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Враховуючи сучасні вимоги до технологічних характеристик оздоблювальних напівфабрикатів, мікронутрієнтного складу, розроблено рецептуру кондитерського напівфабрикату. Основою його є помада цукрова, додатково внесено суміш масла вершкового, порошку банану і поверхнево активної речовини (ефіру лимонної кислоти, моно-, дигліцериду – поверхнево-активних речовин). Напівфабрикат є універсальним та призначений для виробництва широкого асортименту оздоблювальних напівфабрикатів (кремів, начинок, глазури тощо).

Проведено дослідження впливу суміші масла вершкового, порошку банану і поверхнево-активних речовин (ПАР) на теплофізичні властивості і структуру кондитерського напівфабрикату для оздоблення борошняних кондитерських виробів.

Метою роботи було вивчення впливу обраних інгредієнтів на процес формування кристалічної фази помади цукрової, що є основою кондитерського напівфабрикату.

За результатами дослідження встановлено, що під час формування кристалічної фази напівфабрикату присутність компонентів порошку банану приводить до диференціації вуглеводів помади цукрової за температурами плавлення. Це дає можливість припустити, що при зберіганні збагаченої помадної маси процеси перекристалізації у порівнянні з контролем перебігатимуть з меншою інтенсивністю.

Внесення ПАР сприяє отриманню гомогенної поліфазної системи, що підтверджується однорідною пластичною структурою. Мікроструктурними дослідженнями показано, що кристали помади та часточки рослинного порошку оточуються жировою фазою масла, а набухлі часточки порошку не утворюють угрупвань.

За результатами мікроструктурного аналізу і диференційної скануючої калориметрії запропоновано механізм взаємодії частинок порошку банану з жировою фазою і пересиченим розчином сахарози.

Отримані результати обумовлюють агрегативну стійкість і термостабільність універсального кондитерського напівфабрикату при багатократному тепловому та механічному впливі, що має технологічне значення

Ключові слова: кондитерський напівфабрикат, порошок банану, теплофізичні властивості, кристалізація, ендотерма плавлення, фракціонування

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EFFECT OF BANANA POWDER AND BUTTER ON THE FORMATION OF THE CRYSTALLINE PHASE OF SUGAR FONDANT

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1. Introduction

According to data by WHO, in 2015, at the territory of Ukraine the mortality rate of the population aged

30–70 years due to chronic non-infectious diseases (CNID) amounted to 28.9 %, which exceeds the respective statistics of the economically developed countries by 2–4 times [1, 2]. In recent years, based on numerous studies by leading scientific

and medical centers, a list of risk factors that cause the occurrence of chronic pathologies in the human body was compiled. It was found that ~75 % of mortality due to them is directly proportional to the food ration of people, their physical activity, existence of harmful habits, levels of blood pressure, etc. Based on the long-term experience of European countries, it was found that the mortality rate from a range of chronic pathologies decreases by 2.0–2.5 times at the implementation of scientifically grounded preventive measures. On the territory of Ukraine, the problem of prevention of CNID appears particularly acute, since up to now, there has been a growth in the mortality rate of adult able-bodied population from cardio-vascular, respiratory diseases and cancer [2–4].

General tendencies regarding the life style of the last years indicate a considerable increase in people having meals at establishments of restaurant business. That is why the policy of today is reduction of calorie content of products that are sold at these institutions with a simultaneous increase in the content of natural micronutrients.

2. Literature review and problem statement

Flour confectionery (FC) enjoys considerable popularity with the population. Innovative production technologies are widely implemented in public catering establishments. In most cases, wheat confectionery products are high in calories and, accordingly, it is relevant and necessary to correct the formulation composition in order to increase the content of natural micronutrients and to reduce calorie content, which is indicated in the study, conducted in paper [5], in addition, the study proves the feasibility of improvement of formulation composition of traditional foods in the market of Ukraine.

Thus, applying of the method of mechanical-chemical activation, it was possible to obtain the highly dispersed systems, such as nettle pastes with the use of effective extractants – alcohol and sunflower oil [6]. Their recommended dosage in the confectionery bases (fondant, praline, gel) were substantiated from the position of the requirements of the organoleptic properties and enrichment with biologically active substances, which was proved by production tests. However, the paper does not explore the thermo-stable properties of the pastes that determine a wide range of their technological application.

In scientific paper [7], authors tried to solve this problem by using the powders of wild-growing raw materials, such as medlar, dogwood and wild pear to produce fat paste. The obtained pastes are the basis for manufacturing candies and do not act as a multifunctional semi-finished product that demonstrate thermal stability during the technological process and can be meant for a wide range of sugary confectionery and flour products. However, the structure of the paste was not sufficiently characterized and the influence of the components on the processes of formation of crystal phase of the finished product was not explored in the studies.

The feasibility and effectiveness of the use of walnut leaves and the water-alcohol extract from them in the production of milk fondant confectionery were scientifically substantiated and experimentally proved. However, the enriched milk fondant cream acts as a base for the manufacture of sugary confectionery products; in this case it does not enable intensification of the production process at the multiple mechanical and thermal influence, which is relevant in the establishments of restaurant business and food industry [8].

The possibility to use powders from the skins of blackcurrant berries and aronia melanocarpa and corn syrup (as anti-crystallizer) in the technology of candy production based on fondant was explored. It resulted in obtaining fondant of the finely crystalline structure and inhibiting the process of its staling. It should be noted that in addition to enhancing the food value and quality, the selected additives did not make it possible to create a polyfunctional semi-finished product for a wide range of confectionery products [5, 9].

A semi-finished product for milk-and-fruit-based dessert products with the use of the principles of colloidal stabilization of milk was developed [10]. This semi-finished product is designed for a wide range of desserts of establishment of restaurant business and food industry. The paper does not emphasize the use of this semi-finished product as a decoration for flour confectionery [10].

Analysis of contemporary literary sources reveals that various vegetable raw materials are used in order to receive confectionery bases.

However, we did not find any publications regarding creation of a decorative semi-finished product, which would at the same time meet the following conditions: intensification of the technological process, multifunctionality, natural ingredients, and enhancement of food value.

In the confectionery industry, the use of fondant creams was caused by their ability to easily acquire the necessary shape and retain it for a long time, which is especially important when decorating flour confectionery. Along with that, it is worth noticing that the preparation of a decorative semi-finished product for usage, for example, giving it a homogeneous and soft structure, requires considerable time.

Taking into consideration modern requirements to the technological characteristics of decorative semi-finished products of micronutrient composition, the formulation of confectionery semi-finished product was developed. This semi-finished product is universal and is designed for the production of a wide range of decorative semi-finished products (creams, fillings, icings, etc.). The semi-finished product is a confectionery basis, which has high elasticity and heat resistance and does not require special preparation before using in the technological process.

Obtaining new properties is provided by addition to the sugar fondant of the banana powder, obtained by the method of cold spray drying of butter and SAS – citric acid ester, monodiglyceride in doses of 18, 20 and 0.8 %, respectively. The results of experimental research, based on the high consumer and desired technological characteristics of the product, made it possible to propose the technology of production of enriched sugar fondant cream. According to this development, the previously prepared mixture of banana powder and warmed butter with SAS is added at the temperature of the mixture of 40 °C at the stage of sugar fondant whipping [11].

Based on the results of experimental research of rheological characteristics of the studied semi-finished product, its thermostability, hardness, the degree of destruction and structure restoration, it was found that introduction of the selected ingredients to the fondant promotes the formation of the crystalline-coagulation structure with the predominance of the latter. The results of the thermogravimetric studies testify to the influence of the selected additives on a change in the quantitative ratio of the aqueous phase of different forms of bond with the components of the semi-finished product [12, 13]. In this case, it was proved that the chosen additives increase the number of tightly bound moisture of poly- and mono-

molecular layers, which, in turn, facilitates obtaining of the semi-finished product with high elastic properties.

Along with that, it should be noted that a decisive role in forming the texture and structure of the product, which, first of all, are determined by the condition and dispersion of separate elements of its crystal phase, belongs to carbohydrates of semi-finished product. The processes of crystallization of sugar fondant without additives, obtained according to the classical formulation, have been sufficiently studied and characterized. Results of the own experimental studies of the rheological properties of the semi-finished product indicate a significant impact of the plant-butter mixture with the SAS on the processes of crystallization of the semi-finished product. More than two-thirds of butter are milk fat glycerides capable of crystallization. When it is added to the structure of sugar fondant, it is evident that fat components take part in phase transformations of the final semi-finished product.

The lack of data on the influence of butter, vegetable raw materials and SAS on the crystal phase of sugar fondant necessitates research in this direction.

3. The aim and objectives of the study

The aim of present research was to study, using the thermal physical method, the influence of the selected ingredients on the process of formation of crystal phase of fondant, which is the base of the confectionery semi-finished product. This will make it possible to establish the mechanism of formation of interaction between the components and determine the general principles of the process of sugar fondant crystallization.

To accomplish the set aim, the following tasks were solved:

- using the thermal-physical method, to determine the influence of the plant-butter mixture and SAS on the change the crystal phase of the confectionery semi-finished product;
- using the microscopic method, to study the influence of the selected ingredients on crystal-formation of the semi-finished product;
- to propose the mechanism of formation of crystal phase of sugar fondant.

4. Materials and methods to study the thermal-physical properties and structure of a confectionery semi-finished product

The objects of research are newly prepared samples of sugar fondant made by the standard technology and the model systems that comprise sugar fondant with banana powder, butter and SAS made according to the developed technology.

We selected the following as materials for enrichment of the decorative fondant:

1. Banana powder produced by «NaturexAG» company, Switzerland (Conclusion of the State Sanitary-Epidemiological Service No. 05.03.02-03/125796 as of 27.12.2011), which has the mass fraction of moisture of 5 % and a dispersity of 10...20 μm . This powder has a pronounced taste and aroma, is a source of dietary fibers, organic acids, potassium and magnesium.

2. Butter «Selyanske» with the fat mass fraction of 72.5 %, which would make the base of the semi-finished product more elastic: at its subsequent use, the mechanical impact is easier to achieve.

3. SAS – citric acid ether, mono-, diglyceride (E 472 S). According to the developed technology, it is supposed to be introduced at the stage of addition of plant-butter mixture, which allows obtaining a product with more elastic texture, homogeneous structure and improved thermal stability.

The phase transformations of the studied samples were explored using differential scanning calorimeter (DSC) during determining the specific heat capacity of the samples when heated at constant rate [14].

The measuring chamber of DSC consists of two cells, with the test sample in one of them, and the reference sample in the other that is called the comparison cell. The measuring chamber is constructed most symmetrically. Unlike the method of differential thermal analysis (DTA), where the thermocouple is located directly in contact with the bottom and the temperature is measured at one point, in the DSC method, there is a thermo-conductive column between the crucible and the thermocouple, which allows measuring average temperature on the whole area of the crucible. The temporal dependence of the temperature difference between the cell with the sample and the comparison cell is measured experimentally.

Heat in the DSC method is determined through thermal flow, heat derivative of time, the heat flow is measured as the difference in temperature at two points of the measuring system at one moment. Measurements can be conducted both under isothermal conditions, and in the dynamic mode with the programmed change in the furnace temperature.

Two crucibles with lids were used for measurements: the test sample was placed in one of the crucibles, the other crucible (empty) is used as the reference crucible.

A small hole was made in the lid of each crucible, which helps avoid deformation and rupture of the crucible as a result of increasing internal pressure due to thermal expansion of the air in the crucible, evaporation of water and other volatiles during heating.

The empty crucible for the sample (with a lid) was weighed on the balances with the accuracy of at least 0.1 mg and the balances were calibrated. After that, the test sample was placed in the crucible and the crucible was weighed with the sample. The main condition of sample preparation is to provide the maximum possible contact surface between the studied sample and the bottom of the crucible, the larger the contact surface, the stronger and more accurate the signal that is recorded by the calorimeter.

The crucible-reference (empty) and the crucible with the sample, prepared for measurements, were placed in the measuring chamber. Using software for the calorimeter, we created a new file that will contain all information about measurement. In the specified file, the weight of the sample is assigned, the files of calibration by temperature and sensitivity are selected.

The generalized curves of thermal capacity of the semi-finished product, obtained during the research, were expanded with the help of the Peak Fit program into simpler components, using the regularities of normal distribution of Gaussian curves [15, 16].

The microstructure was studied on the raster electron microscope JSM 6060 LA. The test sample was scanned by the focused electronic beam of medium energies under conditions of the industrial vacuum. Secondary electrons that get to the detector of the Everhart-Tornly type are the radiation that forms the image of the sample surface in this model. In this case, the primary image, which after program processing gets on the monitor screen, is formed. Like in the transmission

electronic microscopes, a film was previously used for photographing. An image on a black and white screen of the electronic-ray high definition tube was shot by a photo camera. Immediately formed image is simply displayed in the interface window by the controlling microscope of the computer program and after focusing by an operator can be stored on the hard drive of a computer.

This microscope allows obtaining the image of the sample surface with high resolution (less than a micrometer). The images, obtained using the raster electronic microscope, are three-dimensional and convenient for studying the structure of the scanned surface.

5. Results of studying the thermal-physical properties of the confectionery semi-finished product with banana powder

Fig. 1 shows the results of thermal and physical research into the samples of confectionery semi-finished products with different composition. The process of crystal phase melting of the control sample in the temperature range of -50... 50 °C (Fig. 1, a) is characterized by one intense peak at temperature of 24.7 °C with a wide interval. The diffusive nature of the peak indicates the melting processes of amorphous phase, formed by the oversaturated sucrose solution. During mathematical treatment of the general endotherm of control sample melting, we detected the sections, described by three low-intensity gaussians with the maxima at -6.5-8.5 and 31.8 °C. These peaks and the nature of their mutual location indicate the progress of processes of melting heterogeneous carbohydrates of the amorphous phase of sugar fondant.

The introduction of butter and banana powder to the semi-finished product changes the nature of the melting endotherms. In the DSC curve (Fig. 1, b) in the temperature range of -39...-20 °C, an intense maximum manifested itself at -29.9 °C.

It should be noted that by the nature of the peak and the temperature interval of release, it is similar to the corresponding maximum of the control sample. Analysis of the results of mathematical treatment of the DSC curve of the enriched semi-finished product in the temperature intervals (~30...5 °C) indicates an increase in the number of medium-intensity gaussians and the shift toward lower temperatures when compared with the control sample.

The obtained results indicate that during formation of the crystal phase, the existence of the components of the semi-finished banana product leads to the differentiation of the carbohydrates of fondant at melting temperatures. It makes it possible to assume that during storage of the enriched fondant, the recrystallization processes flow with lower melting intensity in comparison with the control sample. It allows us to assume that during the storage of the enriched fondant, the recrystallization processes will flow with less intensity in comparison with the control sample.

The character of the DSC curve of the enriched semi-finished product in the range of about 8...50 °C indicates that in the product there are crystalline structures of the fat phase, formed by glycerides. This is evidenced by maxima at temperature of 34.4 and 11.9 °C, which correspond to melting of crystalline elements, formed by the group of medium-melting glycerides and joint melting of easily- and medium-melting glycerides of milk fat. Speaking of the results of the endotherm melting approximation, it is necessary to pay

attention to the maximum at the temperature of 11.9 °C. Its total area indicates the joint crystallization of the fractions of easily- and medium-melting glycerides and significant influence on the formation of the crystal phase in the structure of the semi-finished product.

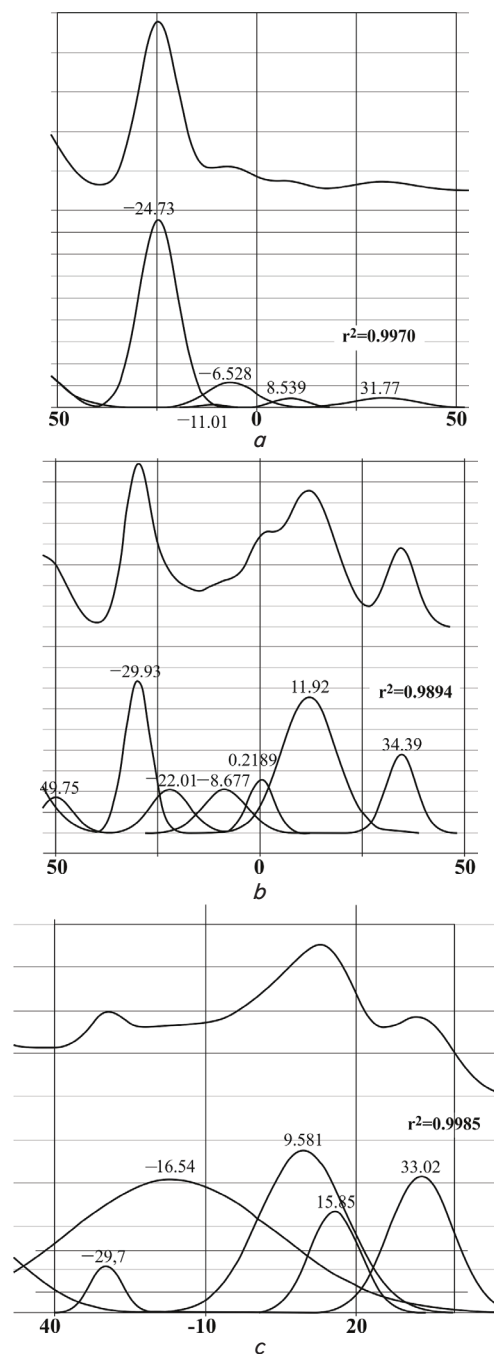


Fig. 1. Mathematically treated curves of thermal capacity of sugar fondant: a – control sample; b – sugar fondant with banana powder, butter and SAS

The general endotherm of melting sugar fondant, enriched with banana powder, butter and SAS, indicates the predominance of heterogeneous crystalline structures in the solid phase of the product [17]. This is proved by the peak with a maximum at -16.54 °C with a wide range of melting. It should be noted that the existence of citric acid ester and

mono-diglyceride significantly alters not only the processes of sugar crystallization in the low temperature area, but also leads to discrete crystallization of milk fat glycerides. To verify this assumption, the microstructure of the control sample and the enriched sugar fondant was explored. Images of the microstructure of test samples are shown in Fig. 2.

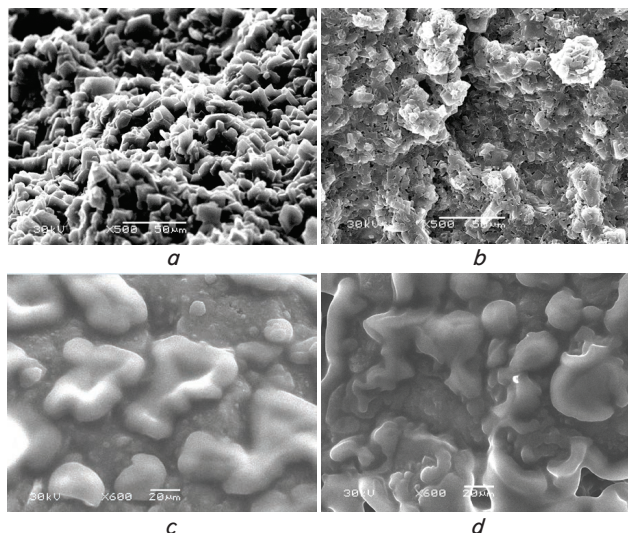


Fig. 2. Microstructure of model systems:
a – sugar fondant – control sample ($\times 500$); *b* – sugar fondant with banana powder ($\times 500$); *c* – sugar fondant with vegetable-butter mixture ($\times 600$); *d* – sugar fondant with vegetable-butter mixture with SAS ($\times 600$)

It is commonly known that the addition of molasses contributes to obtaining smaller crystals during whipping, besides, dimensions of crystals are influenced by temperature of cooling fondant syrup, the most optimum is 35...40 °C [18, 19]. Analysis of these data reveals that the microstructure of sugar fondant (control sample) is formed by plate crystals of carbohydrates having irregular multifaceted shape. The dimensions of the crystals faces are represented by the main fraction from 5 μm to 25 μm (Fig. 2, *a*).

When adding banana powder, it is possible to observe the uneven or conglomerate distribution of the powder particles with crystals of carbohydrates in the studied system. The dimensions of the conglomerates vary in a wide range from 10 μm to 60 μm , which is felt organoleptically (Fig. 2, *b*). It was found that the powder particles are not the crystallization centers during fondant ripening.

A more even power distribution in the model system in comparison with the previous sample is achieved by obtaining the powder-butter mixture. But in the model system, we observed small groupings that were formed by fat phase of butter, powder particles and crystals of carbohydrates with dimensions from 10 μm to 70 μm (Fig. 2, *b*).

The addition of SAS contributes to obtaining a homogeneous polyphase system, which is proved by the homogeneous elastic structure. The microstructure research revealed that the fondant crystals and particles of vegetable powder are surrounded by fat phase of butter, and swollen powder particles do not form groupings. The basic fraction of the fondant is represented by conglomerates with dimensions from 15 μm to 40 μm (Fig. 2, *d*).

6. Discussion of results of studying the thermal-physical properties of the confectionery semi-finished product with banana powder

Based on the results of the conducted studies, the mechanism of interaction of the components of the confectionery semi-finished product during its production and subsequent storage was developed (Fig. 3).

Fig. 3, *a* shows the structure of the confectionery semi-finished product at the stage of introduction of the plant-butter mixture to the fondant base. It is necessary to say that according to the proposed technology, the previously prepared plant-butter mixture and SAS are added to the fondant base at the stage of its whipping. Based on numerous literary data and own experimental studies, it is currently known that the banana powder, obtained by the method of cold spray drying, has high emulgating properties. That is why it is obvious that during the manufacture of the plant-butter mixture, there are processes of interaction of powder particles both with the plasma of warmed butter, which contributes to recovery (4), and with its fat phase that is retained by the surface of the particles. It should be noted that the fat phase can fully or only partially cover the surface of the powder particles. Getting stable vegetable-butter emulsion is ensured by making the introduction of SAS. The structure of the fondant basis before the introduction of the vegetable-butter mixture is represented by the crystals of carbohydrates (1), which are surrounded by a diffusion layer and numerous air bubbles (3).

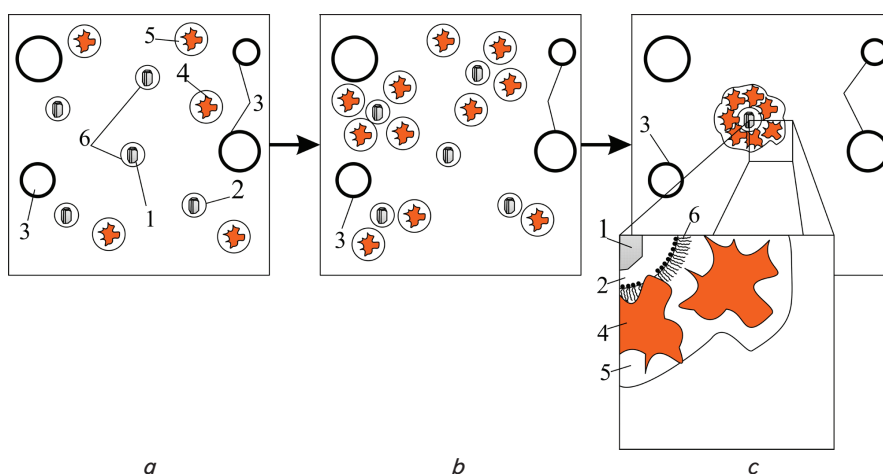


Fig. 3. Mechanism of interaction of components of confectionery semi-finished product: *a* – the stage of introduction of plant-butter mixture with SAS to fondant basis; *b* – the stage of sugar fondant whipping; *c* – ready confectionery semi-finished product; 1 – crystals of carbohydrates; 2 – diffusion layer of over-saturated solution of carbohydrates around the crystal; 3 – air bubble; 4 – recovered particles of plant powder; 5 – fat phase; 6 – SAS

At the stage of sugar fondant whipping (Fig. 3, *b*), the particles of banana powder migrate to the surface of the crystals of carbohydrates, which was caused by hydrophilic properties. During the process of sugar fondant whipping and cooling, the recovered particles of vegetable powder and SAS are oriented by hydrophilic groups to the over-saturated solution of carbohydrates. Accordingly, the surfaces of the particles, demonstrating hydrophobic properties and keeping fat phase of butter, form a fat layer at some distance from the crystal (Fig. 3, *c*). The introduction of SAS to the model system of the confectionery semi-finished product contributes to dense fitting of plant powder particles to the diffusion layer around the crystals and the layer of the fat phase, retained by hydrophobic groups of SAS and banana powder. Formation of the latter prevents carbohydrates from getting to the diffusion layer and, respectively, leads to inhibition of the process of the growth of carbohydrate crystals in the product. The described processes contribute to obtaining a finely crystalline structure and existence of fat phase on the surface of the crystals explains high elastic properties of the finished product.

A gradual bonding of moisture from butter by the particles of vegetable powder and a simultaneous retaining of its fat phase is observed, while the fondant basis is represented by crystals of carbohydrates, surrounded with the oversaturated solution. Addition of plant-butter mixture facilitates the orientation of vegetable powder particles, covered by lipid phase of butter, around the crystals of carbohydrates, which leads to formation of aggregates. The aggregative structure is explained by the complicated recovery and smaller swelling of vegetable powder particles in the over-saturated solution of carbohydrates, which forms a distance between a vegetable powder particle and crystals of carbohydrates.

At adding SAS to the model system of the confectionery semi-finished product, the structure of the aggregate is «stitched» due to the tight fitting of the vegetable powder particles around a carbohydrate crystal. In this case, the vegetable powder particles and SAS are oriented by the hydrophilic groups to oversaturated solution of carbohydrates, by hydrophobic groups – to fat phase of butter.

The obtained results are of technological importance, because they allow predicting the behavior of the semi-finished product in multi-component food systems of decorative semi-finished products (Fig. 4).

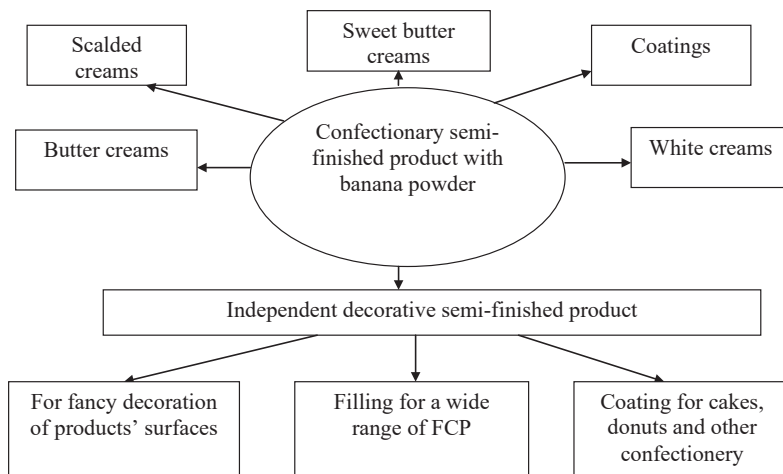


Fig. 4. The use of confectionery semi-finished products with banana powder in the technologies of decorative semi-finished products

The confectionary semi-finished product with the use of natural plant raw material is multifunctional (Fig. 4). It can be used in a variety of technologies of decorative semi-finished products and as an independent product that will significantly expand the range of FCP at restaurant establishments.

The obtained results and the developed mechanism of research describe the processes of crystallization of sugar fondant with the banana powder, butter, and SAS. In case of application of other SAS and powders from vegetable raw materials, the proposed model requires additional refining, since the properties of the components vary significantly, especially at the molecular level, which causes the change in the course of the crystallization process, and accordingly, the formation of other structural-mechanical properties of the semi-finished product.

It is subsequently planned to study the behavior of the formed structural elements during storage of the confectionery semi-finished product. To do this, it is recommended to apply the method of X-ray diffraction analysis in addition to the DSC method and the micro-structural method. This will make it possible to explore not only the processes of differentiation and recrystallization, but also to study the impact of plant components on the formation of micro-structural elements, to characterize polymorphic forms of the crystals of the semi-finished product and to predict the structural-mechanical properties of the product during storage.

Practical value of the research results will be improvement of the technology of decorative confectionery semi-finished products with the assigned technological properties and obtaining products with high consumer properties.

7. Conclusions

1. The thermo-physical research showed that addition of the mixture of butter and banana powder to the fondant cream of the semi-finished product leads to mixing melting temperature toward the lower values comparatively with the control sample, specifically, 34.4 and 11.9 °C, respectively. The addition of the plant-butter mixture to the semi-finished product helps to obtain crystalline structures, formed by glycerides of fat phase of butter, which is indicated by existence of peaks in the temperature range of –8...50 °C. It was

found that the joint use of the plant-butter mixture and SAS contributes to the formation of heterogeneous crystalline structures with discrete crystallization of milk fat glycerides in the solid phase of the semi-finished product, which is proved by the peak with a maximum at –16.54 °C with a wide range of melting.

2. Based on the results of the micro-structural analysis, it was found that the dimensions of the faces of crystals of the main fraction are in the range of 5...25 μm. Addition of banana powder contributes to the formation of conglomerates, the dimensions of which vary in a wide range from 10 μm to 60 μm. Addition of a mixture of banana powder and butter promotes formation of crystal structures with the dimensions of faces from 10...70 μm, on the surface of which powder particles with fat phase are retained.

Introduction of SAS contributes to obtaining a homogeneous finely crystalline polyphase system, formed from crystals of carbohydrates, in the diffusion layer of which banana powder particles with the lipid phase are held on the surface by hydro-

phobic groups of SAS. Based on the results of the micro-structural analysis, the mechanism of interaction of the fondant components was developed and the principles of formation of a crystalline structure of the finished product were explained.

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