potravinárstvo®

Slovak Journal of Food Sciences

Potravinarstvo Slovak Journal of Food Sciences
vol. 14, 2020, p. 1008-1019
https://doi.org/10.5219/1399
Received: 18 May 2020. Accepted: 26 September 2020.
Available online: 28 October 2020 at www.potravinarstvo.com

ISSN 1337-0960 (online)

SUBSTANTIATION OF FOAMY STRUCTURE FORMATION IN A GLUTEN-FREE BISCUIT

Igor Stadnyk, Olena Kolomiiets, Oksana Dziana

ABSTRACT

A promising way to create gluten-free foods based on purposeful use of ingredients with a wide range of technological properties is analyzed. Steps to regulate the structural and mechanical properties of gluten-free dough have been determined. These steps allow to improve the structural-mechanical and organoleptic characteristics of the biscuit semi-finished product, to adjust the nutritional value. To determine the technological effect, we considered the connection between the recipe components and the properties of the dough when forming a foamy structure of gluten-free cupcake products. The influence of the design parameters of the mixer (independent factors xi) on the foaming process (Q) has been determined, that is, determining the productivity magnitude from the changes of three main factors: from the attack angle of the frontal surface of the plate working body α, the distance between the plates (step) t and the rotation frequency of working body n. The stability of the foam formed and the rate of its settling and the role of the liquid phase of the dough during short storage before baking were investigated. The comparative characteristics of the microstructure of wheat flour (WF) and extruded corn flour (ECF) in the ratios are presented: a) WF – 100 wt.%; b) WF: ECF – 80:20 wt.%; c) ECF – 100 wt.%. In the tested mixtures, the moisture-holding capacity increases for the sample containing 20% by weight of extruded corn flour two and a half times, and three times for the sample with extruded flour to 100% by weight. With an increasing proportion of extruded corn flour in the flour mixture, the dough density increases and the optimum value is in the range of 0.444 – 0.446 kg.m^{-3}. The comparative characteristic of the microstructure of the samples is given, which has the appearance of foam with the existing and even distribution of air bubbles which later form the porous structure of the biscuit of the semi-finished product. Thus, the size of the formed bubbles of air with the content of wheat flour and starch have a large difference in diameters, in the sample of biscuit dough using ECF 100 wt.% – almost the same size, and between the channels are formed that promote the equalization of air pressure in the middle of the foam system of biscuit dough. It was found that the use of 20 wt.% and 100 wt.% of corn extruded flour contributes to the formation of a fine porous structure of biscuit dough.

Keywords: dough; adhesion; adhesive; substrate; forming channel; deformation; stress

INTRODUCTION

Today, the popularity of healthy eating is increasing every year. This requires the creation of products that contain ingredients with wellness properties. The tissues of the human body include mineral compounds that make up about 3.5% of its mass. Therefore, when consuming food, they should contain the required amount of salt, phosphorus, calcium, iron, etc. The daily requirement of the human body in trace elements is measured in milligrams (zinc: 10 – 15, manganese: 5 – 10, copper: 2, molybdenum :0.5). Their physiological value is quite significant, as these trace elements play the role of coenzymes of some enzyme systems.

An analysis of the literature shows that the share of gluten-free food on the Ukrainian market is quite small, and the percentage of people who go to health care establishments with increased sensitivity to gluten is increasing, even among children. Also, there is increasing public awareness of gluten intolerance, that is why people choose gluten-free foods as an attribute of healthy eating. In western countries, the consumption of gluten-free products is becoming a lifestyle, which contributes to increasing their production. Thus, according to experts, in the UK in 2019, the market for gluten-free products reached 1 billion dollars. In Ukraine, however, the industrial production of gluten-free products is not established, but to provide the category of people with coeliac disease, specialized food needs constantly.

Considering the directions of technological process in the food industry **(Lamacchia et al., 2014)**, determined in particular by public policies on healthy nutrition, economic and social change in society, new technological opportunities, and competition in the food market, there is a need not only for the improvement of traditional food technology but for the creation of new generation foods which are enriched with important nutrients and have a longer shelf life. Also, an important role is played by equipment, which creates the appropriate conditions for modern technological requirements. Semi-finished flour confectionery products form the basis or constituent of products **(Murray, 2007)**, and significant demand from the population for these products makes them considered important food products.

Today, in particular **(Liu, Willför, and Xu, 2015; Kobets et al., 2015)**, the range of gluten-free food produced in domestic production is insufficient. The range of gluten-free flour products on the Ukrainian market is formed mainly due to imported products, which have a fairly high cost. To solve the problem of nutrition for patients with coeliac disease in Ukraine products of the firm "DR. SCHAR" (Italy), "BEZGLUTEN" (Poland), "3PAULY" (Germany) are certified but their use is limited because of the high price. The range of food products for people suffering from genetically caused and allergic diseases in our country is not wide enough and is about 2%. This indicates that the issue of developing special-purpose technology products, including for the nutrition of people with coeliac disease, in Ukraine is quite acute and relevant. Therefore, one of the promising directions of expanding the range of flour confectionery products is the creation of biscuit semi-finished products, bagels with the development of structural and technological conditions of the process with the complete replacement of gluten-containing wheat flour with extruded corn flour (ECF).

ANALYSIS OF THE LATEST RESEARCH

In the general structure of the market of flour confectionery products (FCP) cupcakes and bagels occupy up to 15% of the total volume of production. These products have a pleasant appearance and taste, are well absorbed by the human body and therefore are popular with the population. Analysis of the literature indicates that the use of gluten-free flour in the production of pastry, including muffins on chemical baking powder causes many technological problems and requires a variety of tools to improve the structure of the gluten-free dough. The fact is that gluten of wheat flour has unique technological properties that play an important part in the formation of flour dough structural and mechanical qualities and texture of finished products. Wheat Glyadine (Prolamine) is responsible for the dough's consistency as well as Gluten (Glutinine) is responsible for the resistance of the tensile test. The combination of these two proteins gives the dough unique viscoelastic properties and the ability to hold gas. After hydration and mixing, proteins of gluten-free flour varieties do not develop into a viscoelastic network **(Kobets et al., 2015)** as wheat proteins.

During the development of the cupcakes, it was found that simply replacing the wheat flour with rice does not allow the product to have the necessary structural characteristics. It has been established **(Stojceska et al., 2010; Drobot, Pysarets and Kravchenko, 2013)** that reducing the amount of rice flour by 10% is sufficient to improve the structure of the cake. The product has a developed porosity and a high specific volume.

The possibility **(Rus'kina et al., 2017)** of using protein and protein-calcium concentrates from white and brown rice in the technology of gluten-free oil cake has been investigated. The obtained rice concentrates were characterized by high foaming capacity and foam stability, which allowed them to be used in the amount of 50% by weight of egg melt in oil cake technology to increase its biological value and structural and mechanical quality indicators.

The main problem of manufacturing gluten-free flour products is an imitation of the structure-forming properties of gluten-containing raw materials. Since the biscuit semi-finished product is a structured foam-emulsion dispersive system, the formation of the necessary rheological properties that provide a texture adequate to a traditional product is an important task for its creation. In the technological aspect, the solution of this problem is to find the optimal ratio of structure-forming components, the choice of design conditions for the formation of a stable structure of the food system, its structural and mechanical qualities, characterized by viscosity, elasticity, plasticity.

Corn flour starch **(Stojceska et al., 2010)** is pasteurized at higher temperatures, more easily attacked by amylase, contains less own sugars, less sugar-forming, and gas-forming ability.

Many studies by several scientists **(Stojceska et al., 2010; Drobot, Pysarets and Kravchenko, 2013)** have developed measures for the use of a mixture of wheat and corn flour while maintaining pre-mixing corn flour. They consist of soaking, brewing, fermenting with mesophilic or thermophilic lactic acid bacteria, adding unfermented malt, phosphates, concentrates, or enzymes to the dough. However, these measures extend the duration of the process and do not provide the significant effect of improving product quality at considerable cost. Recently **(Stojceska et al., 2010; Drobot, Pysarets and Kravchenko, 2013)** began to develop measures for the use of whey.

The availability of fundamental developments in the production and use of various types of extruded flour in food production **(Brekhov and Riazhskykh, 2012; Yehorov, Mardar and Bordun, 2014; Zip Diagnostic, 2012)** indicates the possibility of its use in biscuit technology and production of bagels. The use of plant-based ingredients, such as non-traditional flour types, which could provide valuable nutritional value to the product, may be considered a promising development of interest to confectioners and bakers.

Because of the valuable chemical composition of the ECF, it is possible to predict the positive impact of this raw material on the course of the technological process.

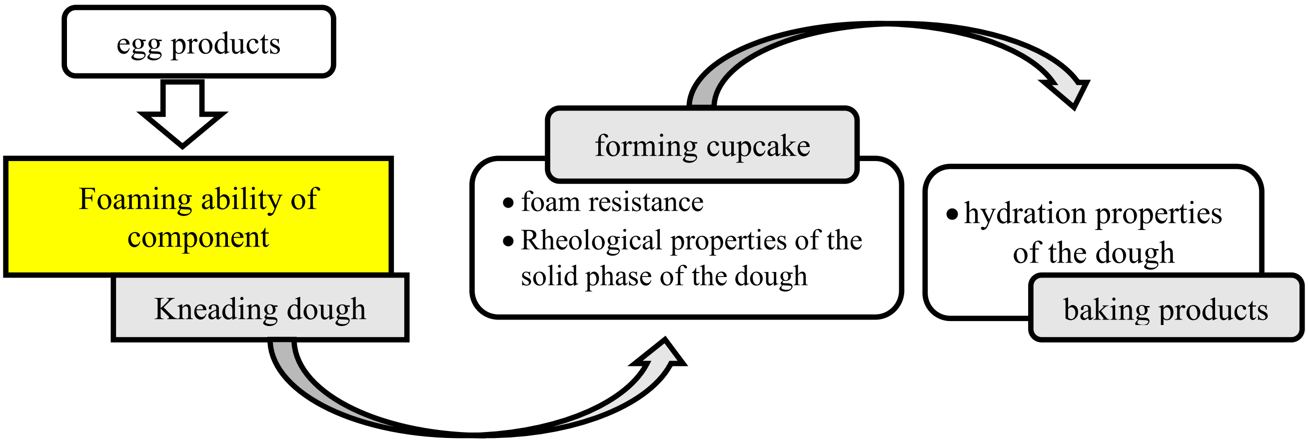

Figure 1 The relationship between recipe components and properties of the dough mass and the foamy structure formation.

In the technological process of mixing the biscuit semi-finished product as a foaming agent, egg mélange is most often used. Due to the saturation of the protein mass with air, the knockdown causes the denaturation of the protein's native structure, which in its turn unfolds the protein chains without destroying their covalent structure. In the process of denaturation, the protein's inherent three-dimensional structure breaks down **(Renzjaeva and Bakirova, 2017),** the polypeptide chain unfolds, simultaneously forming bonds between the polypeptide chains, which generally contributes to the stability of the foam. The foamy structure of the biscuit semi-finished products is due to a greater extent to the presence in their recipe of a considerable quantity of egg products that is almost twice more than flour (Figure 1). This makes it possible to assume that wheat flour will be completely replaced by non-baking flour.

Therefore, biscuit dough is a complex dispersed system consisting of air bubbles separated by liquid pellicle. In this system, the dispersed medium is an egg-sugar mixture and the dispersed phase is air. The technological process **(Drobot, Pysarets and Kravchenko, 2013)** involves dispersion of the egg-sugar mixture, which is saturated with air bubbles and leads to an increase in volume, development of the inner surface of the system, and creation of a foam system.

The main characteristics **(Renzjaeva and Bakirova, 2017; Drobot, Pysarets and Kravchenko, 2013)** that comprehensively characterize the foam system are – foaming solution, foam multiplicity, foam stability, and foam dispersion, i.e. distribution bubbles by the size or surface of the solution-gas separation, per unit volume of foam. The patterns that cause the formation of foam vary significantly depending on the conditions of mixing components.

The beating of the egg-sugar mass in ECF technology is one of the separate operations which results in the formation of a system that is a confectionery foam. The formation of thick foam is positively affected by the surface activity of egg polar white molecules and a noticeable stabilizing effect is present in the sugar mixture. As a result, solid pellicles are formed around the air bubbles which enhance the foam's stability. Increases the marked effect of increasing the viscosity of the liquid when sugar is added.

Along with the prescription components, the duration of the whipping and the speed of rotation of the working organs are influenced by the foam volume and its dispersion, the foaming ability, and the foam resistance. As the whipping time increases, the volume of foam also increases; the whipping rate is directly proportional to the foam dispersion.

Today, a considerable amount of theoretical and applied aspects of foam production **(Holovchenko, Lopatin and Kovbasa, 2001)**, physicochemical properties, structure characterizing the geometric shape of air bubbles and their stability have been accumulated. The structure of the foams is determined by the ratio of the volumes of liquid and gas phases and, depending on this ratio, the foam cells have a spherical or polyhedron shape. Usually, freshly prepared foam of the egg-sugar mixture has a spherical shape of cells separated by thick walls of liquid, because the volume of the gas phase exceeds the volume of the liquid by no more than 10 – 20 times. As the foam ages, the spherical shape of the foam bubbles becomes multifaceted with thin flat pellicles as a result of fluid draining. At the same time, the specific surface of the foam changes due to the diffusion of gas from small bubbles into larger ones, due to the difference in capillary pressures.

In the paper **(Holovchenko, Lopatin and Kovbasa, 2001)**, it is noted that although the foam state with polyhedral cells is close to equilibrium, such foam has greater stability than the one with spherical cells. However **(Holovchenko, Lopatin and Kovbasa, 2001; Mancebo, Rodriguez and Gómez, 2016)**, by reducing the number of small bubbles, the total number of air bubbles in this volume of foam decreases, that is, the coalescence of foam occurs, which reduces its stability. Carried out studies **(Mancebo, Rodriguez and Gómez, 2016)** show that with increasing foam concentration, the viscosity of the solution decreases and foaming improves, and the density of the foaming mass decreases due to more air being drawn into the system.

A characteristic feature of biscuit dough is that in its composition, in addition to foaming agents other recipe components are included that have a significant impact on the quality of the biscuit semi-finished product. The main component that has a significant impact on the quality of the biscuit cake mix is flour.

Compared to the duration of the whisking of the egg-sugar mass, the kneading with the flour lasts only a few seconds, but the flour has a significant effect on the quality of the semi-finished product. The properties of gluten flour and its content significantly affect the quality of the baked semi-finished product, because when kneading occurs the hydration of gluten proteins and longer kneading leads to the tightening of the dough and compacting the structure of the biscuit semi-finished product.

The research **(Stojceska et al., 2010)** identified the steps of regulating the structural and mechanical properties of gluten-free dough. First of all, it is the use of flour mixtures, not certain types of gluten-free flour, which can significantly improve the nutritional and biological value as well as product structure but to expand the raw material base and finished product range. To establish the technological effect, we considered the relationship between the recipe components and the properties of the dough masses in the formation of the foamy structure of gluten-free cupcake products (Figure 1).

In physics and chemical sense, foam is a two-component gas-liquid system. In the process of foam formation, there is a powerful development of the liquid and gaseous phase interface. The surface tension force always seeks to minimize the total surface of the section. In the dough foam mass, the flour component actively absorbs the moisture from the liquid phase contained in the foam. This leads to the rupture of the pores pellicles, followed by their merging into pores of larger sizes. Hence there is the formation of heterogeneous porosity in the finished products prepared based on flour.

In the production of the cupcake, when the mixture turns into the dough, gluten forms a viscoelastic network capable of trapping and storing carbonated bubbles. The state of aeration of the dough immediately after mixing has a huge impact on the texture of the cupcake. And the aerated dough architecture is governed by different physical principles related to foam formation and stabilization.

The specificity of the production of gluten-free dough by beating is that the foam obtained is subjected to unwanted external influences that lead to a decrease in its stability. Such factors include mixing the whipped mixture with flour and placing the dough in molds (Figure 4). In such circumstances, it is important not only to obtain a foam system with the required characteristics but also to preserve them during the technological process. Thus, in our view, it is important to investigate the foaming ability and foam resistance to structure destruction comprehensively.

According to current scientific concepts **(Drobot, Pysarets and Kravchenko, 2001; Haliasnyi, Gavrish and Shanina, 2018)**, in the absence of a hydrated gluten network, one of the important factors for optimizing and stabilizing the process of retaining gas formed in the gluten-free dough is sufficient water amount to hydrate the biopolymers of the dough and obtain the desired viscosity. It is possible to increase the hydration capacity of gluten-free dough by adding protein substances.

For the formation of a stable foam structure, it is necessary to weaken the counteraction of the system surface tension which is achieved by introducing into the mass of the surfactants which can significantly reduce the surface tension at the interface. We have developed **(Stadnyk et al., 2019)** a method of attenuating the surface tension forces of a system by using a discretely pulsed mixing machine. Its purpose is to intensify the technological process by reducing the time of beating the egg-sugar mixture. It should be noted that obtaining a well-loosened dough structure is the first but not the only technological task. Also important is the preservation of the formed structure which determines the corresponding rheological properties of the dough.

Scientific hypothesis

The idea of the development is to establish the relationship of wheat and extruded corn flour (ECF) in the process of mixing the recipe components on the developed mixer with characteristic differences in the formation of a stable foam structure in the technology of cupcakes.

MATERIAL AND METHODOLOGY

Materials

Extruded Corn Flour (ECF) of maize crop (2018, 2019) was grown in Chernihiv region. ECF is a dry mixture of homogeneous consistency in powder and fine grains with taste, smell, and color inherent to raw materials, made by grinding grain parts (endosperm, aleurone layer, fruiting membranes, with pre-removed embryo) and hot extrusion method. Wheat flour of the highest grade with a crude gluten content of 23.0 ±0.4% and a crude gluten deformation value of 60 ±1.1% etc., potato starch, chicken eggs, white crystalline sugar. The characteristics of the batches of flour used in the experimental studies are shown in Table 1.

Research methods

Standard, conventional, special, and modified physics and chemical, microbiological, and organoleptic research methods were used to perform the work.

Wheat and FCE quality were established in each consignment based on the results of the average sample analysis according to **DSTU 3355-96, DSTU ISO 9001:2015 IDT**.

Sampling and sample preparation for laboratory testing of The raw materials was carried out in accordance with a single methodology for the study of domestic food. The test and control samples were prepared from one batch of raw materials (Table 2).

The experimental part of the work was carried out in the research laboratories of the Department of Food Technology, TNTU University, and the laboratory of grain quality at the Institute of Plant Growing named after V.Ya. Yurjev of the National Academy of Agrarian Sciences of Ukraine.

The prototyping technology includes the following operations: the egg-sugar mass is beaten to a 2.5 – to 3-fold increase in volume, ie approximately 30 – 40 × 60 s. Then gradually add the premium wheat flour mixed with starch or extruded corn flour. The mixing was carried out in the developed machine (Figure 2) with a duration not exceeding 35 s.

Ready-made biscuit dough is baked immediately in capsules and on sheets, as the biscuit dough settles when stored. Biscuit dough was placed in shapes at ¾ of their height because when baking it increases in volume Figure 3.

Baking biscuit dough was carried out at a temperature of 200 – 210 °C. Baking time in capsules was 50 – 60 × 60 s. Baked biscuit cake was cooled 20 – 30 × 60 s and removed from the molds. The biscuit semi-finished product is left at 8 – 10 × 60 c2 for standing, after which it is possible to cut and carry out the following technological operations.

The structural and mechanical qualities of the dough include elastic and flexible and viscous and plastic qualities. The elastic and flexible qualities of the dough were determined using a farinograph "Brabender", which describes the process of dough formation and its behavior under continuous machining conditions, and the viscous and plastic qualities on the alveograph "Chopin". The foam resistance of the egg and sugar mixture with the addition of the test flour mixtures was determined as the ratio of the foam column height after holding for 24 × 602 s at a temperature of 18 – 20 °C to the total foam column height of the sample, expressed as a percentage, calculated by the formula: (1)

$$C\Pi = \frac{Bn^{24 \cdot 60^2}}{Bn} \times 100\% \qquad (1)$$

Where:
CП is foam resistance,%;
Bn60 is the height of foam column 24 × 602 s after cessation of whipping, m;
Bn is the initial foam height, m.

The specific volume of products was calculated as the ratio of their volume to mass ($m^3.kg^{-1}$). Baking was defined as the difference between the weight of the dough before baking and the weight of the finished semi-finished product.

The degree of batch penetration of baked semi-finished products after baking and during storage was examined on a Labor Penetrometer (Hungary) according to the standard method. Microscopic studies of the structure of the product were performed **(Rochow and Rochow, 2012)** using a digital binocular microscope series "MicroMed" equipped with a built-in lighting system. The micrographs of the samples were taken at the following magnifications: 40 times, 100 times, 400 times, 1000 times. The porosity of the samples of the biscuit cake **(Stadnyk et al., 2015)** – control (basic biscuit) and extruded corn flour were carried out by measuring the effective pore diameters on the biscuit cross sections by visualizing the microstructure of the biscuit, processing the digital images.

Statistical analysis

The assessment of the basic regularities of changing the qualities of biscuit dough is based on the optimal parameters and modes of its formation. They are based on the initial values of the process, which determines the probability of the obtained results of the structure required to describe the consumer properties. The features of the influence on the treated environment in the formation of the foamy structure of the dough and the conditions to achieve rational parameters of the mixing in the working compartment, it is possible to predict the performance of the mixer. To clarify the role of individual factors of the system, planning and setting up of computational experiments were performed to obtain the corresponding regression equations. Determination of the influence of the design parameters of the mixer (independent factors xi) on the foaming process (Q), conducted full factorial experiments FFE 3^3. They aim to determine the magnitude of productivity and to establish its effect on the structure when mixing components that depend on changes in the three main factors: the frontal surface of the plate working body α, the distance between the plates (step) t and the speed of rotation of the working body *n*. The construction of the plan-matrix of the planning of experiments indicated the conditional factors of the upper, lower, and zero levels of variation, respectively +1, -1, 0. The results of the encoded factors and their levels of variation are shown in Table 3. The construction of this table is as follows. The input values of the FFE 3^3 variable factors are:

-the speed of the plate n (rpm), which is encoded by the index x_1;

-the angle of attack of the frontal surface of the stroke of the plate α (deg) encoded by the index x_2; is the step between the plates t (m) encoded by the index x_3.

Statistical analysis of the results was performed to analyze the dependencies obtained with the help of the software package on the PC "Statistica 6.0". Determinations of the mathematical variance of random variables D were estimated by standard methods. The regression dependence of the performance on the change in the speed of the shaft n, the angle of attack of the frontal surface of the stroke of the plate α, deg and the pitch of the plates t, ie Q X_1 X_2 X_3 = f (n α t), for the encoded values of the factors for mixing has the form:

$$Q_{(n,\propto,T)} = 2.185 - 0.0031x_1 - 0.114x_2 + \\ +1.559x_3 + 0.000012x_1x_2 + \\ +0.000031x_1x_{3+} + 0.00036x_2x_3 \\ +0.0000023x_1^2 + 0.00071x_2^2 - 0.0723x_3^2$$

For the natural values of the factors of the regression equation (4.1) for mixing takes the form:

$Q_{(n,\propto,T)}$=1.224+0.0061n-0.106$\propto_1$+1.591T_2+0.00071$\propto_1^2$-0.0723T_1^2

The obtained regression equation can be used to determine the performance of the mixer for different formulations (Q), depending on the change of speed of the shaft with the working bodies n, the angle of attack of the frontal surface of the stroke of the plate α and the step between the tariaks t within the following limits of change of input factors:

348 ≤ n ≤ 696 (rpm); 30≤ 1 α ≤ 60 (deg); 0.9 ≤ t ≤ 0.14 (m).

From the obtained regression equations it was found that the factors that influence x1, x2, (n, α), and their combination are the biggest influence factors on the change in performance. Productivity is reduced to 20% by increasing the value of factor x2 (α) (Table 3).

By increasing the speed of the shaft and decreasing the angle of attack of the frontal surface of the plate stroke, the performance of the mixer is increased.

The response surfaces and their two-dimensional sections are built on the regression equations obtained to determine the performance from the change in the two factors for x3 = const. The results of the performance dependencies obtained with the Statistica-6.0 program are shown in Figure 4 and Figure 5.

The statistical processing of the experimental results and the obtained regression dependencies adequately reproduce the research processes for determining the mixing performance of the components which is the quality of the whipping of the foaming biscuit dough.

Figure 4 and Figure 5 show that as the shaft speed increases, the value of productivity increases, with the highest productivity being achieved when mixing gluten-free flour. Minimum performance value with minimum shaft speed and maximum attack angle of the frontal surface of the stroke of the plate.

RESULTS AND DISCUSSION

To analyze consumer properties and establish rheological dependencies, the studies were directed in such a sequence as to justify the feasibility of using an ECF.

Features of the methods of mixing we have chosen, the composition and state of the liquid phase of the dough, allow us to solve several technological problems. First, the liquid phase is the binding component for the formation of a continuous dough network. Second, the properties of the liquid phase actively influence the process of foam formation and its retention in the dough. Also **(Lisovska, Chorna and Dyakov, 2016)**, it is an important flavor component of the cupcake recipe.

The authors' research **(Kobets et al., 2015)** established the effect of a mixture of fibers and emulsifiers on the gluten complex of wheat flour by physicochemical quality indicators of the biscuit semi-finished product. To regulate the set quality of confectionery dough, the authors **(Mancebo, Rodriguez and Gómez, 2016)** believe that you can use different ratios of starch and protein.

The results of the authors' research **(Egorova and Reznichenko, 2018; Dorohovych, Hrytsevich and Isakova, 2018)** reflect the influence of technological and design factors on the model systems of biscuit semi-finished products. They analyzed the effect on the volume and shape of the finished products, the structure of their porosity, as well as the nature of the structural, and mechanical properties of the dough, the actual time of dough formation, its stability, degree of depression, consistency and elasticity.

Thus, research **(Haliasnyi, Gavrish and Shanina, 2018)** is aimed at finding structure-forming components for gluten-free flour confectionery. They conducted a comparative analysis of changes in the fractional composition of flour dough proteins with different types of flour raw materials and liquid phases. Problems related to changes in the structural and mechanical properties of the environment and the impact of structural elements and methods of the process, discussed in detail **(Szwedziak et al., 2019)**, taking into account empirical data, theoretical dependences, and the results of physical experiments.

The specificity of the production of gluten-free dough cakes by intensive mixing (whipping) is that the resulting foam structure is subjected to unwanted external influences that lead to a decrease in its stability. Such factors include mixing the whipped mixture with flour and placing the dough in molds. In such circumstances, it is important not only to obtain a foam system with the required characteristics but also to preserve them during the technological process. Accordingly, in our view, it is important to comprehensively investigate the foaming ability and foam resistance to structure destruction. It should be noted that obtaining a well-loosened dough structure is the first but not the only one technological task.

The issue **(Lisovska, Chorna and Dyakov, 2016)** of the preservation of the formed structure, which determines the corresponding rheological properties of the dough is also important. It should be noted **(Lisovska, Chorna and Dyakov, 2016; Dickinson, 2015)** that, unlike the traditional confectionery foam (for example, in the preparation of biscuits, where the amount of sugar is much higher), in gluten-free cupcakes, recipe sugar level is much lower. Therefore, the issue of effective foaming is extremely important.

In their studies **(Murtini and Putri, 2017)** to improve the volume as emulsifiers egg yolk substitute was added that is a suspension of edamam (Glycine max L. Merill). Five different proportions of edamam suspension were added to the dough and their effect on specific volume, porosity, water content, oil absorption, hardness texture, and elasticity was observed. It should be noted that many works **(Lisovska et al., 2020)**, considered the foam structure of the dough for cupcakes with the establishment of the main technological and design parameters of the interaction of prescription mixtures. They substantiated the quality of the cake with the ratio of the main recipe components: egg content (51%); sugar content (24.4%) and content of extruded corn flour (24.6%).

Along with the prescription components, the duration of the whipping and the speed of rotation of the working organs (machine productivity) are influenced by the foam volume and its dispersion, the foaming ability, and the foam stability.

As the whipping time increases, the volume of foam also increases; the whipping rate is directly proportional to the foam dispersion. We chose the traditional mode at high foam whipping.

Table 1 Chemical composition of extruded corn flour and wheat flour of the highest grade, %.

Product	Moisture content	Protein content	Fat content	Starch content	Ash content	Fiber content
Extruded corn flour	9.0 ±0.01	6.1 ±0.02	8.1 ±0.02	70.9 ±0.03	4.8 ±0.03	1 ±0.02
Wheat flour of the highest grade	14.5 ±0.03	11.4 ±0.05	1.08 ±0.04	67.7 ±0.05	0.5 ±0.03	0.1 ±0.01

Table 2 Formulation of experimental samples of biscuit cake.

Raw materials	solids content (SC), %	Cost of raw materials per 100 kg semi-finished product, kg			
		Biscuit semi-finished product Control		Gluten-free cookie cake	
		In kind	In DS	In kind	In DS
Wheat flour of the highest grade	85.50	28.12	24.04	-	-
Extruded corn flour	91.0	8.07	7.34	30.58	27.82
Potato starch	80.00	6,94	5.55		
Eggs	27.0	57.85	15.62	63.44	17.12
White sugar	99.7	34.71	34.65	30.26	30.16
Altogether:		135.69	87.2	124.28	75.1
Output		100.0	87.0	100.0	75.00

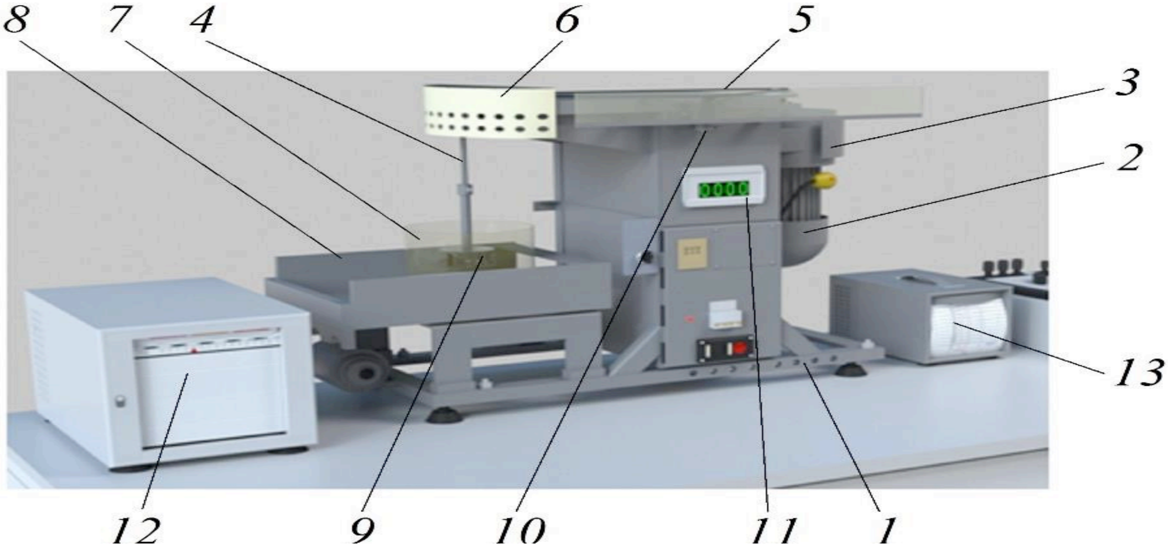

Figure 2 Experimental installation.
Note: 1 – frame; 2 – electric motor; 3 – coupling; 4 – shaft; 5 – V-belt transmission; 6 – the casing; 7 – a bowl; 8 - panel; 9 – disc working bodies; 10 – speed controller; 11 – electronic tachometer; 12 – potentiometer; 13 – wattmeter.

Figure 3 Biscuit dough placed on forms and on a pastry sheet.

Table 3 Characterization of factors and the significance of their levels for experimental performance studies.

Factor designation	code	Name of factor	Factor levels values
x_1		Auger speed n, rmp	348-552-696
x_2		tilt angle of unloading line a_1 degree	30-45-60
x_3		Auger step T_2, m	0.09-0.115-0.14

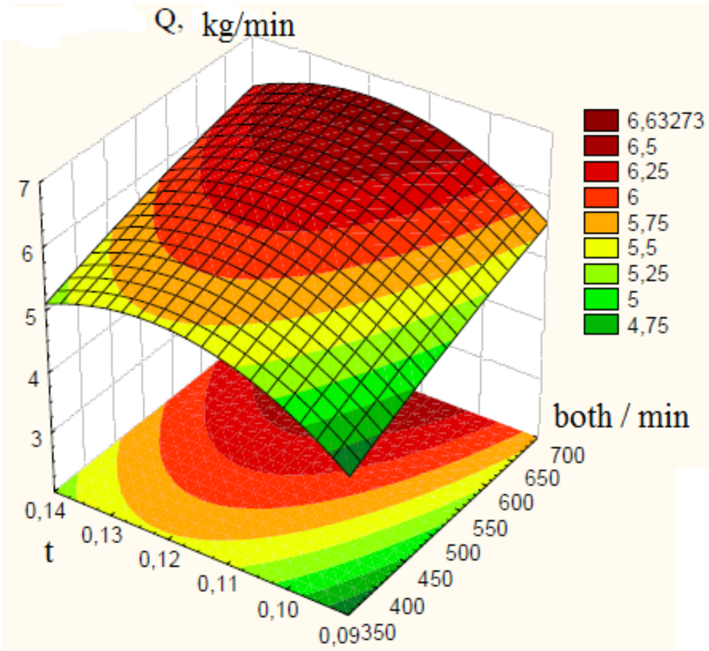

Figure 4 Response surface of the dependence of the mixer Q performance on the shaft speed and the pitch between the plates (α1 = 45 deg).

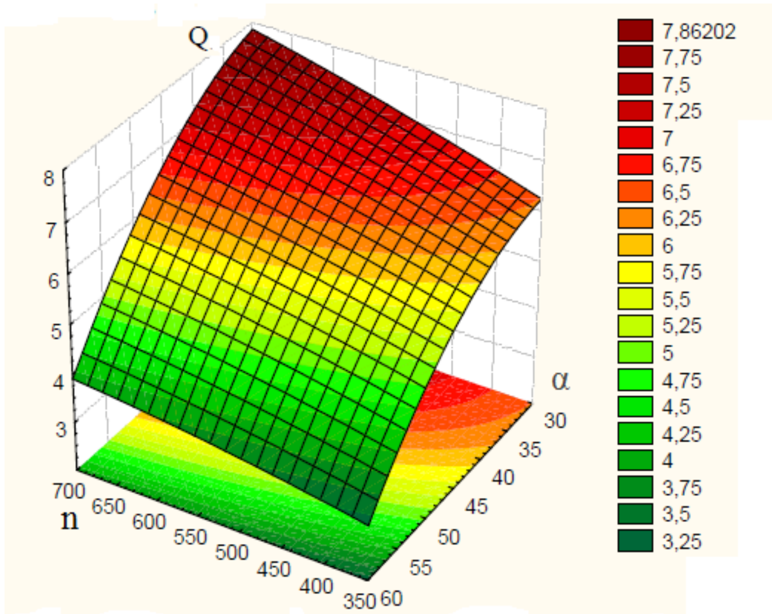

Figure 5 Response surface of the dependence of the performance of the mixer Q on the speed of the shaft and the angle of attack of the front surface of the plate stroke (t = 0.115 m).

Because the offered introduction of ECF to the recipe mixture affects the stability of the system, we conducted a set of experiments to study the dependence of the effective viscosity of biscuit dough samples with the addition of ECF on the velocity and shear voltage. In the tested mixtures, the moisture-holding capacity increases for the sample containing 20% by weight of corn extruded flour by two and a half times, and three times for the sample with extruded flour by 100% by weight. This tendency of change is explained by the swelling of whole starch grains due to the absorption and retention of moisture. With an increasing proportion of corn extruded flour in the flour mixture, the dough density increases and the optimum value is in the range of 0.444 – 0.446 $kg.m^{-3}$. An increase in the flour of corn extruded above 20% by weight leads to a considerable density of the dough, but in the absence of wheat flour of the highest grade indicates the possibility of creating a biscuit gluten-free semi-finished product.

From Figure 6 it is confirmed that the foam stability depends on the flour used. The use of corn extruded flour significantly affects the stability of the sponge dough foam. Foam resistance monotonically increases almost 1.5 times with the complete replacement of wheat flour, which corresponds to a large volume and a thin uniform porosity of the biscuit cake. This ability will help to stabilize the foam of the biscuit dough during mechanical influences during its molding.

The stability of the dispersed system is due to the structural and mechanical properties of the adsorption layers and the thermodynamic stability of the liquid layers. These adsorption layers slow the flow of liquid in the pellicles, reducing the rate of their thinning. This is confirmed in the work **(Zhou et al., 2015)** that revealed the effect on the moisture-holding capacity of the system of flour mixtures. At the same time, it was noted **(Zhou et al., 2015)** that free starch polymers dissolve to form a dispersed system.

Also, these layers give the foam pellicle a high structural viscosity and mechanical strength, creating a framework that gives the foam certain physical and chemical properties of the solid.

An important rheological characteristic of biscuit dough as the foam is the viscosity that acts as a structural and mechanical barrier in the formation and destruction of the foam structure. The dependence of the maximum viscosity of the suspension on the contents of the ECB in flour mixtures is shown in Figure 7.

The stability of the dispersion system, which is a biscuit dough largely due to the strength and resistance to loading, i.e. the creation of an elastic frame, which gives the system certain physical and chemical properties of the solid. Analysis of the studies showed that when adding 5 and 10% of the ECF there is a maximum viscosity, which indicates the starch binding during a large amount of water. When using 100% ECF (Figure 7), the viscosity decreases, because the starch binds a small amount of water during swelling and pasteurization. The water is free in the dough and released when coagulated with protein substances, which promotes the formation of a wetter crumb cake mix.

In the works of authors **(Lisovska, Chorna and Dyakov, 2016; Murray and Ettelaie, 2004)**, it is noted that the schematic structure of the foam is the packing of gas bubbles with thin pellicles of the main fine particulate filler, which is covered with pellicle substance with surfactants. Figure 9 shows the comparative characteristics of the microstructure of the following samples: wheat flour (WF) and extruded corn flour (ECF) in the ratios: a) WF – 100 wt.%; b) WF: ECF – 80:20 wt.%; c) ECF – 100 wt.%.

The thermodynamic correlation relative to the gas phase makes it possible to determine its volumetric deformation, which is the basis for determining the rigidity of the system.

Many studies **(Sandri et al., 2017)** proved that the moisture content of the dough in the case of rice and corn flour should be reduced compared to the moisture content of the dough with wheat flour, in the case of buckwheat flour it should be increased to obtain products high quality. They established and calculated the range of change in viscosity with increasing shear stress according to the viscosity curves.

For example, in the study **(Murray and Ettelaie, 2004)**, it is noted that the destruction of the air bubble film is directed toward the larger bubble because its pressure is lower than that of the small bubble.

On these microstructures of biscuit dough (Figure 9) of prototypes, it has the appearance of foam with an existing and uniform distribution of air bubbles, which later form a porous structure of biscuit semi-finished products. The sizes of the formed air bubbles with the content of wheat flour and starch have a large difference in diameters, that is, some bubbles are almost twice the size of the others. In the sample of biscuit dough using ECF 100 wt.% Figure 9 (4) foam bubbles are practically the same size and channels are formed between them, which help to equalize the air pressure in the middle of the foam biscuit dough system. The sample with an ECF content of 20 wt.% is also characterized by the same size of gas bubbles, which contributes to the stabilization of the foam system.

This leads to an improvement in the structural and mechanical characteristics of ready-made biscuit products.

After baking the samples (Figure 8), a semi-finished biscuit with a volume at the level of the sample of wheat flour with a fine uniform porosity was obtained. The use of 20 wt.% (Figure 8, number 2) and 100 wt.% (Figure 8, number 3) corn extruded flour contributes to the formation of a fine porous structure of biscuit dough.

Thus, the total area of large pores with a size of 0.7 – 1.5 mm in the sample with WF – 100 wt.%. It is equal to 15.36 mm^2 in the field of view and in the test samples variant WF: ECF – 80:20 wt.% and ECF – 100 wt.% is 3.69 and 2.94 mm^2 accordingly.

At the same time, the number of small and very small pores (less than 0.5 mm) is significantly increasing, mostly in the sample with ECF – 100 wt. %. The obtained data are correlated with the data on foaming capacity, which is the highest ECF that is 100 wt.%.

The above indicates that the proposed additives to improve gluten-free dough, improve the porosity of the foamy structure, forming a fine porous structure of the cake. This effect is due to the ability of high-quality deformation impact of the working bodies of the machine.

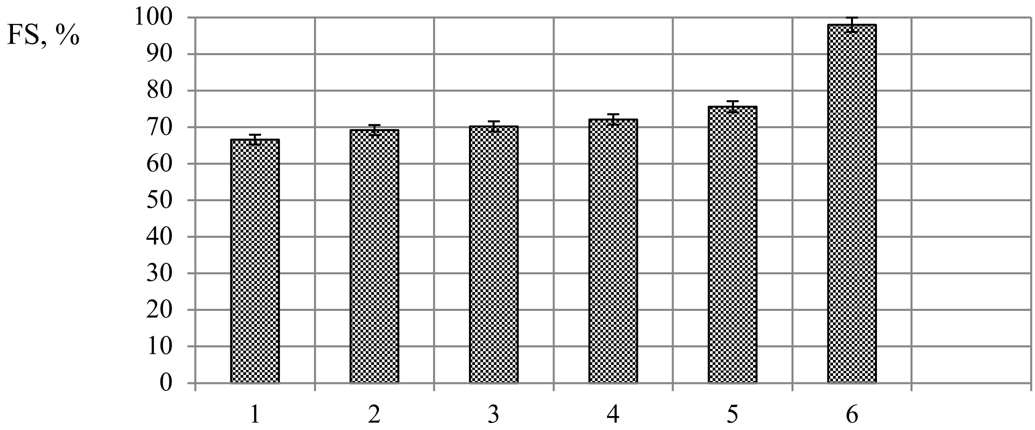

Figure 6 Dependence of biscuit dough foam stability on ECF content.
Note: 1 – WF:ECF– 100: 0 (control); 2 – WF: ECF – 95: 5 wt.%; 3 – WF: ECF – 90: 10 wt.%; 4 – WF: ECF – 85:15 wt.%; 5 – WF: ECF – 80:20 wt%; 6 – WF: ECF – 0: 100 wt.%.

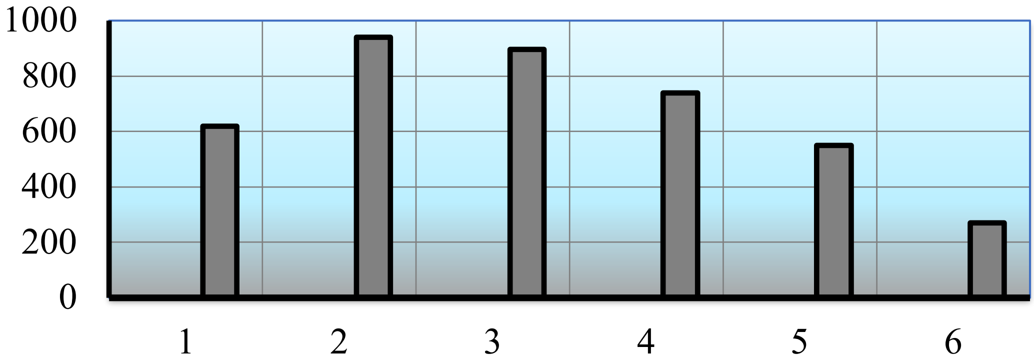

Figure 7 Dependence of the maximum system viscosity on the content of the ECB in flour mixtures.
Note: Wheat flour of the highest grade and ECF in the ratios: 1 – WF: ECF – 100: 0; 2 – WF: ECF – 95: 5; 3 – WF: ECF – 90:10; 4 – WF: ECF – 85:15; 5 – WF: ECF – 80:20; 6 – WF: ECF – 0: 100.

Figure 8 Photos of the surface and porosity of the biscuit cakeusing.
Note: ECF: 1) WF – 100 wt.%; 2) WF: ECF – 80:20 wt.%; 3) ECF – 100 wt.%.

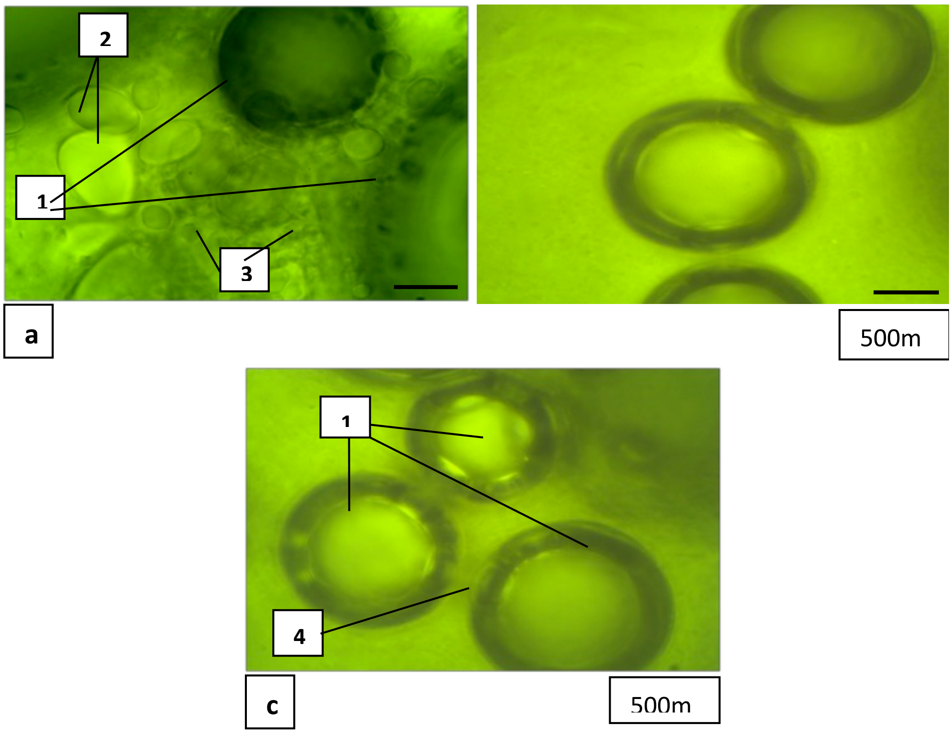

Figure 9 Microstructure (1: 1000) of biscuit dough samples.
Note: Dough samples containing: WF and ECF in the ratios: a) WF – 100 wt.%; b) WF: ECF – 80:20 wt.%; c) ECF – 100 wt.%; 1 – air bubbles; 2 – potato starch grains; 3 – wheat flour starch grains; 4 – channels between air bubbles.

CONCLUSION

Therefore, it can be concluded that the use of the obtained results allows regulating the technological properties of flour mixtures, depending on the concentration of them in the ECB and recommend them in the production of confectionery flour health products.

Stabilization of the rheological properties of the foam system of biscuit gluten-free dough is achieved due to the properties of partially pasteurized starch of extruded flour. Gluten-free biscuit recipe composition is optimized: 51% of egg product content; 24.4% of sugar content and 24.6% of flour content of extruded corn.

The presence of stable hydrodynamic parameters of gas-liquid systems under the action of the geometry of the machine gives reason to consider them metastable. The motive factor is determined by the product of the external pressure on the cross-sectional area of the working room, and the opposing force in the deformation of the gas-liquid medium is the elastic forces and the forces of internal friction.

REFERENCES

Brekhov, A., Riazhskykh, V. 2012. Prohnozyrovanye byolohycheskoi y pyshchevoitsennosty v hotovoi produktsy ypryekstruzyonnoi obrabotke rastytelnoho Syria. (Pronunciation of belonic and nutritional value in hot production by extrusion processing of vegetable raw materials). *Khranenye y pererabotka selkhoz syria*, no. 3, p. 38-42. (In Russian)

Dickinson, E. 2015. Colloids in food: ingredients, structure, and stability. *Annual review of food science and technology*, vol. 6, no. 1, p. 211-233. https://doi.org/10.1146/annurev-food-022814-015651

Dorohovych, V., Hrytsevich, M., Isakova, N. 2018. Effect of gluten-free flour on sensory, physicochemical, uctural and mechanical properties of wafer batter and waffles. *Ukrainian Food Journal*, vol. 7, no. 2, p. 253-263. https://doi.org/10.24263/2304-974X-2018-7-2-8

Drobot, V., Pysarets, O., Kravchenko, I. 2013. Vykorystannia kukurudzianoi krupy u vyrobnytstvi pshenychnoho khliba (The use of corn grits and the production of wheat bread). *Storage and processing (Khranenye y pererabotkazerna)*, no. 9. (In Ukrainian)

DSTU 3355-96. 1996. *Agricultural products. Methods of sampling during quarantine examination and expertise.*

DSTU ISO 9001. 2015. Quality Management Systems. Requirements (ISO 9001: 2015, IDT), Research Institute of Metrology of Measuring and Control Systems (SE "Sistema").

Egorova, E., Reznichenko, I. 2018. Development of food concentrate – semi-finished product with amaranth flour for gluten-free cupcakes. *Food Processing: Techniques and Technology*, vol. 49, no. 2, p. 36-45. https://doi.org/10.21603/2074-9414-2018-2-36-45

Haliasnyi, I., Gavrish, T., Shanina, O. 2018. Research of surface properties of water-flour suspensions in the presence of hydrocolloids and protein supplements. *Technology Audit and Production Reserves*, vol. 1, no. 3 (39), p. 58-63. https://doi.org/10.15587/2312-8372.2018.124286

Holovchenko, V., Lopatin, H., Kovbasa, V. 2001. Ekstrudaty, shrot i kontsentratyi z zernobobovykh mozhna vykorystovuvaty dlia stvorennia novykh vydiv kharchovykh produktiv (Extrudates, meal and concentrates from leguminous plants can be vikoristovuvati for the production of new products). *Kharchova i pererobnapromt*, no. 1, p. 23-25. (In Russian)

Kobets, O., Dotsenko, V, Arpul, O., Dovgun, I. 2015. Wheat fibre impact on flour quality of confectionery products. *Journal of Faculty of Food Engineering*, Ştefancel Mare University - Suceava, vol. 14, no. 4, p. 391-398. Available at: http://dspace.nuft.edu.ua/jspui/bitstream/123456789/25608/1/Kobets.pdf

Lamacchia, C., Camarca, A., Picascia, S., Di Luccia, A., Gianfrani, C. 2014. Cereal-based gluten free food: how to reconcile nutritional and technological properties of wheat proteins with safety for celiac disease patients. *Nutrients*, vol. 6, no. 2, p. 575-590. https://doi.org/10.3390/nu6020575

Lisovska, T., Chorna, N., Dyakov, A. 2016. Research of rheological properties of egg sponge with extruded corn flour. *Eastern-European Journal of Enterprise Technologies*, vol. 2, no. 11 (80), p. 19-23. https://doi.org/10.15587/1729-4061.2016.65732

Lisovska, T., Stadnik, I., Piddubnyi, V., Chorna, N. 2020. Effect of extruded corn flour on the stabilization of biscuit dough for the production of gluten-free biscuit. *Ukrainian Food Journal*, vol 9, no. 1, p. 159-175. https://doi.org/10.24263/2304-974X-2020-9-1-14

Liu, J., Willför, S., Xu, C. 2015. A review of bioactive plant polysaccharides: Biological activities, functionalization, and biomedical applications. *Bioactive Carbohydrates and Dietary Fibre*, vol. 5, no. 1, p. 31-61. https://doi.org/10.1016/j.bcdf.2014.12.001

Mancebo, C. M., Rodriguez, P., Gómez, M. 2016. Assessing rice flour-starch-protein mixtures to produce gluten-free sugar-snap cookies. *LWT – Food Science and Technology*, vol. 67, p. 127-132. https://doi.org/10.1016/j.lwt.2015.11.045

Murray, B. S. 2007. Stabilization of bubbles and foams. *Current Opinion in Colloid & Interface Science*, vol. 12, no. 4-5, p. 232-241. https://doi.org/10.1016/j.cocis.2007.07.009

Murray, B. S., Ettelaie, R. 2004. Foam stability: Proteins and nanoparticles. *Current Opinion in Colloid and Interface Science*, vol. 9, no. 5, p. 314-320. https://doi.org/10.1016/j.cocis.2004.09.004

Murtini, E. S., Putri, D. A. 2017. Potensi edamame sebagai pengganti kuning telur dalam pembuatan donat mengandung kentang (The potential of edamame as a substitute for egg yolk in making donuts containing potatoes). *Jurnal Teknologi dan Industri Pangan*, vol. 28, no. 2, p. 102-110. (In Indonesian) https://doi.org/10.6066/jtip.2017.28.2.102

Renzjaeva, T., Bakirova, M. 2017. Pechen'ei z risovoj muki dlja specializirovannogo pitanija (Rice flour biscuits for specialized meals). *Tehnologii pishhevoj i pererabatyvajushhej promyshlennosti APK-produkty zdorovogo pitanija*, p. 49-54. (In Russian)

Rochow, T. G., Rochow, E. G. 2012. *An Introduction to Microscopy by Means of Light, Electrons, X-Rays, or ultrasound*. New York, USA : Plenum press, 367 p. ISBN 978-1-4684-2454-6.

Ruskina, A. A., Popova, N. V., Naumenok, N. V., Ruskin, D. V. 2017. Analiz sovremennyh sposobov modifikacii krahmala kak instrumenta povyshenija ego tehnologicheskih svojstv (Analysis of Modern Methods for Starch Modification as a Tool for Increasing its Technological Properties). *Bulletin of the South Ural State University, Food and Biotechnology*, vol. 5, no. 3, p. 12-20. (In Russian) https://doi.org/10.14529/food170302

Sandri, L. T. B., Santos, F. G., Fratelli, C., Capriles, V. D. 2017. Development of gluten-free bread formulations containing whole chia flour with acceptable sensory properties. *Food Science & Nutrition*, vol. 5, no. 5, p. 1021-1028. https://doi.org/10.1002/fsn3.495

Stadnyk, I. Y., Pankiv, J., Havrylko, P., Karpyk, H. 2019. Researching of the concentration distribution of soluble layers when mixed in the weight condition. *Potravinarstvo Slovak Journal of Food Sciences*, vol. 13, no. 1, p. 581-592 https://doi.org/10.5219/1129

Stadnyk, I., Dobrotvor, I., Derkach, A., Vasyliv, V. 2015. Methods and results of the study of pore formation in Podilsky bagel, SWorld. *Proceedings*, vol. 3, no. 2(39), p. 9-15.

Stojceska, V., Ainsworth, P., Plunkett, A., İbanoğlu, Ş. 2010. The advantage of using extrusion processing for increasing dietary fibre level in gluten-free products. *Food Chemistry*, vol. 121, no. 1, p. 156-164. https://doi.org/10.1016/j.foodchem.2009.12.024

Szwedziak, K., Stadnyk, I., Golyachuk, S., Grzywacz, Ż. 2019. Justification of the rheological model of process of plastic material injection by the rollers. *Agricultural Engineering*, vol. 23, no. 3, p. 101-114. https://doi.org/10.1515/agriceng-2019-0030

Yehorov, B., Mardar, M., Bordun, T. 2014. Formuvannia spozhyvnykh vlastyvostei kharchovykh produktiv novoho pokolinnia shliakhom ekstruzii (Formation of the living authorities of the grub production of the novoho pokolinnya by the way of extrusion). *Khranenye y pererabotkazerna*, vol. 5, no. 182, p. 64-67. (In Russian)

Zhou, Z., Zheng, P., Wang, Z., Yang, R., Chu, Y. 2015. Enhanced thermal and antibacterial properties of crosslinked waxy maize starch granules by chitosan via dry heart treatment. *Internetional Journal of Food Science & Technology*, vol. 50, no. 4, p. 899-905. https://doi.org/10.1111/ijfs.12728

Zip diagnostic. N. d. Sovremennye tekhnolohyy kontrolia kachestva (Modern technology of quality control). Available at: http://www.zip-i.ru/gluten_podrobno

Contact address:

*Igor Stadnyk, Ternopil Ivan Puluj National Technical University, Department of Food Biotechnology and Chemistry, Ukraine, Ternopil 46001, Hohol str. 6, Tel.: +380975454829,
E-mail: igorstadnykk@gmail.com
ORCID: https://orcid.org/0000-0003-4126-3256

Olena Kolomiiets, Khmelnitskyi cooperative trade and economic institute, Department of Hotel and Restaurant and Tourism Business, Ukraine, Khmelnitskyi 29000, Kamjanetska str. 3, Tel.:+380687863278,
Email: elenakom87@ukr.net
ORCID: https://orcid.org/0000-0003-2195-5394

Oksana Dziana, Khmelnitskyi cooperative trade and economic institute, Department of Hotel and Restaurant and Tourism Business, Ukraine, Khmelnitskyi 29000, Kamjanetska str. 3, Tel.: +380671360900,
Email: oksana.dzyana@gmail.com
ORCID: https://orcid.org/0000-0001-9392-0401

Corresponding author: *