content of ingredients of high energy value due to the inclusion in the recipe of new types of raw materials with an insignificant energy value, but biologically and technologically complete, is very relevant. Biscuit semi-finished products are the main or component part of many flour confectionery products. Biscuit dough is a thermodynamically unstable foamy food system, therefore stabilization of this system is of great technological importance in its production [2].

The analysis of modern scientific and practical trends in the development of the confectionery industry indicates the expediency and relevance of further improvement of technologies, the development of technological solutions for the rational use of traditional and new types of recipe components to expand the assortment and obtain products with improved quality characteristics [3].

The structure of a whole group of confectionery products (whipped candies, marshmallows, protein-whipped and biscuit semi-finished products) is determined by the foaming process, which depends on many factors - the type and properties of the raw material, technological and mechanical processing parameters, etc. However, the effectiveness of this process is largely determined by the presence and properties of foaming agents in the system. Therefore, among the variety of works that study the conditions for the formation and preservation of the stability of foam structures, the majority is devoted to the role of egg products as the main foam generators and their interaction with other components of the system [4, 5, 6].

A significant interest in the development of semi-finished biscuit technology is the use of dry protein and dry yolk in the production of semi-finished biscuits instead of a natural egg. The advantage given to dry egg products in comparison with natural eggs is due to the fact that when using them, the sanitary conditions of production are significantly improved, the possibility of insemination of products with unwanted microorganisms is excluded, and the stability of product quality increases [7].

In recent years, the health indicators of the population of Ukraine have worsened. Nutrition should become rational, i.e. provide a person's physiological need for basic nutrients, taking into account age, professional and other characteristics. At the same time, it is important to maintain a balance between the energy that is consumed and spent. An important point is also the entry into the human body of not only a certain amount of basic food substances, but also their quality, safety and balanced nutrition [8, 9].

Analysis of the Ukrainian market shows [10] that the production and sale of culinary and confectionery products is developing in several directions: improving consumer properties, ensuring product safety, varying storage terms, reducing cost and energy consumption, expanding the range of products, which indicates the need to improve existing and develop new technologies of biscuit semi-finished products. However, the quality of recipe raw materials does not always meet the technological requirements that provide the necessary structural and mechanical properties of the dough to obtain products with planned quality and safety indicators, which leads to the need to adjust the recipe and parameters of the technological process. One of the promising ways to solve this problem is the purposeful use of ingredients that have a wide range of technological properties that allow improving the physico-chemical and organoleptic characteristics of semi-finished products, providing them with new quality indicators, adjusting the nutritional value and chemical composition, and extending the shelf life [10].

Increasing the competitiveness of flour confectionery products is largely determined by their quality and ability to be preserved [11]. In the process of storage, deterioration of consumer properties of finished products is most often characterized by staleness and mold. Preservation of the freshness of flour confectionery products is ensured by the use of moisture-retaining additives. The introduction of emulsifiers into the recipes of flour confectionery products also contributes to the extension of their shelf life due to the prevention of their staleness. There is a large number of food additives based on biopolymers with high moisture retention capacity, the so-called "hydrocolloids", which also contribute to the formation of the necessary structure of flour confectionery products [11].

The creation of new confectionery technologies is based on original technological ideas and inventions using non-traditional raw ingredients, which allow to significantly change the structure and develop new types of semi-finished products and finished products.

Gelatin [12] is an important hydrocolloid that is widely used in food products and in particular in flour confectionery. In general, animal gelatin is widely used due to its rapid melting, gelatinization temperature, and thermal reversibility. Gelatin is a high molecular weight and water-soluble protein. All amino acids are present in gelatin except tryptophan and have a low content of methionine, cystine and tyrosine due to degradation during hydrolysis. The amino acid composition of gelatin, depending on the source, is different, but it always contains a large amount of glycine, proline and hydroxyproline, which stabilize its structure and affect its chemical properties.

The use of gelatin is promising in the technology of food products produced by the food processing complex and restaurants. This hydrocolloid has a significant potential for functional and technological properties, the implementation of which in food technology is limited to temperature ranges of 30-35 °C due to its natural feature of providing a thermoreversible structure [12].

In the presented work, we have developed the technology of a new non-traditional product - a flour whipped semi-finished product of biscuit type, in which instead of egg products as a foaming agent, the use of a gelatin solution is proposed. The use of the functional and technological properties of this gelling agent is scientifically justified, as well as the purposeful modification of its structure due to the use of the transglutaminase enzyme will allow to obtain a thermostable foam-like structure that can withstand the heat treatment characteristic of classic biscuit semi-finished products. The developed flour whipped semi-finished product is suggested after baking to be used as a basis for cakes, cookies, cakes, etc.

1.2 Theoretical foundations of foam formation and foam stabilization in protein flour systems

It is known [13] that gelatin is a pure protein obtained from collagen and is sold as a dry, odorless powder. Gelatin with a high level of light color is increasingly used in human food products as a stabilizer, foaming agent, and capsule base, among other purposes. Low-color gelatin may find application as a food binding ingredient in pet food. Researchers [30] experimentally tested and analyzed different strengths of gelatin jelly with a low level of color and ordinary gelatin gels with a high level of color. Processing was carried out on a control sample without gelatin and gelatins with jelly strength of 100, 175 and 250 bloom. The results showed an increased strength of gelatin jelly, an increase in the volume of the product, its expansion, probably due to the effect of foaming. However, the shelf life of medium and high light colored gelatin jelly has decreased. That is, gelatin with a low level of light color may be promising for improving product characteristics and maintaining long-term storage.

The foam-forming and foam-stabilizing properties of gelatin are used in the confectionery industry in the production of extruded, molded and granular whipped products with low density (0.25-1.0 g/cm³) - marshmallows, dough for waffles [14, 15] - to stabilize foaming, fillings for waffles and chocolate bars, chewing candies, whipped jelly candies, nougat, whipped cream [15], in the dairy industry - in the production of ice cream, and is also used independently or in combination with other foaming agents of a protein nature (milk, egg protein) in restaurant industry in the production of ready-made aerated sweet dishes - mousses, sambuks, soufflés, creams [15], jelly milk desserts, dessert creams, whipped cream, including low-calorie. Separately, gelatin derivatives should be highlighted - instant gelatins (soluble in cold water), which find their purpose in foamy desserts, in particular, quick-cooking (dry mixes) - creams, mousses, as well as gelatin hydrolyzates, which do not form gels due to their low molecular weight, but show good foaming properties and are used in the dairy industry to promote whipping and obtaining light creamy texture with more volume. These products have a wide range of textures, ingredients, solids content and degree of aeration [17].

Technological requirements should also be taken into account. For example, if extruded marshmallows are to be produced using a continuous process, rapid structuring is required after whipping to stabilize the foam. In this case, you should use gelatin with a very high Bloom strength - 240-280 (high-Bloom) at a concentration of 3...5%. In the case of the production of molded marshmallows, the mass after whipping must be able to flow on the punching machine. In this case, rapid gelation is not required, as the product is subject to further drying. For this process, gelatin with medium - 160-200 (medium-Bloom) and high - 200-240 (high-Bloom) strength in Blooms in a concentration of 4...6% is suitable [14-17].

A review of foreign and domestic literary sources has established that a lot of attention has been paid to the study of the foaming properties of gelatin, as well as the influence of other protein substances, sugars, pH, etc. on them. As evidenced by data analysis, the attention of scientists is focused on the study of the influence of certain technological factors (type of source, its type, concentration, ratio of components) on the foaming properties of pure solutions of gelatin [12-14], in combination with other foaming agents of a protein nature [15], polysaccharides [16,17,18], their compositions, as well as simple sugars and sugar substitutes.

The author [17] considered the relationship between surface tension and foaming of solutions based on egg albumin, soy protein, casein, whey protein, and gelatin. It was found that the surface tension of protein solutions did not correlate with the foaming ability, but the rate constant of the decay of the surface tension of protein solutions had a good correlation with the foamability of the protein solution.

Researchers [19] determined the influence of the type of gelatin (from bovine skin – type B and from pig skin – type A) and its concentration on the foaming ability of their solutions and foam stability. It was determined that the maximum values of the investigated indicators were obtained at a gelatin concentration of 3%, while for gelatin from bovine skin they were slightly higher - 94.67±1.53% than for gelatin from pig skin - 93.00±1.00 %. At the above concentration - 4 and 5%, the studied indicators decreased significantly, which, according to the authors, may be due to improper homogenization of the gelatin solution. A similar trend was observed for the foam stability index, which decreased over time.

The work [20] studied the foaming ability of eel skin gelatin solutions at pH 5 and 8, bovine gelatin and the stability of their foam. It was noted that the coefficients of the foaming ability of eel skin gelatin at pH 5 and 8 did not differ significantly and were equal to 2.56 and 2.76, respectively. For bovine gelatin, this indicator was equal to 1.89. The difference in foaming capacity between eel skin and bovine gelatins, according to the authors, is explained by the higher hydrophobic amino acid content of eel skin gelatin, which at pH 8 was also higher than this gelatin at pH 5. The coefficients of foam stability for eel skin gelatin at pH 5 and 8 were 1.02 and 1.16, respectively, and for bovine gelatin - 1.10. Lower foam stability for eel skin gelatin at pH 5, the researchers believe, may be due to a lower percentage of negatively charged amino acids. The higher content of negatively charged amino acids in eel skin gelatin at pH 8 may have prevented charge neutralization in gelatin molecules and additionally increased foam stability.

Research [21] describes the effect of the mixing ratio of biopolymers on the properties of foam based on subcritical water (water with temperatures in the range of +100...+374°C under high pressure to maintain it in a liquid state) with the addition of solutions of egg white and gelatin from fish scales. It was determined that the foaming capacity of the egg white and subcritical water system was higher than the system without subcritical water, although the first one had lower foam stability. At the same time, it was established that the foaming ability of the system based on egg white and subcritical water was additionally increased when gelatin from fish scales was added due to a decrease in surface tension. Gelatin contributed to the creation of an interfacial viscoelastic system at the air-water interface with increased surface dilatational rheological behavior, causing a low level of liquid separation and inhibition of bubble coalescence in the system. In addition, changes in surface elasticity corresponded to an increase in foam stability with increasing concentration of fish gelatin. The above studies made it possible to obtain a protein powder with high foaming and stabilizing ability.

In his work V.M. Vetrov [22] scientifically substantiated the expediency of using gelatin in model systems of protein-polysaccharide gelation based on sulfated polysaccharides in a joint complex with modified pea starch to improve the foaming ability by 15...18% in the technologies of whipped semi-finished products of the souffle type [22].

The effect of the concentration of gelatin and xampane on the course of the foaming process and the quality of the resulting foam structures in model systems based on oiler and skimmed milk was determined. It was found that the indicator of foaming ability reached its maximum values at a temperature of 275 K and a concentration in the milk raw material of gelatin in the amount of 1.0...1.5% and xampan in the amount of 0.5...0.7% and was, respectively, 208...224% and 210 ...234%. At the same time, the stability of the foam of the model systems also increased significantly and amounted to 95...98% and 96...99%, respectively [16].

Badruk V.V. [23] investigated the influence of the ratio of low-esterified pectin and kappa-carrageenan in binary mixtures with gelatin on the foaming ability of their solutions. It was established that the greatest value of the foaming ability was observed when the composition ratio of gelatin-low-esterified pectin and gelatin-kappa-carrageenan was 3:1. It was established that the stability of the foam of the studied systems increased with a decrease in pH, which can be explained, according to the author, by an increase in the viscosity of colloidal solutions due to the electrostatic interaction of hydrocolloids.

The author [24] established that a promising direction in the creation of new structures of cream-whipped candy masses, which are formed by the co-extrusion method, is the use of mixtures of hydrocolloids: gelatin, k-carrageenan, LM pectin, taking into account their technological properties. It was established that the greatest foaming ability was observed at a temperature of 65 - 70 °C at the isoelectric point at a 3:1 ratio of gelatin - LM pectin and gelatin - k-carrageenan. It was proved that the greatest foaming capacity was observed when adding 2.2±0.5% of the mixture of gelatin - LM pectin, and the smallest - LM pectin - k-carrageenan.

So, the review of the sources made it possible to identify patterns of influence of individual technological factors on the foaming properties of gelatin solutions. On the basis of the conducted analytical studies, it can be concluded that it is necessary to conduct additional studies and identify new patterns that will allow solving the tasks of developing the proposed whipped baked semi-finished product using gelatin.

Analytical review established that systematic fundamental researches related to establishment of regularities of foaming properties of gelatin in the literature are of different nature. This determines the relevance of the chosen direction.

1.3 Characterization of functional and technological properties of gelatin in composition with xanthan

Xanthan is a widely studied binding agent [25], discovered in 1961. Acetylation and pyruvylation have a large effect on its rheological properties, and the influence of these groups on the conformation and rheological properties of xanthan has been studied for decades. However, these studies mainly rely on chemical modifications, and thus the degree of pyruvylation and acetylation, as well as the regioselectivity of deacetylation, cannot be controlled. Here, we present an in-depth rheological characterization of native xanthan and seven xanthan variants, with defined acetylation and pyruvylation patterns, generated by genetic modification of Xanthomonas campestris LMG 8031. Thus, xanthan variants with defined acetylation and pyruvylation patterns are naturally occurring due to mild production conditions. It was possible to associate the defined schemes of substituents with the corresponding rheological properties, to provide new insights into the structure-function relationship of xanthan variants in salt-free media and in the presence of monovalent and divalent cations.

Xanthan gum[26] is a cold-swelling, high-molecular-weight microbial exo-polysaccharide produced by the fermentation of carbohydrates by the bacterium Xanthomonas campestris followed by precipitation in alcohol, drying, and grinding. The basic structure of xanthan gum is a polymer of D-glucose units with a trisaccharide side chain. This side chain exhibits two mannose units separated by guluronic acid. Xanthan gum dissolves completely in cold water, and the negatively charged carboxyl groups (COO-) on the side chains of the molecule are responsible for the highly viscous liquid obtained upon contact with water. The main function of xanthan gum is to thicken, emulsify and stabilize water-based products. Xanthan is widely used in processed foods because of its unusual and very useful properties. Many of these properties are undoubtedly due to the structural rigidity of its molecules, which, in their in turn, is the result of its linear, cellulosic base, which is strengthened and protected by side chains of trisaccharides. The high degree of pseudoplasticity of the solution provided by the presence of xanthan facilitates the mixing and pumping of liquid/liquid systems, resulting in pure organoleptic properties in the mouth (i.e. no mucilage perception). The greatest use of xanthan is observed in bakery mixtures. In muffins and related mixes, xanthan provides balanced formulation, volume increase and moisture retention. However, using too much xanthan in flour-based systems can result in density, stickiness, graininess, or other undesirable textural changes. Levels of use in dry mixtures, as a rule, are less than 0.1% (weight of the finished composition). No enzymes found in food ingredients or products will degrade xanthan [26].

Researchers found [27] that mixtures of solutions of GB gelatin and XG xanthan gum in the ratio (GB/XG, (0.2-2%)/0.2% wt./vol.) show improved gelatinization properties compared to solutions of their pure components at similar ratios. Mixed gels include co-localized networks of domains rich in GB and XG. It is proved that these domains consist of intermolecular complexes and their aggregates, stabilized by the effect of GB neutralization, and interconnected by the formation of GB triple helices.

Oxidized xanthan gum with different aldehyde content, which is successfully prepared by periodate oxidation, is used as a crosslinking agent for edible gelatin films. X-ray diffraction measurements and atomic force microscopy demonstrate that the degradation is accompanied by an oxidation process that leads to a decrease in crystallinity and a change in structure. The study of optical properties found that all films are very transparent and have excellent barrier properties against ultraviolet light. The introduction of aldehyde groups improves the UV barrier properties, which arise from the increase of CN groups due to the formation of a Schiff base. Property studies show that xanthan gum can dramatically reduce total soluble matter, moisture content, and water permeability, and significantly improve the mechanical properties and heat resistance of gelatin films. With an increase in the oxidation level of oxidized xanthan gum, there is an increase in the water barrier properties, mechanical properties and thermal stability of xanthan films oxidized with xanthan gelatin, which is mainly explained by the covalent bonding of the two polymers [28].

The authors [29] studied the improvement of the quality of gluten-free products made with the help of hydrothermally treated polysaccharide mixtures (HTT-PSM) from glutinous rice flour and the addition of xanthan gum in different concentrations. It was found that HTT-PSM had a lower gelatinization temperature, higher peak viscosity, and weaker gel strength than liquid glutinous rice flour. The inclusion of HTT-PSM in rice dough significantly reduced the time and stability of dough development and increased its extensibility from 2.8 mm to 11.9 mm. The high tensile strength of the dough allowed the production of gluten-free noodles with higher tensile strength and a similar texture profile compared to wheat noodles. Sensory evaluation showed that the overall texture of the gluten-free noodles was acceptable, but not as comparable to wheat noodles. Positive correlations were observed between xanthan gum content and peak viscosity, gel strength, noodle tensile strength, firmness, and chewiness.

Of interest is the study of the authors [30] on the development of composite food films from three different polymers to test crosslinking reactions that improved the quality of films made from two polymer types, to study the effects of adding xanthan gum at different concentrations (0, 5, 10, 15, 20 and 25%, wt/wt.) to gelatin- carboxymethyl cellulose (CMC) films. The physical and mechanical properties of the corresponding films were evaluated. It was established [30] that the addition of xanthan gum increased the thickness, moisture content, and water permeability of the gelatin-CMC film ($p < 0.05$). In addition, protection against ultraviolet (UV) light increased along with decreased visible light transparency ($p < 0.05$) and increased thermal stability (Tg) ($p < 0.05$). The resulting films also exhibited lower tensile strength with reduced elongation at break point, as well as higher puncture force and lower puncture strain, indicating higher puncture resistance than a comparable gelatin-CMC film. Overall, the gelatin-CMC film with xanthan gum (5% w/w solids) exhibited improved physical and mechanical properties more than films prepared from comparable formulations.

It was investigated [31] the effect of moisture moisture content, xanthan gum (XG) addition, and glucose syrup (GS):sucrose ratio on elastic (G ′) and viscous (G ″) moduli during in situ gelation and on large deformation rheological properties of cured gels. The increase in both moduli of the samples with the addition of XG indicates a strengthening of the network structure. All gels samples had clear destruction. Increasing the GS:sucrose ratio resulted in a decrease in fracture stress and an increase in fracture strain, suggesting a more flexible polymer framework network [31]. A decrease in moisture content can lead to phase separation between the high sugar and polymer phases to form a stronger bond in the network structure. The analysis of the textural characteristics of the samples, using the texture map, proved that increasing the ratio of GS: sucrose and adding XG made the texture of the sample more elastic

Aqueous polymer and surfactant systems are important for various industries. The properties of these systems[32], among other things, depend on the interaction between them. The authors [32] conducted a study to determine the interaction between an anionic polymer - xanthan gum and an anionic surfactant - SDS or a nonionic surfactant - Tween 80. The results obtained as a result of a combination of all these methods showed that the interaction of xanthan gum - SDS / Tween 80 exists. Structural changes of xanthan gum molecules in the presence of both surfactants were obtained using viscometry and SEM. Characteristic interaction points (CAC and PSP) were determined by measuring the surface tension and specific conductivity of aqueous solutions of pure surfactants and their mixtures with xanthan gum. PSP values were proportional to polymer concentration. After overcoming the electrostatic repulsion between xanthan gum and CAC, they form complexes by a hydrophobic mechanism and enhance the adsorption of CAC molecules at the water-air interface. Unlike SDS, Tween 80 mainly interacts with xanthan gum primarily through hydrogen bonding and also through hydrophobic interactions. The results of fluorescence measurements further confirmed that the mechanism of interaction between xanthan gum and the investigated surfactants was mainly due to hydrophobic interaction and through the formation of hydrogen bonds with Tween 80 as electrostatic repulsion with SDS.

It is known [33] that the study of patterns of foaming processes and foam stability is a scientific basis for the development of well-founded recommendations on the optimal composition of various foaming compositions. The author[33] proved that at the same viscosity of foaming solutions with the addition of polymers, the foam containing xanthan has the highest stability. It was found that with an increase in the concentration of xanthan, the foam's resistance to gravitational syneresis and film rupture increases, which is associated with the formation of a thixotropic structure in foam channels and films, as well as in relation to the diffusion transfer of gas (Ostwald ripening).

The pasteurization process leads to undesirable effects on the foaming properties and stability of liquid egg white. Persian gum (PG) as a native hydrocolloid and xanthan gum (XG) were added to liquid egg white [34] to improve the foaming properties of the final solution prior to pasteurization. The increase in egg white viscosity was a natural consequence of the addition of XG and PG. Due to the addition of hydrocolloids to the egg white solution, the flow behavior of the solution changed from Newtonian to pseudoplastic, and therefore, the flow curves fit the power law model. Both hydrocolloids showed a positive effect on foam stability at all levels, but their negative effect on foam overshoot and density was undeniable. It was found [34] that high concentrations of XG and PG (0.1% ≤) resulted in improved foam texture, while XG showed the greatest effect on foam elasticity due to physical interaction with unfolded proteins. Analysis of microscopic images of foam bubbles due to different bulk viscosities of the samples showed a negative effect of excessive beating for some samples, while for some others the beating time was insufficient to reach the maximum gas phase.

The authors [35] investigated the effect of xanthan gum (XG) and hydroxypropyl methylcellulose (HPMC) on the volume of the pie, hardness and sensorial properties of baked biscuit layers. The rheological characteristics, consisting in the flow behavior and viscosity of wheat, were also studied to match the physical properties of biscuit. Dough density and specific gravity were significantly ($p<0.05$) correlated with pomace firmness and volume. Hydrocolloid cakes (both XG and HPMC) had a significantly ($p < 0.05$) lower volume compared to the control cake. The consistency indicator is significantly ($p<0.05$) correlated with hardness (stability index $r = 0.71$), which allows us to determine the texture of the biscuit crust crumbs. It has been proven that a freshly baked cake containing 1% XG has a significantly higher hardness value ($p<0.05$) compared to 1% HPMC and control layers. In addition, the biscuit containing hydrocolloids had a significantly smaller volume ($p <0.05$) compared to the control cake. For the sensory evaluation, the biscuit containing xanthan gum was less attractive to the forum participants compared to the other biscuit formulations, as it had the lowest mean score (6.25) in the overall evaluation.

1.4 Prospects for the use of transglutaminase enzyme in the technology of whipped flour semi-finished product

Transglutaminase (TG) has a unique range of applications due to its technological characteristics, namely, it has a wide range of stability under active pH from 5.0 to 8.0; has high thermal stability in the range of 45...55°C, its inactivation occurs at temperatures of 65°C and above [36].

The transglutaminase enzyme affects proteins exclusively, catalyzing the reaction of the formation of a specific isopeptide bond between the carboxyamide group of glutamine and the amino group of lysine. These bonds can be formed between proteins that differ in type (caseins, myosin, globulins, etc.) and in origin (from soy, wheat gluten, etc.). Transglutaminase forms strong covalent bonds that are difficult to break under conditions of non-enzymatic reactions [37, 38, 39, 40].

Transglutaminase is used in the production of a wide range of food products - meat, fish, bakery, dairy [41]. It is suitable for solving many tasks, can act as an improver of physical properties and structure, reducing the salt content and contribute to the combination of pieces of meat or fish. Considering the reactivity of transglutaminase to effectively interact with various food proteins, its functional properties can be divided into three groups: group 1 - high reactivity of TG with milk (casein) and meat (gelatin) proteins; 2nd group – average reactivity of TG, with proteins of bread crops; Group 3 – reactivity of TG with proteins of serum (α-lactalbumin and β-lactoglobulin), egg (ovalbumin) and meat (myoglobin) [41].

It was established [42] that the transglutaminase enzyme contributes to the formation of cross-links between gluten protein molecules and thus improves the rheological properties of the dough. Effectively complementing other baking enzymes, transglutaminase strengthens the gluten protein and contributes to the formation of optimal dough characteristics. The peculiarity of this enzyme is that the reaction between glutamine and lysine is determined by the temperature and duration of the reaction itself. Transglutaminase can be easily oxidized and inactivated by SH group cysteine. The viscoelastic properties of gluten in the presence of transglutaminase, as well as the sensitivity of the protein to heat treatment, decrease compared to unmodified gluten. These studies contributed to the use of TG for the preparation of noodles and pasta in Japan [43]. Transglutaminase is added to flour, which gives pasta and noodles a firmness that depends on the content of the enzyme.

Foreign authors [44] studied the mechanical properties and morphology of gelatin films containing different levels of physical and chemical bonds obtained by adjusting the relative number of triple helices and covalent bonds catalyzed by transglutaminase due to changes in the drying temperature. The content of the triple helix decreases as a result of increasing the drying temperature above the gelation temperature of gelatin, which was confirmed by research results. Modification of gelatin with the help of transglutaminase led to the creation of films with increased mechanical properties, water resistance and thermal stability regardless of the drying temperature. In addition, stronger and more compact structures of film-forming solutions and films were observed with increasing drying temperature, indicating a higher level of crosslinking.

Scientists [45] stated that the textural properties of gelatin foams are highly valued by chefs around the world, but such gels and foams cannot be used in culinary products that must be served hot, because gelatin melts at a temperature of 30 to 40°C. At the same time, using the enzymatic modification of gelatin with the help of transglutaminase, gels and foams made from gelatin can be made thermostable. According to the results, foams and gels made from gelatin and treated with transglutaminase are stable at 80°C for a certain time, although the textural properties of such gels must be optimized.

The authors [46] studied the regularities of transglutaminase effect on gelatin, from which gels and foams are obtained. Foam stability at 20°C and 80°C, thermal stability and texture of gels were studied. The content of gelatin and transglutaminase significantly increases the stability of the foam at both temperatures, but the effect of exposure to transglutaminase was more significant. The researchers noted that the modification of foams and gels based on gelatin with the addition of transglutaminase can find practical application in culinary technologies where gelatin must be heated.

The expediency of joint use of flour mixtures, transglutaminase and collagen-containing proteins, to which it has a high reactivity (gelatin, Helios-11, Scanpro T95), is justified [47]. It has been experimentally confirmed that the use of additives-correctors of the structure allows to significantly improve the specific volume of bread, its porosity and taste properties.

Domestic scientists [48] studied the effect of transglutaminase on the rate of structure formation of gelatin solution. Mathematical models describing the change in viscosity over time were obtained. A mathematical model and the process of structure formation at different enzyme-substrate ratios are shown.

The effect of transglutaminase [46, 47, 48] on the rate of structure formation of gelatin solution was studied, mathematical models were obtained that describe the change in viscosity over time, a mathematical model and the process of structure formation at different enzyme-substrate ratios were presented.

The use of biotechnological techniques to obtain products containing protein with specified functional and technological properties is relevant. For this, various methods of protein modification are used, the most effective method is enzymatic modification, which allows changes in the properties of proteins and influences such characteristics as gelation and structural and mechanical properties of gels. Modification of food proteins with transglutaminase leads to obtaining textured products, changes solubility and functional-technological properties, allows to obtain proteins with high nutritional and biological value. The obtained results [48] make it possible to predict changes in the structural and mechanical properties of gelatin gels in the presence of the transglutaminase enzyme. The obtained mathematical equations describe the processes of structure formation and allow to calculate the coefficient of dynamic viscosity - an important technological indicator. Two-factor models make it possible to take into account such factors as the mass fraction of the structure-forming agent (gelatin) and the amount.

Research [49] determined the influence of chickpea protein isolate (CPI) (0–7%), transglutaminase (TG) (0–1.5%) and xanthan gum (0–0.6%) on the rheological characteristics and quality indicators of cupcakes from gluten-free millet using response surface methodology (RSM). The results showed that xanthan increased the specific volume and porosity and decreased the hardness with increasing its concentration, while the addition of CPI and TG at lower levels had a different effect than at higher levels. TG and CPI first decreased specific gravity and then increased. Xanthan increased this property at all tested concentrations. The brown color index of the crust decreased with the addition of xanthan and CPI and increased with the addition of TG.

The effect of the addition of different protein isolates (pea, soy, egg albumin, and whey proteins) on the viscosymmetric and rheological properties of rice flour dough and the development of the protein network using microbial transglutaminase (TG) was evaluated [50]. Protein isolates significantly ($p<0.05$) modified the gelatinization and gelation of rice starch determined in a rapid viscoanalyzer (RVA). Pea, soy and whey proteins significantly ($p < 0.05$) decreased the final viscosity, in addition, whey protein also contributed to a significant decrease (27.3%) in the peak viscosity. Both protein isolates and TG significantly ($p<0.01$) affected the modulus of elasticity (G') recorded in vibration tests. The degree of effect depended on the protein source; peas and soy increased this parameter, while egg white and whey protein decreased it dramatically. Modification of emulsification properties was also observed by addition of protein isolates and the influence of TG.

The decrease in the number of free amino groups after the interaction of TG confirmed the cross-linking of the protein, which was catalyzed by TG [50]. Therefore, the use of protein isolates and TG expands the scope of application of rice flour in the bakery industry and leads to an increase in protein content with further improvement of the nutritional properties of the obtained products.

The conducted studies [51] proved the effectiveness of using the transglutaminase enzyme preparation, mostly in the composition with proteins of animal and plant origin (milk, gelatin, Helios-11, flour of various types), to improve the structural, mechanical and organoleptic characteristics of gluten-free bread. It has been proven that this enzyme is an effective improver of the structure of pasta made from wheat flour. The drying curves of dough made from gluten-free types of flour and their mixtures show that depending on the type of flour raw material and the presence of an enzyme, the moisture-holding capacity of the dough changes significantly. The addition of TG to corn flour inhibits the process of moisture evaporation: during the investigated time interval, the control sample (without TG) loses 46% of the initial moisture content (evaporation rate is 88.4 mg/min). Under the action of the enzyme, the moisture-retaining capacity of corn dough increases - moisture loss is 39-43%, and the rate of evaporation is 75-82.6 mg/min.

Since protein aggregation and the formation of a continuous protein matrix in rye dough is very limited, an enzymatic method of protein aggregation was investigated to improve baking properties [52]. The effect of microbial transglutaminase (TG) on rye dough properties was studied by rheological tests, confocal scanning laser microscopy (CSLM), standard scale baking tests, and crumb texture analysis. The addition of TG in the range of 0–4000 kg/kg of rye flour modified the rheological properties of rye flour dough, leading to a progressive increase in the complex shear modulus and a decrease in the loss ratio due to protein cross-linking or protein aggregation [52]. Analysis of CLSM images illustrated a TG-induced increase in the size of rye protein complexes. Standard baking tests showed a positive effect on loaf volume and crumb texture of rye bread with TG applied to 500 kg of rye flour. A higher level of TG (500 U ≤ TG ≤ 4000 U) adversely affected the volume of bread. An increase in the concentration of TG led to an increase in springiness and hardness of the crumb. In conclusion, the results of this work demonstrated that TG can be used to improve rye dough baking by creating a continuous protein network [52].

1.5 Study of the synergism of the action of structural elements in flour mixtures with the addition of gelatin

Structured and restructuring food products are gaining more and more popularity every year. The implementation of scientific principles of enzymatic modification of the properties of gelatin, as well as its combination with structure-forming agents of another nature, will allow creating a class of fundamentally new food products that imitate traditional food products (structured substitutes for meat raw materials, simulated lard, restructured analogs of vegetable and fruit and berry raw materials, candied fruits , snack products, fish roe, etc.), to create new non-traditional types of food products (whipped frozen / baked semi-finished products such as biscuit, hot jelly, etc.), as well as to provide traditional food products (thermostable fillings, dessert products with a jelly-like structure, etc.) of new consumer properties and reduce its cost.

A promising direction in the production technology of various types of restructured products is the process of enzymatic cross-linking of macromolecules, which can be successfully implemented both on protein and carbohydrate substrates [53]. This process can occur with the participation of aromatic groups present in proteins and carbohydrates or with the participation of a number of amino acids that are part of the protein. The most studied method of enzymatic restructuring of fish and meat raw materials is the use of transglutaminase. It is advisable to use gelatin as a gelling agent due to its high ability to create isopeptide bonds due to the catalytic effect of transglutaminase. It was established that the strength of "standard" gelatin gels varies according to a linear law depending on the mass fraction of the transglutaminase enzyme introduced into the system in the range of its concentrations up to 1%. The amount of penetration of the obtained gels is inversely proportional to the amount of the injected enzyme preparation [53].

The authors of [54] studied the mechanical properties and morphology of gelatin films containing different levels of physical and chemical networks obtained by adjusting the relative number of triple helices and covalent bonds catalyzed by TG by changing the drying temperature. It was established [54] that the addition of TG inhibits the formation of the triple helix. Gelatin films modified with TG showed stronger mechanical properties than without TG, and the highest tensile strength was observed in films dried close to the gelation temperature (25°C) and the highest elongation at break above it (35°C). Gelatin modification with TG led to the formation of films with increased mechanical properties, water resistance and thermal stability regardless of the drying temperature due to a decrease in solubility in water and an increase in the glass transition temperature. In addition, with increasing drying temperature, stronger and more compact network structures of film-forming solutions and films were observed, which indicated a high degree of crosslinking due to the synergistic interaction of TG with gelatin.

It was established [55] that aqueous mixtures of gelatin and xanthan gum (GB / XG, (0.2-2%)/0.2%w/v) exhibit increased gelation properties compared to their pure solutions of the components in similar compositions. Mixed gels contain co-localized networks of GB- and XG-rich domains. It has been proved that these domains consist of intermolecular complexes and their aggregates, stabilized by the GB neutralization effect, and interconnected by the formation of GB triple helices. An increase in the molecular weight of GB risks network formation and leads to an increase in the elastic modulus (G), while an increase in the molecular weight of XG causes the opposite effect due to diffusion limitation [55].

Studies of the gelling properties of gelatin-xanthan resins with a high level of common dissolved substances have established [56] the influence of moisture content by adding xanthan gum (XG) and a mixture of glucose syrup (GS) and sucrose on the modulus of elasticity (G') and the modulus of viscosity (G'') during gelation. The increase in both modules confirms the strengthening of the framework structure of the network with the addition of XG. Increasing the ratio of GS:sucrose resulted in a decrease in fracture stress and an increase in fracture strain, implying a more elastic polymer network. A decrease in moisture content can lead to phase separation between sugar-rich and polymer-rich phases, forming stronger bonds in the network structure. Textural characteristics of the samples analyzed using the texture map showed that increasing the ratio of GS: sucrose made the texture more elastic than that of the samples containing only XG [56].

Studies of the physical properties of transglutaminase-modified gelatin films [57] by changing the drying temperature found that transglutaminase-modified films exhibited stronger mechanical properties than blank films, and the highest tensile strength was observed in films dried close to the gelation temperature (25°C). and the greatest elongation at break above (35°C). Modification with transglutaminase increased the water resistance and heat resistance of gelatin films due to a decrease in solubility in water, an increase in the glass transition temperature and the temperature of degradation, which was further enhanced with an increase in the drying temperature.

One of the ways to improve the functionality of proteins in various food matrices is to apply the influence of various enzymes [58]. This study aimed to investigate the effect of transglutaminase-catalyzed cross-linking and neutrase-catalyzed hydrolysis on the rheological properties of egg, gluten, and soy protein derivatives, as well as on the thermomechanical properties of protein-whole rice flour blends. Studies conducted on 15% protein suspensions showed that the rheological behavior varies significantly depending on the substrate and the type of enzyme treatment. The controlled effect of the enzyme improved not only the consistency, but also the strength of suspensions based on egg and soy proteins. Moreover, the values of the modulus of elasticity and viscosity G``, G`, as well as the threshold values of the flow after treatment with enzymes, increased significantly. On the other hand, during the study of the effect of enzymes on the rheological substance, a lower viscosity and stability of the behavior of the gluten suspension was observed [58].

Studies of dough rheological characteristics and shelf life for the development of oat bread technology with improved texture and shelf life have established [59] the effect of transglutaminase (TG) on these characteristics. It was proved that the addition of TG increased the water absorption in the range of 34.80-38.45% and the peak resistance (696.40 - 840.30 FU), but reduced the softness of the dough (93.20 - 67.75 FU), since its level varied from 0.5 to 1.5 g. The storage modulus of oat dough increased slightly due to the addition of transglutaminase in the range of 180.37 - 202.78 kPa [59]. The enzyme contributed to a decrease in the loss modulus of 65.95 - 62.87 kPa of oat dough and an increase in the thermal properties of oat dough. Due to the introduction of transglutaminase into the recipe, the denaturation temperature was increased by 6.53 - 8.33 °C. Physical and textural analysis of oat bread showed that the addition of transglutaminase affected bread crumb parameters, reducing elasticity by 6.47 - 4.14 mm, specific volume by 1.61 - 1.54 ml/g increasing the hardness in the range of 537.85 - 692.41 H.

The conducted studies on the effect of the enzyme transglutaminase in the presence of gelatin on the properties of the protein substances of raw flour have established the non-additive binding of hydrogen ions and hydroxyl ions by the proteins of gluten-free flour [60]. This confirms the interaction between proteins of different origin. The largest differences between theoretical and experimental studies were noted with a decrease in pH towards the acidic side. This is consistent with the known data on the interaction between the amino acids lysine and glutamic acid, which are capable of binding H+ and OH- ions, respectively. This can be explained by the fact that the number of free residues of these amino acids decreases as a result of their active interaction with the addition of the TG enzyme, so it was experimentally established that the number of bound ions is smaller than in the absence of such interaction. The addition of gelatin together with the TG enzyme enhances these trends. It was established [60] that the degree and rate of aggregation of gluten proteins increased with the addition of the enzyme transglutaminase (directly proportional to the amount of the enzyme) and animal protein gelatin (to the greatest extent – when used together with the enzyme).

It has been proven [60] that the use of these additives in the investigated concentration range strengthens gluten. The high efficiency of the enzyme is due to the effective combination of plant flour proteins with animal protein gelatin. These results agree with the findings of researchers [61] regarding the ability of transglutaminase to actively interact with animal proteins and proteins of wheat flour.

The results that were obtained during analytical studies allow us to predict positive changes in the structural and mechanical properties of gelatin gels in the presence of the enzyme transglutaminase in the technology of semi-finished products of whipped flour. It has been proven that the nature of these processes is influenced by the mass fraction of the structure-forming agent (gelatin) and the amount of the enzyme preparation (structure-forming catalyst).

CHAPTER 2. SCIENTIFIC JUSTIFICATION OF THE TECHNOLOGICAL PARAMETERS OF OBTAINING THE WHIPPED FLOUR SEMI-FINISHED PRODUCT

2.1 Justification of the choice of recipe components of the whipped flour semi-finished product using gelatin in the composition with xanthan and the enzyme tranglutaminase

2.1.1 Development of a model of an innovative strategy for the technology of the whipped flour semi-finished product using gelatin and the enzyme transglutaminase

A systematic approach to the problem is one of the most effective ways to solve development tasks, technology improvement processes, and the development of fundamentally new types of products. To obtain the final product with the planned level of quality and expected technological parameters, it is optimal to justify and determine within each subsystem. Also, the practical application of technology modeling is used in the planning of technological processes, the design of certain areas, production shops of the complete technological process within the system [131, 130, 131].

It is important to note that there are practically no whipped flour semi-finished products for confectionery products using gelatin as a foaming component. In our opinion, the main problem for the introduction of this product, manufactured by an industrial method, is the lack of scientific basis for its production.

We carried out modeling of the technological production system in order to establish the possibility of regulation and optimization of the parameters of the technological process, to determine the interrelated parameters of production with quality indicators of semi-finished products of the baked biscuit type without egg products. To simplify the complexity of real technological processes, modeling is used, which allows to detail and specify them. This is a theoretical method that makes it possible to outline a plan and solve technological tasks in the most economical way, to minimize making erroneous decisions regarding real technological systems.

Taking into account the above prerequisites, we developed a model of an innovative strategy (Fig. 2.1) and a model of the recipe composition of food foam-like systems with thermostable properties. (Fig. 2.2) [131, 132, 133].

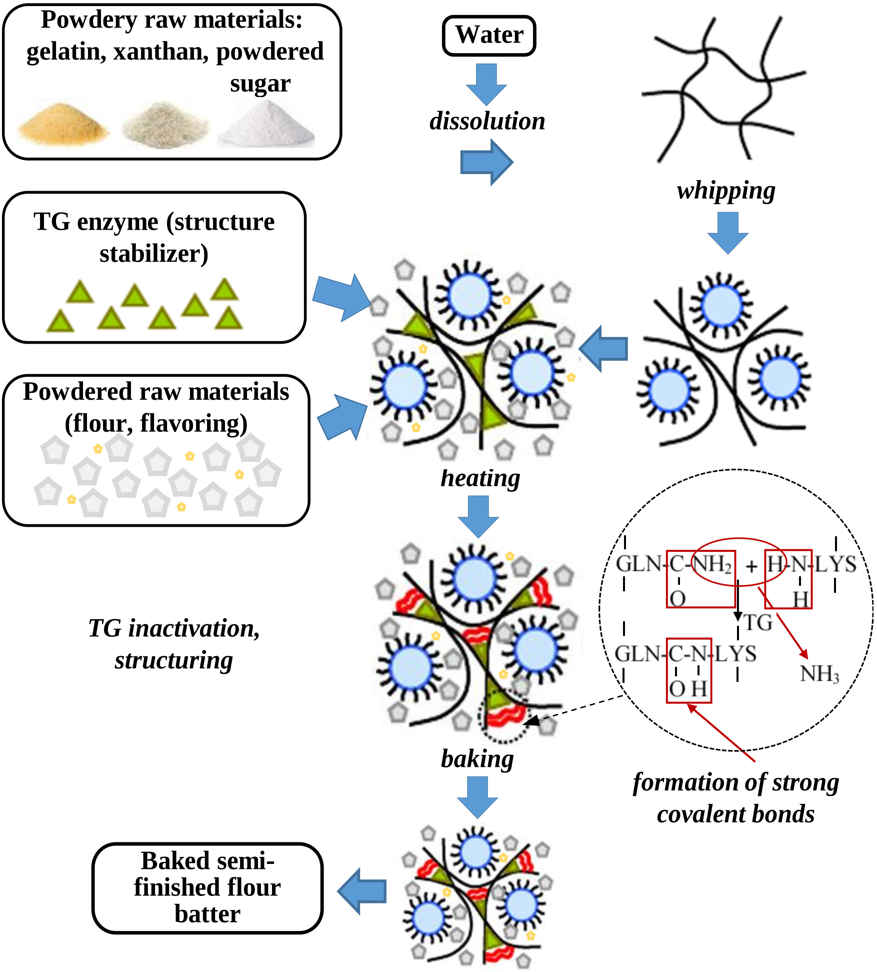


Fig. 2.1. Model of the innovation strategy of the technology of whipped flour semi-finished product using gelatin and transglutaminase enzyme

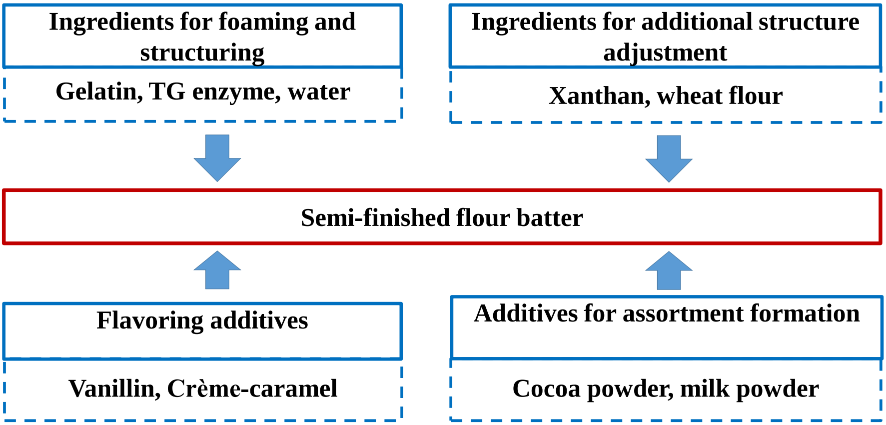


Fig. 2.2. Model of the composition of the whipped flour semi-finished product using gelatin and transglutaminase enzyme

Despite the fact that modeling is the main method of researching technological systems, it is still a theoretical method of research. Therefore, the next stages aimed at the implementation of the innovative strategy model of the technology of the whipped flour semi-finished product were to conduct a number of experimental studies to confirm or refute it.

So, we offer a model of an innovative strategy of the technology of obtaining a model of the composition of a whipped flour semi-finished product without egg products, which makes it possible to determine the recipe composition and technology of new products in general.

On the basis of the working hypothesis, we developed a model of the technological system (Fig. 2.3) for obtaining a whipped flour semi-finished product.

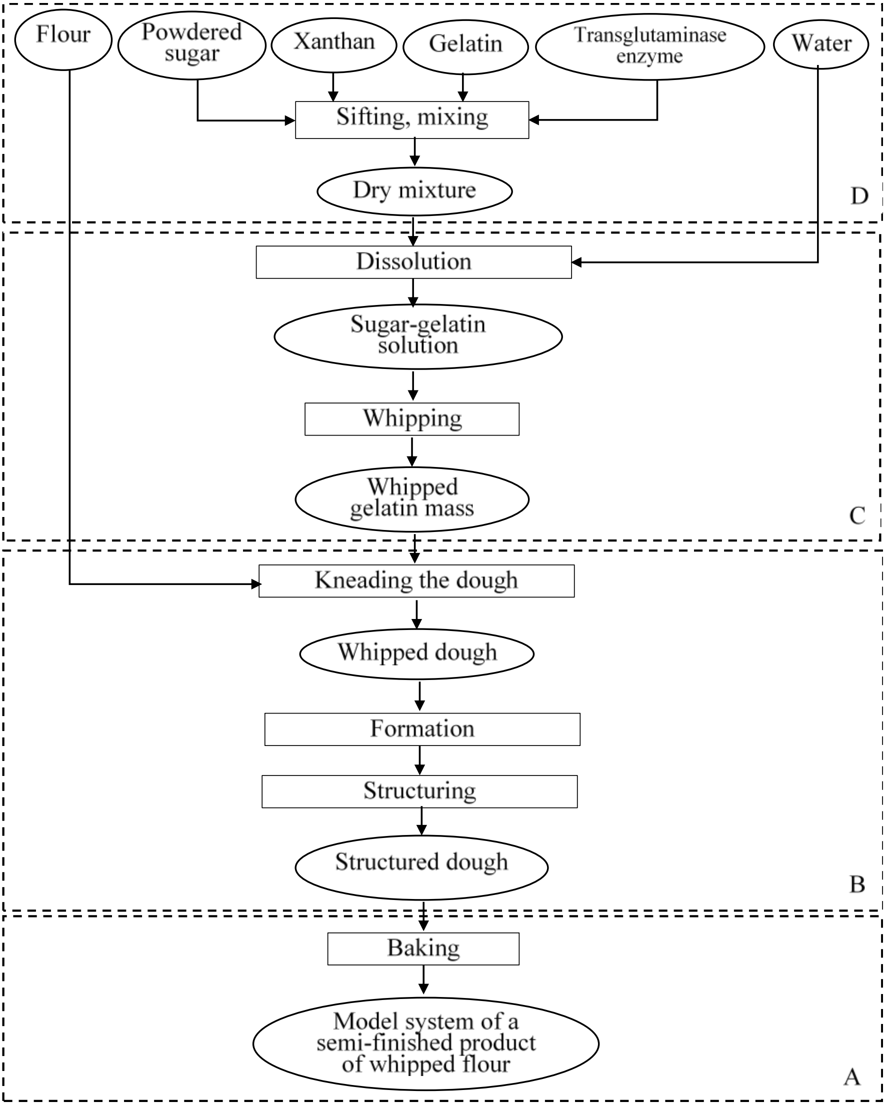


Fig. 2.3. A model of the technological system for obtaining a whipped flour semi-finished product

The analysis of the model of the technological system established that the key stages of obtaining whipped flour semi-finished product with appropriate technological characteristics are the justification of the concentrations and the method of introduction of recipe components to obtain a dry mixture (subsystem D), the preparation of a sugar-gelatin solution with adjustable technological properties and the preparation of a whipped gelatin mass (subsystem C), kneading the dough and obtaining a structured dough blank (subsystem B), formation and stabilization of the structure of the whipped flour semi-finished product (subsystem A).

2.1.2 Study of the influence of concentrations of recipe components and temperature on the viscosity of model systems

Viscosity is an important technological property for dough, as it plays the role of a structural-mechanical barrier during the formation and destruction of a foam-like structure, determines its stability. If the viscosity is not high enough, the formation of air bubbles in the volume of the dough during its beating occurs quickly and with low energy consumption, however, the films of the dispersion medium are easily destroyed by excessive air pressure. Rheological characteristics are closely dependent on the internal structure of the substance [12-14, 19-22].

Viscosity, thermal reversibility, structure, stability of dispersed solutions of hydrocolloids depends on their type and concentration, temperature and time of solidification, pH level of the environment, presence and concentration of additives. To achieve the required level of viscosity, the concentration of most polysaccharides ranges from 0.1 to 3%. When using finely dispersed powders (particle size of about 100 μm), gel and jelly formation takes place in 20...40 minutes (for most polysaccharides). For hydration and swelling of large particles of a number of polysaccharides (200-300 μm), exposure for about 1 hour is necessary. It should be borne in mind that the speed of particle swelling depends significantly on the intensity of mixing and the temperature at which this system is located [134, 135, 136].

To eliminate or reduce the effect of film formation and clumping of hydrocolloids during dissolution, it is necessary to use high-speed mixing equipment and pre-mix the samples with other loose recipe components (sugar, citric acid, etc.), which allows you to increase the distance between particles and prevent their agglomeration [137].

The implementation of scientific principles of enzymatic modification of the properties of gelatin, as well as its combination with structure formers of a different nature will allow the creation of a class of semi-finished food products with fundamentally new functional properties [138,139].

To establish a rational concentration of the main recipe components of the whipped flour semi-finished product: gelatin, xanthan, transglutaminase enzyme, powdered sugar, the dynamic viscosity of the solutions was studied (Fig. 2.4 - 2.6) [27, 28, 30, 31, 50].

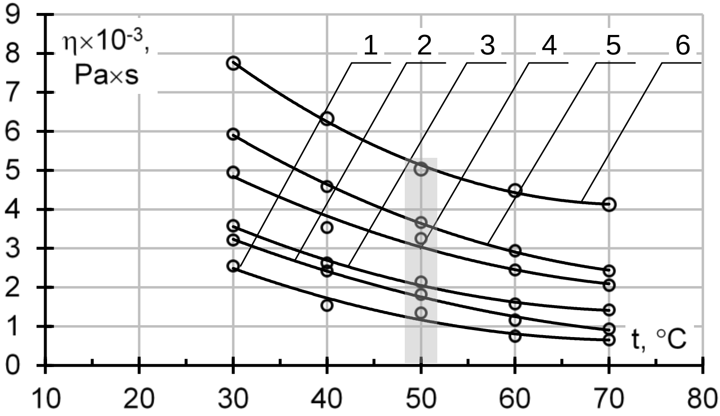


Fig. 2.4. Effect of temperature on the dynamic viscosity of gelatin solution at a concentration of 3.0%; in the composition with xanthan, %: 1–0.1; 2–0.15; 3–0.2; 4–0.25; 5–0.3; 6–0.35

It was established that when adding xanthan at a concentration higher than 0.3±0.05%, the viscosity of the gelatin-xanthan composition increases 1.5 times, probably due to the synergistic interaction of xanthan with gelatin and the redistribution of associated and unassociated hydroxyl groups, which contributes to the formation of a significant amount intermolecular hydrogen bonds.

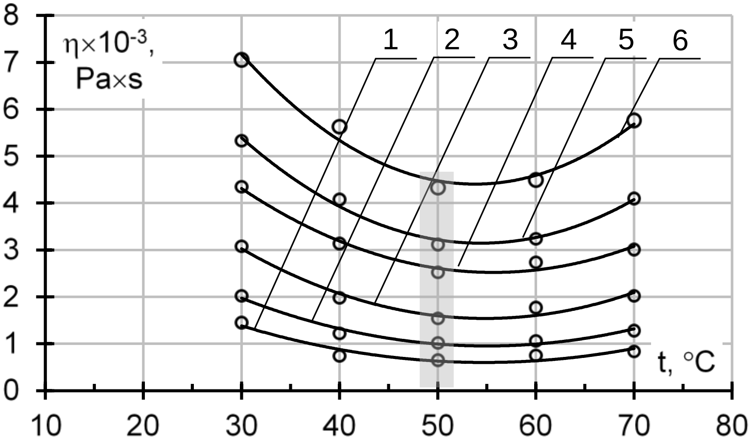


Fig. 2.5. The effect of temperature on the dynamic viscosity of the gelatin-xanthan system at a gelatin concentration of 3.0%; xanthan 0.25; in the presence of transglutaminase enzyme, %:1–0.05; 2–0.06; 3–0.07; 4–0.08; 5–0.09; 6–0.1

It has been proven (Fig. 2.5) that an increase in the content of the enzyme transglutaminase by more than 0.09±0.01% leads to an increase in the speed of crosslinking of the structure and will lead to a too rapid increase in strength, which will complicate the mixing process. When the content of transglutaminase is reduced to less than 0.05%, the finished product does not acquire the necessary structure.

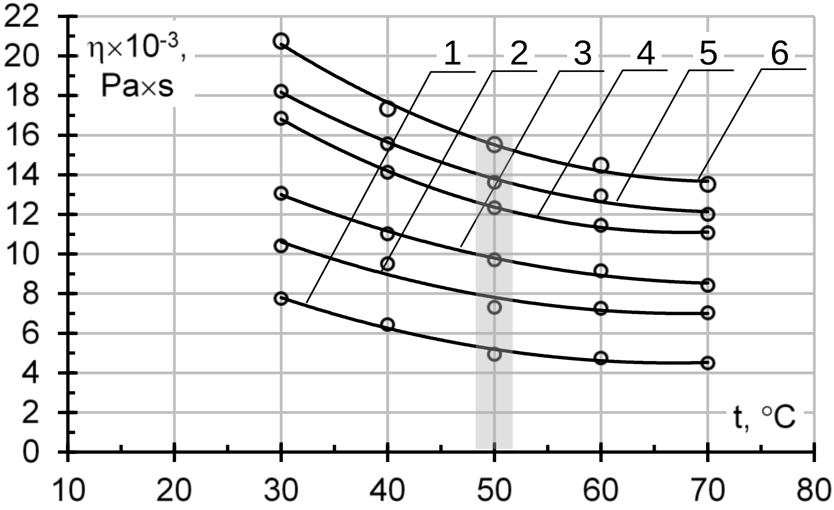


Fig. 2.6. The effect of temperature on the dynamic viscosity of the gelatin-xanthan system at a gelatin concentration of 3.0%; xanthan 0.25; in the composition with powdered sugar,%: 1–26.0; 2–27.0; 3–28.0; 4–29.0; 5–30.0; 6–31.0

It was found that when adding powdered sugar less than 27.7±1.3% or more than 32±1.3%, the desired stable fine structure of the dispersed dough mass system will not be formed. Increasing the content of powdered sugar leads to a significant increase in viscosity and the appearance of an overly sweet taste.

To confirm the rational concentration of the main recipe components of the whipped flour semi-finished, which are involved in the processes of foaming and structuring, a study of the dynamic viscosity (Fig. 2.7) of solutions of the recipe components was carried out at the following concentrations:

gelatin - 3.0±0.2%, xanthan - 0 ,2±0.01%, transglutaminase - 0.08±0.01%, and polyelectrolyte complexes: gelatin + xanthan + transglutaminase, gelatin + xanthan, gelatin + xanthan + powdered sugar, gelatin + xanthan + powdered sugar + transglutaminase, in in the temperature range of 30...70 °C.

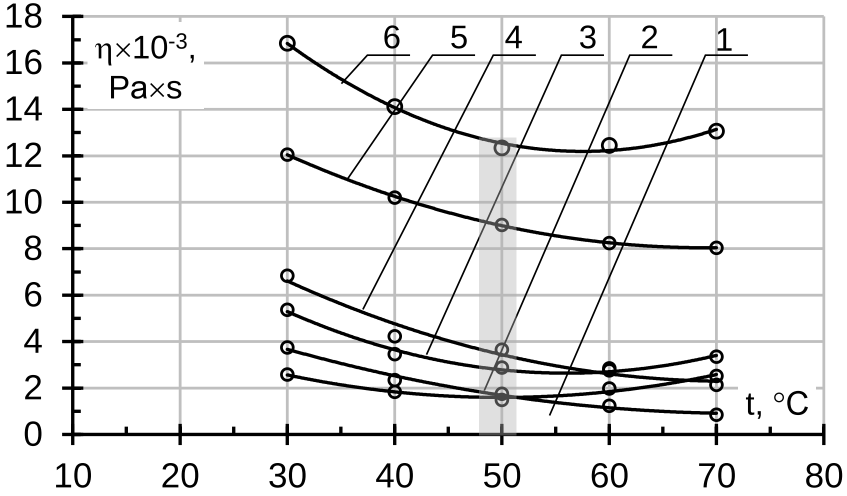


Fig. 2.7. The influence of temperature on the dynamic viscosity of recipe components: 1- gelatin; 2-xanthan; and polyelectrolyte complexes: 3-gelatin + xanthan + transglutaminase; 4-gelatin+xanthan; 5-gelatin+xanthan+sugar powder; 6-gelatin + xanthan + powdered sugar + transglutaminase

It was established that increasing the temperature in the range of 30...70 °C reduces the dynamic viscosity of the gelatin solution by 3.5±0.2 Pa·s, the addition of xanthan increases the dynamic viscosity by 3.2±0.2 Pa·s by at a temperature of 30 °C, adding sugar by 8.4±0.2 Pa·s, adding transglutaminase enzyme to a sugar-gelatin solution in the presence of xanthan at a temperature of 30°C increases the dynamic viscosity by 4.8±0.2 Pa·s. At a temperature of 50.0±2.0°C, the dynamic viscosity of the gelatin+xanthan+sugar powder+transglutaminase system is 12.34 $\pm 10^{-3}$ Pa·s (Table 2.1).

Table 2.1

Dynamic viscosity of the components of the whipped flour semi-finished product at temperature 50°C

Composition of research samples	Dynamic viscosity ($\eta \times 10^3$), Pa·s
Gelatin	1.76
Xanthan	2.50
Gelatin + xanthan	3.66
Transglutaminase	1.49
Gelatin + xanthan + transglutaminase	2.88
Gelatin + xanthan + powdered sugar	9.03
Gelatin + xanthan + powdered sugar + transglutaminase	12.34

If less than 2.5% gelatin is added, the dough will not increase in volume. When more than 3.0% gelatin is added, the structure of the semi-finished product will be too elastic, which will complicate further processing of whipped semi-finished products.

The introduction of xanthan gum less than 0.1% will not affect the structural properties of the dough mass, with the introduction of xanthan gum in the amount of 0.3%, the density of the dough mass increases significantly.

A decrease in the content of powdered sugar to less than 27.7±1.3% leads to a decrease in the amount of dry substances and a deterioration in the taste properties of the finished products.

Thus, an increase in the content of the transglutaminase enzyme above 0.1% leads to an increase in the speed of crosslinking of the structure and will lead to a too rapid increase in strength, which will complicate the mixing process. When the content of transglutaminase is reduced to less than 0.05%, the finished product does not acquire the necessary structure.

In our opinion, the addition of xanthan to the gelatin solution contributes to the increase in viscosity, probably due to the synergistic interaction of xanthan with gelatin, which leads to the redistribution of associated and non-associated hydroxyl groups and contributes to the formation of a significant number of intermolecular hydrogen bonds.

The catalytic effect of the enzyme transglutaminase (Fig. 2.7) on the interaction of amino groups of lysine with the γ-carboxyamide group of glutamine residues linked by a peptide bond in the system of a sugar-gelatin solution in the presence of xanthan was confirmed. This effect provides a higher level of crosslinking of macromolecules of the protein framework and a significant increase in viscosity.

Therefore, the increase in viscosity of the model systems due to the influence of xanthan and TG enzyme occurs due to the binding of free moisture, which will provide increased structural viscosity and mechanical strength of the film on the surface of the bubbles of the foam structure.

The feasibility of using the gelatin-xanthan system in the presence of the transglutaminase enzyme for the production of whipped flour semi-finished is substantiated.

2.1.3 Viscosity modeling

The main task of the mathematical planning of the experiment is to obtain a statistical model of the object in the form of a polynomial (regression equation), which will allow evaluating the effect of factors x_i that affect the viscosity of the model system of the whipped semi-finished. In order to eliminate the correlation between the regression coefficients and the difficulty in estimating the estimated values of the response function, coded values of the factors were used [88, 89, 90]:

$$X_i = \frac{\overline{X}_i - \overline{X}_{i0}}{\varepsilon_i} \tag{2.1}$$

where x_i - natural value of the i-th factor;

x_{i0} - the natural value of the factor is at the zero level;

ε_i – the value of the factor variation interval.

Factor variation levels and variable code designations are given in Table 2.2.

Table 2.2

Factor variation levels and their coding

Factor			Factor variation levels			Variation interval	Calculation factor
Name	Marking						
	natural	code	+1	0	-1		
Content of glutaminase enzyme m_{gl}	X_1	x_1	0,09	0,07	0,05	0,02	$x_1 = \frac{m_{gl} - 0{,}07}{0{,}02}$
Gelatin contentm_g	X_2	x_2	3,0	2,0	1,0	1,0	$x_2 = \frac{m_g - 2{,}0}{1}$
Xanthan contentm_x	X_3	x_3	0,2	0,15	0,1	0,05	$x_3 = \frac{m_x - 0{,}15}{0{,}05}$

When conducting one-factor experiments, it was established that, depending on the studied parameters, the viscosity of the model systems of whipped semi-finished product varies along a parabolic curve. This means that the factor space is described by a regression equation in the form of a second degree polynomial, which has the following form:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3.$$

To obtain the second-order regression equation, an analysis of the choice of the method of mathematical planning of the experiment was carried out, as a result of which it was proposed to implement a non-composite plan according to the Box-Behnken method [89].

The total number of studies according to the Box-Behnken plan for K=3 is:

$$N_{total} = N + N_0 = 12 + 3 = 15,$$

where N_0 – the number of studies in the center of the plan.

To describe the mathematical model of viscosity unevenness, a second-order matrix was constructed according to the selected Box-Behnken method (Table 2.3).

Table 2.3

Matrix of the Box-Behnken plan

№	No. of the experiment	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	$\overline{y}$
1	2	3	4	5	6	7	8	9	10	11	12
1	14	1	1	0	1	0	0	1	1	0	3,06
2	9	-1	-1	0	1	0	0	1	1	0	1,28
3	15	1	-1	0	-1	0	0	1	1	0	2,63
4	10	-1	1	0	-1	0	0	1	1	0	1,36
5	3	1	0	1	0	1	0	1	0	1	1,42

End of the table 2.3

1	2	3	4	5	6	7	8	9	10	11	12
6	5	-1	0	-1	0	1	0	1	0	1	1,38
7	2	1	0	-1	0	-1	0	1	0	1	2,14
8	6	-1	0	1	0	-1	0	1	0	1	2,09
9	7	0	1	1	0	0	1	0	1	1	1,54
10	11	0	-1	-1	0	0	1	0	1	1	1,49
11	4	0	1	-1	0	0	-1	0	1	1	1,38
12	12	0	-1	1	0	0	-1	0	1	1	1,32
13	1	0	0	0	0	0	0	0	0	0	1,47
14	13	0	0	0	0	0	0	0	0	0	1,48
15	8	0	0	0	0	0	0	0	0	0	1,46

Verification of all experimental data for homogeneity was calculated according to the Cochrane criterion:

$$G_{\text{estim.}} = \frac{S^2_{u\max}}{\sum_{u=1}^{N} S^2_u} \leq G_{(0{,}05;f_1;f_2)} \qquad (2.3)$$

where $S^2_{u\max}$ – maximum sample variance in N samples;

S^2_u – sample variance in the j-th experiment;

N – the number of experiments;

j – current trial number.

The sample variance in each sample was determined by the formula:

$$S_j^2 = \frac{\sum_{i=1}^{n}\left(y_j - \bar{y}_j\right)^2}{n-1}, \qquad (2.4)$$

the value of the optimization parameter in the j-th experiment and the i-th duplicate;

i – current duplicates number,1,...,n;

n – the number of duplicates of each of the N experiments;

y_j – the sample mean value in the j-th experiment.

The average arithmetic value of the optimization parameter for each line was determined by the formula:

$$\bar{y}_j = \frac{\sum_{i}^{n} y_j}{n}, \quad j = 1,\dots,N. \tag{2.5}$$

experiment according to the planning matrix (Table 2.3), the results of all studies were entered in Table 2.4 according to a randomized scheme.

Table 2.4

Results of implementation of the planning matrix (optimization criterion - viscosity, η (Pa·s))

No. of the experiment	Viscosity η×10^{-3} Pa·s				DispersionS_j^2
	y_1	y_2	y_3	$\bar{y}_j$	
1	2	3	4	5	6
1	3,18	3,02	2,98	3,06	0.0112
2	1,27	1,35	1,22	1,28	0,0043
3	2,59	2,62	2,68	2,63	0,0021
4	1,29	1,3	1,49	1,36	0,0127
5	1,38	1,46	1,42	1,42	0,0016
6	1,27	1,37	1,41	1,35	0,0052
7	2,25	2,01	2,16	2,14	0,0147
8	2,07	1,97	1,91	1,98	0,0065

End of the table 2.4

9	1,58	1,49	1,55	1,54	0,0021
10	1,42	1,57	1,48	1,49	0,0057
11	1,36	1,47	1,31	1,38	0,0067
12	1,35	1,4	1,21	1,32	0,0097
13	1,61	1,75	1,66	1,67	0,0050
14	1,38	1,42	1,58	1,46	0,0112
15	1,48	1,49	1,29	1,42	0,0127

The coefficients of the regression equation were calculated according to the known method [90]. The dispersion of roughness (experimental error) was:S_y^2 =0,0037

Coefficients of the regression equation:

b_0=1,47 b_{13}=-0,3576

b_1=*0,391* b_{23}=0,0825

b_2=0,0775 b_{11}=0,4680

b_3=- *0,0025* b_{22}=0,1412

b_{12}=0,0875 b_{33}=-0,1820

As a result of calculating the coefficients, the regression equation was obtained in the following form:

$$y = 1,47 + 0,3916x_1 + 0,0775x_2 - 0,0025x_3 + 0,0875x_{12} - 0,3576x_{13} + 0,0825x_{23} + 0,4680x_1^2 + 0,1412x_2^2 - 0,1820x_3^2 \quad (2.6\ )$$

Table 2.5

Change in viscosity due to a combination of factors

No. of the experiment	y_1	y_2	y_3	$\bar{y}$	$\sum_{p=1}^{т}(y_{iu}-\bar{y})$	S_u^2 S_u^2
1	2	3	4	5	6	7
1	3,18	3,02	2,98	3,06	3,06	0.0112
2	1,27	1,35	1,22	1,28	1,28	0,0043
3	2,59	2,62	2,68	2,63	2,63	0,0021
4	1,29	1,30	1,49	1,36	1,36	0,0127
5	1,38	1,46	1,42	1,39	1,42	0,0016
6	1,37	1,37	1,41	1,42	1,38	0,0005
7	2,25	2,01	2,16	1,38	2,14	0,0147
8	2,00	2,23	2,05	2,14	2,09	0,0146
9	1,58	1,49	1,55	2,09	1,54	0,0021
10	1,62	1,37	1,48	1,54	1,49	0,0157
11	1,36	1,47	1,31	1,49	1,38	0,0067
12	1,35	1,40	1,21	1,38	1,32	0,0097
13	1,51	1,59	1,52	1,32	1,54	0,0019
14	1,38	1,42	1,58	1,54	1,46	0,0112
15	1,48	1,39	1,39	1,46	1,42	0,0027

The largest of the dispersions in the rows of the plan:$S_{u\max}^2$ =0,0157

The sum of variances: $\sum_{u=1}^{N} S_u^2$ =0,0932

Estimated value of Cochran's criterion:G_{estim} =0,1405

G_{estim} =0,1405 $G_{\text{table}} = 0{,}3346$

Dispersions characterizing errors in determining regression coefficients:

$S^2\{b_0\}$ =0,00124 $S^2\{b_i\}$= 0,00047 $S^2\{\mathrm{bij}\}$ =0,00093
$S^2\{b_{\mathrm{ii}}\}$ =0,00163

Confidence intervals of regression coefficients:

Δb_0 =0,0752 Δb_i =0,046 Δb_{ij} =0,0651
Δb_{ii} =0,0861

Comparison of regression coefficients with confidence intervals:

b_0 =1,47≥Δb_0 =0,0752 b_{13} =-0,3575≥Δb_{ij} =0,0651
b_1 =0,3916≥Δb_i =0,046 b_{23} =0,825 ≥Δb_{ij} =0,1843
b_2 =0,0775≥Δb_i =0,046 b_{11} =0,4680 ≥Δb_{ii} =0,0861
b_3 =-0,0025 ≤Δb_i =0,046 b_{22} =0,1412≥Δb_{ii} =0,0861
b_{12} =0,875≥Δb_{ij} =0,0651 b_{33} =-0,1820≥Δb_{ii} =0,0861

After discarding insignificant coefficients, the regression equation takes the following form:

$y = 1,47 + 0,3916x_1 + 0,0775x_2 + 0,0875x_1x_2 - 0,3576x_1x_3 + 0,0825x_2 x_3 + 0,4680x_1^2 + 0,1412x_2^2 - 0,1820x_3^2$ (2.7)

Checking the adequacy of the regression equation:

$$F_{\mathrm{estim}} = \frac{S^{2}{}_{\text{ад}}}{S_y^2} \le F_{(0,05;f_{\text{ад}}f_y)}$$

Adequacy variance:

$$S_{\mathrm{ad}}^2 = \frac{\sum_{u=1}^{N}(\bar{y}_u - y_u)^2}{N-(k+1)}=0,0373$$

Then

$$F_{estim\,.} = \frac{S_{ad.}^2}{S_y^2} = 0,354 \leq F_{table} = 2,12$$

The equation is adequate with a confidence probability of 95%.

Substituting the coding data of factor values from Table 1 into equation 7, we get:

$$Y1 = 1170m_{г}^2 + 4.38m_{г}m_{ж} + 357.6m_{г}m_{к} - 99.33m_{г} + 0.1412m_{ж}^2 + 1.65m_{ж}m_{к} - 1.04m_{ж} - 72.8m_{к}^2 + 43.57m_{к} + 1.9569$$

The coordinates of the new center were determined, for which equation (2.7) was differentiated and the derivatives were set to zero:

$$\begin{cases} \frac{dy}{dx_1} = 0,3916 + 0,0875x_2 - 0,3576x_3 + 0,936x_1 = 0 \\ \frac{dy}{dx_2} = 0,0775 + 0,0875x_1 + 0,0825x_3 + 0,2824x_2 = \\ 0 \text{ (2.8)} \quad \frac{dy}{dx_3} = -0.0025 - 0,3576x_1 + 0,0825x_2 - \end{cases}$$

$$0,364x_3 = 0$$

After solving the system of equations, the coordinates of point S were obtained

$$x_{1s} = -0{,}3;\ x_{2s} = -0{,}25;\ x_{3s} = 0{,}24.$$

Decoded factor values: mass of glutaminase enzyme $m_{gl} = 0{,}064$ g, gelatin $m_g = 1.75$ g, xanthan $m_x = 0{,}162$ g. By substituting the values of the factors into equation (2.8), we obtained the values of the optimization parameter:

$$Y = 1{,}35\times10^{-3}\ \text{Pa}\cdot\text{s}$$

To ensure the interpretation of the obtained research results, the method of two-dimensional intersections was used when studying the response surface. Construction of two-dimensional intersections of the response function was performed in the following way. Coded values of all factors, except for any one, were substituted into the previously obtained mathematical model (2.8), and first of all, those intersections that have the most practical significance were studied. Next, the center of the response surface was determined in the obtained value of the expression, and the canonical transformation of the second-order model was carried out. After canonical transformation, the type of response surface was determined and graphoanalytical analysis of the obtained expression was carried out.

Construction of the two-dimensional cross section of the first response function was performed by substituting values $x_3=0$ into the equation (2.7).

As a result, we obtained an equation in the form:

$$y=1{,}47+0{,}3916x_1+0{,}0775x_2+0{,}0875x_1x_2+0{,}4680x_1^2+0{,}1412x_2^2 \quad (2.9)$$

To determine the center of the response surface, a system of differential equations was compiled, which are individual derivatives in terms of factors x_1 and x_2:

$$\frac{\partial y}{\partial x_1}=0{,}3916+0{,}0875x_2+0{,}936\,x_1=0$$

$$\frac{\partial y}{\partial x_2}=0{,}0775+0{,}0875x_1+0{,}2824\,x_2=0$$

$$x_{1s}=-0{,}4;$$

$$x_{2s}=-0{,}15.$$

By substituting the values of x_{1s} and x_{2s} into equation (2.9), we obtained the viscosity value in the center of the response surface:

$$Y_s=1{,}38\times10^{-3}\text{ Pas}$$

For the canonical transformation of equation (2.9), its characteristic equation was solved:

B2+pB+q=0;

The natural roots of the characteristic equation (2.9) will be:

$$B_1=0.47,\quad B_2=0.14$$

Then the equation in the canonical form will have the form:

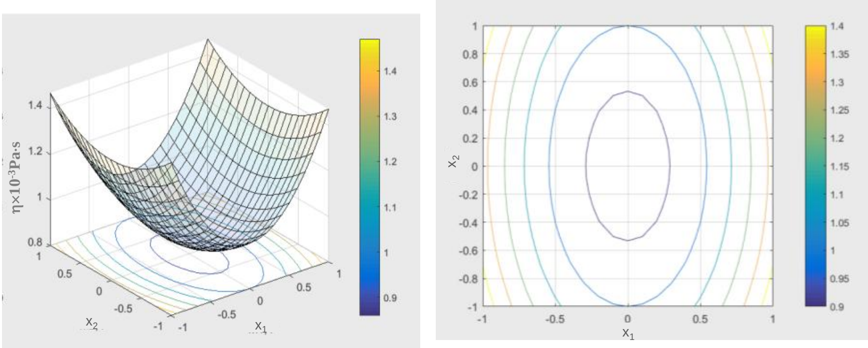
Y-0.86=0.47x¯_1^2+0.14x¯_2^2

The angle of rotation of the new coordinate axes in the center of the response surface was determined from the formula:

$$ctg(2\varphi) = \frac{b_{11} - b_{22}}{2b_{12}}$$

$$\varphi = -7.4^0$$

The response surface has the form of an elliptical paraboloid. Both coefficients B_1 and B_2 have the same signs. The center of the ellipses is a minimum because the coefficients are negative and the ellipses are elongated along the axis.



a b

Fig. 2.8. a - the response surface of the influence of factors X_1 and X_2, b - a two-dimensional section

By substituting the value x_2=0 in equation (2.9), the two-dimensional intersection of the second response function was constructed.

As a result, we obtained equations in the form:

$$Y = 1{,}47 + 0{,}3916x_1 - 0{,}3576x_1x_3 + 0{,}4680x_1^2 - 0{,}1820x_3^2 \quad (2.10)$$

To determine the center of the response surface, a system of differential equations was compiled, which are individual derivatives in terms of factors x_1 and x_3:

$$\begin{cases} \dfrac{\partial y}{\partial x_1} = 0{,}3916 - 0{,}3576x_3 + 0{,}936x_1 = 0 \\ \dfrac{\partial y}{\partial x_2} = -0{,}3576x_1 - 0{,}364x_3 = 0 \\ x_{1s} = 0{,}3; \end{cases}$$

$$x_{3s} = 0{,}29.$$

Substituting the values of x_{1s} and x_{3s} into equation (2.10), we obtained the viscosity value in the center of the response surface equal to:

$$Ys = 1{,}0 \times 10^{-3}\ \mathrm{Pa \cdot s}$$

For the canonical transformation of equation (2.10), its characteristic equation was solved:

$$B^2 + pB + q = 0;$$

The natural roots of the characteristic equation (2.10) will be:

$$B_1 = 0{,}51, \quad B_2 = -0.23$$

Then the equation in the canonical form will have the form:

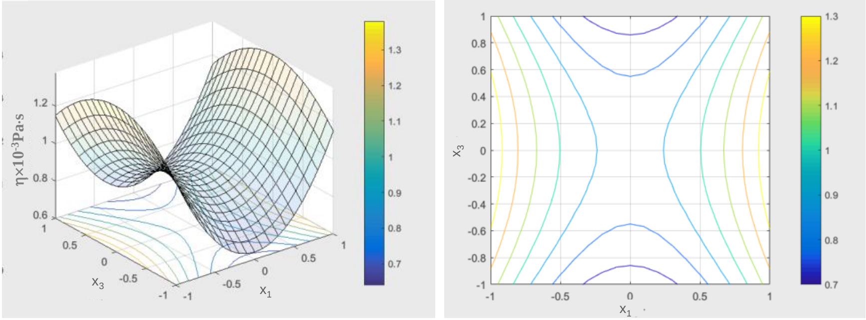
$$Y - 0.87 = 0.51\overline{x}_1^2 - 0.23\overline{x}_3^2$$

The angle of rotation of the new coordinate axes in the center of the response surface was determined from the formula:

$$ctg(2\varphi) = \frac{b_{11} - b_{22}}{2b_{12}}$$

$$\varphi = 14{,}3^0$$

The response surface has the form of a hyperbola. Coefficients B_1 and B_2 have different signs. The center of the surface is the minimax.



a b

Fig. 2.9. a - response surface of the influence of factors X_1 and X_3, b - two-dimensional network

By substituting the value $x_1=0$ in equation (2.7), the two-dimensional intersection of the third response function was constructed.

As a result, we obtained an equation in the form :

$$Y = 1{,}47 + 0{,}0775x_2 + 0{,}0825x_2x_3 + 0{,}1412x_2^2 - 0{,}1820x_3^2 \quad (2.11)$$

To determine the center of the response surface, a system of differential equations was compiled, which are private derivatives with respect to the factors x_2 and x_3:

$$\frac{\partial y}{\partial x_1} = 0{,}0775 + 0{,}0825x_3 + 0{,}2824\, x_2 = 0$$

$$\frac{\partial y}{\partial x_2} = 0{,}0825x_2 - 0{,}364\ x_3 = 0$$

$$x_{2s} = -0{,}26$$

$$x_{3s} = -0{,}06.$$

By substituting the values of x_{2s} and x_{3s} into equation (2.11), we obtained the viscosity value in the center of the response surface, which is:

$$Ys = 1{,}45 \times 10^{-3}\ Pa \cdot s$$

For the canonical transformation of equation (2.11), its characteristic equation was solved:

$$B2 + pB + q = 0;$$

The natural roots of the characteristic equation (2.11) will be:

$$B_1 = 0{,}15, \quad B_2 = -0.19$$

Then the equation in the canonical form will have the form:

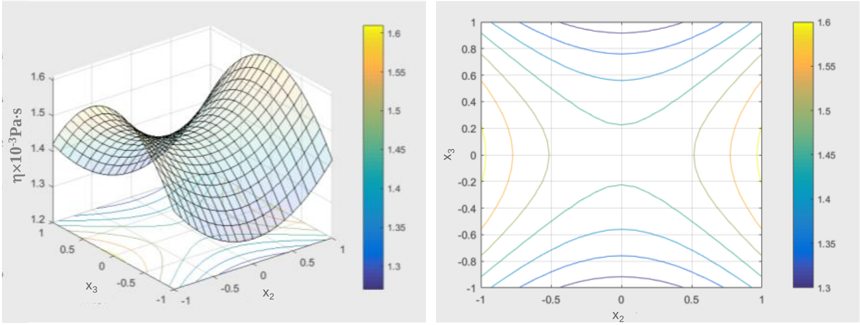
$$Y - 1.46 = 0.15\overline{x}_2^2 - 0.19\overline{x}_3^2$$

The angle of rotation of the new coordinate axes in the center of the response surface was determined by the formula:

$$ctg(2\varphi) = \frac{b_{11} - b_{22}}{2b_{12}}$$

$$\varphi = -7.16^0$$

The contour curves of the response surface have the form of hyperbolas. Coefficients B_1 and B_2 have different signs. The center of the surface is the minimax.



a b

Fig. 2.10. a - response surface of the influence of factors X_2 and X_3, b - two-dimensional section

2.1.4 Study of the influence of the enzyme transglutaminase on the moisture-retaining capacity of the dough of the whipped flour semi-finished product

In the technological process of the production of whipped flour semi-finished products, water is an active participant in many reactions (hydrolysis, hydration, swelling of proteins, whipping, etc.). Free moisture ensures the dissolution of the ingredients of the dry mixture and the formation of a whipped foam-like structure of the gelatin-sugar solution, and the bound water determines the stability and heat resistance of the model system [140].

It is known that biscuit dough belongs to weakly structured systems. That is why in the technology of the whipped flour semi-finished product to ensure the necessary conditions of hydration of the protein during the whipping of the sugar-gelatin solution, structuring of the dough and baking, we used gelatin as the main foaming ingredient, xanthan as an additional thickener of the system and transglutaminase enzyme as a structure stabilizer [141, 142, 143].

Based on the experience of making a whipped flour semi-finished product according to traditional technologies, increasing the proportion of bound moisture in the whipped structured dough prepared for baking was carried out by adjusting the concentration of powdered sugar in the recipe to increase the percentage of dry substances [140].

The presence of a large amount of powdered sugar in the fat-free dough gives the products excessive hardness. Also, the size of the sugar particles has a great influence on the quality of the dough and products. Therefore, to obtain a plastic dough in which the water content is sharply limited, we did not use white sugar, but powdered sugar. This is due to the fact that in a relatively small amount of water, the entire amount of sugar provided by the recipe cannot be completely dissolved, and crystals remain undissolved, which will be visible on the surface of the semi-finished product and will deteriorate its quality [140].

In these studies (Figs. 2.11, 2.12), the goal was set: to obtain quantitative indicators of the moisture-retaining capacity (MRC) of model systems of the whipped flour semi-finished product according to the well-known method of extracting water from the sample by pressing and determining it by mass.

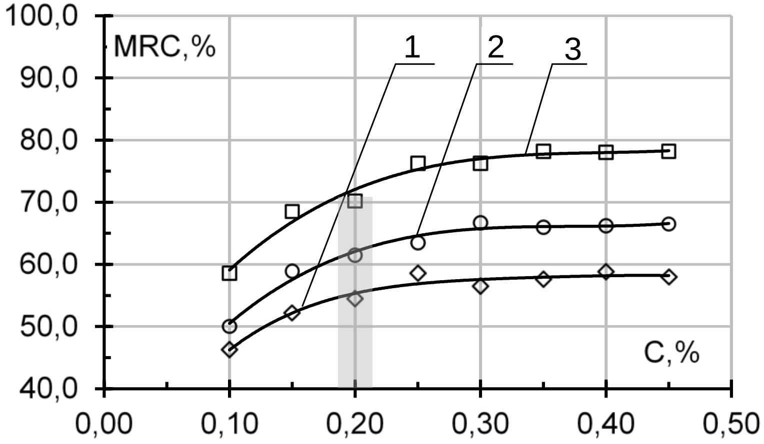


Fig. 2.11. The influence of xanthan concentration on the moisture-retaining capacity of dough of the semi-finished product with 3.0% gelatin before the inactivation of the TG enzyme,%: 1- 0,05; 2- 0,07; 3- 0,09

It was experimentally proven (Fig. 2.11, 2.12) that in order to obtain a dough of the whipped flour semi-finished product with a uniform plastic consistency, to ensure appropriate heat resistance during baking of dough blanks, the use of xanthan and the enzyme transglutaminase is rational and expedient.

It was established that increasing the concentration of xanthan in the recipe of the whipped flour semi-finished product (Fig. 2.12) increases the moisture-retaining capacity of the dough from 9.0±1.0 to 18.0±1.0%. The introduction of TG enzyme in the range of 0.05...0.09% before inactivation (Fig. 2.11) additionally increases the moisture retention capacity of the dough from 6.0±1.0 to 12.0±1.0%. After the inactivation of the

TG enzyme, the moisture-retaining capacity of dough of the whipped flour semi-finished increases by another 5.0±1.0% (Fig. 2.12).

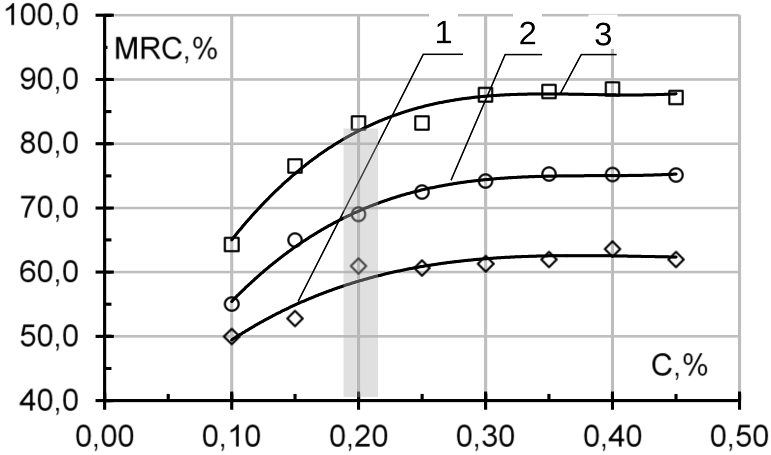


Fig. 2.12. The influence of xanthan concentration on the moisture retention capacity ща dough of the whipped flour semi-finished with 3.0% gelatin after inactivation of the TG enzyme,%: 1- 0,05; 2- 0,07; 3- 0,09

So, as can be seen from the studies (Figs. 2.11, 2.12), under the influence of the TG enzyme, the moisture-retaining capacity of protein substances of dough of the whipped flour semi-finished product significantly increased, especially during inactivation at a temperature of 60±2 °C.

It has been experimentally proven that the ability of the protein substances of dough of the whipped flour semi-finished product to retain moisture under the influence of xanthan at a concentration of 0.2±0.05 under the catalytic influence of the enzyme transglutaminase in the concentration range of 0.05...0.09%. Before the inactivation of the enzyme, the MRC of protein substances increases from 56±2% to 78±2%, and after inactivation - from 62±2% to 88±2%, which is confirmed by a decrease in moisture loss during baking of the dough.

That is, it is possible to predict a decrease in quantitative losses during baking of a whipped flour semi-finished product using xanthan and the enzyme transglutaminase in combination with gelatin as a foaming ingredient.

2.1.5 Modeling of moisture retention capacity

The main task of the mathematical planning of the experiment is to obtain a statistical model of the object in the form of a polynomial (regression equation), which will allow us to evaluate the effect of factors x that affect the moisture-retaining capacity (MRC) of the model systems of whipped semi-finished. In order to eliminate the correlation between the regression coefficients and the difficulty in estimating the estimated values of the response function, coded factor values were used, (formula 1).

Factor variation levels and variable code designations are shown in Table 2.2

When conducting one-factor experiments, it was established that, depending on the studied parameters, the MRC of model systems of whipped semi-finished product varies along an elliptic paraboloid curve, which means that the factor space is described by a regression equation in the form of a second degree polynomial, which has the form (formula 2).

To describe the mathematical model of unevenness of the MRC, a matrix of the second order (Table 2.6) was built according to the selected Box-Behnken method.

Table 2.6

Matrix of the Box-Behnken plan

№	No. of the experiment	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	$\overline{y}$
1	2	3	4	5	6	7	8	9	10	11	12
1	14	1	1	0	1	0	0	1	1	0	0,71
2	9	-1	-1	0	1	0	0	1	1	0	0,73
3	15	1	-1	0	-1	0	0	1	1	0	0,52
4	10	-1	1	0	-1	0	0	1	1	0	0,63
5	3	1	0	1	0	1	0	1	0	1	0,58
6	5	-1	0	-1	0	1	0	1	0	1	0,76
7	2	1	0	-1	0	-1	0	1	0	1	0,78
8	6	-1	0	1	0	-1	0	1	0	1	0,70
9	7	0	1	1	0	0	1	0	1	1	0,60
10	11	0	-1	-1	0	0	1	0	1	1	0,68
11	4	0	1	-1	0	0	-1	0	1	1	0,63
12	12	0	-1	1	0	0	-1	0	1	1	0,52
13	1	0	0	0	0	0	0	0	0	0	0,84
14	13	0	0	0	0	0	0	0	0	0	0,86
15	8	0	0	0	0	0	0	0	0	0	0.89

Reproducibility variance (experimental error): S_y^2 =0,0054

The coefficients of the regression equation were calculated according to the known method [90].

Coefficients of the regression equation:

b_0=0,86
b_1=0,0488
b_2=0,0463
b_3= *-0.05*
b_{12}=-0.02
b_{13}=-0.0475
b_{23}=0.0325
b_{11}=-0.0592
b_{22}=-0.1442
b_{33}=-0,1117

Implementing the experiment according to the planning matrix. After conducting all experiments according to a randomized scheme, the results are entered in Table 2.7.

Table 2.7

Results of implementation of the planning matrix
(optimization criterion – MRC×10^2, %)

No. of the experiment	MRC ×10^2, %				DispersionS_j^2
	y_1	y_2	y_3	$\overline{y}_j$	
1	2	3	4	5	6
1	0,75	0,67	0,71	0,71	0,0016
2	0,75	0,68	0,76	0,73	0,0019
3	0,49	0,56	0,51	0,52	0,0013
4	0,59	0,68	0,62	0,63	0,0021
5	0,55	0,61	0,58	0,58	0,0009
6	0,73	0,80	0,75	0,76	0,0013
7	0,85	0,71	0,78	0,78	0,0049
8	0,77	0,67	0,66	0,70	0,0037
9	0,52	0,65	0,63	0,60	0,0049
10	0,71	0,63	0,70	0,68	0,0019
11	0,68	0,61	0,60	0,63	0,0019
12	0,47	0,58	0,51	0,52	0,0031
13	0,85	0,83	0,84	0,84	0,0001
14	0,84	0,89	0,85	0,86	0,0007
15	0,92	0,84	0,91	0,89	0,0019

As a result of calculating the coefficients, the regression equation was obtained in the following form:

$$y = 0{,}86 - 0{,}0288x_1 + 0{,}015x_2 - 0{,}0563x_3 - 0{,}0725x_1x_2 - 0{,}035x_1x_3 + 0{,}0325x_2x_3 - 0{,}0592x_1^2 - 0{,}1567x_2^2 - 0{,}0992x_3^2 \quad (12)$$

Table 2.8

Changes in MRC due to a combination of factors

No. of the experiment	y_1	y_2	y_3	$\overline{y}$	$\sum_{p=1}^{т}(y_{iu} - \overline{y})$	S_u^2
1	2	3	4	5	6	7
1	0,75	0,67	0,71	0,71	0,0032	0,0016
2	0,75	0,68	0,76	0,73	0,0038	0,0019
3	0,49	0,56	0,51	0,52	0,0026	0,0013
4	0,59	0,68	0,62	0,63	0,0042	0,0021
5	0,55	0,61	0,58	0,58	0,0018	0,0009
6	0,73	0,80	0,75	0,76	0,0026	0,0013
7	0,85	0,71	0,78	0,78	0,0098	0,0049
8	0,77	0,67	0,66	0,70	0,0074	0,0037
9	0,52	0,65	0,63	0,60	0,0098	0,0322
10	0,71	0,63	0,70	0,68	0,0038	0,0019
11	0,68	0,61	0,60	0,63	0,0038	0,0019
12	0,47	0,58	0,51	0,52	0,0062	0,0031
13	0,85	0,83	0,84	0,84	0,0002	0,0001
14	0,84	0,89	0,85	0,86	0,0014	0,0007
15	0,92	0,84	0,91	0,89	0,0038	0,0019

The largest of the dispersions in the rows of the plan: $S_{u\max}^2 =$0,0322

The sum of variances: $\sum_{u=1}^{N} S_u^2 =$0,0322

Estimated value of Cochran's criterion (3):

$$G_{\text{estim.}} = 0{,}1522$$

$$G_{\text{estim.}} = 0{,}1522 \quad G_{\text{table}} = 0{,}3346$$

Dispersions characterizing errors in determining regression coefficients:

$S^2\{b_0\} =$0,00124 $S^2\{b_i\} =$ 0,00047 $S^2\{\text{bij}\} =$0,00093

$S^2\{b_{\text{ii}}\} =$0,00163

Confidence intervals of regression coefficients:

$\Delta b_0 =$0,0752 $\Delta b_i =$0,046 $\Delta b_{\text{ij}} =$0,0651

$\Delta b_{\text{ii}} =$0,0861

Regression coefficients with confidence intervals were compared:

$b_0 =$0.86 $\geq \Delta b_0 =$0,0297 $b_{13} =$0,0325 $\geq \Delta b_{\text{ij}} =$0,0257

$b_1 =$-0,0288 $\geq \Delta b_i =$0,0182 $b_{23} =$0,0325 $\geq \Delta b_{\text{ij}} =$0,0257

$b_2 =$0,015 $\geq \Delta b_i =$0,0182 $b_{11} =$-0,0592 $\geq \Delta b_{\text{ii}} =$0,034

$b_3 =$-0,0563 $\leq \Delta b_i =$0,0182 $b_{22} =$-0,1567 $\geq \Delta b_{\text{ii}} =$0,034

$b_{12}=$0,0725 $\geq \Delta b_{\text{ij}}=$0,0257 $b_{33}=$-0,0992

$\geq \Delta b_{\text{ii}}=$0,034

After discarding insignificant coefficients, the regression equation takes the form:

$$y = 0{,}86 - 0{,}0288x_1 - 0{,}0563x_3 - 0{,}0725x_1x_2 - 0{,}035x_1x_3 + 0{,}0325x_2x_3 - 0{,}0592x_1^2 - 0{,}1567x_2^2 - 0{,}0992x_3^2 \quad (13)$$

Regression equations were tested for adequacy:

$$F_{\text{estim.}} = \frac{S^{2}\text{ad.}}{S_y^2} \leq F_{(0{,}05;f_{\text{ад}}f_y)}$$

Adequacy variance

$$S_{\text{ad.}}^2 = \frac{\sum_{u=1}^{N}(\bar{y}_u - y_u)^2}{N-(k+1)} = 0{,}0006$$

$$F_{estim\,.} = \frac{S_{ad\,.}^2}{S_y^2} = 1{,}0 \leq F_{table} = 2{,}12$$

The regression equation is adequate with a confidence probability of 95%.

By substituting the values of the coded values of the factors from Table 2.2 into equation 13, we obtained:

$$y = 0{,}86 - 0{,}0288 * \left(\frac{x1-0{,}07}{0{,}02}\right) - 0{,}0563 * \left(\frac{x3-0{,}15}{0{,}05}\right) - 0{,}0725 * \left(\frac{x1-0{,}07}{0{,}02}\right) * \left(\frac{x2-2{,}0}{1}\right) - 0{,}035 *$$

$$\left(\frac{x1-0{,}07}{0{,}02}\right)*\left(\frac{x3-0{,}15}{0{,}05}\right)+0{,}0325*\left(\frac{x2-2{,}0}{1}\right)*\left(\frac{x3-0{,}15}{0{,}05}\right)-$$
$$0{,}0592*\left(\frac{x1-0{,}07}{0{,}02}\right)*\left(\frac{x1-0{,}07}{0{,}02}\right)-0{,}1567*\left(\frac{x2-2{,}0}{1}\right)*$$
$$\left(\frac{x2-2{,}0}{1}\right)-0{,}0992*\left(\frac{x3-0{,}15}{0{,}05}\right)*\left(\frac{x3-0{,}15}{0{,}05}\right)=-1.8+11.93m_{\text{к}}-$$
$$148m_{\text{г}}^2-3.625m_{\text{г}}m_{\text{ж}}-35m_{\text{г}}m_{\text{к}}+31.8*m_{\text{г}}-$$
$$0.157m_{\text{ж}}^2+0.65m_{\text{ж}}m_{\text{к}}+0.78m_{\text{ж}}-39.68m_{\text{к}}^2$$

(14)

The coordinates of the new center were determined. For which equation (13) was differentiated and the derivatives equaled to zero:

$$Y=0{,}86+0{,}0463x_2-0{,}05x_3-0{,}0475x_1x_3+0{,}0325x_2x_3-0{,}0592x_1^2-0{,}1442x_2^2-0{,}1117x_3^2$$

$$\begin{cases}\dfrac{dy}{dx_1}=-0{,}0475x_3-0{,}1184x_1=0\\ \dfrac{dy}{dx_2}=0{,}0463+0{,}0325x_3-0{,}2884x_2=0\\ \dfrac{dy}{dx_3}=-0{,}05-0{,}0475x_1+0{,}0325x_2-0{,}2234x_3=0\end{cases} \qquad (15)$$

After solving the system of equations, the coordinates of point S were obtained

$$x_{1s}=0{,}08;\ x_{2s}=0{,}14;\ x_{3s}=-0{,}22.$$

Decoded factor values: mass of transglutaminase enzyme m_{tg} =0,0716 г, gelatinm_g =2,14 г, xanthan m_x=0,139 г. By substituting the values of the factors into equation (14), the values of the optimization parameter were obtained:

$Y=-1.8+11.93*0{,}139-1480{,}0716*0{,}0716-3.625*0{,}0716*2{,}14-35*0{,}0716*0{,}139+31.8*0{,}0716-0.157*2{,}14*2{,}14+0.65*2{,}14*0{,}139+0.78*2{,}14-39.68*0{,}139*0{,}139=0.85$

After substituting the values of x_{1S} and x_{2S} in equation (13), we obtained the values of the optimization criterion in the new center: $Y_s = 0.86$.

By substituting the value x_3=0 into equation (13), the two-dimensional intersection of the response function was constructed

As a result of these actions, the equation in the following form was obtained:

$$y = 0{,}86 + 0{,}0463x_2 - 0{,}0592x_1^2 - 0{,}1442x_2^2 \qquad (16)$$

To determine the center of the response surface, a system of differential equations was compiled, which are individual derivatives in terms of factors x_1 and x_2:

$$\frac{\partial y}{\partial x_1} = -0.1184x_1 = 0$$

$$\frac{\partial y}{\partial x_2} = 0.0463 - 0.2884x_2 = 0$$

$$x_{1s} = 0;$$

$$x_{2s} = 0.16.$$

By substituting the values of x_{1s} and x_{2s} into equation (16), we obtained the value of the MRC in the center of the response surface, which is:

$$Ys = 0{,}87\times10^2, \%$$

For the canonical transformation of equation (16), its characteristic equation was solved:

$$B^2 + pb + q = 0;$$

The natural roots of the characteristic equation (16) will be:

$$B_1 = -0.0592, \quad B_2 = -0.1442$$

Then the equation in the canonical form will have the form:

$$Y-0.86=-0.0592\overline{x}_1^2 - 0.1442\overline{x}_2^2$$

The angle of rotation of the new coordinate axes in the center of the response surface was determined from the formula:

$$ctg(2\varphi) = \frac{b_{11} - b_{22}}{2b_{12}}$$

The response surface (Fig. 2.13) is an elliptical paraboloid. Both coefficients B_1 and B_2 have the same signs. The center of the ellipses is a maximum, because the coefficients are negative and the ellipses are stretched along the x_2 axis.

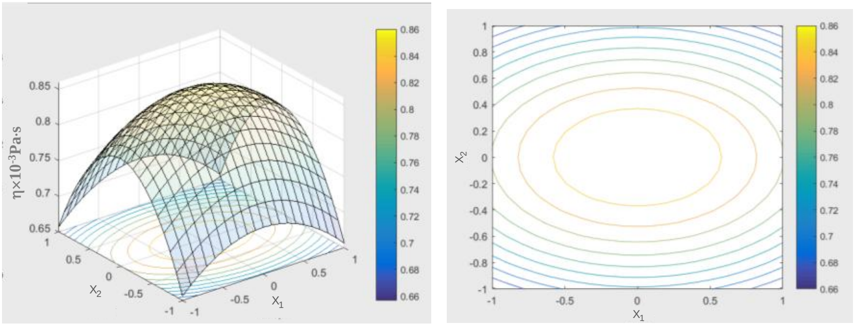


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Fig. 2.13. a – the response surface of the influence of factors X_1

and X_2, b – a two-dimensional section

By substituting the value $x_2=0$ into equation (13), the two-dimensional intersection of the response function was constructed

As a result, we obtained equations in the following form:

$$Y = 0{,}86 - 0{,}05x_3 - 0{,}0475x_1x_3 - 0{,}0592x_1^2 - 0{,}1117x_3^2 \quad (17)$$

To determine the center of the response surface, a system of differential equations was compiled, which are individual derivatives in terms of factors x_1 and x_3:

$$\frac{\partial y}{\partial x_1} = -0{,}0475x_3 - 0.1184x_1^2 = 0$$

$$\frac{\partial y}{\partial x_2} = -0{,}05 - 0{,}0475x_1 - 0.2234x_3^2 = 0$$

$$x_{1s} = 0{,}098;$$

$$x_{3s} = -0{,}24.$$

By substituting the values of x_{1s} and x_{3s} into equation (17), we obtained the value of the VUZ in the center of the response surface, which is:

$$Ys = 0{,}87\times10^{-2}, \%$$

For the canonical transformation of equation (17), its characteristic equation was solved:

$$B^2 + pb + q = 0;$$

The natural roots of the characteristic equation (17) will be:

$$B_1 = -0.05, \quad B_2 = -0.12$$

The equation in canonical form will have the form:

$$Y\text{-}0.87=-0.05\overline{x}_1^2-0.12\overline{x}_3^2$$

The angle of rotation of the new coordinate axes in the center of the response surface was determined from the formula:

$$cot(2\varphi)=\frac{b_{11}-b_{22}}{2b_{12}}$$

$$\varphi=21{,}2^0$$

The response surface (Fig. 2.14) is an elliptical paraboloid. Both coefficients B_1 and B_2 have the same signs. The center of the ellipses is a maximum, because the coefficients are negative and the ellipses are stretched along the x_3 axis

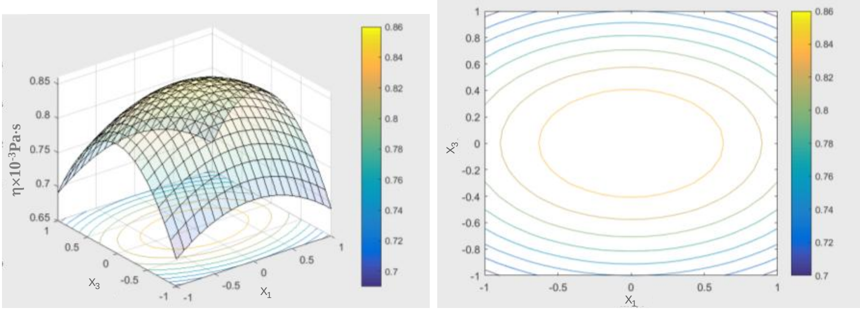

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Fig. 2.14. a – the response surface of the influence of factors X_1 and X_3, b – a two-dimensional section

By substituting the value x_1=0 into equation (13), the two-dimensional intersection of the response function was constructed

As a result, we obtained equations in the following form:

$$Y=0{,}86-0{,}0563x_3+0{,}0325x_2x_3-0{,}1567x_2^2-0{,}0992x_3^2 \quad 18)$$

To determine the center of the response surface, a system of differential equations was compiled, which are individual derivatives in terms of factors x_2 and x_3:

$$\frac{\partial y}{\partial x_1} = 0{,}0325x_3 - 0.3134x_2=0$$

$$\frac{\partial y}{\partial x_2} = -0{,}0563 + 0{,}0325x_2 - 0{,}1984x_3^2=0$$

$$x_{2s} = -0.03;$$

$$x_{3s} = -0{,}29.$$

By substituting the values of x_{2s} and x_{3s} into equation (18), we obtained the value of the MRC in the center of the response surface, which is:

$$Ys = 0{,}87\times10^{-2},\ \%$$

For the canonical transformation of equation (18), its characteristic equation was solved:

$$B^2 + pb + q = 0;$$

The natural roots of the characteristic equation (18) will be:

$$B_1 = -0.09,\quad B_2 = -0.16$$

The equation in canonical form will have the form:

$$Y-0.87=-0.09\overline{x}_2^2 - 0.16\overline{x}_3^2$$

The angle of rotation of the new coordinate axes in the center of the response surface was determined from the formula:

$$ctg(2\varphi) = \frac{b_{11} - b_{22}}{2b_{12}}$$

$$\varphi=14{,}9^0$$

The response surface (Fig. 2.15) is an elliptical paraboloid. Both coefficients B_1 and B_2 have the same signs. The center of the ellipses is a maximum, because the coefficients are negative and the ellipses are stretched along the x_3 axis.

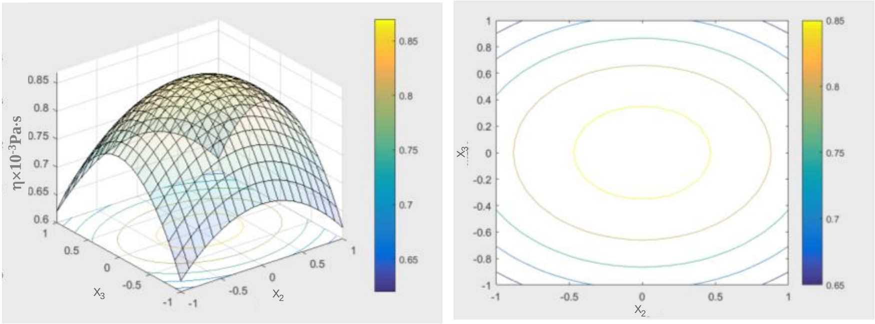

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Fig. 2.15. a – the response surface of the influence of factors X_2 and X_3, b – a two-dimensional section

2.1.6 Study of the catalytic effect of the transglutaminase enzyme in the gelatin-xanthan composition in the recipe of the whipped flour semi-finished product

The solution to the scientific problem of creating product technologies using gelatin and xanthan is based on a comprehensive approach based on the theoretical and experimental justification of the use of hydrocolloids of various nature, which made it possible to predict the production of food products of different textures with high quality characteristics. The essence of the approach is to study the interactions of hydrocolloids of different nature, chemical composition and molecular weight, which are used as stabilizers and structure formers in multicomponent food systems [144].

In order to clarify the mechanism of formation of gelatin-xanthan polyelectrolyte complexes, the interaction of gelatin and xanthan at the molecular level was studied using IR spectroscopy, and the influence of recipe components was studied [145, 146]. A qualitative study of the composition and structural organization of model systems based on gelatin was carried out using infrared spectroscopy on a Fourier spectrometer Perkin-Elmer Spectrum One FTIR Spectrometer by the crushed drop method. Samples were recorded in a thin film between zincum selenide plates.

Gelatin biopolymer – a product of collagen protein destruction – has positively and negatively charged groups as part of the macromolecule. Positively charged groups are free amino groups of lysine residues. The negative charge of gelatin is due to the residues of glutamic Glu and aspartic Asp acids, the number of which per 1000 amino acid residues of polyampholyte from various natural sources is 69 – 72 and 47 – 48, respectively [147-153].

The main absorption bands for gelatin are: a broad band with a maximum at frequencies 3400 cm^{-1} (Amide band A, ν_{N-H}– valence vibrations of –NH group), characteristic absorption at frequencies 1654 cm^{-1}(Amide I, $\nu_{C=O}$– valence vibrations of C=O group), 1541 cm^{-1} (Amide band II, frequency components of deformation oscillations N–H and valence vibrations CN) i 1240 cm^{-1} (Amide band III, frequency components δ_{N-H}– of deformation vibrations N–H and ν_{CN}– valence vibrations CN). Additionally, frequencies are also noted for proteins 620 cm^{-1} (Amide band IV, $\delta_{O=C-N}$– deformation vibrations O=C–N), 750 cm^{-1} (Amide band V, δ_{N-H}– deformation vibrations N–H). It is known that the Amide I band is the most informative as an analytical band for characterizing the secondary structure of protein (gelatin) during the analysis of IR spectral data. The absorption bands of the characteristic groups of gelatin are presented in Table. 2.9 [147-153].

Table. 2.9

Frequency positions (cm^{-1}) of the main bands of the absorption IR spectra of functional groups of gelatin

Functional group	Wave number, cm^{-1}
Amide A (N–H)	3370–3320
Amide I (C=O)	1680–1650
Amide II (N–H, CN)	1550–1485
Amide III (N–H, CN)	1240

In the IR spectrum of xanthan gum (Table 2.10), according to research data [147-153], there are intense absorption bands of valence vibrations of –OH bonds in the region of 3613–3236 cm^{-1}, scillations of adsorption bound water at

3500–3200 cm^{-1} with a maximum at 3360–3355 cm $^{-1}$, bands of average intensity of valence vibrations of –CH– i –CH_2– bonds at 2926, 2903 cm^{-1} respectively, intense bands of vibrations of ionized carboxyl groups –COO^- at 1729 cm^{-1} ether groups -C-O-C- at 1060 cm^{-1}.

Table 2.10

Frequency positions (cm^{-1}) of the main bands of the absorption IR spectra of functional groups of xanthan

Functional group	Wave number, см$^{-1}$	Source
1	2	3
–OH (valence vibrations)	3613–3236, 3386	[1–4], [3]
H_2O adsorption bound	3500–3200 (maximum: 3360–3355)	[1–4]
–CH– i –CH_2– (valence vibrations)	2926, 2903	[1–4]
–COO^-	1729	[1–4]
–COOH pectin substances –C=O –COOH	1650–1500 1630–1627 1535–1529	[4] [3] [3]
Glucuronic acid ("fingerprints")	1416, 1331, 1240	[5]
–CH$(OR)_2$–	1167–1160	[3]
–C–O–C–	1060	[1–4]

–OH bound	1200–700 (maximum: 1026)	[4]
Pectin substances ("fingerprints")	1200–850	[5]

According to the results of the research, the assignment of the bands of the IR spectra and the identification of the functional groups of the test substances of the samples of colloidal solutions gelatin, gelatin+xanthan, gelatin+xanthan+powdered sugar were obtained (Fig. 2.16).

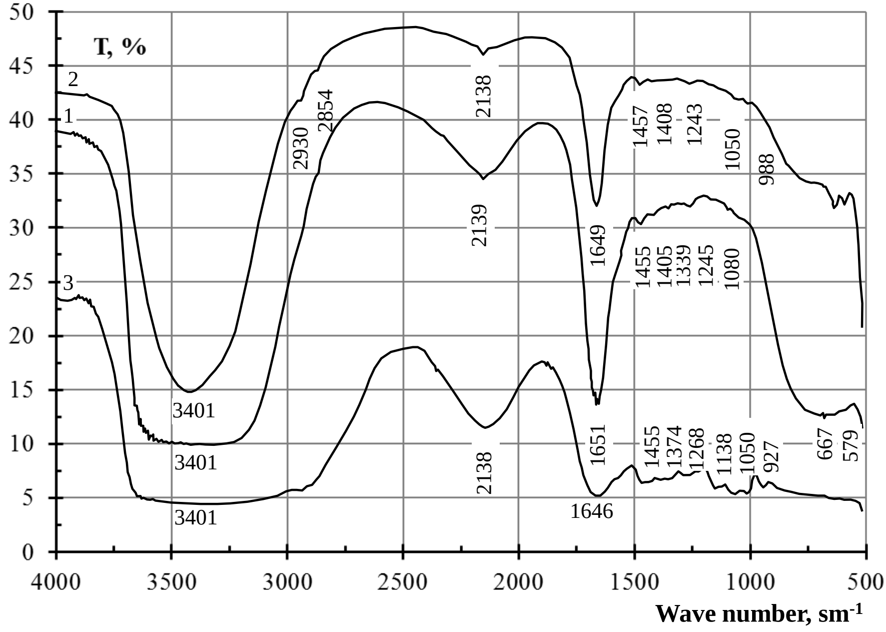


Fig. 2.16. IR absorption spectra of samples: 1 – gelatin; 2 – gelatin+xanthan; 3 – gelatin+xanthan+powdered sugar

The IR spectrum of the gelatin solution (Fig. 2.16, sample 1) shows features characteristic of gelatin: a broad blurred band at frequencies of 3600–3100 cm $^{-1}$, complicated by overlapping bands ($\nu_{N–H}$ of associated groups $–NH_2$, $\nu_{O–H}$ of associated groups –OH of gelatin hydroxyproline, $\nu_{–OH}$, scillations of adsorption bound water), absorption of Amide I ($\nu_{C=O}$) and Amide III ($\delta_{N–H}$, ν_{CN}) at frequencies of 1651 cm^{-1} i 1245 cm^{-1} respectively. In the range of 1550–1485 cm^{-1} at frequencies of 1537 cm^{-1}, 1491 cm^{-1} a weak Amide II band is observed II ($\delta_{N–H}$ of secondary amides, ν_{CN}, δ_{NH3+} amino acids containing amino groups $–NH_2$, n particular lysine), caused by the interaction of ν_{CN} and $\nu_{C=O}$ vibrations.

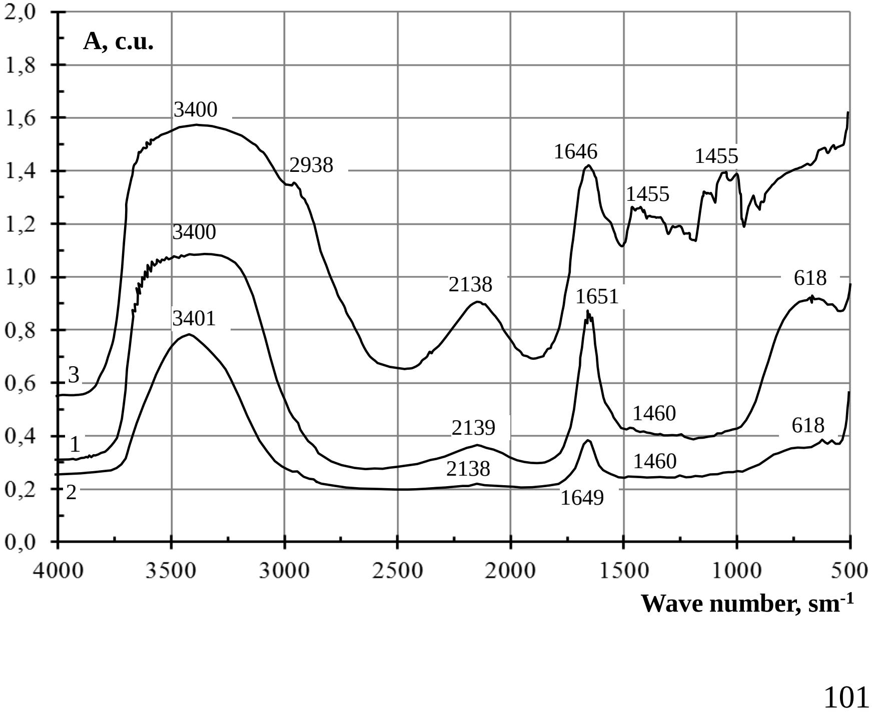


Fig. 2.17. Comparison of intensity of IR absorption bands of samples: 1 – gelatin; 2 – gelatin+xanthan; 3 – gelatin+xanthan+ powdered sugar

In the range of 800–500 cm^{-1} an absorption band is observed, caused by deformation out-of-plane fan vibrations of the N–H group, deformation vibrations of the O=C–N group. The marked band has a low-frequency shift to 667 cm^{-1} relative to the characteristic band of Amide V (750 cm^{-1}) and a high-frequency shift – relative to Amide IV (620 cm^{-1}). The spectrum of the gelatin+xanthan sample (Fig. 2.16, 2.17, sample 2) shows the following absorption bands are characteristic of gelatin and xanthan: a broad intense band with a maximum at 3401 cm^{-1}, bands of valence vibrations of –CH– i –CH_2– bonds at 2930, 2854 cm^{-1} respectively.

In the spectrum of the sample gelatin+xanthan (Fig. 2.16, 2.17 sample 2), the profile of the band of valence vibrations of N–H groups and there is a noticeable narrowing of the band in the region of high frequencies with the appearance of a distinct maximum at 3401 cm^{-1} compared to gelatin at 3400 cm^{-1} (Fig. 2.16, 2.17 sample 1). This is due to a certain increase in the number of O–H groups as a result of the introduction of xanthan and redistribution of associated and non-associated groups.

At the same time, a wide absorption band is observed for gelatin and gelatin+xanthan samples (Fig. 2.16, 2.17 sample 1, 2) in the region of 2600–1900 cm^{-1} with a maximum at 2139 and 2138 cm^{-1}, respectively. It is characteristic of valence vibrations of associated hydroxyl groups and is caused by the formation of a significant number of intermolecular hydrogen bonds. The absorption band of the gelatin+xanthan sample has a lower intensity, which indicates a lower number of hydrogen bonds formed compared to the gelatin sample. Compared to the spectrum of water (2150 cm^{-1}), the maxima of the absorption bands of the samples shift toward lower wave numbers to 2138 cm^{-1}, 2139 cm^{-1}, the intensity of the band increases, as well as the intensity of its deformation component (V_{δ}–1645 cm^{-1}).

In the frequency range1800–1500 cm^{-1}(рис. 2.16, зразок 1, 2) there is an overlap of the characteristic bands of gelatin and xanthan: $\nu_{C=O}$, $\nu^{as}{}_{C–O}$, $\delta_{–OH}$ with the formation of a broad band with a maximum at 1649 cm^{-1}With the introduction of xanthan (sample 2), the intensity of the band decreases, which is probably caused by a decrease in the carbonyl groups –C=O of gelatin due to their interaction with the hydroxyl groups –OH–xanthan. Also, the indicated absorption maximum of the band for the gelatin+xanthan system has a low-frequency shift compared to the maximum for the gelatin solution (1651 cm $^{-1}$). The high-frequency shift of this band (1649 cm^{-1}) compared to the absorption maximum, which corresponds to the deformation vibrations of water (1645 cm^{-1}), indicates a transition from monomers and dimers of water molecules to trimers and oligomers.

A more blurred absorption band in the region of 1400–950 cm^{-1} may indicate an increase in the degree of bonding of –OH groups in the gelatin+xanthan system compared to gelatin. In the range of 800–500 cm^{-1} (Figs. 2.16, 2.17), sample 2 has two narrow bands of weak intensity with maxima at 764 and 576 cm^{-1}.

The results of the introduction of sugar into the aqueous solution of gelatin and xanthan are indicated at all considered characteristic frequencies of the IR spectrum of the gelatin+xanthan+powdered sugar sample (Fig. 2.16, 2.17, sample 3). Thus, the profile of the band of valence vibrations of N–H, O–H groups changes and there is a significant broadening of the band with a maximum at 3400 cm^{-1} in the region of low frequencies compared to gelatin (sample 1) and gelatin+xanthan (sample 2). At the same time, the low-frequency band maximum shifts from 3401 cm^{-1} to 3400 cm^{-1} (Fig. 2.16, sample 3), there is a significant increase in band intensity, which is associated with an increase in the number of –OH groups due to sucrose, formed hydrogen bonds, redistribution of associated and non-associated groups.

An increase in the intensity of the absorption band of valence vibrations of C–H bonds (2938 cm^{-1}) is observed. The intensity of the absorption band for gelatin+xanthan+powdered sugar samples increases significantly in the region of 2600-1900 cm^{-1} with a maximum at 2138 cm^{-1} due to the formation of a significant number of intermolecular hydrogen bonds. The introduction of powdered sugar into a solution of gelatin and xanthan (sample 3) leads to an increase in the intensity of the absorption band of valence vibrations of the –C=O groups and a shift of the maximum to 1646 cm^{-1} (1651 cm^{-1} sample 1, gelatin; 1649 cm^{-1} sample 2, gelatin + xanthan). Such a shift indicates the electrostatic interaction of the positively charged amide groups of the gelatin polypeptide with the negatively charged groups of the glucuronic and pyruvic acid residues of xanthan and the more active formation of polyelectrolyte complexes of gelatin and xanthan in the presence of powdered sugar.

The absorption band of sample 3 (Fig. 2.17) with a maximum at 1050 cm^{-1} testifies to valence vibrations of C–O glycosidic bonds, characteristic of sucrose (1072 cm^{-1}) and xanthan (1060 cm^{-1}).

In fig. 2.18 shows the IR spectra of samples based on gelatin, xanthan, powdered sugar (sample 3), which were structured in the presence of trans-glutaminase (sample 4), including a sample with the addition of flour (sample 5).

Comparative analysis of the results of the study of samples with transglutaminase (Fig. 2.18) shows that the spectrum of sample 4 gelatin+xanthan+powdered sugar +transglutaminase is similar to the spectrum of sample 3 gelatin+xanthan+powdered sugar. Profiles of these spectra, maxima of characteristic frequencies practically coincide. Some differences of the absorption band in the region of 2600□1900 cm–1 of samples 4 □ with transglutaminase □ are that the band has a lower intensity and a shifted low-frequency maximum (2137 cm–1) compared to sample 3 (2137 cm–1).

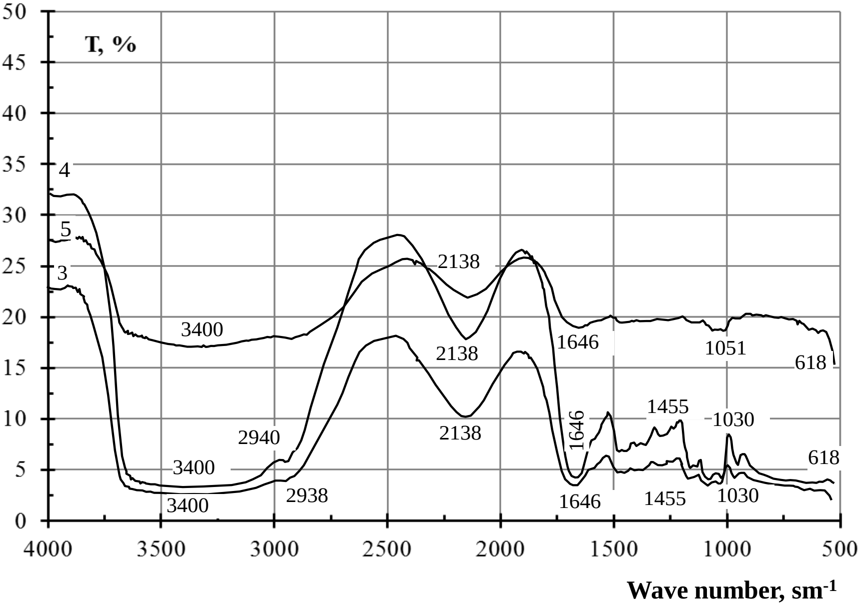


Fig. 2.18. IR absorption spectra of samples: 3 – gelatin+xanthan+ sugar powder; 4 – gelatin+xanthan+sugar powder+transglutaminase; 5 – gelatin + xanthan + powdered sugar + transglutaminase + flour

Probably, during the structuring at a temperature of 50 °C of a solution of gelatin and xanthan in the presence of powdered sugar and transglutaminase, a smaller number of intermolecular hydrogen bonds is formed than under the conditions of the process in the absence of transglutaminase.

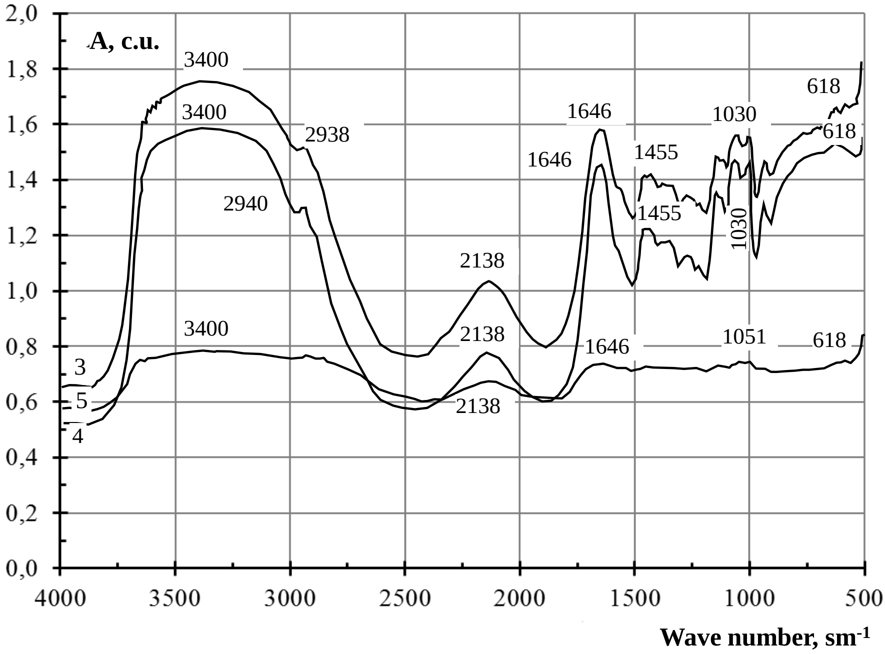


Fig. 2.19. Comparison of the intensity of the IR absorption bands of the samples: 3 – gelatin+xanthan+powdered sugar; 4 – gelatin + xanthan + powdered sugar + trans-glutaminase; 5 – gelatin + xanthan + powdered sugar + transglutaminase + flour

Since transglutaminase catalyzes acyl transfer reactions between the γ-carboxyamide group of peptide-bonded glutamine residues (acyl-donor) and various primary amines, including the ε-amino group of lysine residues (acyl-acceptor), the intensity should be considered and compared, position of the maxima of the absorption bands of Amide I, Amide II, Amide III of samples 3 and 4.

The introduction of transglutaminase (Fig. 2.19, sample 4) compared to the introduction of powdered sugar (sample 3) leads to a slight decrease in the intensity of the absorption band with a maximum at 1646 cm^{-1} ($\nu_{-C=O}$). At the same time, there is no shift of the absorption maximum at the frequency of 1646 cm^{-1}, which is evidence of the absence of interaction of the specified functional groups under the influence of transglutaminase

A broad band with several maxima in the region 1500–900 cm^{-1}, which appears in samples 3, 4, may be evidence of the interaction of certain groups. Thus, for the sample gelatin+xanthan+powdered sugar+transglutaminase (Fig. 2.18, sample 4), an increase in the intensity of absorption bands is observed: at frequencies of 1455, 1374, 1339 cm^{-1} (δ_{O-H} of the tertiary alcohol groups of powdered sugar and xanthan, δ_{N-H} amino groups of lysine); Amide III (δ_{N-H}, ν_{CN}) with a maximum of 1262 cm^{-1}; glycosidic bonds of sucrose and xanthan at 1047 cm^{-1} (ν_{CO}); of primary amino groups with a maximum at 999 and 927 cm^{-1}. Amide III band has a low-frequency shift to 1262 cm^{-1} (sample 4) compared to 1268 cm^{-1} (sample 3), which is evidence of interaction under the action of transglutaminase of amino groups of lysine with acyl donors of polyelectrolyte complex gelatin-xanthan.

The IR spectrum of gelatin+xanthan+powdered sugar+transglutaminase+flour (Fig. 2.18, 2, 19, sample 5) shows a broad blurred band at frequencies of 3600–3100 cm^{-1}, complicated by overlapping bands (ν_{N-H} associated groups –NH_2, ν_{O-H} of associated groups –OH of gelatin hydroxyproline, ν_{-OH}, oscillations of adsorption bound water), absorption of Amide I ($\nu_{C=O}$) and Amide III (δ_{N-H}, ν_{CN}) at frequencies of 1646 cm^{-1} and 1268 cm^{-1}, respectively. In the range of 800–500 cm^{-1}, a weak absorption band is observed, due to the deformation fluctuations of the O=C–N group. The marked band has a low-frequency shift to 616 cm^{-1} relative to the characteristic band of Amide IV (620 cm^{-1})

In the IR absorption spectrum of sample 5 with flour (Fig. 2.19) at the considered characteristic frequencies, there is a decrease in the intensity of the absorption bands, which practically repeat the profile of the bands of samples with powdered sugar (sample 3), powdered sugar and transglutaminase (sample 4). For sample 5 with flour, the weak band at 2138 cm^{-1} (valence vibrations of associated hydroxyl groups) has a low-frequency shift compared to sample 4 (2137 cm^{-1}), which leads to the possible formation of intermolecular hydrogen bonds with proteins of the gluten complex of flour.

The absorption band (Fig. 2.19, sample 5) with a maximum at 1051 cm^{-1} indicates the valence vibrations of C–O glycosidic bonds of sucrose and xanthan and has a high-frequency shift compared to the sample that does not contain flour (Fig. 2.19, sample 4). A blurred absorption band in the region of 1400–950 cm^{-1} may indicate an increase in the degree of bonding of –OH groups in the system with flour.

Another direction of research of associative interactions in hydrocolloid systems is the study of the joint presence of starch, non-starch polysaccharides (NSP) and TG contained in the protein-carbohydrate base of the baked

flour semi-finished product. Since starch is a mixture of two polymers, when one more polymer is added, a system of four biopolymers is formed - gelatin, amylopectin, amylose and xanthan. Combining starch with other hydrocolloids, which when dissolved in water have a thickening effect, gives some advantages in terms of the texture of the finished product. The introduction of a small amount of NSP when combined with starch and TG helps to increase the viscoelastic properties of the food system [144-148, 150, 152-154].

The possibility of combining starch and NPS in combination with TG has been studied theoretically and experimentally. Experimental data on the dynamic viscosity of the protein-carbohydrate base when starch is partially replaced by non-starch polysaccharides are shown in Table 2.10.

The solution to the problem of creating technologies for products using gelatin is based on a comprehensive approach based on the theoretical and experimental justification of the use of NSP, which made it possible to predict the production of food products of different textures with high quality characteristics. The essence of the approach is to study the interactions of hydrocolloids of different nature, chemical composition and molecular weight, which are used as stabilizers, thickeners and structure formers in multicomponent food systems [144].

To improve the properties of gelatin gels, a second biopolymer is used - a natural polysaccharide capable of interacting with gelatin at the molecular level. In this work, the regularities of structure formation in gelatin-polysaccharide systems are investigated, because the properties of the resulting gels are of interest from a scientific and practical point of view.

Numerous studies [148-154] have shown that when an ionic polysaccharide is introduced into a low-concentration gelatin gel, their rheological properties change. At the same time, the polysaccharide itself does not form a gel in the low concentration range without gelatin. Then, at $Z \geq 0.1$, the yield strength in a very narrow range of the mass ratio of the components increases sharply, by more than an order of magnitude. Xanthan was added in low concentrations, in which the polysaccharide itself does not act as a structuring agent, but has a positive synergistic effect on the gelatinizing properties of the mixed systems.

It is known that the rheological characteristics of gels based on gelatin change over time as a result of structuring processes that occur in gels below the temperature of gel formation. Dragle formation at the core of the gelatin system has been demonstrated to be a kinetically controlled process that continues virtually indefinitely after initiation. And this makes rheological research difficult. However, it turned out to be possible to determine the time of gelatinization, after which the mechanical characteristics increase slightly.

The mechanisms of the formation of various types of bonds between the protein and polysaccharide components of the recipe mixture of the whipped flour semi-finished product, which contribute to the formation of the protein-polysaccharide framework of the baked semi-finished product, have been established.

The synergism of the action of the components of the mixture, namely, gelatin + xanthan, has been proven, probably due to the reduction of the carbonyl groups –C=O of gelatin due to their interaction with the hydroxyl groups of –OH– xanthan; gelatin+xanthan+sugar powder, which is characterized by an increase due to sucrose in the number of –OH groups, formed hydrogen bonds, redistribution of associated and non-associated groups; gelatin+xanthan+sugar powder+transglutaminase, resulting from the interaction of lysine amino groups with acyl donors of the gelatin+xanthan polyelectrolyte complex under the action of transglutaminase, probably due to the formation of a smaller number of intermolecular hydrogen bonds than in the conditions of the process in the absence of transglutaminase; gelatin + xanthan + powdered sugar+ transglutaminase+ flour, which probably leads to the formation of intermolecular hydrogen bonds with proteins of the gluten complex of flour and an increase in the degree of bonding of –OH groups in the system with flour.

Thus, during the interaction of gelatin with xanthan under external conditions conducive to the formation of gels, the secondary structure of the protein changes, including increased spiralization of gelatin. The increase in the share of the collagen-like triple helix during complexation in gelatin-polysaccharide systems can cause a significant increase in the viscoelastic properties of modified gelatins.

Therefore, it is rational to introduce such ingredients as gelatin, xanthan, powdered sugar, transglutaminase, flour into the component composition of whipped semi-finished product.

2.2 Justification of the technological parameters of obtaining a whipped flour semi-finished product

2.2.1 Study of the influence of the degree of grinding of the components of the dry mixture on the duration of dissolution

It is known [26, 155] that the solubility of xanthan in water is determined by the presence of regular side chains with acidic groups, which cause mutual repulsion of individual molecules, which leads to an increase in their hydration. In this regard, xanthans dissolve in water already at room temperature, in addition, they dissolve well in hot and cold milk, in solutions of salt and sugar. Xanthan gum has a white or cream color and is produced in powder form. It dissolves in both cold and hot water, but does not dissolve in most organic solvents.

It is known [26-28, 156] that gelatin swells in cold water and dissolves when heated above 50 °C. To determine the duration of dissolution (Fig. 2.20-2.23), the solubility of the gelatin-xanthan composition with different degrees of dispersity was studied at a stirrer speed of 20×60 s^{-1}.

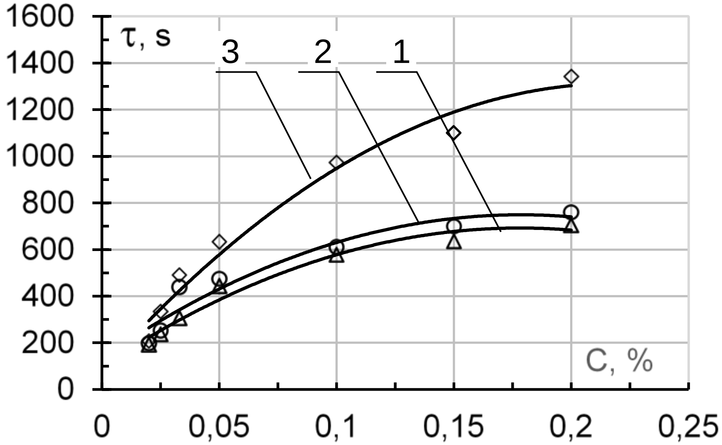


Fig. 2.20. The effect of xanthan on the duration of dissolution of gelatin 3.0±0.5% with different particle sizes, mm: 1-0.1; 2-0.2; 3-0.3, at a temperature of 60±1 °C

It was established that at a temperature of 60±1 °C, an increase in the size of xanthan particles from 0.2 to 0.3 mm increases the duration of dissolution by 520±5 s.

From the analysis of fig. 2.21 it can be seen that reducing the temperature to 50±1 °C for xanthan particle sizes from 0.3 mm increases the duration of dissolution by 600±5 s.

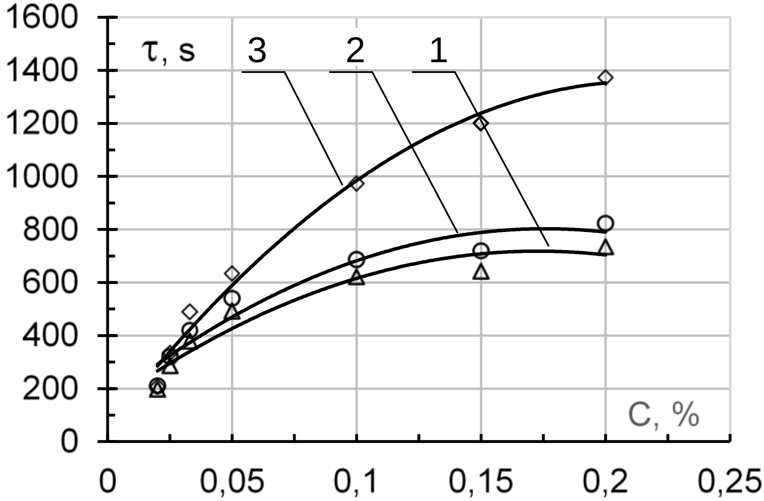


Fig. 2.21. The influence of xanthan on the duration of dissolution of gelatin 3.0±0.5% with different particle sizes, mm: 1-0.1; 2-0.2; 3-0.3, depending on the temperature 50±1°C

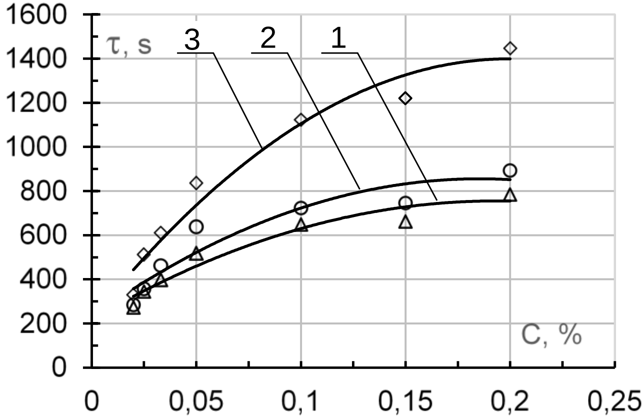


Fig. 2.22. The effect of xanthan on the duration of dissolution of gelatin 3.0±0.5% with different particle sizes, mm: 1-0.1; 2-0.2; 3-0.3, at a temperature of 40±1 °C

To determine the rational temperature, the duration of dissolution of a mixture of gelatin 3.0±0.5% xanthan 0.2±0.05% with different degrees of dispersity was studied (Fig. 2.23) at a stirring speed of 20×60 s $^{-1}$.

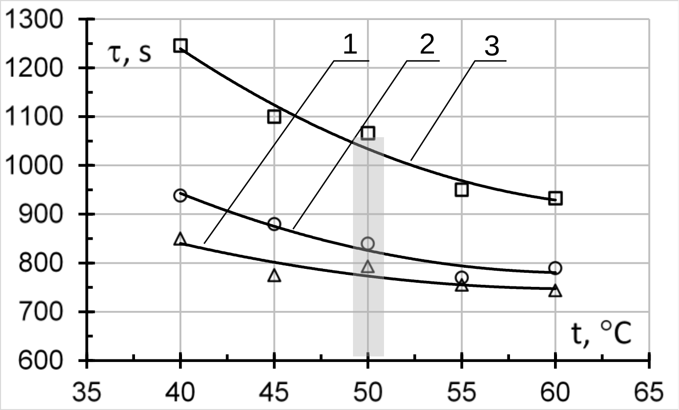


Fig. 2.23. The influence of temperature on the duration of dissolution of a mixture of gelatin 3.0±0.5% xanthan 0.2±0.05% with different particle sizes, mm: 1-0.1; 2-0.2; 3-0.3

The rational value of the particle sizes of the recipe components of the dry mixture and the dissolution temperature has been experimentally proven. The necessary conditions for rapid dissolution of the dry mixture and obtaining a solution of appropriate quality are provided by the particle size of 0.2±0.05 mm (Fig. 2.20-2.23) of the ingredients: gelatin at a concentration of 3.0±0.2% and xanthan at a concentration of 0.2±0.05% at the dissolution temperature of 50.0±2.0°C.

2.2.2 Study of the effect of temperature on the foaming process of the "water-gelatin-xanthan" system modified with the enzyme tranglutaminase

The ability to form and stabilize foams based on gelatin solutions is related to its surface-active properties and depends on the molecular structure. The surface properties of gelatin are based on the fact that the side chains of gelatin, like all proteins, have charged groups. At the same time, certain parts of the collagen sequence contain either hydrophilic or hydrophobic amino acids. Both hydrophobic and hydrophilic moieties tend to migrate to surfaces, which lowers surface tension. This promotes foaming and also stabilizes the surface of the liquid/air interface by forming a charged film around the components of the dispersed phase [16, 156, 157].

At the same time, stabilization of the foam based on gelatin solutions occurs as a result of an increase in the viscosity of the aqueous phase, which at the same time significantly depends on the temperature. The resulting structure can also be additionally strengthened by jelly formation [154, 156, 157], which occurs in gelatin below a temperature in the range of 17...20°C.

Thus, important criteria for choosing the appropriate type of gelatin are charge distribution and gelatin gel strength. The importance of the last indicator is related to the fact that the higher the strength, the stronger the gelatinous protective shell around the air bubbles at the same temperature and concentration is formed by gelatin.

It should be noted that during the whipping process, the temperature of the solution must remain above the solidification temperature of gelatin. This is due to the fact that the films that form around the air bubbles during gelatinization will be irreversibly destroyed during mechanical action.

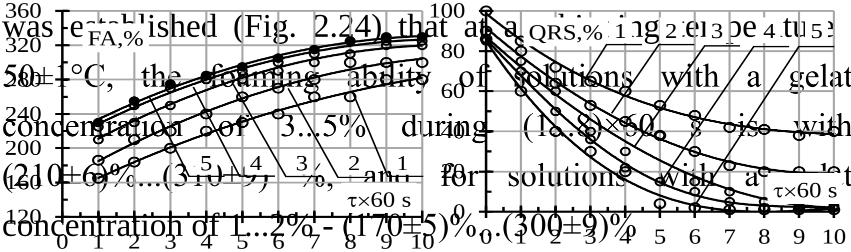
As stated in the literature, in the production of whipped products, the color of the gelatin solution is not particularly important, since when whipped, even dark types of gelatin at low concentrations give white foam. The transparency of the gel in this application is also irrelevant. Many manufacturers prefer gelatin with high strength in Bloom (high-Bloom) for the production of whipped products. As the setting time decreases, aerated products quickly reach the required strength [155-157].

In many fields of application, foaming of gelatin solution is a normalized parameter. It is stated in the literature that there is no standard method for determining foaming ability for gelatin solutions, and most tests are specific to the application [155-157]. Abroad, the standardized method of whipping with a perforated disc is most often used to determine the foam-forming ability of gelatin solutions. In this method, the foam is obtained by whipping 200 ml of a 5% gelatin solution at a temperature of 35°C with a perforated disk attached to the rod in a measuring glass cylinder. The volume of the foam will be determined after 40 blows within 40 seconds, and the stability - after 10 and 20 minutes.

According to data [155-157], there is a basic rule that governs the selection of the most suitable type of gelatin for the production of whipped products: type A gelatin has better foaming ability and foam stability than type B gelatin.

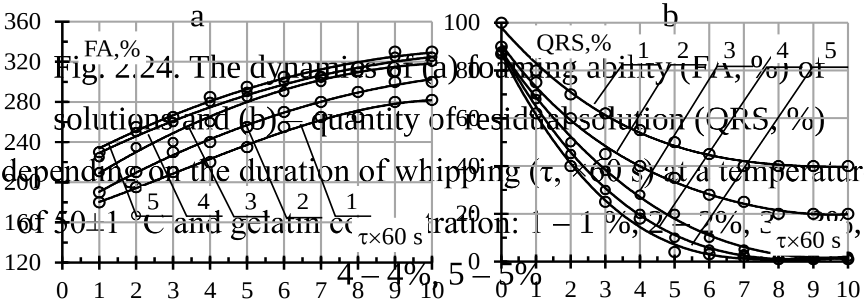
The results of the study of the dynamics of the foaming ability and the amount of residual gelatin solution after whipping are shown in Fig. 2.24-2.27. The analysis of experimental data established that the general trend for the studied model systems is a slow increase in foaming capacity and a decrease in the amount of residual solution during whipping for (1...8)×60 s and stabilization of these indicators for (8...10)×60 s. This is the basis for recommending the specified duration as rational. At the same time, the absolute values of both the foaming ability and the amount of residual solution are close to each other for model solutions with a gelatin concentration of 3...5%, and a decrease in the concentration of gelatin within 1...2% leads to a corresponding decrease in this indicator.

At the same time, the whipping temperature does not have a significant effect on the foaming ability of gelatin solutions. It was established (Fig. 2.24) that at a whipping temperature of 50±1 °C, the foaming ability of solutions with a gelatin concentration of 3...5% during (1...8)×60 s is within (210±6)%...(310±9)% and for solutions with a gelatin concentration of 1...2% - (170±5)%...(300±9)%



a b

Fig. 2.24. The dynamics of (a) foaming ability (FA, %) of solutions and (b) – quantity of residual solution (QRS, %) depending on the duration of whipping (τ, ×60 s) at a temperature of 50±1 °C and gelatin concentration: 1 – 1 %, 2 – 2%, 3 – 3%, 4 – 4%, 5 – 5%



a b

Fig. 2.25. The dynamics of (a) foaming ability (FA, %) of solutions and (b) – quantity of residual solution (QRS, %) depending on the duration of whipping (τ, ×60 s) at a temperature of 40±1 °C and gelatin concentration: 1 – 1 %, 2 – 2%, 3 – 3%, 4 – 4%, 5 – 5%

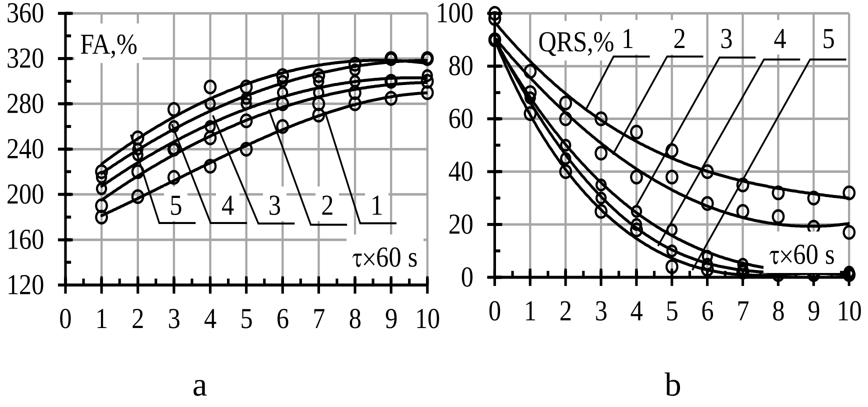


Fig. 2.26. The dynamics of (a) foaming ability (FA, %) of solutions and (b) – quantity of residual solution (QRS, %) depending on the duration of whipping (τ, ×60 s) at a temperature of 30±1 °C and gelatin concentration: 1 – 1 %, 2 – 2%, 3 – 3%, 4 – 4%, 5 – 5%

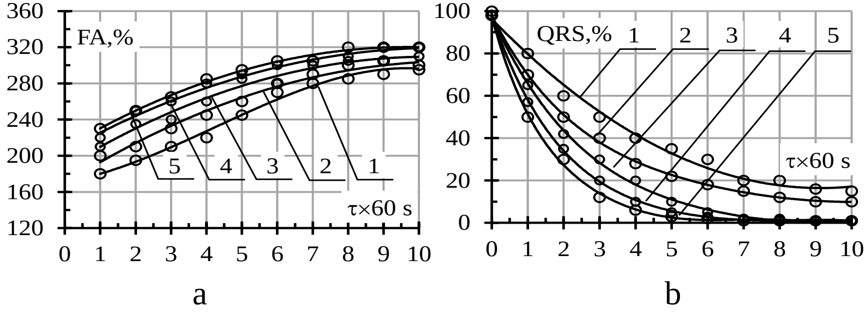


Fig. 2.27. The dynamics of (a) foaming ability (FA, %) of solutions and (b) – quantity of residual solution (QRS, %) depending on the duration of whipping (τ, ×60 s) at a temperature of 20±1 °C and gelatin concentration: 1 – 1 %, 2 – 2%, 3 – 3%, 4 – 4%, 5 – 5%

The amount of residual gelatin solution during its whipping under the considered parameters slowly decreases, which completely disappears after 5×60 s, 7×60 s, and 9×60 s for solutions with a concentration of 5%, 4%, and 3%, respectively. In model solutions with a gelatin concentration of 2% and 1%, after whipping for (8...10)×60 s, 20±1 cm^3 and 40±2 cm^3 remain, respectively

Data analysis (Figs. 2.24-2.27, a) established that at whipping temperatures of 40±1°C, 30±1°C and 20±1°C, the foaming ability of solutions with a gelatin concentration of 3...5% during (1...8) ×60 s lies within similar limits (Fig. 2.24, a). This allows us to conclude that the whipping temperature in the range of 20...50°C does not affect the foaming ability of the studied model gelatin solutions.

The amount of residual gelatin solution under the considered parameters (Fig. 2.24-2.27, b) also slowly decreases and disappears after 5×60 s, 6×60 s and 7×60 s during its whipping at a temperature of 40±1°C 30±1 °C and after 4×60 s, 5×60 s and 6×60 s - at a temperature of 20±1°C for solutions with a concentration of 5%, 4% and 3%, respectively.

For solutions with a gelatin concentration of 1...2%, the foaming capacity is (180±5)%-(290...300)±9% at a whipping temperature within (20...40)±1°C. At the same time, at a concentration of gelatin of 2% for the indicated parameters of whipping (Fig. 2.24-2.27, b), the amount of residual solution is (5.0±0.3...20±1) cm^3, and for a concentration of 1% – (10.0±

0.5...40±2) cm^3. It should be noted that within the set values, this indicator decreases with a decrease in the whipping temperature.

The presence of a gelatin solution at concentrations of 1% and 2% after whipping the model systems may indicate insufficient protein concentration and the production of a kinetically unstable foam-like system.

The conducted research made it possible to establish patterns of influence of temperature and duration of whipping, concentration of gelatin from the German company Gelita with a gel strength of 240 bloom on the foaming ability of its solutions. It was determined that for the investigated temperatures (20...50)±1°C, the maximum foaming capacity - (300±9...320±9)% is possessed by the "water-gelatin" model systems with a gelatin concentration of 3...5%. For low gelatin concentrations of 1...2%, this indicator is (280±8...300±9)%. It was established that to ensure the maximum volume of foam, it is necessary to beat for (8...10)×60 s.

The influence of these parameters on the amount of residual solution as a result of the instability of foam systems after whipping was determined. The obtained data indicate that when mixing model systems "water-gelatin" with a gelatin concentration of 1%, (10.5±0.5...40±2)% of the solution remains, 2% - (5.0±0.3...20± 1)%, and after whipping the model systems with a gelatin concentration of 3...5% for (8...10)×60 s, no solutions remain.

2.3 Justification of the parameters of heat treatment of the whipped flour semi-finished product

2.3.1 Study of the influence of the synergistic interaction of xanthan with gelatin on the amount of weight loss of the semi-finished product

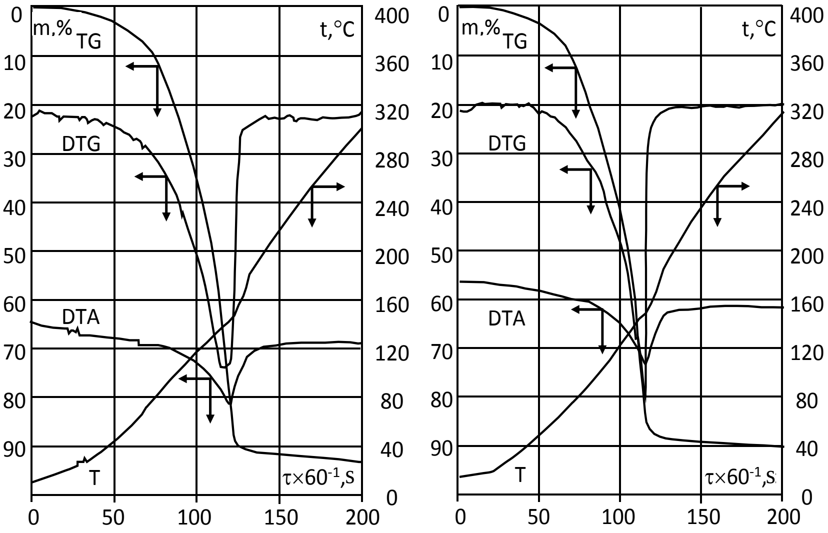
In order to determine the dynamics of the loss of moisture, which has different forms of connection with protein [158–164] during heat treatment at the base of the model system with different content of recipe ingredients and in the model system of the whipped flour semi-finished product, using experimental curves, the mass was estimated kinetically unequal water molecules by the method of thermogravimetry (DTG) and differential thermal analysis (DTA) under non-isothermal conditions (Fig. 2.28).

During the study of the influence of recipe ingredients on the moisture-retaining capacity of the model system of the whipped flour semi-finished product, it was established that the decomposition process of all samples occurs in different ways.

Decomposition of the first sample (gelatin) and the second sample (gelatin+xanthan) (Fig. 2.28 a, b) occurred in two stages in the temperature ranges 1 – 80±3 °C, 2 – 108±3 °C, and 1 – 80±3 °C, 2 – 114±3 °C.

The DTA curves (Fig. 2.28, a, b) record endothermic reactions with intense heat absorption. On the DTA curves (Fig.

2.28, b), the process is not accompanied by thermal reactions [158–164]. Each stage characterizes the mass loss process that occurs in the basis of the model system and in the model system of the whipped flour semi-finished product under the influence of temperature.



a b

Fig. 2.28. Derivatograms of the model system basis of the semi-finished product according to the content: a – gelatin 3 g and water 97 g; b – gelatin 3 g, xanthan 0.2 g and water 96.8 g

The first stage characterizes the beginning of the process of removing immobilization moisture, which is retained by the frame of the whipped flour semi-finished product, the second characterizes the process of intensive removal of adsorption and osmotically bound moisture, the third - the completion of the process of intensive moisture removal with partial removal of chemically bound moisture.

From the character of the TG curves of the derivativeograms (Fig. 2.28, a, b), it can be seen that in the temperature range of 35...80°C (range I - the beginning of polymorphic transformations of the protein), there is an intensive removal of free unbound or mechanically bound water. Water losses in the basis of the model system of whipped flour semi-finished product (samples 1, 2) are 12.5±0.5%; 10.0±0.3%, respectively.

In the temperature range of 80...120 °C (range II - the beginning of heat treatment), the removal of mechanically bound water occurs,which is in the cells of protein-containing components, and osmotically bound water during the process of beating and forming the dough blank. Water losses (samples 1, 2) are 65.5±0.2%; 32.0±0.2% respectively. The model system containing xanthan (sample 2) has a higher hydration capacity.

In the temperature range of 120...160 °C (range III - the main range of heat treatment), water loss (samples 1, 2) is 95.5±0.2%; 80.0±0.2% respectively. The decrease in moisture loss by 15.5% (sample 2) occurs as a result of the synergistic interaction of xanthan with gelatin, obviously, due to the redistribution of associated and non-associated hydroxyl groups, which contributes to the formation of a significant number of intermolecular hydrogen bonds.

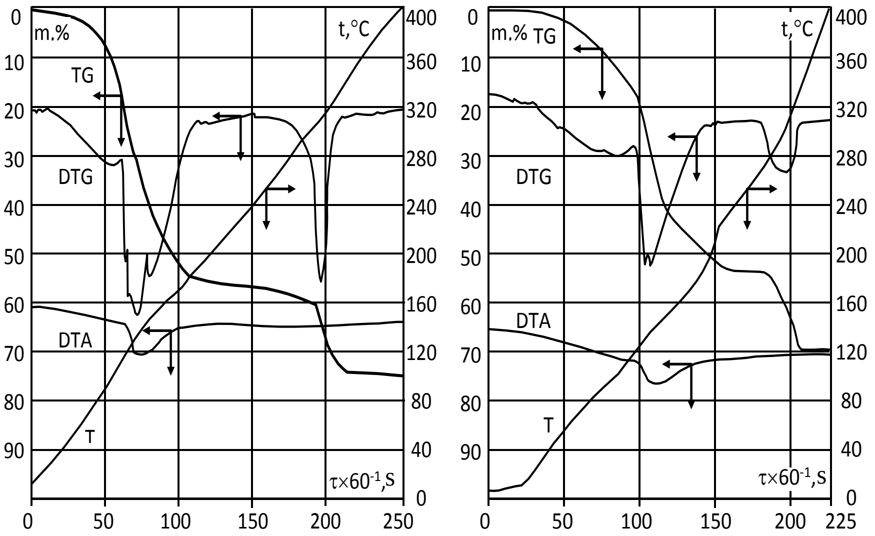
2.3.2 Study of the catalytic effect of the transglutaminase enzyme in the gelatin-xanthan system on the weight loss of the semi-finished product

The DTA curves (Fig. 2.29, a) record endothermic reactions occurring with intense heat absorption. On the DTA curves (Fig. 2.29, b), the process is not accompanied by thermal reactions [158–164].

Decomposition of the third sample (gelatin+xanthan+ powdered sugar) and the fourth sample (gelatin+xanthan+powdered sugar+transglutaminase) (Fig. 2.29 a, b) takes place in three stages in the temperature ranges of 1–85±3 °C, 2–120±3 °C, 3 –124±3 °C.

The analysis of the TG curves of the derivatograms (Fig. 2.29 a, b) established that in the temperature range of 35...80°C (range I – the beginning of protein polymorphic transformations), the water loss of the basis of the model system of the whipped flour semi-finished product (samples 3, 4), , amounts to 8.5 ±0.2%; 6.5±0.2% respectively.

In the temperature range of 80...120 °C (range II - the beginning of heat treatment), water loss (samples 3, 4) is 25.5±0.2%; 23.0±0.2% respectively.



a b

Fig. 2.29. Derivatograms of the model system basis of the whipped semi-finished product according to the content: a – 3 g of gelatin + 0.2 g of xanthan + 30 g of powdered sugar + 66.8 g of water; b – 3 g of gelatin + 0.2 g of xanthan + 0.09 g of transglutaminase + 30 g of powdered sugar + 66.6 g of water

In the temperature range of 120...160 °C (range III - the main range of heat treatment), water loss (samples 3, 4) is 58.5±0.2%; 49.0±0.2% respectively. That is, the introduction of the powdered sugar and the enzyme transglutaminase into the basis of the model system of the whipped flour semi-finished product helps to increase the hydration capacity by 21.5±0.2% and 31.0±0.2%, respectively, relative to sample 2 (gelatin-xanthan system). The model system containing the enzyme transglutaminase (sample 4) has a higher hydration capacity.

From the analysis of the TG curves of derivatograms of the whipped flour semi-finished product (Fig. 2.29 a, b), it was established that the decrease in moisture loss is probably due to the catalytic effect of the transglutaminase enzyme in the gelatin-xanthan system, the interaction of the amino groups of lysine with the γ-carboxyamide group connected by a peptide bond glutamine residues.

2.3.3 Study of weight loss of the whipped flour semi-finished product under the conditions of programmed temperature change and determination of the rational temperature range of baking.

On the DTA curves (Fig. 2.30), the mass loss process of the whipped flour semi-finished product model system is not accompanied by thermal reactions [158–164]. Decomposition of the fifth sample (gelatin+xanthan+ powdered sugar+transglutaminase+ flour) takes place in three stages in the temperature ranges 1–100±3 °C, 2 – 140±3 °C, 3 – 200±3 °C.

The analysis of the TG curves of the derivatogram (Fig. 2.30) established that of all the studied samples of the model system of the whipped flour semi-finished product, sample 5 has the lowest water loss. In the temperature range of 35...80°C (range I - the beginning of protein polymorphic transformations), water loss is 5.0±0.1%.

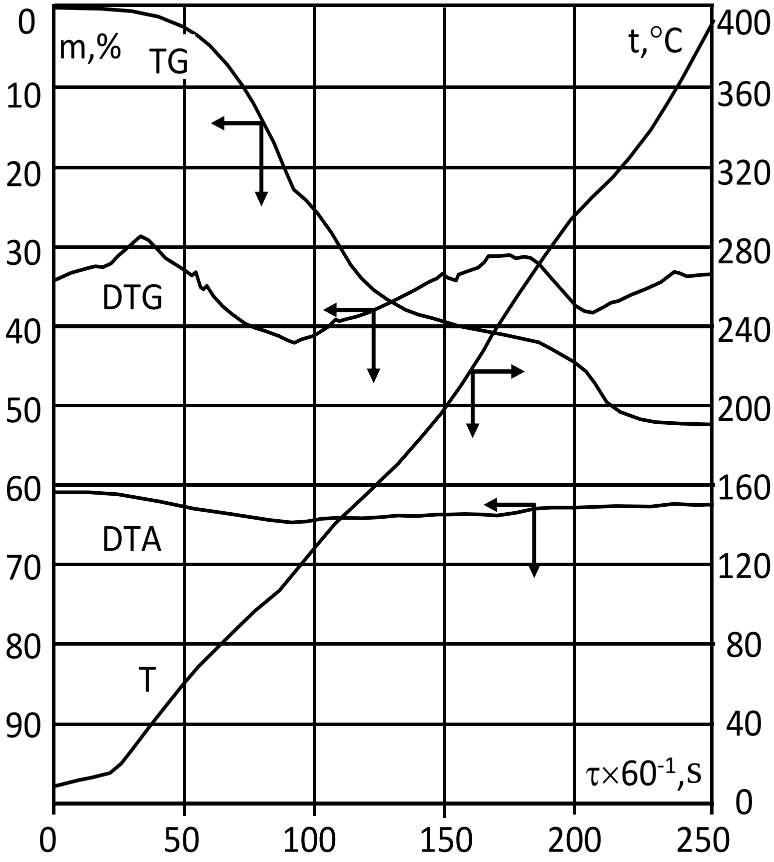


Fig. 2.30. Derivatogram of the model system of the whipped flour semi-finished product according to the content: 3 g gelatin + 0.2 g xanthan + 0.09 g transglutaminase + 30 g powdered sugar + 66.6 g water + 60 g flour

In the temperature range of 80...120 °C (range II - the beginning of heat treatment), water loss (sample 5) is 21.0±0.2%.

In the temperature range of 120...160 °C (range III - the main range of heat treatment - baking), water loss (sample 5) is 41.0±0.2%. That is, the introduction a flour of the appropriate concentration in to the model system of whipped semi-finished product contributes to a significant reduction of moisture loss, presumably as a result of the increase in the degree of bonding of –OH groups with flour proteins, which causes the formation of intermolecular hydrogen bonds with the proteins of the gluten complex. In addition, the temperature of 150±5°C, which is included in this temperature range, can be considered rational for baking whipped flour semi-finished product.

2.3.4 Study of the influence of recipe components of the whipped flour semi-finished product on the mechanism of moisture removal

To obtain data on the mechanism of moisture removal along the TG curve, the degree of mass change α was calculated (Fig. 2.27) and built the $|-\lg\alpha|$ dependence from the return temperature value of 1000/K for the interval 328...378 K, because it is in this range that the dehydration processes of the model system of whipped flour semi-finished product take place most intensively, as evidenced by the endo-effects on the derivative graphs (Figs. 2.31-2.32) [158-160].

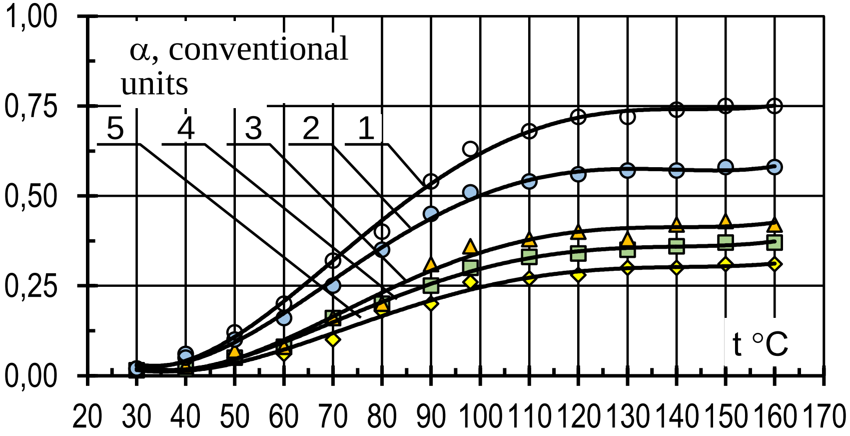


Fig. 2.31. Dependence of the degree of mass changes in the model system of the whipped semi-finished product on the temperature according to the content of the recipe components: 1 – 3 g of gelatin and 97 g of water; 2 – 3 g of gelatin, 0.2 g of xanthan and 96.8 g of water; 3 - 3 g of gelatin + 0.2 g of xanthan + 30 g of powdered sugar + 66.8 g of water; 4 – 3 g of gelatin + 0.2 g of xanthan + 0.09 g of transglutaminase + 30 g of powdered sugar + 66.6 g of water; 5 – 3 g of gelatin + 0.2 g of xanthan + 0.09 g of transglutaminase + 30 g of powdered sugar + 66.6 g of water + 60 g of flour

It is known that the rate of mass loss (DTG curve) corresponds to the dehydration process, therefore, during heat treatment (baking) of whipped semi-finished product, this factor was used to obtain the dependence of mass change on temperature. For this, on the TG curve at constant temperature intervals of 10 °C, the change in mass Δm_1 of a whipped flour semi-finished product sample was found, which corresponds to the amount of moisture that evaporated under the influence of temperature [158, 159, 163. 165].

The degree of mass change α (Fig. 2.31) was calculated as the ratio □m1 to the total amount of moisture contained in the base of the model system (samples 1, 2, 3, 4) and in the model system of thewhipped flour semi-finished product (sample 5) and removed at the end of the process dehydration (TG curve).

The TG curves, obtained in coordinates α-t (Fig. 2.32), have an S-shaped appearance, which characterizes the complex forms of interaction of water and dry substances of the base and model system of the whipped flour semi-finished product and predicts the difference in the rate of water release in different sections of the curves. Therefore, the curves of the temperature dependence of the mass change of the model system of the whipped flour semi-finished product make it possible to study the activation energy of water, the kinetics of non-equivalent forms of the moisture bond and reflect the different rates of dehydration of the finished product [158-160, 163,165].

At the first stage, at a temperature of 303...323 K (Fig. 2.32, section AB), the removal of "free" or mechanically bound (capillary) moisture, which has a low bond energy with the protein of the base and whipped flour semi-finished product, takes place.

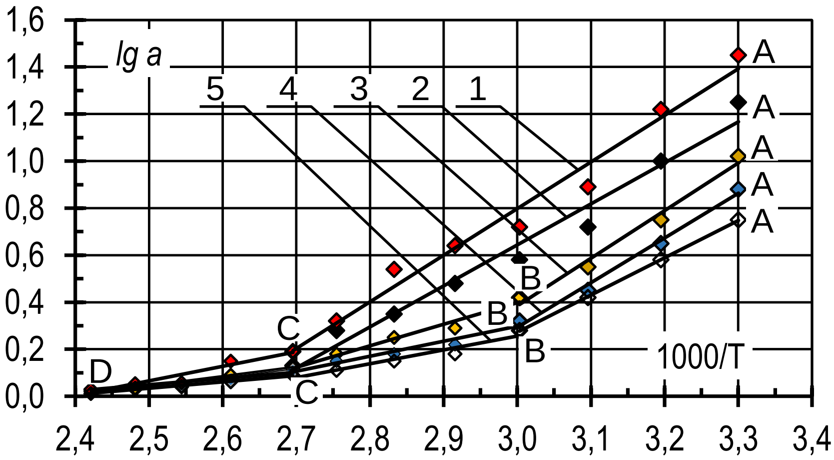


Fig. 2.32. Dependence of the logarithm of the mass changes degree in the model system of the whipped semi-finished product on the temperature according to the content of the recipe components: 1 – 3 g of gelatin and 97 g of water; 2 – 3 g of gelatin, 0.2 g of xanthan and 96.8 g of water; 3 - 3 g of gelatin + 0.2 g of xanthan + 30 g of powdered sugar + 66.8 g of water; 4 – 3 g of gelatin + 0.2 g of xanthan + 0.09 g of transglutaminase + 30 g of powdered sugar + 66.6 g of water; 5 – 3 g of gelatin + 0.2 g of xanthan + 0.09 g of transglutaminase + 30 g of powdered sugar + 66.6 g of water + 60 g of flour

First, water is released, which forms a structural network of water molecules interconnected by hydrogen bonds. At the same time, desorption of capillary water is characterized by lower values of activation energy compared to water, which is released at the second stage of the process [158-160]. At the second stage (section BC), in the process of heating at a temperature of 323...378 K, part of the osmotically and immobilized moisture contained in the closed cells of the protein micelles of the whipped semi-finished product is released due to the unfolding of their polypeptide chains as a result of the disruption of micellar and hydrophobic interactions of proteins and carbohydrates with water [158-160].

In the temperature range of 378...416 K, in the third stage (section CD), the release of a part - 41% of the weakly bound adsorption moisture of polymolecular layers inside the particles of the model system of whipped the semi-finished product with the release of gaseous fractions begins. The water released at the same time forms several subsequent layers of molecules, which are more tightly bound to the protein of the model system of the whipped flour semi-finished product.

2.4 Study of the forms of moisture connection in model systems of the whipped flour semi-finished product during freezing-heating by the method of thermograms of differential scanning calorimetry (DSC)

Water is an important substance in food products because it determines their rheological characteristics. The degree of interaction of water with chemical components and the effect on the consistency of the food product is determined both by its thermodynamic state, the so-called chemical potential (or water activity), and by its amount in the product - moisture content. However, the mass fraction of moisture indicates the amount of moisture, but does not characterize its relationship to chemical, biochemical and microbiological changes in the product. Due to its structural bonds, water in food products is characterized by various properties and availability, which allows it to be fundamentally divided according to these characteristics into free and bound [165, 166].

Therefore, in the technology of food products, along with such a characteristic as total moisture, no less important indicators of bound moisture, moisture-retaining and moisture-releasing capacity are distinguished. One of the influential factors in ensuring the stability of the gel system during storage is the ratio of free and bound moisture, which is often the dominant indicator that characterizes the technological, merchandising and microbial stability of products [165, 166].

Of great scientific interest are the studies of the forms of moisture connection in model systems of whipped flour semi-finished containing gelatin, xanthan and transglutaminase enzyme in the temperature range from -30°C to 240°C and can significantly affect the final quality of the finished product. These studies were carried out using the method of differential scanning calorimetry [164, 167, 168].

The following model systems of the whipped flour semi-finished product were the study objects of moisture connection forms : gelatin (3%) and water (92%); gelatin (3%), xanthan (0.2%) and water (96.8%); gelatin (3%), xanthan (0.2%), powdered sugar (30%) and water (66.8); gelatin (3%), xanthan (0.2%), powdered sugar (30%), transglutaminase (0.09%) and water (66.71%); gelatin (3%), xanthan (0.2%), powdered sugar (30%), transglutaminase (0.09%), flour (60%) and water (6.71%).

Thermograms of the studied model systems (Figs. 2.33-2.37) were obtained under the condition of heating to a temperature of 240°C after freezing to -30°C. DSC thermograms are plotted in the following coordinates: along the abscissa axis – temperature in degrees Celsius t; along the ordinate axis, j_q is the heat flux normalized to the maximum amplitude, which is reached during the melting of the corresponding sample. Normalization of the heat flow was carried out in order to establish a more visual appearance of DSC thermograms for their comparison with each other.

For a detailed analysis of heating features and accurate establishment of the temperature ranges at which heat absorption peaks occur in each of the model systems of the whipped flour semi-finished product in the studies (Fig. 2.33-2.37), DSC thermograms are given together with the integral value of the heat flow.

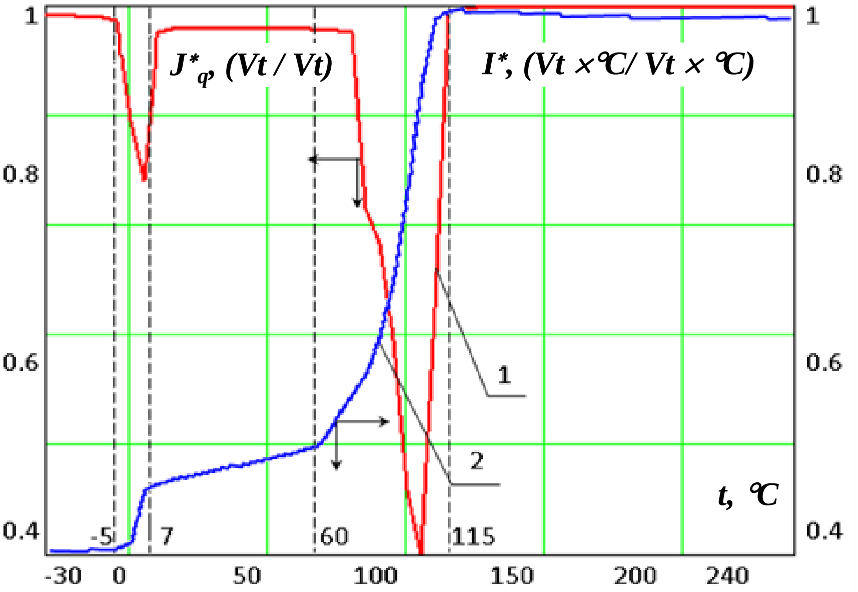


Fig. 2.33. Dependence of the heat flow (1) and its integral value (2) on temperature according to the contents of the model system: gelatin (3%), water (97%)

The temperature values at which the beginning of the peak of heat absorption by the sample under study occurs correspond to the beginning of the jump-like growth of the integral curve. Accordingly, the final temperature of the absorption peak was determined by the point that corresponds to the end of the jump-like growth of the same integral curve.

It is known [165, 166] that for free water the phase transition from solid to liquid occurs at a temperature of 0°C. From the analysis of DSC thermograms (Fig. 2.33), it can be seen that the phase transition of the system fluid of the model system from a solid and solid-amorphous state to a liquid occurs in the temperature range from -5°C to 7°C. For the model system of the whipped flour semi-finished product, which contains gelatin, it was established that the temperature range at which the phase transition of the 1st kind occurs (transition of system water from a liquid state to a gaseous state) is in the range from 60°C to 115°C. Obviously, the reason for this is a certain inertia of the method, as well as the presence of various forms of connection of system water with dry substances of the model system, which indicates the formation of a primary hydrate structure and binding of moisture.

In the model system of the whipped flour semi-finished product, which contains gelatin and xanthan (Fig. 2.34), xanthan is used as a cross-linking agent with the formation of triple helices, probably as a result of the covalent binding of two polymers, which leads to a more intense structuring of the model system and a decrease mobility of water molecules.

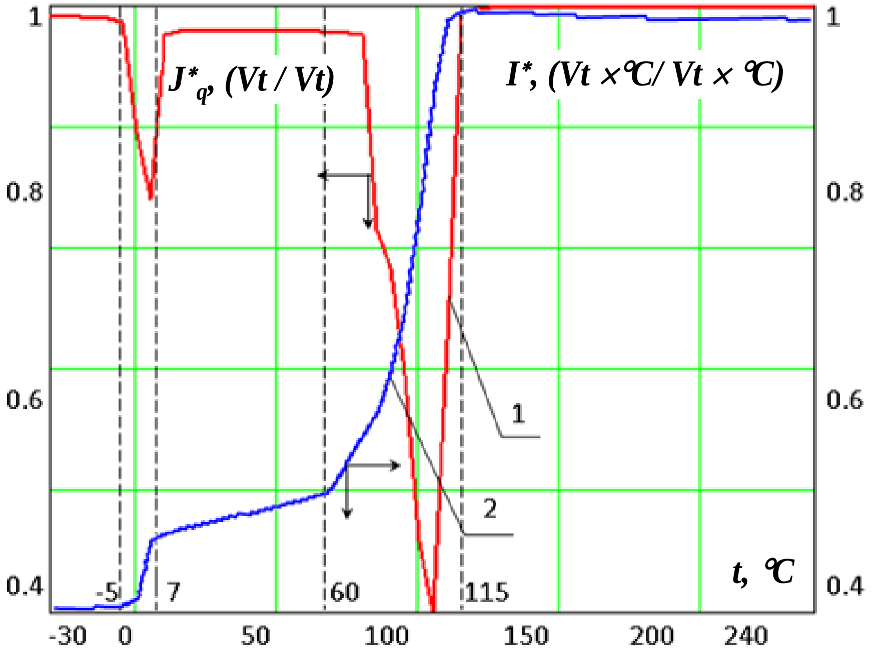


Fig. 2.34. Dependence of the heat flow (1) and its integral value (2) on temperature according to the content of the model system: gelatin (3%), xanthan (0.2%), water (96.8%)

From the analysis of DSC thermograms (Fig. 2.34), it can be seen that the phase transition of free water of the model system from a solid and solid-amorphous state to a liquid occurs in the temperature range from -5°C to 10°C. It was established that the temperature range for this model system, at which the phase transition of the 1st kind occurs (transition of system water from a liquid state to a gaseous state) is in the range from 70°C to

115°C. Obviously, the interaction of xanthan with gelatin, contributing to the formation of a significant number of intermolecular hydrogen bonds, leads to a decrease in the amount of free water in the system.

When heated in the range t=75...90° C, two endothermic transitions associated with the unfolding of macromolecules are observed. Upon further heating in the temperature range of 80...110°C, an exothermic transition with release of swelling heat was observed. This phenomenon is obviously caused by the intra-structural stage of swelling of the system, in which, with an increase in the diffusion coefficient, water molecules begin to penetrate inside the macromolecules, forming new intra-structural bonds.

Water adsorption of the model system of the whipped flour semi-finished product by xanthan molecules with the formation of a network of triple spirals, interaction with gelatin molecules, as well as the introduction of powdered sugar into the system increases its hydration capacity (Fig. 2.35).

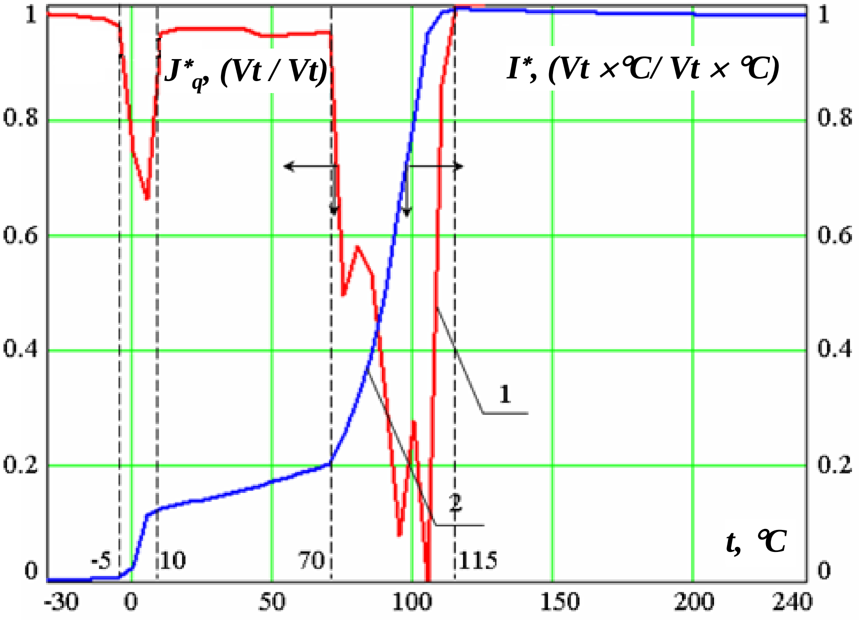


Fig. 2.35. Dependence of the heat flow (1) and its integral value (2) on the temperature according to the content of the model system: gelatin (3%), xanthan (0.2%), powdered sugar (30%), water (66.8%)

In the model system of the whipped flour semi-finished product, which contains gelatin, xanthan, powdered sugar and the enzyme transglutaminase (Fig. 2.36), due to the high reactivity of transglutaminase, strengthening of the covalent bonds occurs, catalyzed by transglutaminase, and a higher level of crosslinking of the structure is ensured.

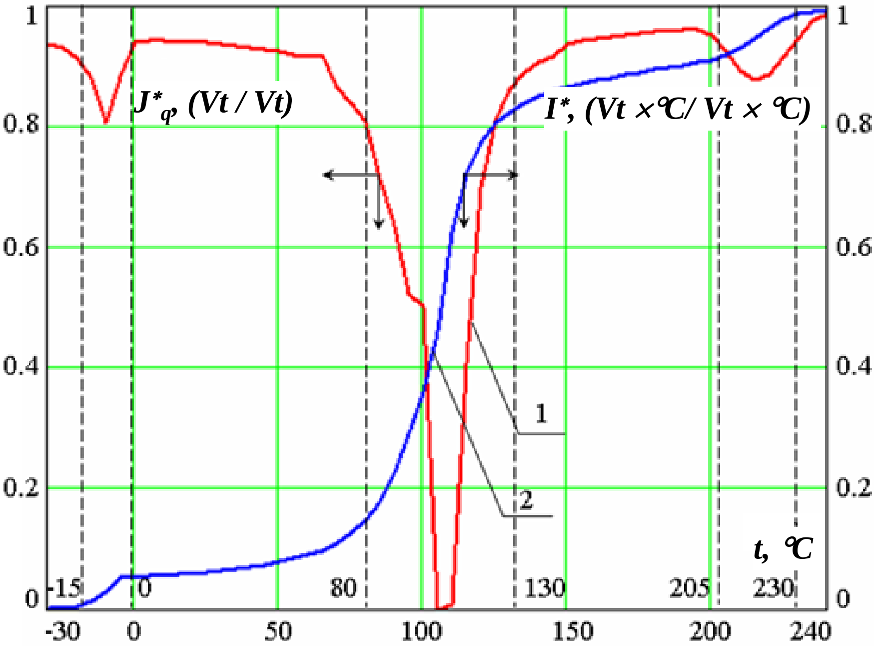


Fig. 2.36 – Dependence of the heat flow (1) and its integral value (2) on the temperature according to the content of the model system: gelatin (3%), xanthan (0.2%), powdered sugar (30%), transglutaminase (0.09 %), water (66.71%)

It was established (Fig. 2.37) that when flour is introduced into the model system of the semi-finished product, the width of the temperature range for both the first and the second absorption peak increases as a result of the decrease in the part of the system water, which has properties close to free (bulk) water. This is facilitated by an increase in the number of new forms of water connection (in particular, osmotic moisture and mono- and polyadsorption moisture) with dry substances due to the formation of colloids (gelatin solution, xanthan solution), changes in the concentration of dissolved substances in water (powdered sugar solution), swelling of polysaccharides (colloidal solution of flour starch), the formation of cross-links between gluten protein molecules (as a result of the catalytic action of the transglutaminase enzyme).

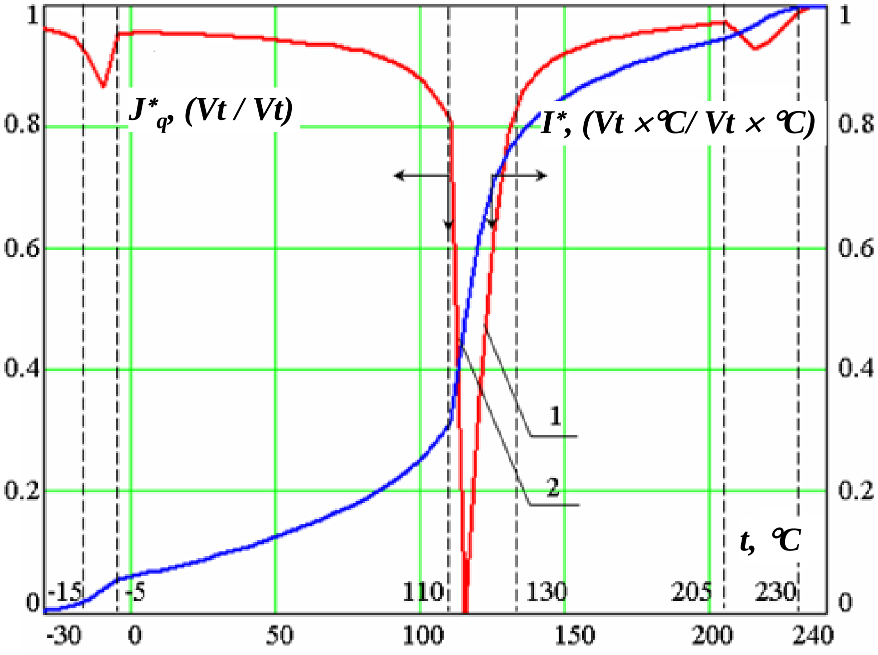


Fig. 2.37. Dependence of the heat flow (1) and its integral value (2) on temperature according to the content of the model system: gelatin (3%), xanthan (0.2%), powdered sugar (30%), transglutaminase (0.09%), flour (50%), water (16.71%)

From the analysis of DSC-thermograms (Fig. 2.37) it can be seen that the phase transition of free water of the model system from a solid and solid-amorphous state to a liquid shifted towards low temperatures by –5°C and occurs in the temperature range from -15°C to -5°. At the same time, the temperature range at which a phase transition of the 1st kind occurs (the transition of system water from a liquid state to a gaseous state) has shifted towards high temperatures by another +30°C and is in the range from 110°C to 130°C, obviously, as a result under the influence of the transglutaminase enzyme, a higher level of crosslinking of macromolecules of the protein framework is ensured, the degree of bonding of -OH groups with flour proteins increases, which causes the formation of intermolecular hydrogen bonds with the proteins of the gluten complex and significantly slows down the dehydration process.

Therefore, the analysis of DSC thermograms (Figs. 2.33-2.37) established that the thermograms in general have a similar character. The differences are in the shape of the absorption maxima and the temperature range of their occurrence on the abscissa axis. It is possible to draw some general conclusions arising from the type of obtained DSC thermograms.

Thus, the first peak, located in the temperature range from -15°C to 10°C, corresponds to the transition of system water from a crystalline and solid amorphous state to a liquid state. The second absorption peak, observed in the temperature range from 60°C to 130°C, corresponds to the transition of the system water of the investigated model systems from a liquid state to a gaseous state. The third peak, present only for three samples, namely, containing powdered sugar (Fig. 2.35); containing powdered sugar and transglutaminase (Fig. 2.36), containing powdered sugar, transglutaminase and flour (Fig. 2.37), is observed in the temperature range from 205°C to 230°C. Obviously, this peak corresponds to the destruction of polysaccharides containing the specified model systems, namely: powdered sugar and flour starch.

Confirmation of the result of the formation of new forms connection of system water with dry substances is the "splitting" of the temperature of its phase transitions of the 1st kind and, as a result, the expansion and shift of the range of temperatures at which these transitions take place. These extensions are characterized by the presence of physico-chemically bound water, namely, osmotic and mono- and polyadsorbed moisture in the model systems of the whipped flour semi-finished product of , which contain, in addition to gelatin, other ingredients: xanthan, powdered sugar, transglutaminase enzyme, flour.

2.5 Study of the structural and mechanical characteristics of the whipped flour semi-finished product

The structural and mechanical properties of real bodies, dispersed and high-molecular systems are directly related to the molecular interactions occurring in them, the features of the structure and thermal movement of their structural elements. That is, the structural and mechanical properties characterize the appearance of different types of structures in the system of whipped flour semi-finished product. On the one hand, the elastic-plastic-viscous properties, on the other hand, the strength properties of the model system of the semi-finished product determine the nature of its deformation processes and destruction processes.

As you know, the main thing in the process of dough formation is the formation of the necessary structure of the dough and obtaining a system with specified properties. At the beginning of dough kneading, flour comes into contact with water, powdered sugar, fat, salt and other components. At the same time, a number of processes begin to occur in the formed dough. The most important are physical, colloid and biochemical processes that ensure the consistency of the dough - a set of rheological properties that characterize its resistance to self-flow [3, 10, 48, 169].

The enzyme transglutaminase is an effective component involved in the structure formation of the dough. The TG enzyme contributes to the creation of larger protein compounds from protein chains. Thanks to the unique ability of the TG enzyme, cross-linking is ensured not only of functional flour proteins, but also of gluten proteins [43, 170, 171].

In the research, we characterized the resistance of the dough structure for the whipped flour semi-finished product by the ultimate shear stress of the intact structure, which was investigated using a semi-automatic Labor penetrometer with a hemispherical indenter [172].

The ultimate shear stress was determined by the calculation method according to [172].

Based on studies of the dependence of the ultimate shear stress [8] of model systems of freshly prepared dough (Fig. 2.38) for whipped flour semi-finished product from on the content of the main structure-forming components, organoleptic studies of consistency, the dependence of changes in the structure of the model system of dough for semi-finished products on the ratio of the main recipe components was established.

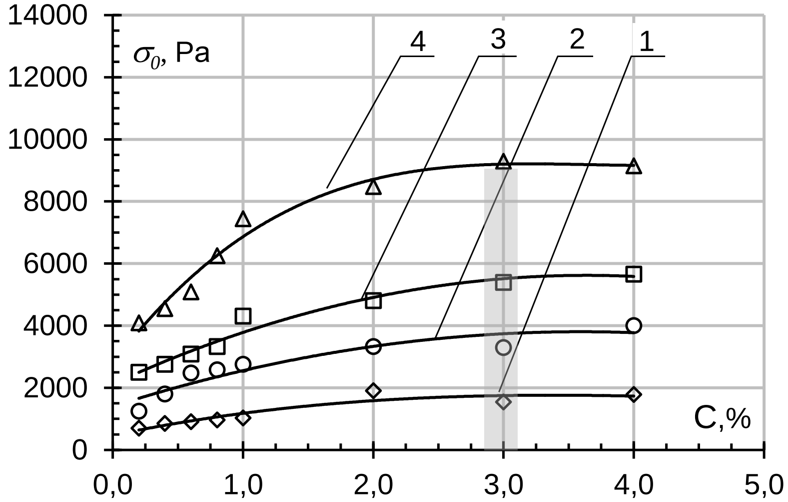


Fig. 2.38. Effect on ultimate shear stress of freshly prepared whipped semi-finished product of gelatin in composition with xanthan 0.2% due to interaction with transglutaminase enzyme, %: 1- 0.05; 2- 0.07; 3- 0.09; 4- control

Thus, in the model system of the freshly prepared whipped flour semi-finished product of (Fig. 2.38), which contains 3.0% gelatin in a composition with 0.2% xanthan, at a concentration of 0.09% of the transglutaminase enzyme, the consistency defined as dense and elastic with ultimate stress corresponds to shear strength of 86.0±1.0 kPa, at a concentration of 0.07% - as dense, elastic and moderately elastic with an ultimate shear stress of 58.0±1.0 kPa, at a concentration of 0.05% - as soft , elastic, plastic with ultimate shear stress of 19±1.0 kPa.

It has been proven that the rational concentration of the transglutaminase enzyme in the recipe of the dough of the model system of the whipped flour semi-finished product is a concentration of 0.07±0.01%, which best corresponds to the value of the limit value of the shear stress of the dough of the control sample.

2.6 Optimizing the influence of the concentrations of the structuring components of the model systems of the whipped flour semi-finished product on the parameters of the viscosity and moisture-retaining capacity of the dough blank

In order to check the adequate and effective use of the main structuring components of the whipped flou rsemi-finished product dough, in order to optimize their concentrations and determine the optimal limits of influence on the physicochemical properties, the three-level Box-Behnken plan [91,92] was chosen to model the viscosity η (Па·с) and moisture-retaining capacity of the MRC (%) - the main optimization parameters. Optimization parameters depended on the content of structuring components: glutaminase $m_{тг}$, gelatin $m_{ж}$, xanthan $m_{к}$, as well as on the value of the factors and their variation intervals

The levels of factor variation were chosen based on the results and analysis of previous experimental studies of model systems of whipped semi-finished product, namely:

– study of the influence of concentrations of recipe components and temperature on the viscosity of model systems;

– study of the mechanism of formation of gelatin-xanthan polyelectrolyte complexes in the presence of TG enzyme using IR spectroscopy;

- study of the influence of technological factors on the foaming process of the "water-gelatin-xanthan" system with modification by the enzyme tranglutaminase (chapter 2.2);

– study of the effect of the transglutaminase enzyme on the moisture-retaining capacity of the whipped flour semi-finished product dough;

- substantiation of parameters of heat treatment of whipped flour semi-finished product;

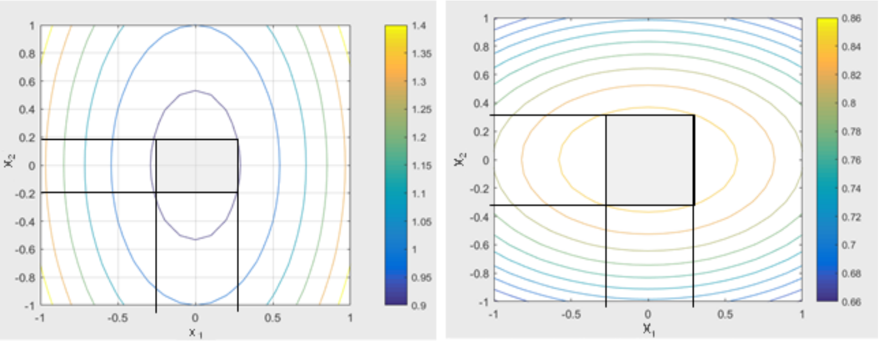
– study of the forms of moisture connection in model systems of the whipped flour semi-finished product during freezing-heating by the method of thermograms of differential-scanning calorimetry;

- research of structural and mechanical characteristics of the dough blank of the whipped flour semi-finished product.

The lower and upper limits of variation of the components were determined experimentally (Fig. 2.39...2.42) during the creation of solutions and measurement of their viscosity.

Research was conducted on model systems containing the enzyme transglutaminase, gelatin and xanthan.

The methods of correlation-regression analysis within the framework of paired models: enzyme transglutaminase-gelatin, enzyme transglutaminase-xanthan gelatin-xanthan were determined the rational concentrations of the components of the model systems of whipped flour semi-finished product. Adequacy of the physico-chemical viscosity model, similarity of bond forms, factor levels, termination coefficients were taken as a basis.

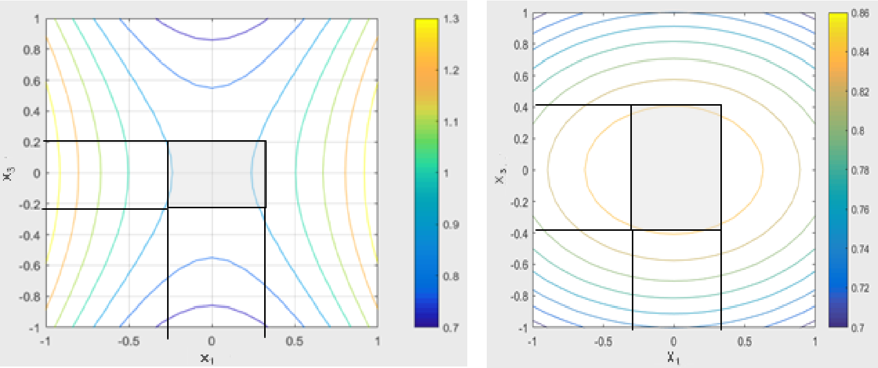


а б

Fig. 2.39. Dependence of lines of equal viscosity values (a); MRC (b) of the paired model of whipped flour semi-finished product from the content of the main components: x_1 – tranglutaminase enzyme; x_2 – gelatin

The obtained dependences of the lines of equal values of viscosity as a function of the concentration of the main components $\eta=f(x_i;x_j)$ and MRC as a function of the concentration of the main components $W=f(x_i;x_j)$ it is proved that within the limits of the paired model at concentrations of the enzyme transglutaminase 0.05 ...0.09% and gelatin 1.0...3.0%, the optimal viscosity value is in the interval $(1.15\pm0.1)\times10^{-3}$ Pa·s; (Fig. 2.39, a), the optimal value of MRC is in the range of 76±3% (Fig. 2.39, b).

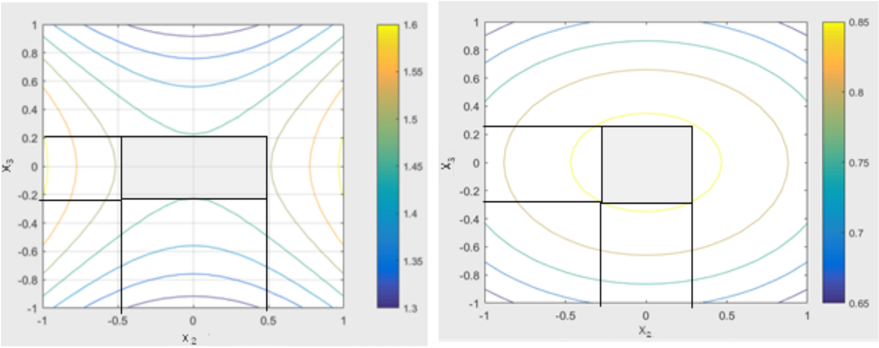
Within the limits of the paired model, at concentrations of the enzyme transglutaminase 0.05...0.09% and xanthan 0.1...0.3%, the optimal viscosity value is in the interval $(1.0\pm0.1)\times10^{-3}$ Pa·s (Fig. 2.40, a); the optimal value of MRC is in the interval of 78±3% (Fig. 2.40, b)



a b

Fig. 2.40. Dependence of lines of equal viscosity values (a); MRC (b) of the paired model of whipped flour semi-finished product from the content of the main components: x_1 – tranglutaminase enzyme; x_3 – xanthan

Within the limits of the paired model, for the concentration of gelatin 1.0...3.0% and xanthan 0.1...0.3%, the optimal viscosity value is in the interval (1.45±0.1)×10^{-3} Pa·s (Fig. 2.41, and); the optimal value of the MRC is in the interval of 75±3% (Fig. 2.41, b).



a b

Fig. 2.41. Dependence of lines of equal viscosity values (a); MRC (b) of the paired model of whipped flour semi-finished product from the content of the main components: x_2 - gelatin; x_3 – xanthan

According to the Cochran criterion, at least 95% of the statistical dependence of viscosity and moisture retention capacity on the concentration of the main components of the model system of the whipped flour semi-finished product is described by the obtained regression curves [90, 91, 92].

After determining the rational limits of the parameters, a three-dimensional model (Fig. 2.42) of the dependence of viscosity on the concentration of two parameters ($C_3^2 = 3$options) was built.

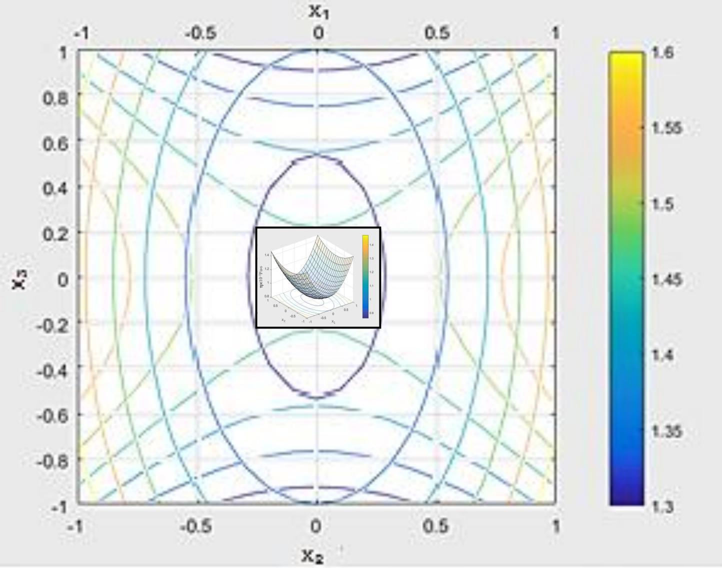


Fig. 2.42. Dependence of the lines of equal values of the viscosity of the paired model of the whipped flour semi-finished product on the content of the main components: x_1 – tranglutaminase enzyme; x_2 – gelatin; x_3 – xanthan

The mathematical modeling made it possible to determine the optimal values of the main structuring components in the basic recipe of the model system of the whipped flour semi-finished product: transglutaminase enzyme 0.05...0.09% and gelatin 1.0...3.0%, xanthan 0.1...0.3%; the optimal value of viscosity in the interval 1, 45±0.1 Pa·s and moisture-retaining capacity in the range of 78.0±3.0%, which is consistent with previous experimental studies.

The model system of the whipped flour semi-finished product in its composition does not contain egg products, characteristic of this type of product - biscuits, in addition, the addition of the enzyme transglutaminase to the recipe allows the formation of a stable protein framework network in the whipped flour semi-finished product, which makes it possible to store the semi-finished product in dry form mixture for a long time.

CHAPTER 3. DEVELOPMENT OF THE WHIPPED FLOUR SEMI-FINISHED PRODUCT TECHNOLOGY WITH THE USE OF GELATIN AND TRANSGLUTAMINASE ENZYME

3.1 Development of recipe and technology of the whipped flour semi-finished product

A number of experimental studies with individual main recipe components, their polyelectrolyte complexes: gelatin + xanthan + transglutaminase, gelatin + xanthan, gelatin + xanthan + sugar powder, gelatin + xanthan + sugar powder + transglutaminase and the finished semi-finished product allowed us to scientifically substantiate the recipe (Table 3.1) [93, 94] normatively enshrined in the developed and approved technical conditions of TS U 10.6-42087560-001:2019 "Dry mixture for whipped semi-finished product" (appendix A) and the scheme of the technological process of production (Fig. 3.2) of whipped flour semi-finished product, normatively enshrined in the developed and approved technological instruction.

During the determination of the recipe composition in order to preserve the basic laws of the technological process, a model of the technological scheme for obtaining a whipped flour semi-finished product as a technological system was developed (Fig. 3.1), the functional components of which can be distinguished by the method of decomposition-aggregative approach in the form of separate subsystems A_1, A_2, B, C, D.

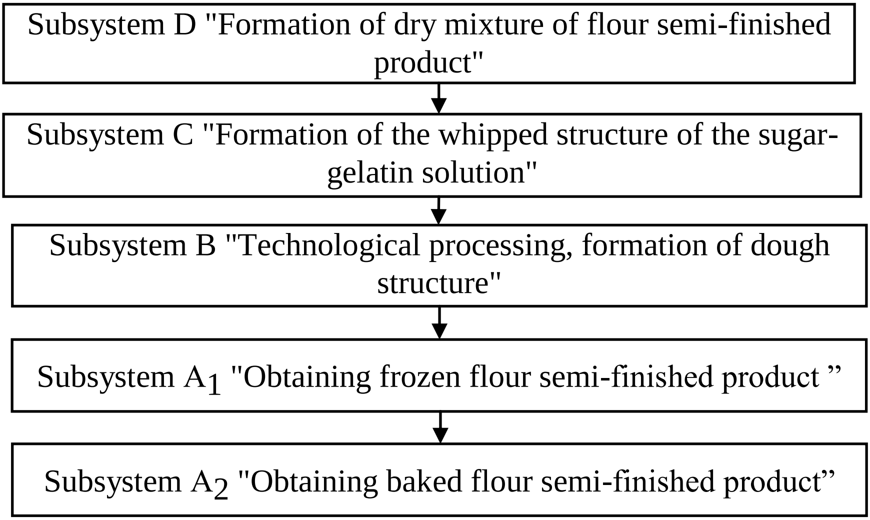


Fig. 3.1. Model of the technological system for the production of whipped flour semi-finished product

To substantiate the technological stages (Fig. 3.2), we decomposed the developed model of the technological scheme of the production of whipped flour semi-finished product (Fig. 3.1) as a complete technological system into the following subsystems:

Subsystem A_2 "Obtaining baked flour semi-finished product" is formed as a result of the synthesis of subsystem B "Technological processing, formation of dough structure". Subsystem A_1 "Obtaining frozen flour semi-finished product" is also formed as a result of the synthesis of subsystem B

"Technological processing, formation of dough structure", if the semi-finished product is subject to long-term storage.

Table 3.1

Summary recipe of whipped flour semi-finished product per 100 kg

Raw material	Mass fraction of dry substances, %	Total costs of raw materials taking into account losses in the technological process, kg	
		in nature	in dry substances
Gelatin	84,0	3,0	2,52
Xanthan gum	85,0	0,2	0,05
Tranglutaminase enzyme	99,9	0,07	0,09
Powdered sugar	99,85	29,0	0,09
Whole wheat flour	85,5	50,0	42,75
The identical to the natural flavoring "Cream Caramel"	99,85	0,2	0,19
Drinking water		29,38	–
Total		111,85	45,69
Output		100,0	

In turn, the formation of subsystem B "Technological processing, formation of dough structure" takes place in the process of synthesis of subsystem C "Formation of the whipped structure of sugar-gelatin solution", which is hierarchically dependent on subsystem D "Formation of dry mixture of flour semi-finished product".

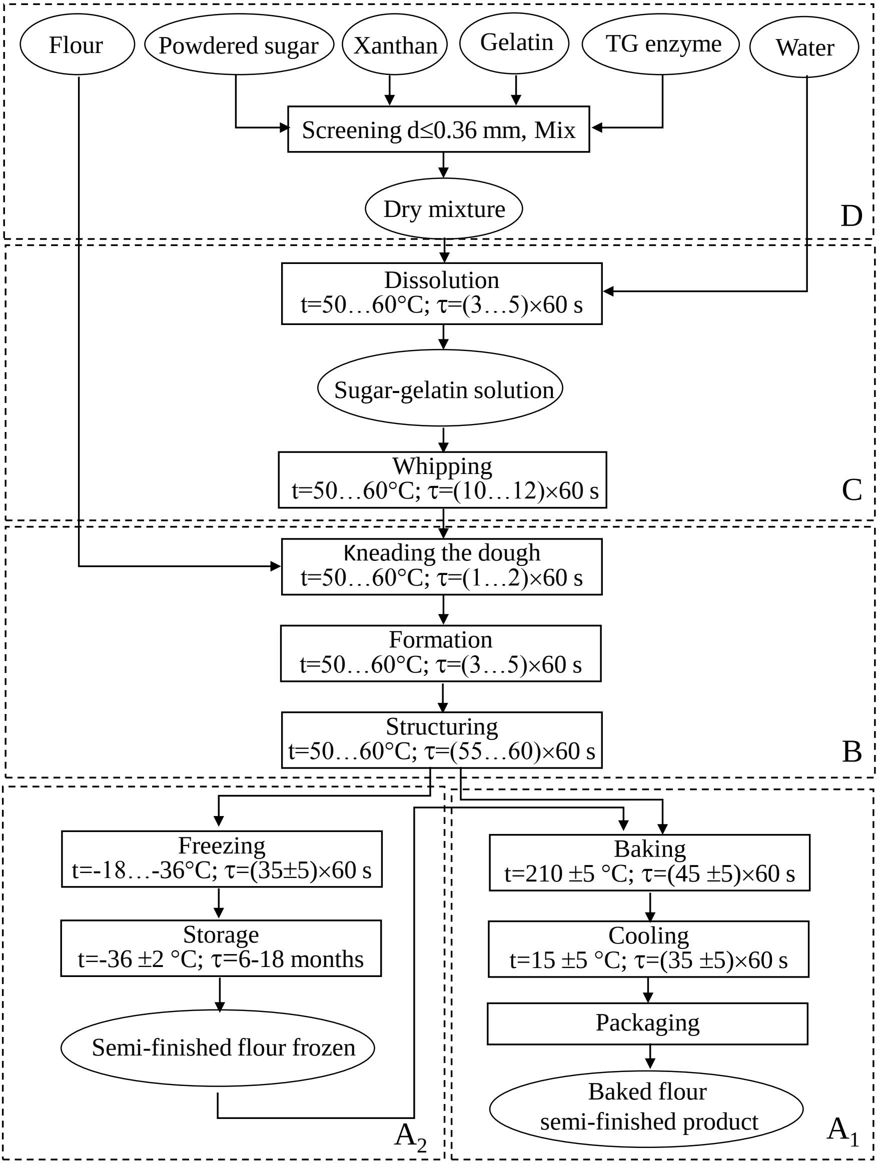


Fig. 3.2. Technological scheme of whipped flour semi-finished product

So, taking into account that the existence of this technological system as a whole is ensured by the functioning and hierarchical dependence of its separate subsystems A1, A2, B, C, D, for the study and scientific justification of the technological stages of obtaining whipped flour semi-finished product within these subsystems, we decomposed them into separate tasks (Table 3.2), the solution of which generally ensures the achievement of the main goal of the technological system [132, 140, 144, 173, 174].

Subsystem D "Formation of a dry mixture of flour semi-finished product" ensures the formation of a homogeneous dry mixture, which will allow the formation of the required dissolution quality with a minimum duration of the process due to the rational dispersion and ratio of recipe components.

The rational value of the particle sizes of the recipe components of the dry mixture was established experimentally. The necessary conditions for rapid dissolution of the dry mixture and obtaining a solution of appropriate quality are provided by the particle size of 0.2±0.05 mm (Fig. 2.18-2.20) of the ingredients: gelatin at a concentration of 3.0±0.2% and xanthan at a concentration of 0.2± 0.05% at a dissolution temperature of 50.0±2.0°C (Fig. 2.21).

Subsystem C "Formation of whipped structure of sugar-gelatin solution" ensures the formation of a sugar-gelatin solution with a foam structure, which affects the duration of structure formation and thermal stability during heat treatment, structural and mechanical indicators, increases the nutritional value of flour semi-finished product.

Table 3.2

The structure and tasks of the constituent parts of the technological system

Subsystem		Subsystem task
marking	name	
1	2	3
A_2	Obtaining a baked flour semi-finished product	Obtaining a baked flour semi-finished product capable of maintaining the specified properties during the manufacture of cakes and the sale of finished products, substantiation of the temperature and duration of heat treatment.
A_1	Obtaining a frozen flour semi-finished product	Obtaining a frozen flour semi-finished product capable of maintaining the specified properties for baking during the storage period by realizing the functional and technological properties of the recipe ingredients, justifying the temperature and duration of storage.

End of the table 3.2

1	2	3
B	Technological processing, formation of the dough structure	Justification of the temperature and duration of kneading, formation and structuring of the dough, justification of the concentration of flavoring ingredients.
C	Formation of the whipped structure of the sugar-gelatin solution	Justification of the concentration of recipe components in the gelatin-xanthan-powdered sugar composition in the presence of TG enzyme, technological parameters of dissolution and whipping of the sugar-gelatin solution.
D	Formation of dry mixture of flour semi-finished product	Formation of the necessary dispersion and homogeneity of the dry mixture to ensure the speed and quality of its dissolution.

The implementation of the tasks of this subsystem was carried out by dissolving and whipping the prepared recipe components at a temperature of 50±2°C.

It is known that biscuit dough belongs to weakly structured systems. That is why in the technology of the whipped flour semi-finished product to ensure the necessary conditions of protein hydration during the whipping of the sugar-gelatin solution, the structuring of the dough and baking, we used gelatin as the main foaming ingredient and its high ability to create isopeptide bonds under the catalytic influence of transglutaminase, xanthan in as an additional thickener of the system and the transglutaminase enzyme as a structure stabilizer [48, 51, 143].

Also, taking into account modern trends regarding egg products, which are included in the list of food products that can cause allergic reactions or intolerance, the recipe uses gelatin in a composition with xanthan in the presence of the TG enzyme, instead of melange.

which, when whipped with powdered sugar, allows the formation of a stable protein framework network in semi-finished flour. At the same time, the viscosity increases probably due to the partial binding of moisture and the more active formation of polyelectrolyte complexes of gelatin and xanthan in the presence of powdered sugar.

The presence of a large amount of sugar in the dough without fat gives the products excessive hardness. Also, the size of the sugar particles has a great influence on the quality of the dough and products. To obtain a plastic dough, in which the water content is sharply limited, we used not granulated sugar, but powdered sugar. This is due to the fact that in a relatively small amount of water, the entire amount of sugar provided by the recipe cannot be completely dissolved, and crystals remain undissolved, which will be visible on the surface of the semi-finished product and will deteriorate its quality [140, 167, 168].

It was established that within the temperature range of (30...50)±1°C, the maximum foaming capacity - (300±9...320±9)% is possessed by the "water-gelatin" model systems with a gelatin concentration of 3...5%. It has been experimentally proven that the maximum volume of foam provides whipping for (8...10)×60 s.

Subsystem B "Technological processing, forming the structure of the dough" ensures the production of dough based on a whipped sugar-gelatin solution by kneading flour together with flavoring, forming in silicone molds or from parchment paper and structuring for 60±5 min at a temperature of 50°C, followed by heating the dough mass to 90...95°C to inactivate the TG enzyme. The catalytic effect of TG causes the possible formation of intermolecular hydrogen bonds with the proteins of the gluten complex of flour, contributes to the formation of the texture and taste qualities of the finished product.

The introduction of flavoring into the recipe is dictated by the need to provide specific organoleptic properties to the flour semi-finished product.

It was experimentally established that the introduction of transglutaminase enzyme into the gelatin-xanthan composition increases the hydration capacity by 31.0±0.2% and thermal stability during baking of the semi-finished product.

If less than 2.5% gelatin is added, the dough will not increase in volume. With the introduction of gelatin more than 3.0%, the structure of the semi-finished product will be too elastic, which will complicate the further processing of whipped semi-finished product.

The introduction of xanthan gum less than 0.1% will not affect the structural properties of the dough mass, with the introduction of xanthan gum in the amount of 0.3%, the density of the dough mass increases significantly.

When adding powdered sugar less than 27.7% or more than 32%, the desired stable fine structure of the dispersed dough mass system will not be formed. Increasing the content of powdered sugar leads to a significant increase in viscosity and the appearance of an overly sweet taste. A decrease in the content of powdered sugar leads to a decrease in the amount of dry substances and a deterioration in the taste properties of the finished products.

An increase in the content of the transglutaminase enzyme above 0.1% leads to an increase in the rate of crosslinking of the structure and will lead to a too rapid increase in strength, which will complicate the mixing process. When the content of transglutaminase is reduced to less than 0.05%, the finished product does not acquire the required structure.

If less than 50% wheat flour is added, the dough will not acquire the necessary structure and will be too liquid. If more than 60.0% of flour is added, the dough will be too thick.

Subsystem A_1 "Obtaining frozen flour semi-finished product". To implement the tasks of the subsystem, the structured and inactivated by TG dough blank was frozen at temperatures from -18°C to -36°C for 35±5 min in a shock freezing chamber, packed under vacuum in polyethylene film Polyethylene film FLT 0.110 TS U 25.2-14022407-00 8 2010 and stored in a refrigerating chamber at a temperature of -36°C for 6 months.

Subsystem A_2 "Obtaining baked flour semi-finished product ". To implement the tasks of the subsystem, freshly prepared structured and inactivated by TG dough blank, or after storage in a refrigerator, was baked without defrosting at a temperature of 210±5°C for 40-45 minutes. After baking and cooling - 20-30 minutes, removing from the molds and standing for 8-10 hours at a temperature of 15±2°C for cooling, packed and sold.

3.2 Study of nutritional and biological value of the whipped flour semi-finished product

The nutritional value of food products is determined by their content of proteins, fats, carbohydrates, minerals and vitamins. In the developed baked whipped flour semi-finished product, the content of food substances in each individual name will be individual, but the fluctuations of the absolute values of the indicators will be insignificant and will lie within the rational concentration of recipe components. In this regard, we consider it possible to conduct a study of the nutritional value and its changes under the influence of various technological factors on a specific example of a whipped flour semi-finished product.

Nutritional value indicators were determined according to known methods [80, 97, 98, 100, 102, 103].

The general chemical composition (Table 3.3) and nutritional value (Table 3.4) of whipped flour semi-finished product was determined by the content of proteins, fats, vitamins and minerals in its composition [96, 103, 108, 109, 110].

Analyzing the general chemical composition (Table 3.3), it should be noted that the recipe of whipped flour semi-finished product contains 8.9±0.3% protein substances, which make up 19.5% of the total dry matter content and are provided by the main protein-rich recipe component - flour and slightly gelatin.

Table 3.3

The general chemical composition of whipped flour semi-finished product

Name	Contents, %	In solids %
Mass fraction of moisture	54,3±1,0	0
Mass fraction of dry substances	45,7±1,0	100
Mass fraction of protein	8,9±0,1	19,5
Mass fraction of fat	1,4±0,1	3,06
Mass fraction of carbohydrates	28,2±0,3	61,7
Mass fraction of ash	7,2±0,1	15,7

It should be noted the significant content of carbohydrates, which make up 52.9% of the total content of dry substances

From the point of view of biological value, in addition to the total protein content in the product, its quality is also quite important, which is characterized primarily by the content and ratio of essential amino acids.

The content of amino groups in the samples was determined according to the Lowry method, which is based on the formation of colored products during the interaction of

Folin's reagent with alkaline solutions of proteins according to the calibration schedule. The color intensity depends on the content of tryptophan and tyrosine amino acids in the experimental protein.

The availability of amino acids is affected by a number of factors, mainly related to their incomplete digestion, which is observed in the presence of cross-links in the protein molecule in the presence of protease inhibitors, as well as when inhibiting the absorption of amino acids by peptides and peptide-like compounds [102...107].

To establish the biological value of whipped flour semi-finished product, its amino acid composition was determined (Table 3.4).

In the course of research (Table 3.4), 18 amino acids were identified and quantified, the total content of essential amino acids is 27.3%, which allows us to characterize whipped flour semi-finished product as a product of high biological value.

The balance of the amino acid composition, its primary structure, in particular the content and quantitative ratio of essential amino acids (Table 3.5), is one of the most important indicators of the nutritional value of the whipped flour semi-finished product [102, 103].

By analyzing the content of amino acids in comparison with the physiological norms of nutrition, it was established that the ratio of amino acids has certain differences from the optimal one. An insufficient content of such amino acids as lysine, methionine and deficiency of the amino acid tryptophan is observed [102, 103].

Table 3.4

The content of amino acids in whipped flour semi-finished product

Amino acid	Content	
	mg /%	%
Essential amino acids		
Valin	292,7	4,27
Isoleucine	249,9	3,64
Leucine	473,3	6,90
Lysine	231,6	3,38
Methionine	93,0	1,36
Threonine	198,2	2,89
Tryptophan	47,5	0,69
Phenylalanine	285,6	4,17
Together	**1871,7**	**27,30**
Nonessential amino acids		
Aspartic acid	326,8	4,77
Arginine	413,8	6,04
Alanine	415,4	6,06
Histidine	115,9	1,69
Glutamic acid	1709,4	24,93
Proline	916,2	13,36
Serin	318,5	4,64
Tyrosine	93,9	1,37

Cystine	105,0	1,53
Glycine	570,0	8,31
Together	**4984,8**	**72,70**
In total	**6856,5**	**100,00**

Table 3.5

Biological value of whipped flour semi-finished product

Amino acid	FAO/WHO scale		Semi-finished product of whipped flour	
	mg/1g of protein	Amino acid rate	mg/1g of protein	Amino acid rate
Valin	50	1,0	47	0,40
Isoleucine + leucine	110	1,0	134	0,90
Lysine	55	1,0	27	0,25
Methionine	25	1,0	10	0,52
Threonine	40	1,0	31	0,67
Tryptophan	10	1,0	10	-
Phenylalanine + tyrosine	60	1,0	89	1,05

It is known that the consumer properties of the baked whipped flour semi-finished product are determined, in addition to the organoleptic and physico-chemical quality indicators, by the nutritional value and physiological effect on the human body. Since the main components of the overall chemical composition of the finished product are protein 8.9±0.1% and carbohydrates - 28.2±0.3% (Table 3.3) and, taking into account the fact that, in terms of solids, the protein content is 19.5%, carbohydrates - 61.7%, there is a need to study their hydrolysis under in vitro conditions [175-178].

The increase in the nutritional value of the finished biscuit-type product is determined not only by the content of physiologically functional ingredients, such as protein and carbohydrates, contained in it, but also by the degree of their digestibility in the human body. Therefore, we determined the degree of invitro digestibility of protein substances (Fig. 3.3) and carbohydrates (Fig. 3.4) of the backed whipped flour semi-finished product. The intensity of digestibility of the proteins of the backed whipped flour semi-finished product was determined by the increase in the mass fraction of the final products of the enzymatic hydrolysis of protein substances - free amino acids (Fig. 4.3) and the mass fraction of reducing sugars (Fig. 4.4).

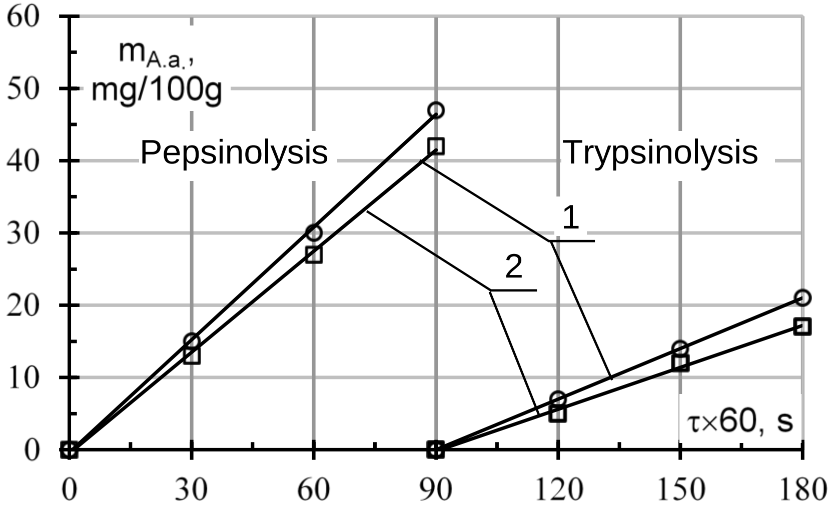


Fig. 3.3. In vitro digestibility of proteins: 1 - baked whipped flour semi-finished product; 2 - control

It has been confirmed (Fig. 3.3) that the rate of enzymatic hydrolysis of the protein of the baked whipped flour semi-finished product of takes place in two stages. A slight decrease in the degree of digestibility of proteins of the baked whipped flour semi-finished product containing gelatin-xanthan complex in the presence of TG enzyme by 5.1% at the stage of pepsinolysis and by 7.2% at the stage of trypsinolysis compared to the control sample can be explained by the synergistic interaction of xanthan with gelatin and redistribution associated and unassociated hydroxyl groups, the formation of intermolecular hydrogen bonds with proteins of the gluten complex of flour, which complicates the access of proteolytic enzymes to the substrate due to the formation of protein-polysaccharide complexes, increasing the degree of cross-linking of the structure and the degree of bonding of OH groups, also due to activation energy of bound water [176].

The intensity of enzymatic hydrolysis of carbohydrates of the baked whipped flour semi-finished product was studied by analyzing the increase in the mass fraction of reducing sugars in terms of solids (Fig. 3.4) in the extract from the pulp of the finished semi-finished product during hydrolysis. Determination of carbohydrate hydrolysis products (reducing sugars) accumulated in the hydrolysis process was carried out according to Bertrand's method [177]. A biscuit made according to traditional technology was used as a control sample.

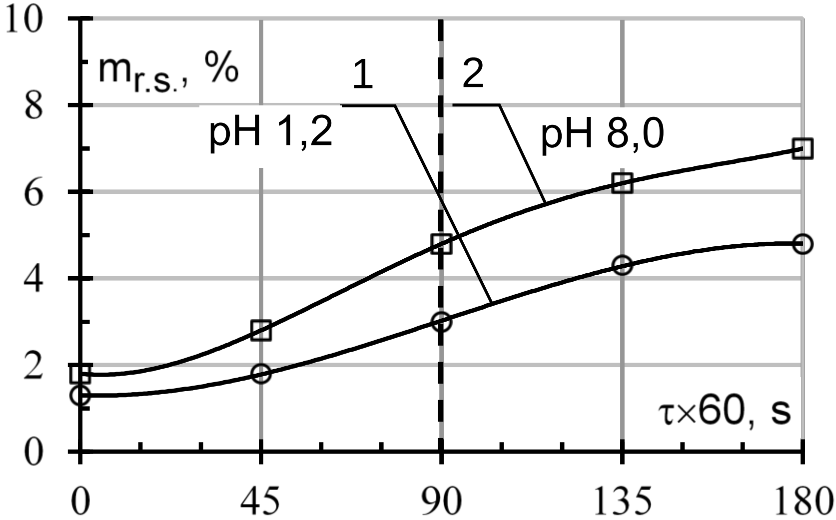


Fig. 3.3. In vitro digestibility of carbohydrates: 1 - baked whipped flour semi-finished product; 2 – control

The main carbohydrate of the baked whipped flour semi-finished product is starch. The degree of its digestibility can be characterized by the rate of enzymatic hydrolysis in the gastrointestinal tract under the action of amylolytic enzymes.

It was established (Fig. 3.4) that the rate of enzymatic hydrolysis of carbohydrates of the baked whipped flour semi-finished product containing hydrocolloids gelatin and xanthan in the presence of TG enzyme is 2.2% lower compared to the rate of transformation of carbohydrates of the control sample. Thus, after 180□60 s of hydrolysis of the whipped flour semi-finished product, 4.8% of reducing sugars accumulate, and 7.0% of the control sample - a biscuit made according to traditional technology.

This can be explained by the formation of protein-polysaccharide complexes, the cross-linking of the structure of the baked whipped flour semi-finished product, which increases the viscosity of the system and reduces the availability of carbohydrates for the action of digestive enzymes [176].

Therefore, the stronger the bound water, the less it supports the processes that destroy the food product, the less it supports the hydrolytic processes in the developed products, slowing down the process of digestion of protein substances of the baked whipped flour semi-finished product, both at the pepsin and trypsin stages and reducing the rate of enzymatic hydrolysis of carbohydrates than the control sample, which is positive because the carbohydrate load on the body decreases [178].

Conducted studies of the mineral composition (Table 3.6) showed that the ash residue of the whipped flour semi-finished product contains macro- and microelements. Baked whipped flour semi-finished product is a significant source of potassium, phosphorus, sulfur, and calcium. In addition, it is rich in such important minerals as magnesium and sodium.

Table 3.6

The results of research on the mineral composition of the whipped flour semi-finished product

Name	Content mg/100g
Potassium, K	122,0±0,1
Calcium, Ca	18,0±0,1
Silicon, Si	4,0±0,1
Magnesium, Mg	16,0±0,1
Sodium, Na	3,0±0,1
Sulphur, S	70,0±0,1

Phosphorus, P	86,0±0,1

The study of the vitamin composition of the whipped flour semi-finished product (Table 3.7) showed that the product is rich in choline (B4), a water-soluble vitamin necessary for the treatment of liver diseases and atherosclerosis. The most important from a biological point of view is phosphocholine, which plays an important role in various syntheses, for example, anabolism of lecithin and methionine.

Table 3.7

The results of studies of the vitamin composition of whipped flour semi-finished after baking

Name	Content mg/100g
B1, thiamine	0,08
B2, riboflavin	0,03
B4, choline	26,0
B5, pantothenic complex	0,15
B6, pyridoxine	0,09
B9, folates	0,0274
E, alpha tocopherol	0,85
H, biotin	0,0009
PP,	2,4
Niacin	0,7

It is known that the level of water mobility determines its ability to participate in physical and chemical processes and promote the development of microorganisms [167]. In the presence of high osmotic pressure in products, the development of microorganisms is blocked due to dehydration of their cells. That is, due to the transition of water molecules into a bound state, the process of microbiological damage to bakery and biscuit products is slowed down [168].

Microbiological studies of freshly baked whipped flour semi-finished product and after storage for 8 days at a temperature of +2...+6 °C are given in table. 3.8, toxicological studies are given in table. 3.9. It was established that coliform bacteria were consistently absent in the finished product that was stored; pathogenic microorganisms, salmonella, staphylococcus aureus, yeast and mold fungi were not detected in the studied samples.

Table. 3.8

Results of microbiological research of baked whipped flour semi-finished product

Indicator	Requirements of regulatory documents	Research results	
		freshly baked sample	after storage 8 days
1	2	3	4

Mesophilic aerobic and facultatively anaerobic microorganisms, CFU in 1 g of product	Not more 5×10^2	not found	$0,8\times10^1$

End of the table 3.8

1	2	3	4
Escherichia coli bacteria, including polymorphic ones, in 0.01 g of the product	not allowed	not found	not found
Coagulase-positive staphylococci in 0.01 g	not allowed	not found	not found
Pathogenic microorganisms, including salmonella bacteria in 25 g	not allowed	not found	not found
Yeast, CFU in 1g	not allowed	not found	not found
Moldy mushrooms, CFU in 1g	not allowed	not found	not found

Therefore, according to microbiological indicators, the baked flour semi-finished product after storage for 8 days is safe for consumption and meets the established standards.

The conducted studies proved that the microbiological indicators are consistent with the national standards.

Table 3.9

The results of toxicological studies of baked whipped flour semi-finished product

Indicator	Permissible level, mg/kg, no more	Actual content, mg/kg
1	2	3
Plumbum	0,5	0,1
Cadmium	0,1	0,03
Arsenic	0,3	0,1
Copper	10,0	7,2
Mercury	0,02	0,01
Aflatoxin B_1	0,005	0,003

End of the table 3.9

As shown by the results of toxicological studies of the baked whipped flour semi-finished product (Table 3.9), it meets the safety criteria for the content of toxic elements significantly less than the regulatory requirements [108].

Therefore, it can be concluded that according to the results of microbiological studies (Table 3.8), the baked whipped flour semi-finished product of in a packaged form can be stored for 8 days at a temperature of +2...6 °C.

3.3 Study of the physicochemical and microbiological characteristics of dough of the whipped flour semi-finished product during storage

3.3.1 Changes in structural and mechanical characteristics

To study the changes in the structural and mechanical characteristics of the dough for whipped flour semi-finished product during storage, the dough, after transglutaminase enzyme inactivation, was frozen at temperatures -36.0±2.0°C and stored at -36.0±2.0°C for 8 months. The study of the ultimate shear stress of the dough model system of the whipped flour semi-finished product (Fig. 3.5), which contains gelatin 3.0% in a composition with xanthan 0.2% by interaction with the enzyme transglutaminase of different concentrations, was carried out after defrosting after certain periods of storage time.

It has been proven (Fig. 3.5) that when the content of transglutaminase enzyme increases within the range of 0.05...0.09, the ultimate shear stress during storage of dough of the model system of the whipped flour semi-finished product increases from 30 to 120 kPa, obviously as a result of the formation of intermolecular hydrogen bonds with proteins of the gluten complex of flour and increasing the degree of bonding of –OH groups in the system with flour.

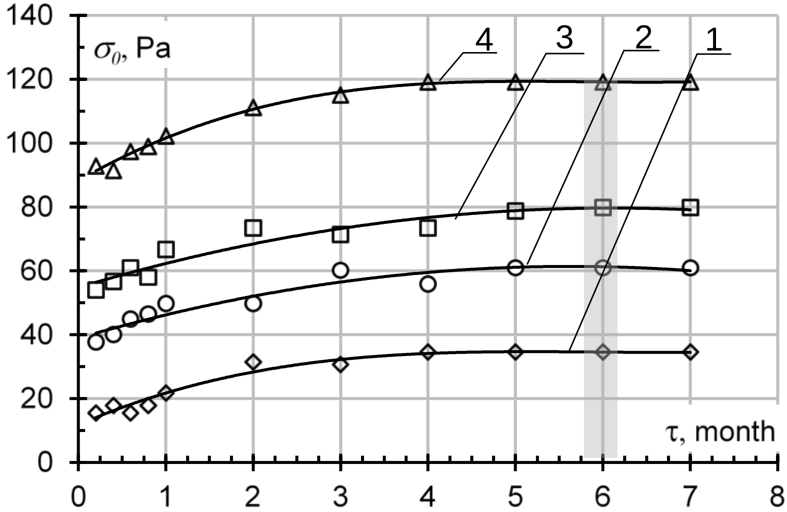


Fig. 3.5. Infusion of gelatin 3.0% in a composition with xanthan 0.2% by interaction with the enzyme transglutaminase,%: 1- 0.05; 2- 0.07; 3- 0.09; 4- control, on the ultimate shear stress of dough of the whipped flour semi-finished product during storage at a temperature of -36°C

The analysis of the ultimate shear stress of the dough blank of the model system of the whipped flour semi-finished product of during storage (Fig. 3.5) found that during storage for the first 3 months at a concentration of the transglutaminase enzyme of 0.05%, the ultimate shear stress increases by 14 kPa and is 30 kPa, according to concentration of transglutaminase enzyme 0.07%, increases by 21 kPa and is 89 kPa, which is only 8 kPa more and best corresponds to the value of the ultimate shear stress of the dough of the control sample. At a transglutaminase enzyme concentration of 0.09%, the ultimate shear stress increases by 28 kPa and is 120 kPa. When stored for the next 2 months, the ultimate shear stress increases insignificantly and, at a concentration of the transglutaminase enzyme from 0.05 to 0.09%, is within 5...6 kPa.

Therefore, taking into account the dynamics of the ultimate shear stress of the dough blank of the whipped flour semi-finished product, storage at a temperature of -36 °C for 6 months is a rational duration, as well as the rational concentration of the transglutaminase enzyme in the recipe of the dough of the dough of model system of the whipped flour semi-finished product is 0.07%, which is the best corresponds to the value of the ultimate shear stress of the control sample.

3.3.2 Changes in moisture retention capacity

Protein products contain water in various forms. One part of it is represented by free water, and the other by so-called bound water. The quantitative content of moisture in the product, as well as the ratio of free and bound water, play an important role in the structuring and stabilization of the system. An important property of food proteins is their hydration, or the ability to bind water. It is known that the moisture-retaining capacity largely determines the organoleptic properties of many food products and is closely correlated with the elasticity, juiciness, tenderness of finished products [169, 170].

When kneading the dough of whipped flour semi-finished product, the flour particles, swelling, begin to quickly absorb water. The sticking of swollen particles of flour into a solid mass, which occurs as a result of the mechanical action of the stirrer during kneading and ensures the formation of dough. The leading role in the formation of dough with its inherent properties of elasticity, plasticity and viscosity belongs to the protein substances of flour. The water-insoluble protein substances of flour (gliadin and glutenin), which form gluten, bind water in the dough not only by adsorption, but also osmotically. Osmotic swelling occurs as a result of the diffusion of water molecules inside the cells of the protein molecule. Osmotic binding of water mainly causes swelling of proteins. Gluten proteins are able to swell in cold water and retain water in an amount approximately 2-2.5 times greater than its weight. Swollen protein substances during kneading form a spongy "framework" in the dough, which largely determines the specific physical properties of the dough - its stretchability and elasticity. This protein structural framework is often called gluten [160, 170, 181].

The interaction of protein substances of flour with water consists of two main stages, which are closely related to each other. The first stage of swelling consists in the adsorption binding of water with the formation of water shells around the flour particles. At the same time, the interaction of water with hydrophilic groups occurs not only on the surface of flour particles, but also inside them. The first stage of swelling is an exothermic process (with the release of heat) and is not accompanied by a significant increase in the volume of particles, because the amount of water bound in this way is small and is about 30%. The second stage is the so-called osmotic swelling, which occurs as a result of the diffusion of water molecules inside the flour particles. The second stage of swelling proceeds without the release of heat, but with a significant increase in the volume of protein micelles, because the amount of water bound by proteins in this way is more than 200%. Most proteins, including gluten proteins, are not homogeneous and represent a complex of different fractions with different molecular weights and different water absorption capacity [140, 169, 170].

In the technological process of the production of whipped flour semi-finished products, water is an active participant in many reactions (hydrolysis, hydration, swelling of proteins, whipping, etc.). Free moisture ensures the dissolution of the ingredients of the dry mixture and the formation of a whipped foam-like structure of the gelatin-sugar solution, and the bound water determines the stability and heat resistance of the model system [140, 169, 170].

Based on the experience of making a whipped flour semi-finished products according to traditional technologies, increasing the proportion of bound moisture in the whipped structured dough prepared for baking was carried out by adjusting the content of powdered sugar in the recipe to increase the percentage of dry substances [140, 169, 170].

During the storage of product of whipped flour semi-finished dough at a temperature of -36°C, a redistribution of bound and free moisture occurs. Free water freezes and, as a result of the transition of a part of weakly bound water to a free state, the system acquires a new equilibrium state.

It is known that polysaccharide molecules are chains rolled into a ball that, in the event of falling into water or an environment containing free moisture, untwist, thereby limiting the mobility of water molecules. Thus, the presence of polysaccharides in the solution leads to an increase in its viscosity, which affects the structure of the ice and prevents the movement of frozen water [182-185].

The introduction of gelatin, xanthan and transglutaminase enzyme into the recipe of the semi-finished product makes it possible to bind and immobilize a large amount of water, which makes it possible to regulate the viscosity of the system, the texture, reduce the surface tension, form structured layers on the surface of the interface and ensure the stabilization of the protein-carbohydrate complex in conditions of a significant decrease in temperature.

The study of the moisture-retaining capacity of dough the of whipped flour semi-finished product wrapped in parchment (Fig. 3.6) was carried out during storage at a temperature of -36 °C for 8 months. The purpose of these studies was to establish a rational duration of storage of semi-finished dough until the moment of baking.

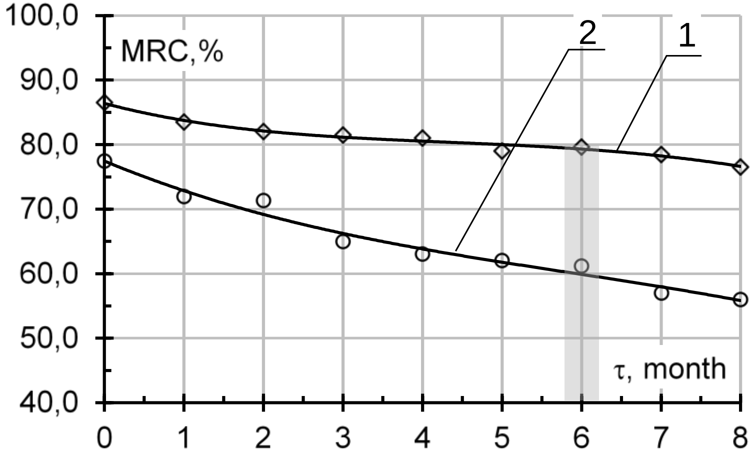


Fig. 3.6. Dynamics of the moisture-retaining capacity of dough of whipped flour the semi-finished product during storage: 1- with gelatin 3.0%, xanthan 0.2%, TG enzyme 0.09% (after inactivation); 2- control sample

It has been experimentally proven (Fig. 3.6) that at a temperature of -36 °C, the rational duration of storage of dough of whipped flour semi-finished product is 6 months. The use of hydrocolloids of gelatin, xanthan and the transglutaminase enzyme in the recipe of the semi-finished product provides the MRC of system within 80.0±5.0%, which is 20% higher than that of the control sample.

It was established that the interaction of gelatin with a concentration of 3.0±0.5% with xanthan with a concentration of 0.2±0.05 under the catalytic effect of the transglutaminase enzyme at a concentration of 0.09% ensures the ability of the protein substances of the dough of whipped flour semi-finished product to retain moisture within 80.0±5.0%, within 6 months.

That is, it is possible to predict a decrease in the quantitative losses of the finished product during the baking of whipped flour semi-finished product using xanthan and transglutaminase enzyme in combination with gelatin as a foaming ingredient.

So, according to the results of research on the moisture retention capacity of the dough (Fig. 3.6) of swhipped flour semi-finished product in a packaged form can be stored for 6 months at a temperature of -36 °C.

3.3.3 Changes in microbiological characteristics

Freezing is the most common method of food storage. At the same time, the required effect is achieved not due to the formation of ice, but due to the effect of low temperatures [186-190].

The formation of ice in the cellular structures of the whipped flour semi-finished product has two important consequences. First, non-aqueous components are concentrated in the non-freezing phase (the non-freezing phase of bound water exists in food products of any low storage temperature). Second, free water increases in volume by ~9%, crystallizing and turning into ice [186-190].

The conducted microbiological studies of the dough of whipped flour semi-finished product after storage at a temperature of -36 °C are shown in the Table. 3.10.

Table. 3.10

Results of microbiological studies of the dough of whipped flour semi-finished product after storage at a temperature of -36 °C

Indicator	Requirements of regulatory documents	Research results	
		freshly made dough	after 8 months of storage
Mesophilic aerobic and facultatively anaerobic microorganisms, CFU in 1 g of product	Not more 5×10^2	not found	Not more $0,8\times10^2$
Escherichia coli bacteria, including polymorphic ones, in 0.01 g of the product	not allowed	not found	not allowed

End of the table 3.10

Coagulase-positive staphylococci in 0.01 g	not allowed	not found	not allowed
Pathogenic microorganisms, including salmonella bacteria in 25 g	not allowed	not found	not allowed
Yeast, CFU in 1 g	not allowed	not found	not allowed
Moldy mushrooms, CFU in 1 g	not allowed	not found	not allowed

During freezing, free water passes into a crystalline state, which leads to the concentration of all non-aqueous components in a reduced amount of non-freezing bound water. At the same time, the non-freezing phase significantly changes pH, titrated acidity, viscosity, ionic strength, freezing point, surface tension, and redox potential. That is, the bound state of water molecules helps to slow down the processes of microbiological spoilage of food products [168].

It was established (Table 3.10) that coliform bacteria were stably absent in the semi-finished product dough, which was stored at a temperature of -36 °C for 6 months; pathogenic microorganisms, salmonella, staphylococcus aureus, yeast and mold fungi were not detected in the studied samples. Therefore, according to the results of microbiological studies (Table 3.10), whipped flour semi-finished product in a packaged form can be stored for 6 months by temperature -36 °C.

3.4 Study of the physicochemical characteristics of baked whipped flour semi-finished product during storage

3.4.1 Study of aging process

The aging of the baked whipped flour semi-finished product is associated with the processes of changing the state of starch and gluten in flour. During baking, the starch grains are partially gelatinization, binding the free moisture of the dough and the water released as a result of protein coagulation. And starch partially changes from a crystalline state to an amorphous state, its grains swell and increase in volume. When storing the baked whipped flour semi-finished product the reverse process occurs: gelatinized starch partially changes from an amorphous state to a crystalline state and its retrogradation occurs [191, 192].

During baking, denatured gluten loses moisture, its hydration capacity decreases, and this leads to compaction of the structure. Since in biscuit semi-finished products, gluten forms a framework of thin films, in which partially gelatinized starch grains are placed, it can be assumed that the loss of water by proteins causes an increase in the hardness of the pulp. That is, the process of staling is determined by the retrogradation of starch, and also by the transformation of gluten proteins [10, 191, 192].

One of the rational ways to ensure the freshness of the baked whipped flour semi-finished product during storage is the use of gelatin and xanthan ingredients, which, in combination with the transglutaminase enzyme, have a wide range of technological properties and at the same time contribute to improving the consumption characteristics of the products, adjusting the nutritional value, and extending the shelf life.

The process of staling of the baked whipped flour semi-finished product was analyzed by studying the degree of drying of the finished products during storage (Fig. 3.7). A decrease in this indicator confirms the increase in the degree of binding of free moisture, which allows to increase the shelf life of finished products.

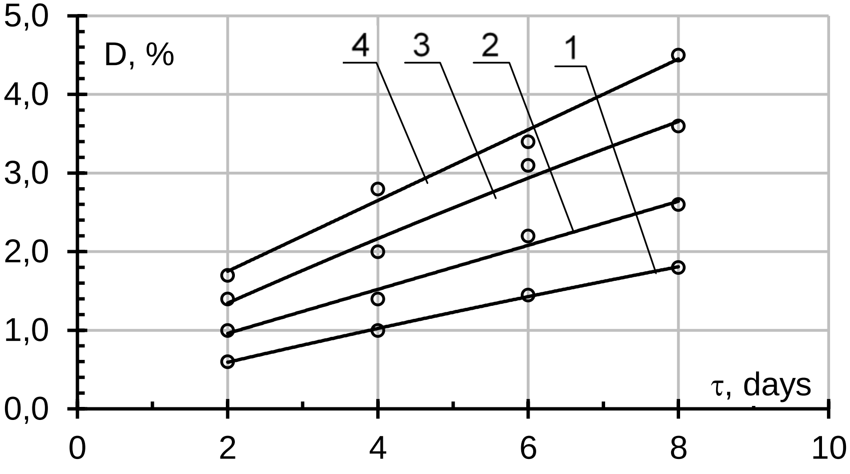


Fig. 3.7 Drying dynamics of the baked whipped flour semi-finished product with a concentration of gelatin 3.0%, xanthan 0.2% with different content of TG enzyme,%: 1- 0.05; 2- 0.07; 3- 0.09; 4 – control sample

The analysis of the curves (Fig. 3.7) showed a decrease in the degree of drying up by 0.9% for storage for 2 days and by 2.7% for storage for 8 days relative to the control sample of ready-made of baked whipped flour semi-finished product , which in the recipe contain gelatin-xanthan complex in the presence of the transglutaminase enzyme in the range of 0.05...0.09%.

So, the retardation of the staling of the baked whipped flour semi-finished product is explained by the interaction of gelatin and xanthan hydrocolloids with the enzyme transglutaminase, which prevents the evaporation of moisture from the swollen starch grains, the formation of intermolecular hydrogen bonds that envelop the starch molecules and protect the finished product from rapid drying up.

3.4.2 Study of the deformation of the pulp

Drying up of the baked whipped flour semi-finished product during storage also contributes to slowing down the rate of reduction of the deformation index of its pulp [10, 180]. The study of the deformation of the pulp was carried out every 2 days of storage (Fig. 3.8).

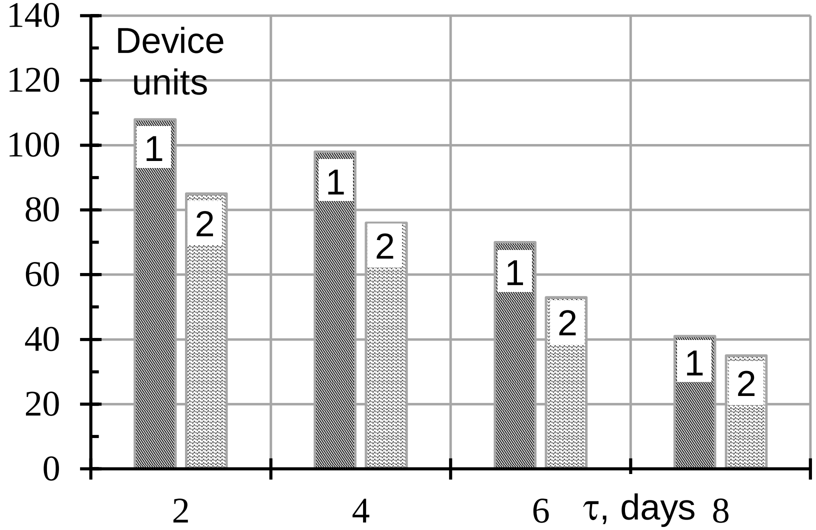


Fig. 3.8 Dynamics of pulp deformation during storage of the baked whipped flour semi-finished product - 1 (by content: gelatin 3.0%, xanthan 0.2%, TG enzyme, 0.09%); control sample - 2

The obtained experimental data confirmed the decrease of this indicator both in the studied sample and in the control sample. However, the quantitative values of the sample containing gelatin and xanthan in the presence of the transglutaminase enzyme are higher than those of the control.

It was established that the value of the deformation of the pulp of the baked whipped flour semi-finished product after 2 days of storage is greater than that of the control by 21.3%, after 4 - by 22.4%, after 6 days - by 24.3%, after 8 days - by 14.6%. After 6 days of storage, the deformation of the pulp of the sample of the baked whipped flour semi-finished product decreased by 35.2% and amounted to 70 units of the device, and of the control sample by 37.6% and amounted to 53 units of the device.

So, it was established that after 6 days of storage of the baked whipped flour semi-finished product, the drying is slower by 2.4% than that of the control sample, probably due to a decrease in the amount of free water in the finished product. We accept 6 days as a rational duration of storage. During further storage, a rapid staling of the product is observed, which is confirmed by a significant decrease in the deformation of the baked whipped flour semi-finished product and the control sample. The difference in pulp deformation between samples was only 14.6%.

3.4.3 Study of the fragility of the pulp

The fragility of the baked whipped flour semi-finished product its freshness or degree of staleness [79, 80, 193, 194]. The study of pulp fragility was carried out every 2 days of storage (Fig. 3.9).

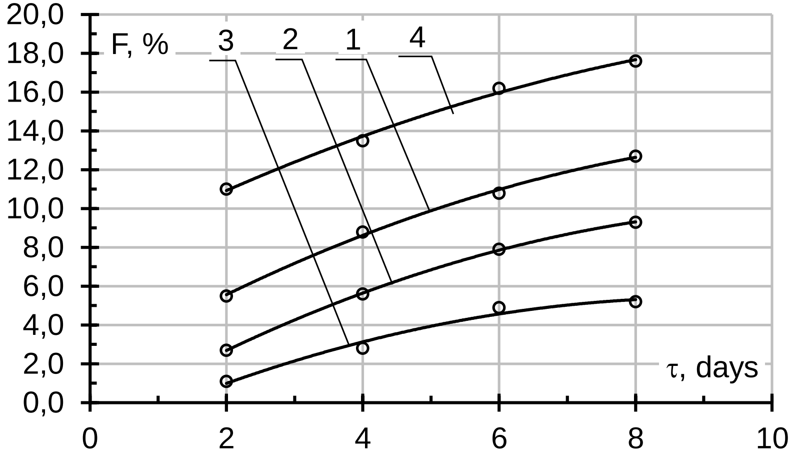


Fig. 3.9. Dynamics of the pulp fragility of the baked whipped flour semi-finished product at the concentration of gelatin 3.0%, xanthan 0.2% with different content of TG enzyme,%: 1-0.05; 2-0.07; 3- 0.09; 4 – control sample

By analyzing the fragility of the pulp of the baked whipped flour semi-finished product (Fig. 3.9), it was established that the fragility of the control sample and samples of the semi-finished product with different content of TG enzyme increases during 8 days of storage. However, after 2 days of storage, the fragility of the studied samples was less than the control for the content of transglutaminase enzyme (%) 0.05 by 10%; - 0.07 by 24.5%; 0.09 by59%, respectively. After 8 days of storage, the fragility of the tested samples was lower than the control sample by 30.7%; 52.8%; 72.2% respectively.

Studies have proven that during storage of a baked whipped flour semi-finished product for 8 days, the deformation of the pulp decreases, and the fragility increases. Drying of samples of the semi-finished product of whipped flour baked is slower than that of the control sample. That is, it can be assumed that fragility decreases due to the interaction of hydrocolloids, which ensure the binding of free water.

3.5 Research of organoleptic indicators of the quality of baked whipped flour semi-finished product

3.5.1 Study of the porosity of the whipped flour semi-finished product.

It is known that the quality of biscuit semi-finished products is determined by the volume, porosity, elasticity of the pulp, moisture, taste, aroma, color and condition of the crust [80, 81, 195, 196, 197]. During the study of the quality of the baked whipped flour semi-finished product, we paid special attention to the porosity, which, first of all, characterizes the organoleptic, structural-mechanical and technological indicators of the finished products. We took the value of the total porosity of the whipped flour semi-finished product as a quantitative characteristic of the splendor of the finished product, taking into account that an increase in this indicator indicates an increase in the volume of the product and a decrease in its hardness.

To establish changes in structural and mechanical properties, the porosity of the baked whipped flour semi-finished product with different content of transglutaminase enzyme was studied (Fig. 3.10).

From the analysis of the graphs (Fig. 3.10), it can be seen that the introduction of the enzyme transglutaminase in the range of 0.05...0.09% increases the porosity of the structure of the baked whipped flour semi-finished product of from 4 to 9%. Obviously, the formation of intermolecular hydrogen bonds with the proteins of the gluten complex of flour as a result of the catalytic effect of transglutaminase helps to reduce the degree of free water absorption by flour gluten [198], which ensures the formation of a softer structure with thin-walled porosity and improves the taste of the finished product and has a positive effect on slowing down the staling process of the finished product, and therefore increasing its storage time while keeping the semi-finished product within regulatory limits [199, 200].

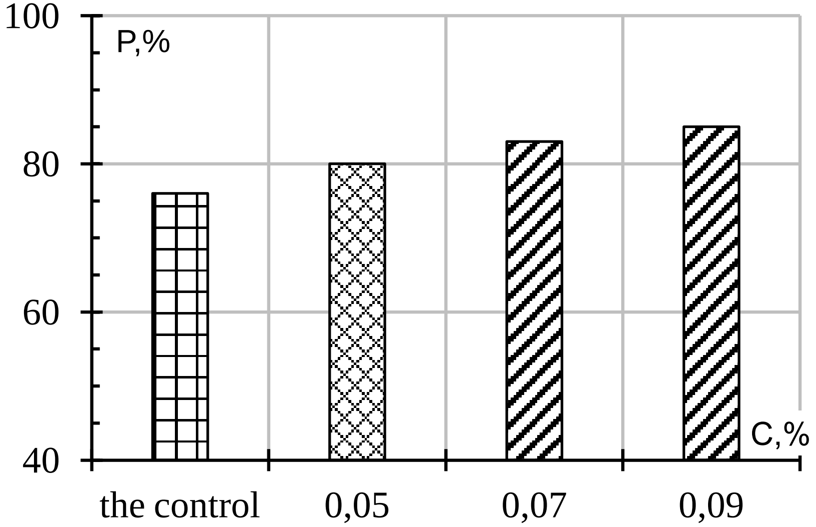


Fig. 3.10 The effect of the transglutaminase enzyme on the porosity of the structure of the baked whipped flour semi-finished product with a concentration of gelatin 3.0%, xanthan 0.2% with different contents of the TG enzyme

So, according to the experimental data of all considered samples of the baked whipped flour semi-finished product with a concentration of gelatin 3.0%, xanthan 0.2% with different content of TG enzyme porosity is from 70% to 82%, which corresponds to the average and high indicators of this product and indicates a well-made dough.

3.5.2 Determination of the main organoleptic quality indicators

The organoleptic properties of food products are evaluated by the senses (taste, smell, consistency, color, appearance, etc.).

Organoleptic analysis of food and taste products is carried out with the help of tastings, that is, research that is carried out with the help of the senses of a specialist - a taster without the use of measuring devices [201].

To determine the main organoleptic indicators of the quality of the baked whipped flour semi-finished product, research was conducted aimed at the development of a quantitative scale of sensory evaluation of the finished product according to a 5-point system with the determination of weighting coefficients for indicators of product quality (Table 3.11) [202-205].

Table 3.11

Development of a sensory evaluation scale for evaluating the the baked whipped flour semi-finished product

Quality level, mark	Quality indicators, importance coefficient				
	Appearance	Color	Smell	Taste	Sectional view
	0,1	0,15	0,25	0,35	0,15
1	2	3	4	5	6
5	The surface is clean, even, without cracks	Homogeneous, natural, saturated, inherent in this type of product	Pleasant, clean, expressed, corresponds to the name, slowly released	Natural, balanced, expressed, clean, corresponds to the name, without extraneous aftertaste	Uniform porosity, no voids, no traces of non-processing, preserved forms

End of the table 3.11

1	2	3	4	5	6
4	The surface is even, without cracks	Uniform, natural, inherent in this type of product	Natural, clean, corresponds to the name, but quick release	Natural, expressed, clean, corresponds to the name, without extraneous aftertaste	Uniform porosity, preservation forms
3	The surface is even, with small cracks	Natural, inherent in this type of product	Natural, unexpressed, quickly released	Natural, unexpressed, corresponds to the name, without extraneous aftertaste	Uniform porosity, preservation of shape, presence of traces of non-processing
2	The surface is uneven, with cracks	Natural, unexpressed, inherent in this type of product	Unexpressed, very quickly released	Unexpressed, with an aftertaste of the main recipe ingredients	Uneven porosity, presence of voids, traces of non-processing
1	The surface is uneven, porous with cracks	Natural, non-uniform, with the presence of burning	Sharp, unnatural smell of flavoring	With a pronounced aftertaste of the main recipe ingredients, with an extraneous aftertaste	Irregular porosity, presence of voids, weak elasticity, significant traces of non-processing

In the course of organoleptic research of a freshly prepared baked whipped flour semi-finished product, it was established that in the formation of the organoleptic indicators of this product, the most determining factors are surface uniformity and without cracks, naturalness and homogeneity of color and without burning, uniformity of porosity and without voids, preservation of shape and absence of traces of non-processing, cleanliness, naturalness and the balance of taste, the expression and speed of release of smell and taste.

The results of the sensory evaluation confirmed the high organoleptic properties of the developed baked whipped flour semi-finished product biscuit type (Fig. 3.11, 3.12), which are consistent with the requirements of DSTU 8001:2015 [206].

Table 3.12

The results of the sensory evaluation of the baked whipped flour semi-finished product

Name	Number of descriptor	Characteristic	Assessment, score	
			freshly made	after 6 days of storage
Appearance	1	Homogeneity	5,0	5,0
	2	Heterogeneity	0,9	0,9
	3	Flat surface	1,5	0,5
	4	Surface irregularities	4,0	4,0

	5	Cracks on the surface	0	0
Color	1	Homogeneity	4,0	4,0
	2	Natural	4,5	4,0

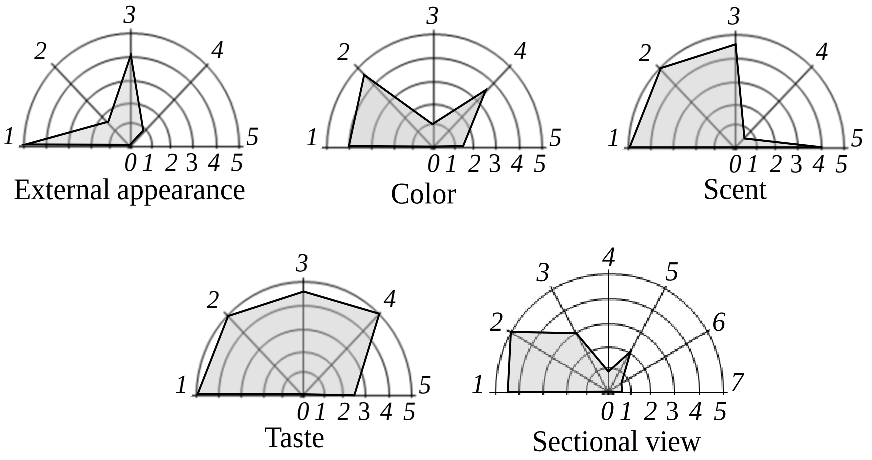
End of the table 3.12

	3	Saturated	1,0	0,8
	4	Inexpressive	3,5	3,0
	5	Heterogeneous, burnt	1,5	1,5
Smell	1	Clean	5,0	5,0
	2	Natural	5,0	5,0
	3	Expressed	4,5	4,0
	4	Abrupt	0,5	0,5
	5	Release rate	4,0	3,5
Taste	1	Natural	5,0	5,0
	2	Balanced	5,0	4,5
	3	Expressed	4,5	4,0
	4	Clean, corresponds to the name	5,0	4,5
	5	Extraneous aftertaste	4,0	3,5
Sectional view	1	Uniform porosity	4,5	4,0
	2	Shape retention	5,0	5,0
	3	Plasticity	3,0	4,0
	4	Springiness	0,8	0,8
	5	The presence of voids	2,0	1,5

	6	Uneven porosity	0,5	0,5
	7	Сліди непромісу	0,5	0,8

Taking into account the fact that the developed baked whipped flour semi-finished product is a new product on the modern food market and taking into account the marginal deviations in the functioning of subsystems A, B, B, D (Fig. 3.1) to ensure obtaining a product with the same level of quality, taking into account weighting factors with the help of experts based on the sensory evaluation scale, we conducted a sensory analysis [201-206] of the general organoleptic evaluation of the semi-finished product freshly prepared and after storage for 6 days (Table 3.12).

On the organoleptic evaluation profiles of freshly prepared (Fig. 3.11) and after 6-day storage (Fig. 3.12) baked whipped flour semi-finished product in the form of a fixed area, the importance of each indicator within a specific characteristic is visually emphasized, namely appearance, color, smell, taste, sectional view.



External appearance Color Scent

Taste Sectional view

Fig. 3.11. Profiles of organoleptic assessment of freshly prepared baked whipped flour semi-finished product

The study of the organoleptic indicators of the baked whipped flour semi-finished product in the process of storage at a temperature of +2...6 °C and an air humidity of no more than 50% for up to 6 days in consumer containers - boxes made of cardboard or polymer materials, closed with lids (Fig. 3.12) showed that slight changes in sectional view are observed, a decrease in intensity and an increase in the rate of release of smell and taste.

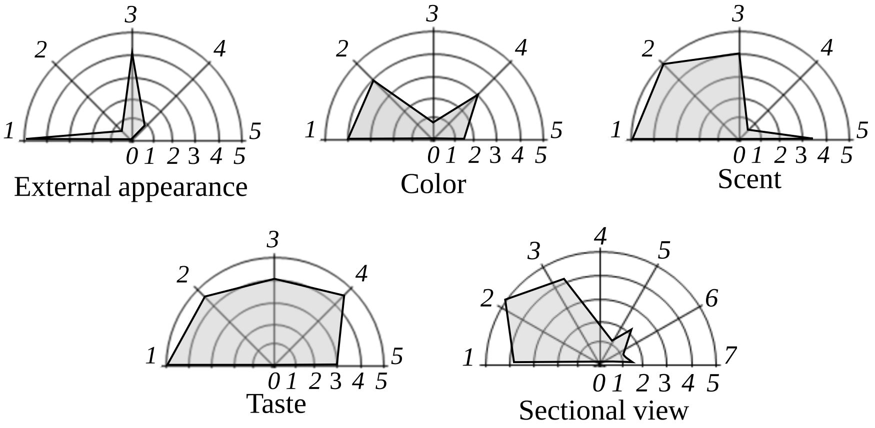


Fig. 3.12. Profiles of the organoleptic evaluation of the baked whipped flour semi-finished product after storage for 6 days

Usually, the manufacturer and the consumer strive to optimize the comprehensive indicator of the quality of the baked whipped flour semi-finished product, taking into account the real conditions (limitations) of production and consumption of products. At the same time, the manufacturer focuses on obtaining a higher profit while minimizing costs, which may be accompanied by a decrease in the level of quality, and the consumer needs the maximum level of quality at the lowest price [207]. This affects the weighting coefficients (Table 3.13) of the previously determined single quality indicators k_i and the assessment of the uncertainty c of the value of the complex quality indicator K_q, which are reflected in the opinion of experts. Experts, depending on the specific situation, can be a group of specialists or representatives of interested parties, in particular, the consumer himself. Food manufacturing processes must be accompanied by constant quality control at all stages of the technological cycle. The usefulness of the quality system function is based on the feedback of the control results with the corresponding influences (technical, technological, economic and organizational) on the product creation processes.

In order to check the adequacy of the influence of optimal concentrations of the main recipe components [103, 104] of a kinetically stable foam-like system on the quantitative dependence and the form of the relationship of the quality coefficient from technological factors to determine the complex quality indicator (Fig. 3.13), an expert evaluation of samples of baked whipped flour semi-finished products in within the limits of gelatin - 2.0...5.0%; xanthan - 0.1...0.35%, transglutaminase enzyme -0.05...0.09% to ensure a kinetically stable foam system, and the kinetics of K_q were studied within the framework of two-parameter models.

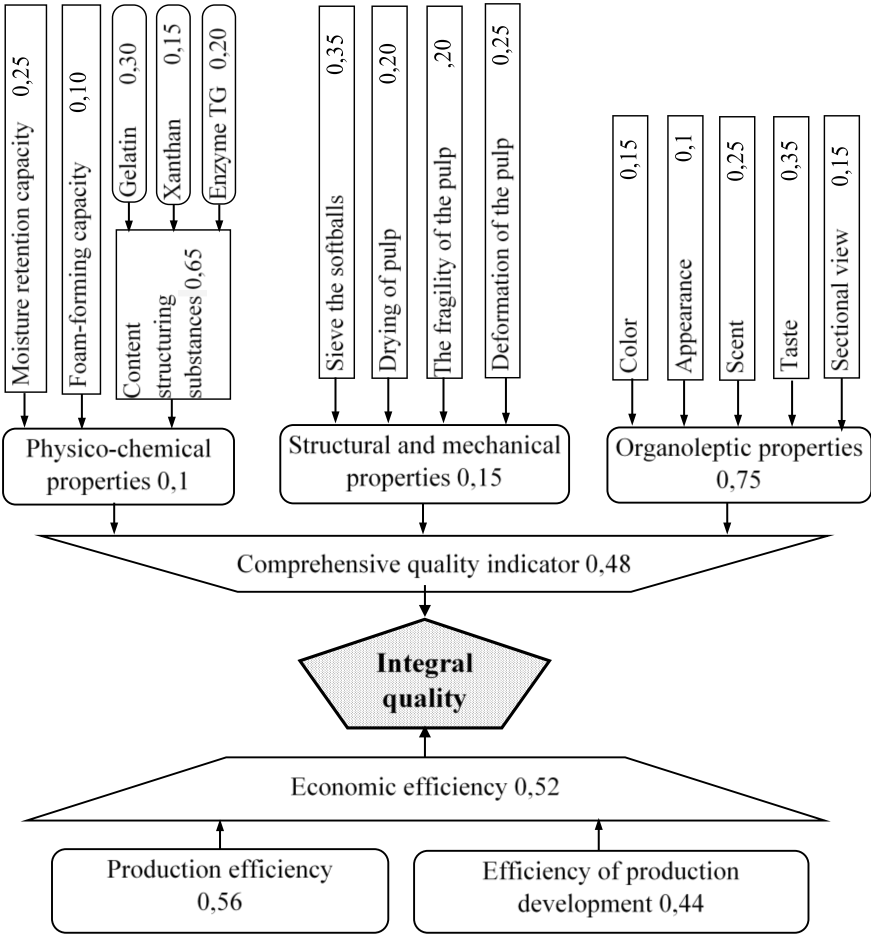


Fig. 3.13. Formation of an integral indicator of the quality of the baked whipped flour semi-finished product

The influence of technological factors on the quality of baked whipped flour semi-finished products was evaluated by modeling the complex coefficient of quality of the finished product

(K_q), which was obtained by an expert method, taking into account the agreement of experts. The concordance coefficient (Kendel) was chosen to be at least 0.95. In the case of weak agreement of expert assessment, the number of experts increased [208-210]. We believe that K_q has one local extremum within the limits of changing technological factors (gelatin, transglutaminase enzyme and xanthan).

Modeling [208-210] established that the equations of the dependence of K_q (x) in the recipe of the baked whipped flour semi-finished products on the content of: gelatin (equation 3.1), xanthan gum (equation 3.2) and transglutaminase enzyme (equation 3.3) have the form of a second degree polynomial.

$$K_q(x)=1{,}47+0{,}3916x_1+0{,}0775x_2+0{,}0875x_1x_2+0{,}4680x_1^2+0{,}1412x_2^2 \quad (3.1)$$

$$K_q (x) = 1{,}47 + 0{,}3916x_1 - 0{,}3576x_1x_3 + 0{,}4680x_1^2-0{,}1820x_3^2 \quad (3.2)$$

$$K_q (x) = 1{,}47 + 0{,}0775x_2 + 0{,}0825x_2x_3 + 0{,}1412x_2^2-0{,}1820x_3^2 \quad (3.3)$$

To determine the optimal values of moisture-retaining capacity - one of the main factors in the formation of the qualitative structure of the baked whipped flour semi-finished product and the influence of gelatin content on it, K_q was calculated and its dependence on the content of gelatin, transglutaminase enzyme and xanthan was constructed within the framework of two-parameter models: gelatin-enzyme TG; xanthan - TG enzyme; gelatin-xanthan.

It was established that the relative coefficient of quality of K_q has a maximum value for the gelatin content of 3.0%, while the moisture retention capacity (Fig. 3.13) is 85%, which is consistent with the results of modeling of the complex indicator of the quality of the baked whipped flour semi-finished product.

It has been proven that K_q has a maximum value at the content of the transglutaminase enzyme of 0.09%, while the moisture retention capacity is 87% (Fig. 3.13). The obtained result is consistent with the data of the expert assessment regarding the effect of the TG enzyme on the quality of the baked whipped flour semi-finished product.

It was determined that with a xanthan content of 0.2%, the relative coefficient of quality of KP has the maximum value, while the moisture retention capacity is 78.5% (Fig. 3.14). The obtained result is consistent with the data of the expert assessment regarding the influence of xanthan on the quality characteristics of the the baked whipped flour semi-finished product.

3.6 Development of recommendations for the formation of the assortment and the use of baked whipped flour semi-finished product in the composition of confectionery products

The combination of gelatin in the composition with xanthan and TG enzyme in the recipe of the semi-finished product gave the products uniform porosity, lightness and fluffiness, ensured the preservation of taste properties during 6 days of storage. The baked whipped flour semi-finished product with the replacement of egg products with gelatin as a foaming ingredient is a new product in the existing range of traditional biscuit-type products and can be used as part of confectionery culinary products: pastries, rolls, cakes, etc [8, 15, 94, 132].

The conducted studies of the nutritional value, structural-mechanical, physico-chemical and quality indicators of the whipped flour semi-finished product (subsections 3.1...3.4) formed the scientific basis for the development of recommendations for the use of the semi-finished product as part of confectionery products [211].

According to the results of a complex of experimental studies and based on the generalization of technological characteristics, it was established that the whipped flour semi-finished product made from a dry mixture (TS U 15.5-01566330-190:2006) can be used as a food product for the production of culinary products, in particular cupcakes, cakes and rolls (Fig. 3.14, 3.15, 3.16).

During technological research and testing, the recipe composition, production technology and range of confectionery products - pastries, cakes and rolls were developed, and the technological cards listed in the appendices (appendices E1, E2, E3) were approved in the established order [211].

"Cherry" pastry is a light and extremely airy dessert. A confectionary product consisting of several sheets of baked whipped flour semi-finished product with layers of cream between the sheets (Fig. 3.14). The top of the cake is decorated with patterns of "Creamy" cream and fruits (cherries) (Fig. 3.14).

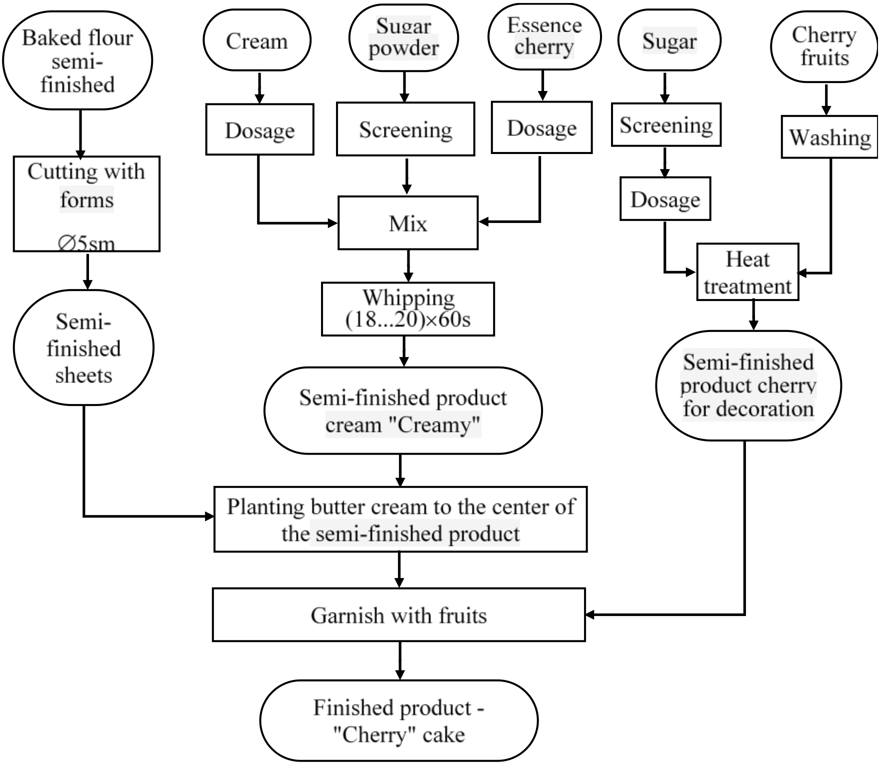


Fig. 3.14. Technological scheme of "Cherry" pastry production

Also, butter cream, butter custard cream, butter-chocolate cream, yogurt cream, protein cream, creamy cream are used for the layers between the cake sheets. Candied fruits, fruits (raspberries, strawberries, etc.) are used for decoration.

Cake "Chocolate miracle" is a light and extremely airy dessert (Fig. 3.15).

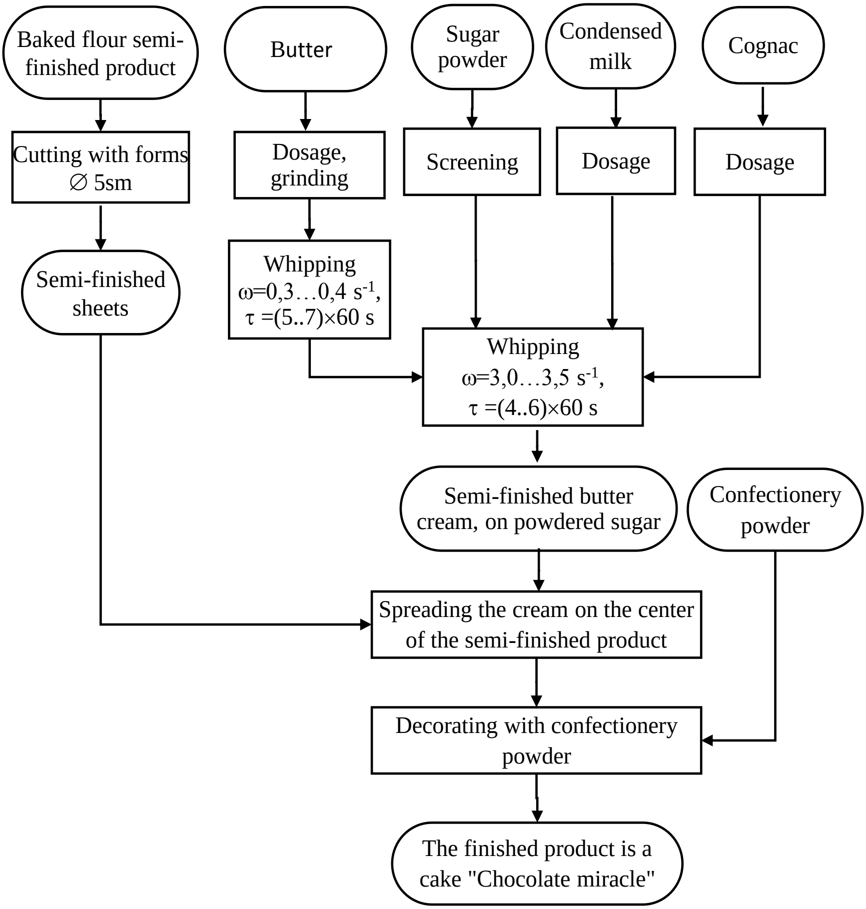


Fig. 3.15. Technological scheme of "Chocolate miracle" cake production

This is a confectionery product consisting of several layers of baked whipped flour semi-finished product, with the addition of cocoa with of cream between the layers. The top of the cake is decorated with patterns of cream and fruit, or confectionery powder (Fig. 3.15).

Butter cream, butter custard cream, butter-chocolate cream, yogurt cream, protein cream, creamy cream are used between the cakes.

Rolls are rolled layers of baked whipped flour semi-finished product layered with various fillings. The thickness of the layer of the baked semi-finished product is 6.0...9.0 mm. Fruit (jam, seedless jam, canned fruit), as well as cheese, nut, honey, almond, poppy, or chocolate-cream fillings are used for fillings (Fig. 3.16).

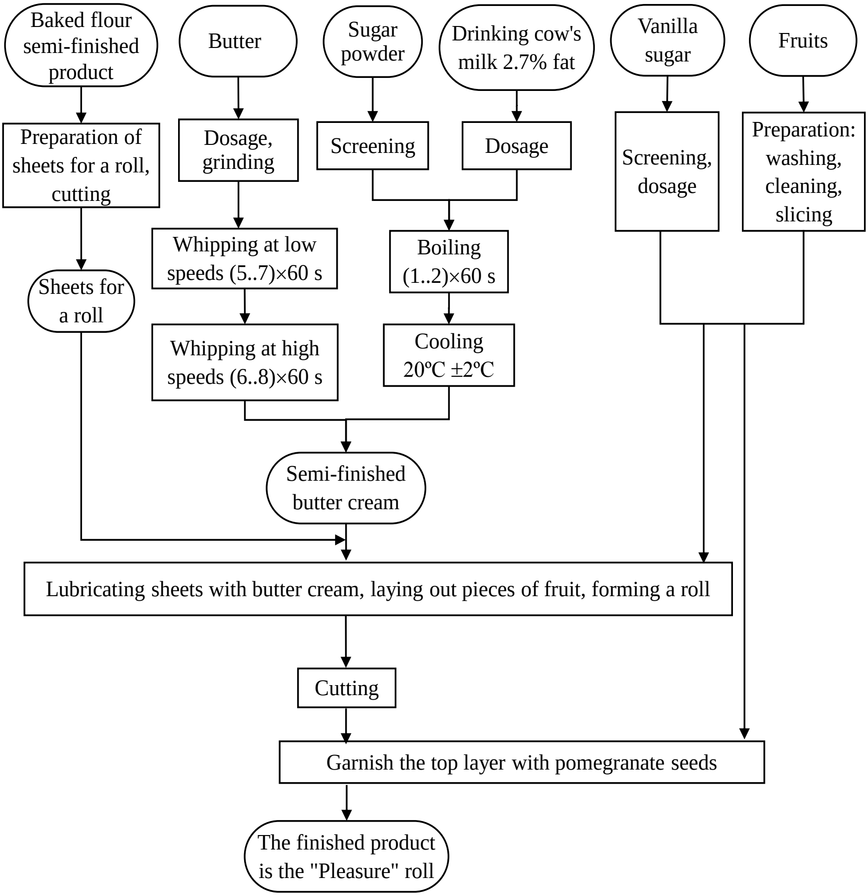


Fig. 3.16. Technological scheme of "Pleasure" rolls production

Chocolate glaze and powdered sugar are used to finish the surface. Rolls are produced in pieces with a net weight of no more than 500 g and by weight. The assortment of rolls is diverse: fruit roll, chocolate roll, roll with jam, honey roll with jam, roll with almond filling, roll glazed with chocolate fondant, roll with poppy filling, roll glazed with lemon fondant, etc.

According to the results of the experimental studies, it was established that the use of whipped flour semi-finished product can be offered to mass catering establishments as part of culinary products - confectionery products: pastries, cakes and rolls with new consumer properties, will allow to expand the assortment of confectionery products, increase the efficiency of the restaurant industry due to use of new functional products.

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