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EXPLORING A POSSIBILITY OF USING ULTRASOUND IN THE TECHNOLOGY OF CONFECTIONERY PRODUCTS

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Останнім часом в різних галузях харчової промисловості набули широкого використання нетрадиційні способи обробки сировини та напівфабрикатів. Це сприяє інтенсифікації виробництва, подовженню терміну збереження свіжості нових виробів, дозволяє впроваджувати ресурсо- та енергозберігаючі технології.

Актуальними слід вважати дослідження можливості використання ультразвуку в технології борошняних кондитерських виробів, а саме бісквітів.

Запропоновано технологію збивання меланжу з цукром за допомогою міксера, чаша якого встановлена в ультразвукову ванну, заповнену водою.

Досліджено вплив дії ультразвуку на показники якості піни яєчно-цукрової суміші (піноутворювальну здатність, стійкість піни, її мікроструктуру) та готових бісквітних напівфабрикатів.

Встановлено, що піноутворювальна здатність дослідних зразків з використанням ультразвуку збільшувалась на 35 %. Крім того, максимальне значення піноутворювальної здатності зразку з використанням ультразвуку досягалося за майже у двічі коротший час ніж у контрольного. Порівняльний аналіз стійкості піни після 60 хв вистоювання показав, що найбільш стійкою виявилася система меланж-цукор під дією ультразвуку – 90 %. Визначено, що дія ультразвуку на яєчно-цукрову суміш забезпечила отримання піни, майже з рівномірними однаковими бульбашками невеликого розміру, розташованими близько один до одного.

Встановлено оптимальні параметри збивання яєчно-цукрової суміші бісквітного тіста в полі ультразвуку: потужність ультразвуку – 0,6 кВт, температура води в ультразвуковій ванні – 26 °С, час збивання меланжу з цукром – 6,5 хв.

Доведено, що використання ультразвуку в технології бісквітних напівфабрикатів сприяє: інтенсифікації процесу піноутворення яєчно-цукрової суміші; дає змогу збивати всі компоненти одночасно, що значно спрощує сам процес виробництва бісквітів; підвищенню пористості готових виробів та більш рівномірному розподілу пор

Ключові слова: ультразвук, яєчно-цукрова суміш, піноутворювальна здатність, стійкість піни, бісквітні напівфабрикати

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1. Introduction

Flour-based confectionary products (FCPs) are increasingly popular among different age groups of consumers. The range of FCPs is diverse and has more than a hundred titles. A significant proportion of products within a given group belongs to sponge-cake dough products. It is characterized by easy digestibility, pleasant taste and aroma, as well as pleasant physical appearance.

Sponge cake dough is a complex dispersed system consisting of about 45 % of air bubbles, separated from each other by films of the liquid dispersed medium, which includes eggs, sugar, and flour. The structure of a baked semi-finished product depends on the size and quantity of air bubbles in the dough [1].

The formation of a foam-like structure of a sponge cake semi-finished product is primarily affected by the properties of a base raw material, the duration of whipping process, and the mechanical impact on dough when mixing it.

Ultrasound (US) is quite widely used in the food industry. It was established that ultrasonic vibrations are able to change the aggregate state of a substance, thereby dispersing and emulsifying it, to modify the rate of diffusion, crystallization, and dissolving of substances, to intensify reactions, and to boost technological processes. When examining the influence of US waves on the technological process of making food products, one observes a decrease in energy consumption and labor intensity. It becomes possible to make food products with new consumer properties, improved quality and extended shelf life [2].

The base of sponge cake dough is egg-sugar foam, which represents a dispersed system that easily reacts to any changes in the technological process. At the same time, significant changes could be observed in terms of quality indicators for sponge cake dough, and, consequently, in the finished sponge cake. Therefore, it appears relevant to undertake a research aimed at exploring a possibility to apply ultrasound to the technology of sponge cake semi-finished products.

2. Literature review and problem statement

In recent years, US oscillations have been wide spread in various sectors of the food industry. The use of US is known in the dairy, meat industries, production of beverages, making bread and confectionery products.

Paper [3] investigated changes in the microstructure of micelles in yogurt with casein under the influence of US. Experimental data showed that the microstructure of the milk yoghurt exposed to US over 0.5...30 minutes had more interrelated micelle chains with a decrease in particle size. The yogurt demonstrated a more uniform and homogeneous structure. Scientists have come to similar conclusions in [4], in which they investigated the influence of US on the process of making yoghurt from soy milk. It was found that the samples of yoghurt exposed to US exhibited improved consistency indicators and gel textures than samples prepared according to a standard technology.

In [5], it was proven that the US effect contributes to the more rapid extraction of collagen from the tendon of cattle. These results correlate with the study reported in [6]. Thus, the application of US oscillations could improve meat quality, as well as accelerate the processes of its processing, to increase the degree of tenderness of meat obtained from the tendinous muscle of cattle.

As regards the technology of soft drinks, US promotes the intensification of extraction process and improves the organoleptic properties of beverages [7]. It was found that the juice exposed to US retains more nutrients than juices made in line with conventional technology.

Scientists have investigated the positive impact of US oscillations on the rheological properties of dough and quality of wheat bread [8]. The effect of US resulted in improved indicators of water absorption, dough stability, and rarefaction. The bread baked from the flour exposed to ultrasound had a more saturated color, a more uniform texture, increased specific volume, and improved physical appearance.

Work [9] established that the process of making bakery products in an US field is significantly reduced in comparison with a traditional method.

The results reported in study [10] demonstrated that US waves improve the aeration of cupcakes from the flour triticale. At the same time, such parameters as the specific volume and porosity of finished products are improved.

Scientists have proven the stabilizing effect of US oscillations on egg foam [11]. It was established that the treatment with US within 5 and 10 min. led to an increase in the antioxidant activity and solubility of the egg protein. Stability of the foam formed from egg whites previously exposed to US oscillations increased.

Up to now, no research has been reported both into direct influence of US on the foaming capacity and stability of foam in an egg-sugar mixture that serves as a base for sponge cake dough, and quality indicators of finished products.

The above scientific and technical information testifies to the prospects of using US in a FCP technology, specifically sponge-cake semi-finished products.

3. The aim and objectives of the study

The aim of this study is to examine the effect of US on qualitative indicators of finished sponge-cake semi-finished products. The study results would make it possible to control and simultaneously modify basic qualitative characteristics of finished semi-finished products, in particular, porosity and specific volume.

To achieve the set aim, the following tasks have been solved:

– to determine the influence of US on the foaming capacity (FC) of egg-sugar mixture of sponge cake dough, foam stability, and its dispersion;

– to establish optimum technological parameters for whipping egg-sugar mixture in an US field;

– to explore quality indicators of finished products that are baked considering the new parameters for whipping egg-sugar mixture.

4. Materials and methods to study the effect of ultrasound on quality indicators of sponge cake semi-finished products

The following raw materials were used in the course of our research and production tests: wheat flour (DSTU 46.004-99), sugar (DSTU 4623:2006), chicken eggs (DSTU 5028:2008), cocoa powder (DSTU 4391:2005), and butter (DSTU 4399:2005).

4. 1. Methods to study quality indicators of egg-sugar mixture foam

The kinetics of foaming and foam stability were determined by the Lurie method, whereby foaming capacity at a certain point during whipping was calculated from formula:

$$\text{FC} = 100 \times \frac{h_i - h_0}{h_0}, \tag{1}$$

where FC is the foaming capacity, %; h_0 is the initial value of the egg emulsion column height, mm; h_i is the average value of foam height at the i-th minute of whipping, mm.

Foam stability (2) was determined as the ratio of a foam column height after aging over a certain time to a foam column height prior to aging, expressed in %.

$$\text{FS} = \frac{h_i \times 100}{h_{\max}}, \tag{2}$$

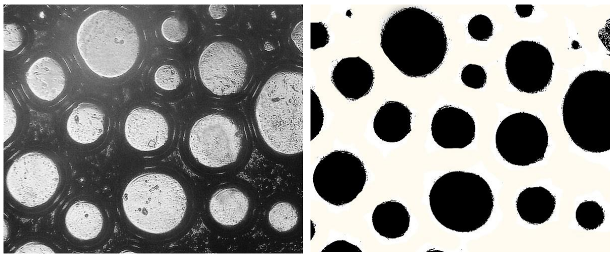
where FS is the foam stability, %; $h_{\max}$ is the height of a foam column prior to aging, mm; h_i is the height of a foam column in 30, 60, 90, 120 min, of aging, mm.

We examined foam microstructure using an optical microscope.

To calculate and analyze the size of air bubbles, microphotographs of foam were processed employing the software ImageJ-2015. Fig. 1 shows an example of the transformed image of a foam microstructure.

For each experimental sample, we acquired 4 microphotographs from different sections of the subject glass.

Fig. 2 shows a flowchart of image processing to assess the morphology of air bubbles in egg foam.



a *b*

Fig. 1. Microphotographs of egg protein foam: *a* — before processing by ImageJ-2015; *b* — after processing by ImageJ-2015

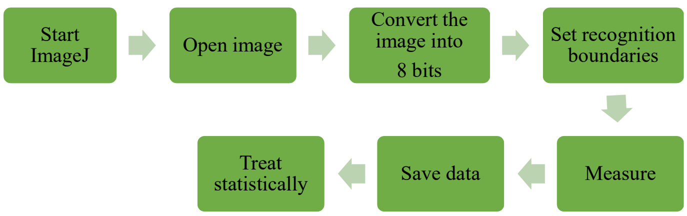


Fig. 2. Flowchart of processing a digital image of foam

The Analyze→Set measurements parameter was used to determine the size and other air bubble characteristics, by setting the corresponding characteristics (area, shape descriptors).

4. 2. Methods to study quality indicators of finished sponge cake semi-finished products

We examined the finished products for butter sponge cake semi-finished products, whose control sample was prepared by the cold technique [12]. According to the conventional technology, egg yolks are separated from whites, yolks are rubbed with 50 % of granulated sugar. Egg whites are whisked, at the end of whipping the rest of sugar is added and egg-sugar mixture is mixed.

Porosity of the finished products was determined at a Zhuravlev device in line with a known procedure [13].

The organoleptic quality assessment was conducted by the method of expert assessments.

4. 3. Methods for statistical and mathematical treatment of experimental data

To processing the study results, we employed the Excel 2010 tabular processor and the problem-oriented software package for mathematical computations Statistica 2010.

5. Results of studying a possibility to use ultrasound in the technology of sponge cake semi-finished products

The quality indicators of a whipped egg-sugar mixture are affected by the properties of egg products, their quantitative ratio to sugar, as well as whipping parameters (intensity, duration, temperature, medium pH, etc.).

The degree of whipped egg raw materials affects the properties of dough and such quality indicators of semi-finished products as specific volume and porosity. Although egg products are good foaming agents, they demonstrate unstable technological properties.

Foams are dispersed systems, which consist of bubbles of gas, delimited with layers of liquid, that is, the disperse phase is a gas, and the dispersed medium – liquid. When whipping egg whites, a lush foam forms under the influence of mechanical stress in the form of air bubbles, surrounded by a thin shell in the form of films made of whites' solution. Foam systems are characterized based on indicators such as: FC, multiplicity, stability, and dispersity.

5. 1. Determining foaming capacity of egg-sugar mixture

FC is the amount of foam, which is expressed by its volume (in cm^3) or by a column height (in mm), obtained under certain conditions over a specified time, respectively, to the mass of whites in the starting solution. Among the proteins of eggs, ovoglobulin is the primary and most effective foaming agent. It should be noted that the presence of yolk containing fat reduces the FC of whites.

The optimum temperature of mélange whipping is considered to be a range of 20–30 °C. Therefore, at the first stage of the research, we determined the FC of egg white foam, mélange, and mélange with sugar at 20 °C (Fig. 3).

The data obtained have shown that the largest value of FC was demonstrated by egg white. Mélange with sugar has the lowest value of FC, which can be explained by the increase in the surface tension of the liquid phase, which complicates its foaming. In addition, a reduced value of FC can be explained by a more stable protein structure in sugar solutions, owing to which the protein molecules are worse unwound at adsorption at the interphase. However, the technology of sponge cake semi-finished products recommends whipping mélange and sugar in one stage, which greatly simplifies the process of preparation, but reduces quality indicators of foam. The review of literature [14] reveals that changes in conditions for whipping mélange would neutralize this effect of sugar.

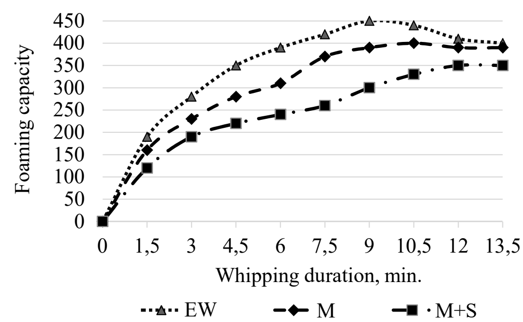


Fig. 3. FC of whites depending on whipping duration: EW — egg white, M — mélange, M+S — mélange with added sugar

One can control the process of foaming by influencing the conditions for forming an intraphase adsorptive layer. There is a certain correlation between the process of forming an intraphase adsorption layer and the mixture whipping mode: rate, whipping duration, the shape of a working body, and whipping conditions.

5. 2. Results of research into dependence of the foaming capacity of whites on ultrasound effect

A promising direction of research towards improving the technology of sponge cake semi-finished products is the application of US tubs. Currently, the market of professional technological equipment offers quite a wide range of devices with US generators.

For our experiment, we used an US tub (manufactured by LLC "Titan Technics") with an adjustable capacity of 0.4–0.8 kW. We whipped the components of egg-sugar mixture using a household mixer Zelmer, whose bowl was installed in an US tub filled with water (Fig. 4). All other whipping parameters remained unchanged.

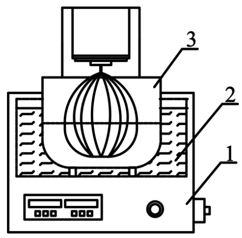


Fig. 4. Schematic of installation for whipping egg-sugar mixture with a system of US tub:
1 – US tub (body), 2 – working environment of US tub filled with water, 3 – mixer bowl

The US field generates significant acoustic currents. Therefore, the impact of US on a medium generates specific effects: physical, chemical, and biological. These include cavitation, sound-capillary effect, dispersing, emulsifying, degassing, disinfection, local heating, and many others.

The effect of US waves is associated primarily with the development of such an effect as the acoustic cavitation occurring in a medium at ultrasonic propagation, which represents an effective means of converting energy from a sound wave of low density into the high-density energy, associated with pulsations and collapse of cavitation bubbles [15].

We studied the dependence of FC on the duration of whites whipping under standard conditions and in an US field. The results are shown in Fig. 5.

Fig. 5 shows that the maximum value of FC for a sample of mélange+sugar+US was higher by 35 % compared to a sample of mélange+sugar. In addition, there is a significant reduction in the time of foaming for a sample of mélange+sugar, exposed to US. Thus, the maximum value of FC for a given sample was achieved already at minute 7 of whipping the egg-sugar mixture, while the maximum FC value for a sample of mélange+sugar was established after almost 12 minutes of whipping.

The next stage of our study was to establish optimum parameters of the US influence on egg-sugar mixture, through mathematical planning. Control factors were the duration of mélange whipping, min. (X_1), water temperature in an US tub, °C (X_2), and US power, kW (X_3). FC (Y) was selected as a criterion for optimization. The experiment's matrix is shown in Table 1.

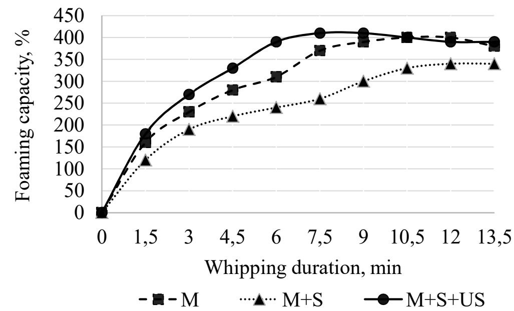


Fig. 5. FC of whites depending on whipping duration:
M – mélange, M+S – mélange with added sugar, M+S+US – mélange with added sugar, exposed to ultrasound

Table 1

Range of factor space

Level and step of variance	X_1, min.	X_2, °C	X_3, kW
Zero level	7	24	0.6
Variance interval	2	3	0.2
Upper level	9	28	0.8
Lower level	5	20	0.4

The optimality criterion in this experiment was chosen to be one of the output parameters, which characterizes quality of the finished product provided that all other factors affecting this indicator would fit the permissible range of values. Based on the plan of the experiment, we conducted a series of model experiments and determined the FC of each sample.

The result of treating the initial and statistical material employing the 2010 Statistica is the derived regression equation in the encoded form and the established values for a full-factor regression function in the following form:

$$Y = 176{,}67 + 29{,}21 \times X_1 + 3{,}25 \times X_2 + \\ +144{,}91 \times X_3 - 0{,}02 \times X_1 \times X_2 - \\ -2{,}31 \times X_1 \times X_3 - 0{,}38 \times X_2 \times X_3 - \\ -1{,}71 \times X_1^2 - 0{,}05 \times X_2^2 - 82{,}30 \times X_3^2.$$

Multiple coefficient of determination R^2=0.62. By analyzing the data obtained, we can conclude that the greatest impact on FC is exerted by duration of whipping the mixture. Fig. 6 shows a graphic interpretation of the computational experiment.

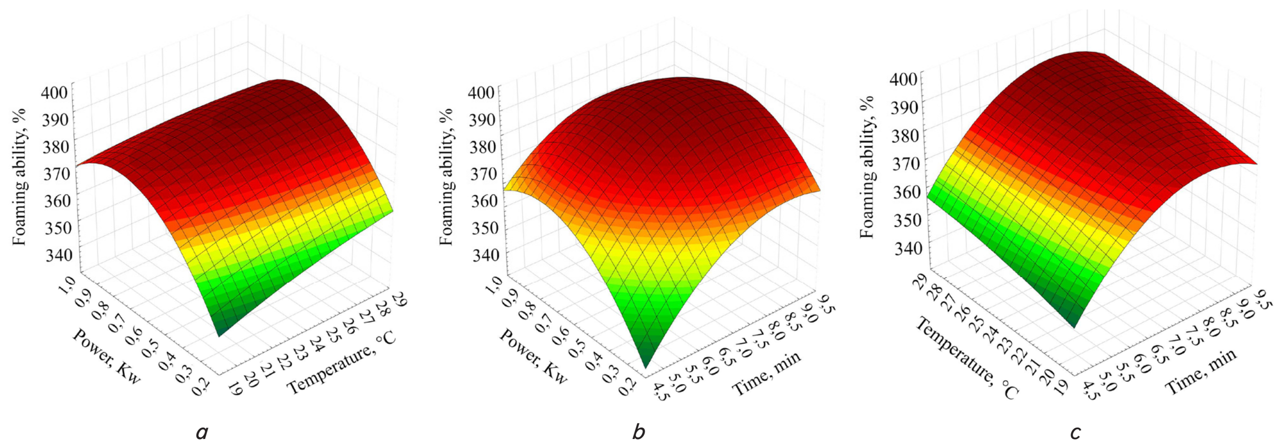


Fig. 6. Response surfaces: *a* – dependence of porosity on US power and whipping temperature; *b* – dependence of porosity on US power and whipping duration; *c* – dependence of porosity on temperature and whipping time

The shape of the response surfaces indicates stability of the results obtained. A high value for FC can be achieved via a wide range of parameters for the technological process. The results from mathematical calculations have established the following:

– optimum power of US is 0.6 kW;

– optimum water temperature in an US tub is 26 °C;

– optimal time of whipping up mélange with sugar is 6.5 min.

5. 3. Results from studying the effect of ultrasound on the stability and structure of egg-sugar foam

Foam stability is the ability to keep the total volume, dispersed composition, and to resist syneresis. Foam stability is characterized by the period of its half-life, that is the time necessary to destruct half a volume of foam. The results from studying the foam stability of experimental samples are shown in Fig. 7.

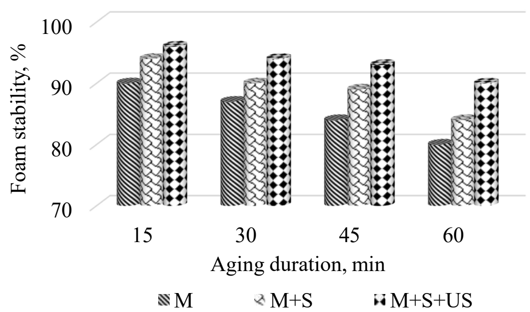
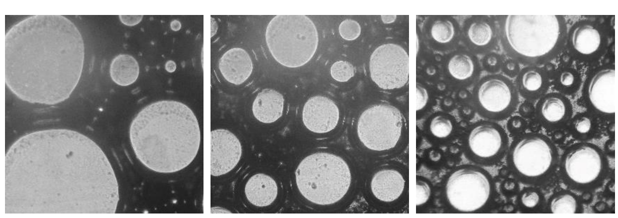


Fig. 7. Foam stability: M — mélange, M+S — mélange with added sugar, M+S+US — mélange with added sugar, exposed to US

It was established that a sample of mélange with added sugar that was whipped when exposed to US is characterized by increased stability compared to the sample not exposed to US and mélange without sugar.

Foam stability is directly dependent on its dispersion, which can be set by the mean size of an air bubble, by bubbles distribution for size, or by the interface "solution–gas" per a foam volume unit. To define the structure and the dispersion of foams obtained during whipping of mélange, mélange with addition of sugar, and mélange with sugar, exposed to US, we used microphotography. Microphotographs are shown in Fig. 8.



a *b* *c*

Fig. 8. Microstructure of the examined samples: *a* — mélange; *b* — mélange with added sugar; *c* — mélange with added sugar, exposed to US

Based on our study, it has been proven that the structure of foam from mélange with sugar, exposed to US, changed, compared to mélange without sugar and mélange with added sugar, while part of the bubbles decreased in size. The effect of US on egg-sugar mixture (Fig. 6, *c*) ensured obtaining foam with almost identical bubbles of small size, located close to each other. A dispersion medium is able to hold more air bubbles, preventing the coalescence of the system; thereby its viscosity is increased. Increasing fluid viscosity under the influence of US positively influences the ductility of films, which makes it possible to increase the volume of air phase in the system. The thickness of the films decreases, but they gain strength, as evidenced by data on the stability of foam over time.

Given the data obtained, it can be argued that whipping of egg-sugar mixture in an active US field would result in the acceleration of the process of making sponge cake semi-finished products (by reducing the duration of mélange whipping); one can also predict obtaining products with better porosity and, accordingly, increased specific volume.

Therefore, the next step was to investigate a change in the physical and chemical quality indicators of finished products. The data on a rise factor and porosity coefficient of the examined samples are shown in Fig. 9.

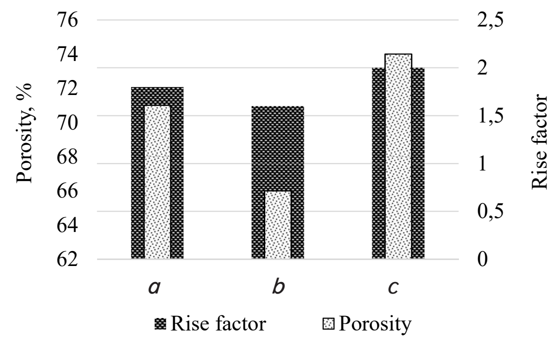


Fig. 9. Physical-chemical parameters for quality of sponge cake semi-finished products: *a* — control (whipping egg-sugar mixture with the preliminary separation of whites from yolks); *b* — sample 1 (whipping egg-sugar mixture in 1 stage); *c* — whipping mélange with sugar in an US field

An analysis of data from Fig. 9 indicates that the porosity indicator increases by almost 7.5 % compared to control sample, baked according to conventional technology [12], and by 11 % compared with the sample for which the whipping of egg-sugar mixture occurred without the prior separation into whites and yolks.

Table 2 gives resulting assessment of the full characteristic of organoleptic parameters of the examined samples based on the level of quality, taking into consideration the coefficient of significance. Control sample was the sponge-cake semi-finished product for which the egg-sugar mixture was whipped with the preliminary separation of whites from yolks. For examined sample 1: the whipping of egg-sugar mixture was carried out in a single stage, without preliminary separation of eggs into whites and yolks. For sample 2: mélange was whipped with sugar according to the proposed technology, in an US field.

Based on results from the organoleptic evaluation of the above samples of sponge-cake semi-finished products, we constructed a profilogram using a 5-point scale (Fig. 10).

The results of our organoleptic assessment have established that the sponge cake semi-finished products, which were made based on the egg-sugar mixture prepared in a single step (sample 1), are inferior to control sample in terms of indicators for porosity and crumb elasticity. The sponge cakes, prepared according to the proposed technology (sample 2), demonstrated a more uniform, thin-walled, elastic crumb, compared to sample 1 and to control.

Table 2

Results of organoleptic evaluation of sponge-cake semi-finished products, points

Indicator	Significance coefficient	Control	Sample 1	Sample 2
Physical appearance:				
Product shape, surface state	0.5	5	5	5
Crust color	0.3	5	5	5
Crumb state:				
Porosity character	0.4	4	3	5
Crumb color	0.3	5	5	5
Elasticity	0.5	4	3	5
Aroma (flavor)	0.8	5	5	5
Taste	0.8	5	5	5
Chewiness	0.4	5	5	5
Total score:		38	36	40

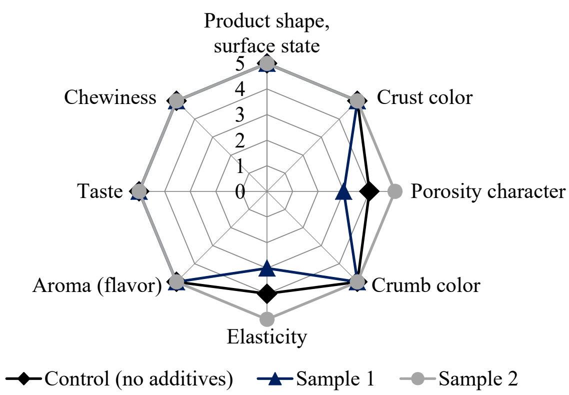


Fig. 10. Profilogram of organoleptic quality indicators of sponge-cake semi-finished products

6. Discussing the results of studying a possibility to use ultrasound in the technology of sponge-cake semi-finished products

An increase in FC and a decrease in the time of foaming under the action of US (Fig. 5) can be associated with a more intense process of protein denaturation. We believe that US influences the protein molecule: there is a rupture of protein chains into fragments that are more evenly distributed at the surface of interphase water–air, thereby contributing to the improvement of volume and stability of egg foam.

The effect of adding sugar to mélange is manifested in its binding the moisture and the appropriate increase in the viscosity of the system, leading to the improved foam stability indicator (Fig. 7). The destruction of the foam is due to the run-off of a solution from the thin films, which separate the air bubbles, and their coalescence. It might be possible that the increased stability of foam in the egg-sugar system is predetermined by the dehydrating effect of sucrose on whites.

It can be assumed that the increase in the porosity of the finished products (Fig. 9) was influenced by the phenomenon of acoustic cavitation, due to short-term pulses occurring in the breaking of cavitation bubbles and the emergence of microflows near them, which in turn contributes to a more uniform distribution of gases and vapors in dough.

The study results obtained allow us to assert the prospects of using US in the technology of flour-based confectionery products, in particular sponge cake semi-finished products.

It is expedient to implement the proposed technology under conditions of small enterprises, for example, restaurant establishments. As regards large-scale production, there is an issue of finding and selecting the US equipment capable to provide for large volumes of FCPs.

In further studies, it is advisable to determine the impact of US on the viscous-plastic indicators of sponge cake dough and the terms over which prepared semi-finished products retain freshness.

7. Conclusions

1. Our study has established a positive influence of US on the FC of egg-sugar mixture of sponge cake dough, foam stability, and its dispersion. Given this, it can be argued that the use of US in the technology of sponge cake semi-finished products contributes to the reduction in foaming duration of egg-sugar mixture by almost 2 times; makes it possible to whip all the components simultaneously, which significantly reduces the labor intensity of the sponge cake production process.

2. The optimum parameters for whipping the egg-sugar mixture of sponge cake dough under conditions of US have been determined: power of ultrasound is 0.6 kW, water temperature in an ultrasonic tub is 26 °C, whipping duration of mélange with sugar is 6.5 min.

3. Patterns in the crumb structure formation of finished sponge cake semi-finished products, dough for which was prepared according to the proposed technology, imply the increased porosity and specific volume of finished products and a more uniform distribution of pores. In this case, a porosity indicator increases by almost 7.5 % compared to the control sample, and by 11 % compared to the sample for which the egg-sugar mixture was whipped without the prior separation into whites and yolks. That allows us to argue about the effectiveness of the proposed method for whipping egg-sugar mixture for sponge cake dough.

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