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IMPROVEMENT OF CUPCAKE TECHNOLOGY WITH THE ADDITION OF DRIED BEET POMACE

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The object is de-sugared beet pomace, which contains a large amount of dietary fiber in its composition, as well as the technology of cupcakes with its addition. The task of enriching cupcakes with useful substances is tackled. A production technique of dried powdered beet pomace has been substantiated, which is characterized by low-temperature concentration modes in the rotary evaporator and post-drying in the roller IR dryer, which could contribute to the preservation of physiologically functional ingredients. The rheological characteristics of concentrated beet pomace in the rotary evaporator in the temperature range of 65–75 °C were determined. The established indicators revealed a tendency to reduce the effective viscosity depending on the temperature in the range of 42 to 27 Pa•s. For the speed of the rotary evaporator agitator of 200–300 min^{-1}, the maximum level of effective viscosity of beet pomace of 3–5 Pa•s was established.

Studies of the rheological characteristics of the dough with the introduction of dried beet pomace have made it possible to establish an increase in its elastic-viscous properties with an increase in the amount of additive. The highest indicator of effective viscosity ηef (Pa·s) of the studied dough samples for cupcakes with the addition of an additive of 10 % is 347; 15 % – 384; 20 % – 442; and control – 287, respectively. The compression of the crumb of finished cupcakes was also determined, which increases by 10.2–22.4 % with an increase in the amount of beet pomace powder. The organoleptic and physical-chemical indicators of the quality of cupcakes revealed the optimal amount of application of dried beet pomace – 15 %. The selected sample contains physiologically functional ingredients, namely dietary fiber, low molecular weight phenolic compounds, minerals. The technology can be introduced into the confectionery industry

Keywords: cupcake, plant-based supplement, dried beet pomace, effective viscosity, physiologically functional ingredients

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1. Introduction

Healthy eating is an integral part of a balanced diet under conditions of deterioration of the ecological situation of many European countries, pandemics, etc., which will lead to exacerbation of chronic diseases and the acquisition of various complications of an immune nature [1]. The introduction into production of improved innovative technologies for the production of environmentally friendly food products enriched with functionally physiological ingredients (FPI) is possible thru the high-quality implementation of rational processing of organic plant materials.

Competitive production of food products with a significant content of FPI will expand the range of health and treatment and prophylactic products of a wide range of uses with acquired original organoleptic properties, forming stabilization of the immune component of consumers in the daily diet [2]. Introduction into the diet of functionally physiological ingredients based on organic raw materials, including those with a high content of dietary fiber, will reduce the risk of a number of diseases, namely cardiovascular and other diseases [3].

Resource-efficient processing of organic plant materials is based on minimizing the level of raw material waste at technological stages, in particular the use of pomace, seeds, etc. with a significant content of FPI. The use of organic natural FPI in many recipes of food: confectionery, meat, and others, can significantly reduce the content of the main raw materials, which will provide the quality properties of the products obtained and expand their range [4].

So, the development of a method for the production of cupcake enriched with physiologically functional ingredients based on dried beet pomace, obtained under conditions of rational low-temperature processing, is relevant and timely. The developed products of increased nutritional and biological value can be recommended for mass consumption, health and therapeutic and preventive nutrition of various types of the population, including military personnel, the elderly, etc.

2. Literature review and problem statement

Work [5] provides data on the positive effect of nutrients of organic raw materials to increase the functionality of the daily diet for the formation of strong immunity. The rapid pace of industrialization paved the way for environmentally organic products that are more useful, and this assumption, among other things, is based on its principles and production standards [6, 7]. The main problems of food production systems with a high content of FPI include insufficient base of natural raw materials, low-rational processing, concerning both technological and hardware components. The production of "health-improving products" of food of natural origin requires the formation of a daily consumption rate, taking into account not only the initial content of FPI organic raw materials but also the final one – in finished products after technological and hardware processing [8, 9]. This emphasizes the relevance of scientific and practical research into the search for resource-efficient technologies with a rational combination of the hardware complex for maximum preservation of the properties of natural raw materials. Work [10] presents comparative data of "traditional" methods of processing plant materials, which are widely used by the processing and food industries to form prerequisites for the creation of resource-efficient technologies. In works [11, 12], human diets are considered taking into account the generalized parameters for assessing the effectiveness of a healthy diet and without affecting them by the properties of organic raw materials. This is partly due to the need for additional comprehensive research that is necessary in the production of "health-improving" food products based on plant materials. Daily increase in the needs for natural food requires the formation of comprehensive recommendations, taking into account the therapeutic and prophylactic properties and consumer demand for original products, which emphasizes the relevance of research in this direction. In particular, to ensure a balanced diet, mixing of various plant materials is used with the formation of the projected FPI content, consistency, and acquired original organoleptic properties, providing a wide range of use in a variety of products [13].

Resource-efficient production of health-improving food products requires a comprehensive study to ensure the rationality of the technological component in combination with hardware and technical solutions for the effective processing of plant materials with the subsequent manufacture of competitive products. Semi-finished products of a high degree of readiness with a wide range of uses include blended concentrated and dried fractional products. It should be noted that the available hardware and technological solutions for the processing of organic raw materials are characterized by a low level of resource efficiency. This is due to the use of intermediate high-temperature heat carriers, highly dynamic sources of heating, which in general leads to an artificial increase in metal consumption and minimization of the use of energy-saving complexes. Paper [14] presented a model of concentration in a film evaporator with an analysis of changes in the properties of experimental raw materials from technological parameters. However, determining the influence of the heat supply method on the quality of the process implementation and the final properties of the raw materials remained to be studied. This is primarily due to the use of a traditional evaporator based on intermediate heat carriers and technological solutions in the formation of a process model. For example, one of the ways to intensify the processes of concentration and heating of plant materials implemented in rotary vertical type devices is the use of conductive heat supply from electric ones without dynamic heaters [15]. It was established to ensure uniform distribution of heat flow on the heating surface (60.3...60.5 °C) and on the reflective surface of the hinged blade with a cutting edge (60.0...60.3 °C), which causes gentle heat treatment of plant materials. However, for the qualitative implementation of the processes of heating and concentration of plant materials, it is necessary to determine the dispersion of raw materials, especially when blending various organically raw materials. As well as the determination in the future of changes in structural and mechanical properties during heat and mass transfer processing. This formulates the need for further research in this direction.

Paper [16] provides a comparative analysis of the effectiveness of the proposed design solutions on the effect of heat transfer under the conditions of use of non-Newtonian pseudoplastic liquid in a scraper heat exchanger. However, these results are based only on the technological component, without taking into account the design features of the process, which is also associated with the use of traditional equipment. One of the solutions is given in [17] by using an improved vacuum evaporator based on electric heating of working surface for the production of high-quality pasty semi-finished products. However, the issues related to the effectiveness of the proposed equipment for concentration with the existing traditional one, which forms the need for research on resource-efficient low-temperature equipment, remain out of attention.

In the production of plant concentrates and dried semi-finished products, an important component is the resource efficiency of the main heat and mass transfer processes (heating, concentration, and drying) taking into account the changes and the resulting structural and mechanical properties [18], emphasizing the feasibility of research. In [19], the solutions for the production of blended semi-finished products with a high FPI content when using a thermoradiation single-drum roller dryer with a combined method of heat supply, application and cutting of the dried layer of raw materials. In addition to the results of structural and mechanical properties of blends of plant materials, the results of changes in color formation depending on the duration of drying, which confirm resource-efficient processing, are given.

Works [20, 21] emphasize the relevance of resource-efficient processing of organic plant materials with a significant content of nutrients. In [22], it is noted that for resource-efficient processing of organic raw materials, extraction processes are replaced by gentle drying, and the resulting functional plant semi-finished products on innovative equipment are characterized by high organoleptic and physical-chemical properties. It can be used in various spheres of processing and food industry for the production of "healthy" products under the conditions of rational prescription application, which emphasizes the feasibility of further research in this direction.

In [23], the analysis of the demand for confectionery products in the production of which the sugar component was replaced by plant semi-finished products with a high FPI content was carried out. The authors established the effect of the introduction of dried acai berries (10.0 g/100 g in a dry basis) into finished confectionery products and the effect on the obtained organoleptic properties. However, out of attention, there remained studies of the effect of powdering confectionery with powdered sugar, which is associated with a low level of research in this direction and search for a way to minimize the sugar content in confectionery. Study [24] reports a method of production of blended fruit and berry paste of the resulting concentration in the rotary apparatus to the solids content of 28...30 % within 25...50 s with preheating of mashed potatoes to 50 °C. Rational amount of added blended paste when replacing applesauce with the necessary degree of structure formation is determined (with the introduction of 75 % of the blend, the viscosity is 616 Pa·s, and in the control – 354 Pa·s). The conclusions of the work emphasize that it is the rational content of a plant-based supplement that will ensure the production of "healthy foods" of food with a high content of FPI, confirming the relevance of research.

Work [25] determines the effectiveness of adding honey to the marshmallow recipe on the content of vitamins and minerals but these components do not make it possible to partially replace certain components of the product, such as applesauce. In [26], the technology of production of marshmallow using vegetable paste blends is given; but determining the influence and efficiency of heat and mass transfer processing of mashed on the final quality of the product is left out of attention. Thus, in particular, in [27], a study was carried out into the determination of changes and the formation of foaming, taking into account the rheological properties in the production of marshmallow without gelatin. However, determining the effect on the resulting consistency of marshmallow by replacing the structure-forming ingredients with blended plant semi-finished products of a high degree of readiness remained out of attention, confirming the feasibility of further research. Paper [28] proposed a technology of marmalade production with the addition of kelp in the amount of 5 % providing quality improvement and expand the range of products. Also, the authors of [29] developed a technology of functional marmalade based on dietary fiber from apples, bamboo, and wheat, but the work lacks research into the FPI content as a whole, requiring investigation in this area. Work [30] shows the method of production of marshmallow based on vegetable puree with partial replacement of applesauce, followed by the determination and confirmation of the provision of functional properties and increased FPI content. Partial or complete replacement of artificial ingredients (dyes, flavors, etc.) in confectionery recipes due to natural ingredients also provides original properties. Structural and mechanical properties of dough for the production of flour confectionery products, in particular cupcakes, are important characteristics that affect both the course of the technological process and the quality of the products obtained [31]. It is known that plant-based supplements, which contain a significant content of physiological and functional ingredients, affect the dough in different ways, and, as a result, the structure of finished products [32]. For example, beet pomace with a significant content of betalains are used to prepare functional foods (confectionery, bakery, beverages, etc.) [33–35], emphasizing the relevance of research on the rational processing of beets and further use in confectionery. So, increasing the functionality of confectionery products by adding to the recipe composition of vegetable semi-finished products obtained on resource-efficient equipment under gentle modes, minimization of artificial colors and flavors is ensured. Providing predictable structural and mechanical properties, taking into account changes in the introduction of plant blends and obtaining original competitive properties by products with a high content of FPI. All this necessitates practical and experimental research to ensure resource-efficient processing of beet pomace for the production of "healthy" confectionery products on the example of cupcakes, ensuring the expansion of the range.

3. The aim and objectives of the study

The aim of this study is to improve the technology of cupcake production with the addition of dried beet pomace. This will provide an opportunity to expand the range of flour confectionery products, which are a source of physiologically functional ingredients.

To accomplish the aim, the following tasks have been set:

– to substantiate a technique of obtaining dried beet pomace and determine its quality indicators;

– to determine the rational percentage of dried beet pomace in the recipe of cupcakes, to establish the structural and mechanical properties of the dough and organoleptic and physical-chemical properties of finished products.

4. The study materials and methods

The object of our study is de-sugaring of beet pomace, which contains in its composition a large amount of dietary fiber, as well as the technology of cupcakes with its addition. The main research hypothesis is to ensure resource-efficient processing of plant materials with further improvement of food production technology, ensuring the expansion of the range of "health" products with a high content of physiologically functional ingredients.

The raw material is de-sugared beet pomace, which contains in its composition a large amount of dietary fiber. Structural and mechanical properties of concentrated beet pomace and the resulting dough for cupcakes with the addition of dried beet pomace are determined. Structural and mechanical properties of prototypes were determined on the rotational viscometer "Reotest-2" (Germany).

As the control sample, cupcakes without filling on chemical baking powder were selected in accordance with 4505:2005 "Cupcakes". In experimental studies, it is proposed to replace wheat flour with the developed powder of dried beet pomace in the amount of 10 %, 15 %, 20 %. Beet pomace was mixed with flour and added to the dough as it was kneaded.

The structural and mechanical properties of cupcakes were determined using an automatic penetrometer "Labor" (Hungary). We investigated the physical and chemical indicators of the quality of baked products (humidity, specific volume, alkalinity) according to generally accepted procedures.

The obtained organoleptic properties of cupcakes with beet pomace were studied by an expert board, consisting of 5 specialists from the State Biotechnological University (Kharkiv, Ukraine), on a 5-point scale.

The content of hemicellulose was determined by the modified Dreywood method, cellulose – by the nitrogen-alcohol method (Kürschner's method), pectin substances – by the calcium-pectate method. The content of low molecular weight phenolic compounds was determined by the colorimetric method according to DSTU 4373:2005. The mineral composition of beet pomace was determined by atomic emission spectrography with photographic registration on the DFS-8 device.

The magnitude of the error for all studies was σ=3...5 %, the number of repeatability of experiments – n=5, probability – p≥0.95. For data processing, the MS Office software package, including MS Excel (USA), as well as the standard Mathcad software package (USA) were used.

5. Results of investigating the quality indicators of dried beet pomace and cupcakes based on it

5. 1. Justification of the method of obtaining dried beet pomace and determining its quality indicators

The production of dried beet powdered fraction was carried out from de-sugared beet pomace, which is actually waste from the primary processing of sugar beet. Beet pomace is pre-pressed and sent for heat treatment with saturated steam to universal heat and mass exchangers. The duration of heat treatment is 15-20 minutes at a vapor temperature not exceeding 100 °C, ensuring the removal of specific beet taste and odor. After that, aqueous extraction of soluble substances is carried out at a temperature of 78–84 °C. This method of extraction makes it possible to remove existing toxins, salts of heavy metals, the inclusion of pesticides, diffusion juice, sucrose, etc. from desalted beet pomace as much as possible. To improve the quality of the resulting product (powdered fraction), beet pomace is clarified with a 3–5 % solution of hydrogen peroxide for 15–20 minutes for whitening. Due to this, beet pomace not only discolors but also changes functional and technological indicators, in particular water-absorbing and sorbing abilities.

The resulting beet fibers are pressed to a solids content of 15–16 %, crushed to a particle size of 0.2–0.25 mm. After that, they are sent for concentration to the rotary evaporator at a temperature of 65–75 °C to a solids content of 45 % and then to the final drying to the roller dryer. Drying is carried out in an IR field at a temperature of 65–75 °C to a solids content of 87.0–90.0 %. The combined method of heat and mass transfer treatment in combination with preliminary concentration and drying is characterized by low-temperature conditions under conditions of the minimum duration of the technological operation, thereby improving the quality of the resulting beet powdered fractional semi-finished product.

During the production of beet powdered fractions from pomace, it is necessary to take into account the structural and mechanical properties of concentrated beet pomace in the rotary evaporator when changing the shear rate and heat treatment temperature. Obtaining in this way the values of rheological indicators of prototypes will make it possible to identify the optimal temperature regime for the process of concentration of beet pomace and will make it possible to carry out its appropriate calculations. The study was carried out on the rotational viscometer "Reotest-2". The movement of a sample of beet pomace in a viscometer is similar to the process of mixing and transportation in a rotary evaporator, namely centrifugal movement along a spiral trajectory. Therefore, the rheological indicators established in this way maximally reflect the real picture of the process.

Our study was carried out into changes in the effective viscosity of concentrated beet pomace with a solids content of 45 % under the influence of changes in the shear rate in the temperature range of 65–75 °C (Fig. 1).

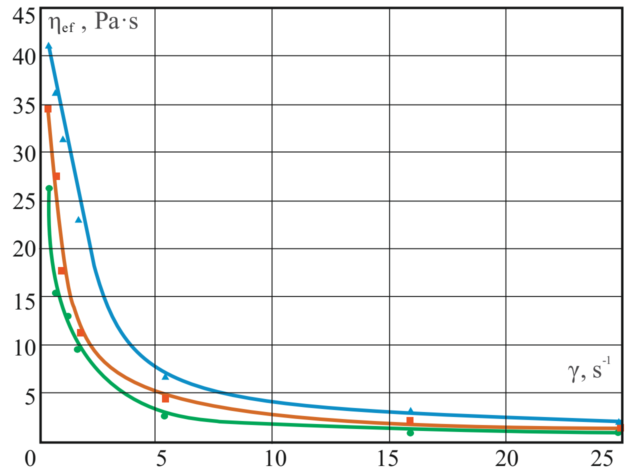

Fig. 1. Dependence of the viscosity of beet pomace on shear rate: 1 – 75 °C; 2 – 70 °C; 3 – 65 °C

The dependence shown in Fig. 1 demonstrates that as the temperature of beet pomace samples rises in the operating range of the rotary evaporator from 65 to 75 °C, their viscosity decreases from 42 to 27 Pa·s.

With reduced viscosity indicators, a greater degree of mixing of the prototype during concentration is provided, which contributes to higher values of the heat transfer coefficients of the rotary evaporator, reducing the duration of heat treatment. Therefore, during the heat treatment of beet pomace, it is recommended to use the highest temperature indicator of 75 °C, which corresponds to 27 Pa·s with an undestroyed structure. When calculating a rotary evaporator with a frequency of agitator rotations of 200–300 min^{-1}, the effective viscosity will be 3–5 Pa·s, respectively (Fig. 1).

The nature of the rheological dependences of concentrated beet pomace indicates that prototypes belong to pseudoplastics, the viscosity of which is a property of the equilibrium state between the process of destruction and recovery. The obtained dependences of pseudoplastic liquids are described by the equation:

$$\eta_{ef}=B\cdot\gamma^{-m}, \qquad (1)$$

where B is the effective viscosity at the unit value of the velocity gradient, Pa·s;

γ – shear velocity, s^{-1};

m – rate of destruction of the structure.

Concentrated beet pomace is dried to a solids content of 87.0–90.0 % to a powdered fractional state. The dried beet pomace obtained in this way contains in their composition: dietary fiber – 68.7 g/100 g, including cellulose – 21.6; hemicellulose – 22.8; pectic substances – 24.3. Low molecular weight phenolic compounds – 7.8 mg/100 g; magnesium – 136 mg/100 g; sodium – 255 mg/100 g; calcium – 350 mg/100 g.

The resulting dried beet pomace has a particle dispersion of 0.2–0.25 mm, yellow in color, active acidity of 4 degrees. The resulting powdered fractional beet pomace can be used, in particular in the technologies of various flour confectionery products, such as cupcakes.

5. 2. Determining the rational amount of beet pomace in cupcake technology and defining quality indicators

The influence of dried beet pomace on the structural and mechanical properties of the dough for cupcakes was determined (Fig. 2).

The highest indicator of effective viscosity η_{ef} (Pa·s) of the studied dough samples for cupcakes with the addition of dried beet pomace is 10 % – 347; 15 % – 384; 20 % – 442, and control – 287, respectively. Experimental dependences indicate an increase in the values of effective viscosity compared to the control (without additive), which is a qualitative indicator of strengthening the resulting structure of the dough.

Fig. 2 shows that the effective viscosity index for control is 287 Pa·s with an undestroyed structure. The addition of dried fractional powder of beet pomace in the amount of 10-20 % as a replacement of wheat flour makes it possible to increase the value of effective viscosity by 1.2–1.5 times.

Analysis of the above dependences of the cupcake dough gives the idea that they all begin to flow not at the beginning of the application of the shear rate, which characterizes prototypes as imperfect-plastic solid-like bodies. A gradual increase in the shear stress leads to the destruction of the structure of prototypes and at a speed index of 15 s^{-1}, all samples behave like a Newtonian liquid.

Along with the quality indicators of the dough, the characteristics of baked cupcakes are important. Thus, the addition of beet pomace contributes to a change in the structural and mechanical properties of baked cupcakes. This is confirmed by the penetration data of the cupcake crumb, which is a characteristic of its compressibility (Fig. 3).

The data in Fig. 3 indicate that the compressibility of the cupcake crumb with an increase in the amount of beet pomace powder increases by 10.2–22.4 %. This, in our opinion, may be due to an increase in the moisture content of products (Table 1) due to the significant water-absorbing capacity of beet pomace, which is a source of dietary fiber.

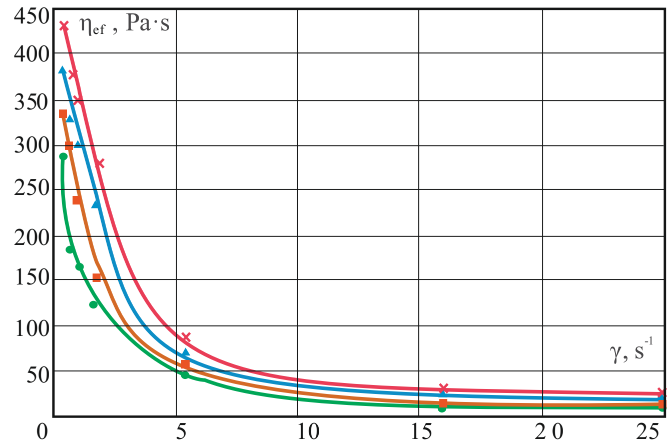

Fig. 2. Dependence of viscosity on the shear rate of the dough for cupcakes with dried beet pomace at t=20 °C: 1 – control (without additive); 2 – 10 %; 3 – 15 %; 4 – 20 %

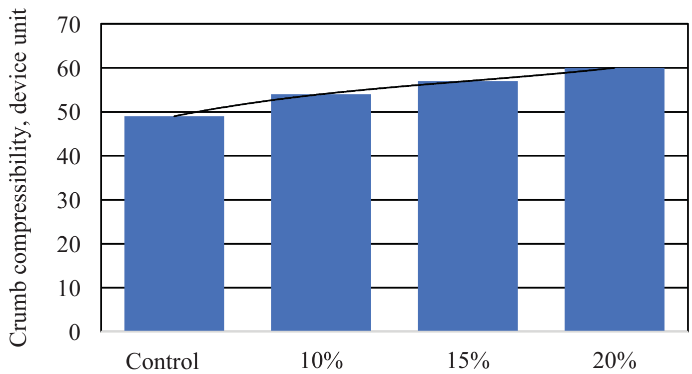

Fig. 3. Compressibility of the crumb of cupcakes with beet pomace in the amount, % of flour replacement: control (without additive): 10 %; 15 %; 20 %

Table 1

Organoleptic and physical-chemical indicators of the quality of cupcakes with dried beet pomace

Indicator	Characteristics of indicators (% of flour replacement with beet pomace)			
	Control (without additive)	10	15	20
Appearance	Correct, without breaks	Correct, no breaks	Correct, no breaks	Correct, without breaks, with cracks and fractures
Color	The crust is golden, the pulp is light yellow	Crusts – beige, crumbs – yellow	Crusts and crumbs – light brown	Crusts – brown, crumbs – light brown
Taste and smell	Inherent in the product, without foreign smell and taste	Inherent in the product, pleasant, with a barely perceptible smell and taste of the additive	Inherent in the product, with a pleasant smell and taste of the additive	Inherent in the product, with a pronounced smell and taste of the additive
View in the fracture	Well-baked cupcake, without spell and traces of non-penetration	Well-baked cupcake, without darkening and traces of non-preparation, interspersed with additives	Well-baked cupcake, without feces and traces of non-preparation, interspersed with additives	Well-baked cupcake, without darkening and traces of non-preparation, interspersed with additives, somewhat tightened structure
Mass fraction of moisture, %	18.0±0.9	19.0±0.9	19.7±0.9	20.1±0.9
Alkalinity, degree	2.0±0.05	1.9±0.05	1.8±0.05	1.7±0.05
Specific volume, cm^3/g	2.7±0.5	2.7±0.2	2.7±0.2	2.6±0.2

Table 1 demonstrates that the addition of dried beet pomace in the amount of 10–15 % with the replacement of flour does not change the appearance of the products compared to the control sample. Increasing the amount of additives up to 20 % worsens the appearance of cupcakes as fractures appear on their surface. The introduction of dried beet pomace helps change the color of the crust of cupcakes from golden (control) to beige (10 %), light brown (15 %), and brown (20 %). And the color of the crumb is from light yellow (control) to yellow (10 %) and light brown (15–20 %). The taste and smell of cupcakes with dried beet pomace in the amount of 10–15 % is pleasant with the smell and taste of the additive. Increasing the amount to 20 % contributes to the presence of a pronounced taste and smell of beet raw materials. The view in the fracture indicator indicates that when introducing 10–15 % of dried beet pomace cupcakes are well baked and have uniform blotches of the additive that meets the requirements of regulatory documentation. An increase in the number to 20 % causes tightening of the cupcake crumb.

The addition of dried beet pomace in the amount of 10–20 % with the replacement of flour increases the mass fraction of cupcake moisture by 5.5–11.6 %, respectively, compared to the control sample. The alkalinity of products is reduced by 5.0–15.0 % at the introduction of 10–20 % of the additive, respectively, compared to the control. The specific volume of cupcakes with beet pomace in the amount of 10-15 % does not change, and with an increase in their number to 20 %, it decreases by 3.7 %.

In general, for all quality indicators, cupcakes with dried beet pomace meet the requirements of regulatory documentation. Taking into account the data in Table 1, we choose a prototype of a cupcake containing dried beet pomace in the amount of 15 % with the replacement of flour. This is due to the content in it of a sufficient amount of physiologically functional ingredients with good organoleptic and physical-chemical quality indicators.

In the developed cupcakes with beet pomace, the content of dietary fiber, minerals, low molecular weight compounds was determined. It was established that cupcakes contain (per 100 g): dietary fiber – 3.08 g, including cellulose – 0.97 g, hemicellulose – 1.02 g, pectin substances – 1.09 g. And also (mg/100 g): low molecular weight phenolic compounds – 0.35; magnesium – 6.12; sodium – 11.47 and calcium – 15.75, respectively.

It was found that the addition of 15 % of dried beet pomace makes it possible to increase the content of physiologically functional ingredients while ensuring good organoleptic and physical-chemical quality indicators.

6. Discussion of results of improving the technology of cupcake with the addition of dried beet pomace

A technique of obtaining dried powdered fractional beet pomace has been substantiated. The technique involves the preliminary concentration and drying of beet pomace in compliance with low-temperature regimes to preserve the natural properties, in particular, pectin substances.

The change in the effective viscosity of pre-concentrated beet pomace to the solids content of 45 % was investigated with a change in the shear rate in the temperature range of 65–75 °C (Fig. 1).

It was established that with an increase in the temperature of beet pomace samples in the operating temperature range of the rotary evaporator from 65 to 75 °C, the viscosity of concentrated beet pomace decreases from 42 to 27 Pa·s. Reducing the viscosity index contributes to a more active degree of mixing of beet pomace during processing in a rotary evaporator, which also provides greater values of the heat transfer coefficient and, as a result, leads to a reduction in the effect of heat treatment. For working range of the agitator speed of 200–300 min^{-1} of the rotary evaporator, the maximum level of effective viscosity will be 3–5 Pa·s, respectively (Fig. 1).

Studies have been carried out on the structural and mechanical properties of dough for cupcakes with the addition of dried beet pomace. The obtained indicators (Fig. 2) indicate an increase in the elastic-viscous properties of the dough for cupcakes with an increase in the number of beet pomace, that is, the internal resistance of the structure to shear forces increases. In general, this is positive in terms of forming the structure of the dough sheet.

The quality indicators of baked cupcakes with dried beet pomace in the amount of 10–20 % with the replacement of flour were determined. Thus, the change in structural and mechanical properties and baked cupcakes for the addition of beet pomace by determining the compressibility of its crumb was confirmed (Fig. 3). The increase in this indicator by 10.2-22.4 % is associated with changes in the physico-chemical and organoleptic parameters of cupcakes (Table 1). The addition of beet pomace in the amount of 10–20 % with the replacement of flour increases the mass fraction of cupcake moisture by 5.5–11.6 %, respectively, compared to the control sample. This is due to the high content of dietary fiber, which is able to bind and firmly retain moisture, which is a prerequisite for increasing the shelf life of cupcakes. The alkalinity of products is reduced by 5.0-15.0 % for the introduction of 10–20 % of the additive, respectively, compared to the control, which can be explained by an increase in the number of dried beet pomace with an acidity higher than that of wheat flour. The specific volume of cupcakes with dried beet pomace does not change. A decrease in this indicator by 3.7 % in cupcakes with 20 % beet pomace is associated with the formation of a somewhat tightened structure of products.

The addition of dried beet pomace in the amount of 10–15 % with the replacement of flour does not worsen the organoleptic quality indicators of cupcakes (Table 1). Beet pomace gives them a pleasant aroma and taste of the additive. The color of the crust changes from golden to beige and light brown, and the crumbs from light yellow to yellow and light brown. Samples of cupcakes from 20 % dried beet pomace have fractures on the surface and a tightened crumb.

A sample of cupcakes containing dried beet pomace in the amount of 15 % with flour replacement was selected, due to high organoleptic and physical-chemical quality indicators and the content of physiologically functional ingredients. Namely (per 100 g of cupcakes): dietary fiber – 3.08 g, including cellulose – 0.97 g, hemicellulose – 1.02 g, pectic substances – 1.09 g, low molecular weight phenolic compounds – 0.35 mg, magnesium – 6.12 mg, sodium – 11.47 mg and calcium – 15.75 mg, respectively.

It was found that the addition of 15 % of dried beet pomace makes it possible to increase the content of physiologically functional ingredients to ensure good organoleptic and physical-chemical quality indicators.

Thus, the technology of cupcakes with the addition of dried beet pomace has been improved, which makes it possible to expand the range of "healthy products". The production technique of dried beet pomace, which is characterized by low-temperature processing modes, is substantiated. The use of a previously developed rotary evaporator and a roller IR dryer allows for resource-efficient processing of plant materials.

The practical significance of the obtained results is primarily in justifying the technique of production of dried fractional powdered beet pomace in a low-temperature way and expanding the range of cupcakes with a high content of physiologically functional ingredients. However, issues with the definition of rational application of organic raw materials into the formulations of products, including blended fillers of a high degree of readiness and impact on the resulting quality, remain completely unlit. To search for resource-efficient technologies for processing plant materials and substantiate the feasibility of gentle technological heat and mass transfer processes, simulation is used [31], but the theory requires practical approbation, and therefore setting up the process. High-quality natural semi-finished products obtained by resource-efficient technologies are widely used in various processing and production complexes: bakery, confectionery, etc. [32], but there is no research on changes in the structural-mechanical and organoleptic properties of finished products. The limitations of the above studies are the need to comply with technological and hardware recommendations since neglecting them will lead to changes in the structural and mechanical properties and the resulting quality of products as a whole. One of the drawbacks is the approbation of dried beet pomace obtained according to the proposed method with further use in cupcake technology without determining the possibility and efficiency of using blended organic semi-finished products of a high degree of readiness. Further research is planned to be carried out in the direction of determining changes in products during storage and economic efficiency of production during their implementation.

7. Conclusions

1. The technique of production of dried fractional powdered beet pomace, which is characterized by the use of low-temperature modes of concentration in the rotary evaporator and drying in the roller IR dryer, respectively, has been substantiated. The use of this equipment makes it possible to process at a gentle temperature regime at the level of 65–75 °C, which will contribute to the preservation of physiologically functional ingredients. The rheological characteristics of concentrated beet pomace in the rotary evaporator in the temperature range of 65–75 °C were found. The established indicators revealed a tendency to reduce the effective viscosity depending on the temperature in the range of 42 to 27 Pa·s. Also taking into account the operating parameters of the rotary evaporator (agitator speed, 200–300 min^{-1}), the level of effective viscosity of beet pomace of 3–5 Pa·s was established.

2. Our studies of the rheological characteristics of the dough for cupcakes with the introduction of dried beet pomace have made it possible to establish an increase in elastic-viscous properties with an increase in the amount of additives. The highest indicator of effective viscosity η_{ef} (Pa·s) of the studied dough samples for cupcakes with the addition of an additive of 10 % – 347; 15 % – 384; 20 % – 442, and control – 287, respectively. The compression of the crumb of the finished cupcakes was also determined, which increases by 10.2–22.4 % with an increase in the amount of beet pomace powder. To identify the optimal amount of dried beet pomace in the recipe of cupcakes, organoleptic and physical-chemical indicators of the quality of cupcakes were determined. We established that the optimal amount of powder application is 15 %.

The selected sample of cupcakes containing dried beet pomace in the amount of 15 % with flour replacement contains physiologically functional ingredients, namely dietary fiber, low molecular weight phenolic compounds, and minerals.

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Conflict of interests

The authors declare that they have no conflict of interests in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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