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IMPROVING THE PRODUCTION TECHNOLOGY OF FUNCTIONAL PASTE-LIKE FRUIT-AND-BERRY SEMI-FINISHED PRODUCTS

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The object of this study is a functional fruit-and-berry paste for health purposes with the selection of components (apples, Ziziphus jujuba, blueberries), which are sources of dietary fiber, vitamin C, low molecular weight polyphenolic compounds and phytosterols, which are used as an immunostimulant to create products with cholesterol-lowering effect. The task to increase the content of these substances is solved by concentrating in a rotary film evaporator (RFE) under mild regime parameters (60...65 °C) to a dry matter (DM) content of 30...32 % for 45...50 s and by the pasteurization of concentrated paste in a scraper heat exchanger (SHE) at a temperature of 95...98 °C followed by packing.

The effective viscosity (Pa•s) of the mixtures of the original purees (DM 16...17 %) and resulting pastes (30...32 %) has been determined and its increase was found in the pastes compared to puree, by 1.65...1.85 times. The obtained data indicate a strengthening of the structure of the resulting functional paste, which, compared to control, has an effective viscosity of 3.6 times more. A significant advantage has a paste containing 45 % of apple; 35 % of Ziziphus jujuba; 20 % of blueberries. It is characterized by an enhanced content of dietary fiber, by 3.8 times; vitamin C, by 2.25 times; low-molecular polyphenolic compounds and tannins, phytosterols. Therefore, it can be used as an immunostimulant to manufacture products with cholesterol-lowering effect.

It was established that in order to effectively conduct the process of concentration in RFE and subsequent pasteurization in SHE, it is rational to grind puree to a particle size within 0.1...0.5 mm. The heat transfer coefficient when concentrating samples with a particle size of 0.5 mm has a higher rate, by 6 %, compared to the sample with a particle size of 1.5 mm. The technology could be introduced at the enterprises of the canning and confectionery industries

Keywords: paste (apple, Ziziphus jujuba, blueberry), effective viscosity, heat transfer coefficient, dispersion, pectin, vitamins, phytosterols

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1. Introduction

Many countries are engaged in solving one of the strategic problems of nutrition of society to reduce the existing deficiency necessary for the functioning of the immune component of the human body through the consumption of physiologically functional ingredients (PFI) of organic origin. The introduction of innovative technologies with improved methods of processing organic plant materials into functional semi-finished products will ensure the production of "healthy food" with a high content of PFI. Disappointing statistics of the XXI century are high mortality and disability from cardiovascular diseases, which in most cases are associated with high cholesterol in the blood. Production of functional organic ingredients and food products based on them will make it possible to obtain special-purpose products, including those with cholesterol-lowering effect, primarily using innovative technological processes [1]. Production of functional organic ingredients and food products based on them will make it possible to obtain special-purpose products, including those with cholesterol-lowering effect, primarily using innovative technological processes [2].

One of the directions of production of these products is the use of plant materials – sources of phytosterols that have cholesterol-lowering ability (apricot, lemon, Ziziphus jujuba, blueberries, etc.) to obtain functional semi-finished products. There are valid WHO recommendations regarding the need to consume vegetable raw materials (fruits, berries, spicy-aromatic raw materials, etc.), regardless of age categories, which emphasize the need for research in the field of creating a healthy diet of the nation [3]. The production of food products of increased nutritional and biological value for special purposes is recommended for mass consumption to ensure health and therapeutic effects on the immune component of various categories of the population, in particular military personnel and doctors.

Therefore, studies aimed at improving the technology of production of functional semi-finished products of plant origin are relevant since they have wide production implementation in the food industry, pharmacology, medicine, etc. In addition, they will make it possible to expand the range of functional products for special purposes (puree, pastes, powders, juices, etc.), which will be highly competitive due to production according to modern technological requirements.

2. Literature review and problem statement

In [4], an interventional strategy is proposed to expand the choice of healthy food by prompting consumers at the expense of the color scheme of the proposed meal, which has been tested in practice. The authors have proved the expediency of preserving the properties of organic raw materials at all stages of the hardware and technological process of production of health-improving food products. Paper [5] analyzes the demand for consumption by the population of food of a balanced nature based on plant materials in the daily diet, which made it possible to form a generalized picture of human preferences. However, questions remain related to the provision of rational methods for determining the effectiveness of blending raw materials not only to improve the health properties but also the competitiveness of the products obtained, requiring research in this direction. One of the convenient ways to solve this issue is to introduce in improved ways of rational blending of plant materials, taking into consideration the obtained PFI, organoleptic properties, etc. Prospects for the use of plant materials for the production of functional semi-finished products and products based on them are organicity and naturalness, which will minimize and even abandon the use of artificial flavors and colors [6].

One of the solutions is given in [7], where a technique for production of multicomponent fruit and vegetable paste from apple, viburnum, chokeberry, pumpkin, and beets is proposed. The content of raw materials is selected taking into consideration the amount of physiologically functional ingredients in the created blend. A feature of the technique is the use of multifunctional equipment for pre-heat treatment and a rotary-film evaporator for further concentration of puree. The specified structural and mechanical properties of the obtained blends make it possible to reasonably approach the resulting consistency and change it due to the content of the components, but the effect of the dispersion of the blended mixture on the heat transfer coefficient remains to be explored. This may be partly due to the fact that the technological component was investigated rather than the hardware and technological complex as a whole. Consequently, forecasting the obtained structural and mechanical indicators during the production of blended functional semi-finished products requires a detailed determination not only of the formulation effect of components but also of technological operations, which confirms the relevance of research. Thus, one of the solutions is to take into consideration the influence of the heat transfer coefficient from the working surface to the product during concentration, which optimizes the heat and mass transfer properties of the process and reduces the duration of heat treatment.

In [8], it is noted that for centuries, the study and introduction of innovative technologies for processing and production of food products for the acquisition of special purpose and health-improving properties have been carried out. However, important factors remain unattended, in particular the level of countries in terms of economic and technical development, the percentage of local production to ensure the domestic market, etc. Improvement of production methods taking into consideration the hardware and technological component under the conditions of rational blending of plant materials will ensure the production of functional semi-finished products with an enriched chemical composition. At the same time, the issue of the formation of daily diets requires a detailed definition. Intensification of the technological process of production of functional semi-finished products of plant origin requires the use of innovative technological processes that provide heat and mass transfer processing. Thus, in [9] a heat and mass exchange model of concentration in a film evaporator is given to analyze changes in product properties depending on the operational parameters. However, the effectiveness of the concentration process, taking into consideration the method of heat supply, which significantly affects the preservation of the natural properties of plant materials, which requires research in this direction, remained to be examined. One solution [10] is the use of an improved heating system for rotary film apparatus to ensure an effective thermal regime in the production of compositions of high-quality multicomponent plant pastes. Approbation of concentration is implemented on the formulation ratio of the blended paste, taking into consideration the healing properties of raw materials from apples, cranberries, and hawthorn. The influence of each component on the change in the structure of the resulting pasty semi-finished product with confirmation of the preservation of the original value in the final product was determined. However, the influence of the particle size of blended compositions for concentration and their influence on the heat transfer coefficient from the working surface to raw materials are not considered, which requires further research in this direction. In [11], the analysis of the process of heat transfer to a non-Newtonian pseudoplastic liquid during heat and mass exchange treatment in a scraper heat exchanger was carried out. The proposed structural solutions for the hardware design of the heat exchanger provide an increase in heat transfer, taking into consideration the energy spent on boiling under static and dynamic conditions. However, the conclusions in the cited work are based on the achievement of technological needs without taking into consideration the resource efficiency of the process. This determines the feasibility of determining the heat transfer coefficient as a factor affecting the duration of the process, and therefore the cost of energy. For example, in [12] it is noted that scraper heaters are used to increase the efficiency of the technological process for the production of blended vegetable semi-finished products before concentration. To intensify heating, a hinged blade with a cutting edge (with a reflective heating surface) is proposed in order to obtain a uniform distribution of the thickness of the product layer on the working surface and its additional heating with the reflective surface of the blade. The device enables the uniform distribution of the heat flux 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). The scraper heat exchanger is characterized by a decrease by 1.48 times of the specific energy consumption spent on heating a unit of product volume compared to a heater with a steam shell. An integral part of modern production is the intensification of techniques for the production of functional plant semi-finished products, taking into consideration the hardware and technological component. Nevertheless, heat and mass exchange operations require clear control, taking into consideration the properties of raw materials, which determines the relevance of scientific and practical research.

One of the solutions for the production of functional vegetable semi-finished products is the use of thermoradiation single-drum roller dryer with a combined technique of heat supply, the application and cutting of the dried layer of raw materials [13]. The studies have found that adding apple paste to sea buckthorn blends, chokeberry aronia, beets and pumpkins with different percentages of raw materials leads to an increase in effective viscosity by 9...18 %. The specified indicators of color changes in blends depending on the duration of drying confirm the effectiveness of using the proposed device to obtain high-quality vegetable semi-finished products of the dried fraction. The resulting functional plant semi-finished products with the help of innovative equipment are characterized by high organoleptic and physical-chemical properties, and therefore can be used in various areas of the food industry for the manufacture of special-purpose products.

In [14], an analysis of the demand for consumption of confectionery products without sugar content is reported, by adding to their recipes of vegetable functional semi-finished products of organic origin. In particular, by adding dried açaí powder (10.0 g/100 g in a dry base) to finished confectionery products, followed by determining the organoleptic properties. The issues that are left unattended are associated with an increase in the indicator of sugar content due to sprinkling with powdered sugar and the possibility of minimizing this indicator by using vegetable blended cholesterol-lowering semi-finished products in order to obtain special-purpose products.

It was established that the use of vegetable raw materials in the form of natural vegetable, fruit and berry and cereal fillers, vegetable fats contributes to the effective improvement of the range of food products enriched with physiologically functional ingredients [15]. However, the review of literary sources shows that the use of this raw material to create special-purpose products is rather limited, especially with a cholesterol-lowering effect. Therefore, studying the quality of plant materials, which is adapted for cultivation in a number of countries and the improvement of the nutritional properties of products with their use is relevant.

In [16], the authors proposed an improved technique for production of multicomponent fruit paste based on apples, cranberries, hawthorn. The feature is the concentration in a rotary device to a dry matter content of 28...30 % within 25...50 s and on the condition that the puree is preheated to 50 °C. Also determined and justified is the rational amount of addition of fruit paste – 75 %, with the replacement of apple puree, which is confirmed by a high degree of structure formation, namely, a viscosity index of 616 Pa·s compared to control (354 Pa·s). It is noted that it is rational blending and innovative technological processes that ensure the production of "healthy foods" by partially replacing raw materials with a low content of PFI with a blended composition, which ensures an increase in the nutritional value of marshmallows. In [17], a technique for production of marshmallow is proposed, with the introduction into the recipe composition of puree from vegetable raw materials when replacing the content of apple puree; the resulting functional properties are given. At the same time, the issues of determining changes in structural and mechanical properties remained unresolved. For example, in [18], the structural and mechanical properties of children's vegetable purees were established at different temperatures (5...65 °C), followed by determining the shear speed range (5...200 s^{-1}) depending on the duration of heat treatment. Thus, determining the influence of structural and mechanical indicators on the processing modes of plant materials is relevant from the point of view of further research. It should be noted that the use of dried vegetable semi-finished products is also possible in the low-temperature production of meat culinary products, which makes it possible to ensure the original organoleptic properties of products [19]. Our review of the literary sources makes it possible to form generalized prerequisites for ensuring an innovative and high-quality process of production of functional pasty fruit and berry semi-finished products with a high content of physiologically functional ingredients. It is necessary to determine the issue of formulation component composition based on plant materials and changes in structural-mechanical, physical-chemical, and organoleptic indicators at the main technological and hardware stages of production. In addition, it is necessary to determine the effect of dispersion of blends under conditions of taking into consideration the optimal heat transfer coefficient during concentration. All this predetermines the need for experimental and practical research to ensure the production of functional fruit paste, which, in turn, will expand the range of competitive natural semi-finished products for a wide range of application.

3. The aim and objectives of the study

The aim of this study is to improve the technology of production of functional pasty fruit and berry semi-finished products with a high content of physiologically functional ingredients for further use in the production of special-purpose food. The introduction of the proposed technology into production complexes for the processing of plant materials will expand the range of functional fruit and berry semi-finished products that can be used in food production. In addition, the problem of increasing the content of dietary fiber, vitamins, low molecular weight polyphenolic compounds, phytosterols is being solved.

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

– to determine the structural-mechanical, organoleptic, physical-chemical properties and increase in the chemical composition of the resulting functional fruit-and-berry paste compared to control (apple paste);

– to determine the effect of the dispersion of the blended compositions on the heat transfer coefficient of the equipment design for the production of fruit-and-berry paste for functional purposes.

4. The study materials and methods

4. 1. The study materials

Experimental and practical research for the implementation of the tasks was carried out at the research laboratory "Improvement of the processes of concentration and drying of organic raw materials of plant origin" of the State Biotechnological University (Ukraine, Kharkiv).

For the manufacture of the functional fruit-and-berry paste, the following raw materials were used: apples (Antonivka variety), Ziziphus jujuba (Ta-yang-tsao variety), blueberries (Toro variety) with a high content of functional and physiological ingredients (Table 1).

Table 1

Content of physiologically functional ingredients of raw materials (per 100 g of raw materials)

Substance	Measuring unit	Apple	Ziziphus jujuba	Blueberry
Dietary fibers, g	%	1.8	6.0	2.4
Organic acids converted to malic acid		0.8	1.7	1.2
Folic acid	mg per 100 g	1.8	0.2	6.0
Vitamin A		0.05	2.0	32.0
Vitamin K		2.2	–	19.3
Vitamin B_1	mg per 100 g	0.002	0.02	0.037
Vitamin B_2		0.02	0.04	0.041
Vitamin B_3		0.025	0.9	0.418
Vitamin B_4		0.4	–	6.0
Vitamin B_5		0.07	0.9	0.124
Vitamin C		4.9	69.0	9.7
Vitamin E		–	–	0.57
Low-molecular polyphenolic compounds	mg per 100 g	114	252.2	4199
Tanning substances	%	0.02	5.0	4.0
Potassium	mg per 100 g	278.0	250.0	77.0
Calcium		16.0	21.0	6.0
Magnesium		9.0	10.0	6.0
Sodium		26.0	3.0	1.0
Phosphorus		11.0	23.0	12.0
Manganese		0.047	–	336.0
Phytosterols	mg per 1000 g	–	646.5	22.0

The selection of raw materials for the paste was carried out taking into consideration the content of pectin substances, making it possible to obtain a semi-finished product with a structure-forming effect, phytosterols that have cholesterol-lowering ability, vitamins, minerals, low-molecular polyphenolic compounds. Thus, the apple contains (per 100 g): dietary fiber, 1.8 g; vitamin C, 4.9 mg; a number of minerals (calcium, potassium, magnesium, sodium). Ziziphus jujuba is a source of phytosterols, pectin substances, a number of vitamins and minerals. Bilberry is characterized by a significant content of dietary fiber (2.4 g/100 g), vitamins, minerals, low-molecular polyphenolic compounds, folic acid. In addition, blueberry fruits are a source of phytosterols (per 100 g – 40.0 % of the daily requirement), a significant part of which is represented by beta-sitosterol.

The combination of paste compositions was carried out by trial laboratory tests, which made it possible to obtain the following formulation ratio of fruit and berry raw materials in blended compositions, given in Table 2.

Table 2

Formulation of prototypes of fruit and berry puree

Component composition	Composition		
	1	2	3
Apple	65	55	45
Ziziphus jujuba	25	30	35
Blueberry	10	15	20

During the selection, the ratio of components was based on apple as the most common and affordable raw material, characterized by a structure-forming effect, but having not very pronounced organoleptic quality indicators. A significant amount of Ziziphus jujuba in the formulation of the pastes is also justified by the structure-forming effect of its pectin substances and different taste from the apple. The lower blueberry content in the paste compositions is due to the significant volume of organic acids and polyphenolic compounds that affect the taste and color of the paste, respectively.

4. 2. Production technology of functional pasty fruit-and-berry semi-finished products

Selected fruit-and-berry raw materials based on apple, Ziziphus jujuba, and blueberries are supplied for separate sorting and washing, followed by the manufacture of puree from them (Fig. 1). Ziziphus jujuba fruits are kept in 9...10 % NaCl solution at a temperature of 20...25 °C for 30...35 minutes, which ensures the removal of mechanical contaminants, stabilization of polyphenolic components (anthocyanins, leukoanthocyanins, etc.). The technological operation of keeping Ziziphus jujuba in NaCl solution takes place with the addition of 1 % citric acid to inactivate enzymes, and after aging, the fruits of Ziziphus jujuba are blanched with steam at a temperature of 105...110 °C for 5 min. The apple is crushed in a crusher, followed by blanching with steam at a temperature of 105...110 °C and lasting about 3 minutes. Blueberries are blanched in water at a temperature of 85...87 °C for 3 min. It should be noted that technological operations for the maintenance of fruit-and-berry raw materials in solutions and blanching are carried out in stages for each raw material using a unified multifunctional apparatus.

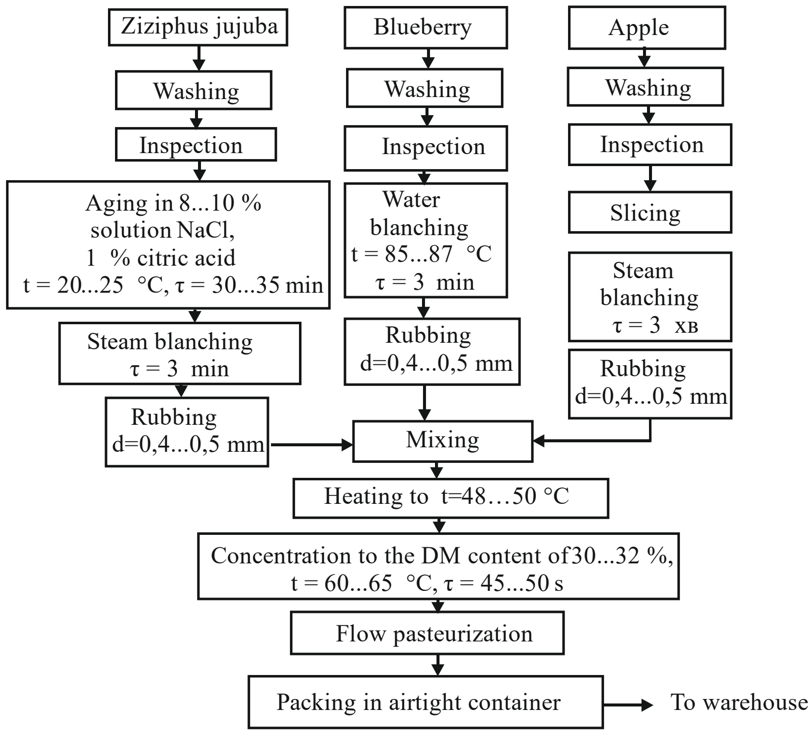

Fig. 1. Functional-technological scheme for the manufacture of fruit-and-berry paste

The blanched fruits of Ziziphus jujuba and blueberries, as well as the crushed apples, are separately rubbed on a rubbing machine with a hole size of 0.4...0.5 mm. The squeezes formed during rubbing of raw materials are sent for drying. The resulting mashed apples, Ziziphus jujuba, and blueberries are blended according to the recipe ratio (Table 2).

After blending the components of apple puree, Ziziphus jujuba, and blueberries according to the formulation ratio, the resulting mass is sent for vacuum film concentration to a rotary film evaporator (RFE). The use of RFE for concentrating fruit-and-berry purees is justified by the fact that the process takes place with continuous intensive mixing by the working bodies of a thin layer of the flowing blend of puree. The use of RFE makes it possible to get fruit-and-berry paste with a dry matter (DM) content of 30...32 % for 45...50 s at a temperature of 60...65 °C. To reduce the duration of heat treatment and the viscosity of the original puree, it is preheated to 48...50 °C before concentration in RFE. Intensive mixing of raw materials by mobile working bodies leads to additional movement and grinding of raw materials. The resulting paste is pasteurized continuously in a scraper heat exchanger (SHE) at a temperature of 95...98 °C in the stream and sent for packaging in a sealed aseptic container.

4. 3. The study methods

We determined structural and mechanical properties during the blending of the component composition (purees and pastes) using the rotary viscometer "Reotest-2" (Germany). The content of pectic substances was determined by calcium-pectate method; low-molecular phenolic compounds – by colorimetric method according to DSTU 4373:2005. The mineral composition was determined by the method of atomic emission spectrography with photographic registration on the DFS-8 device. We determined organoleptic properties of prototypes at the technological stages of production by an expert board consisting of 5 members from the State Biotechnological University (Kharkiv, Ukraine) on a 5-point scale.

The magnitude of the error for all studies was σ=3...5 %, the number of repeatability of experiments – n=5, probability – $p\geq0.95$. To process the data, we used the MS Office software package, including MS Excel, as well as the standard Mathcad software package.

5. The results of research on improving the technology of production of functional pasty fruit-and-berry semi-finished products

5. 1. Determining the structural-mechanical, organoleptic, physical-chemical properties and chemical composition of the functional fruit-and-berry paste

To organize a high-quality process of concentration and calculations of the working bodies of the apparatus, it is necessary to study the structural and mechanical indicators of purees and pastes obtained in the developed way. In addition, when creating competitive food products on the basis of the obtained functional semi-finished product (fruit-and-berry paste), it is necessary to control their viscosity at all stages of production. For example, structural and mechanical properties are among the main indicators reflecting the quality characteristics during the production of various confectionery masses with the addition of vegetable pastes to their recipe. The advantage of using fruit-and-berry pastes is the minimization of the content of artificial colors and flavors, and in some cases, their complete elimination.

The complete rheological curve of fruit-and-berry purees and pastes has been determined (Fig. 2, 3). Analysis of the obtained curves indicates that all presented experimental blended compositions belong to pseudoplastics, the viscosity of which is an indicator of the equilibrium state between the process of destruction and reduction.

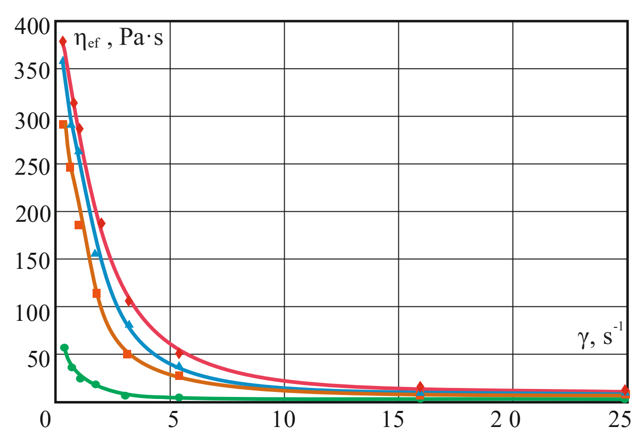

Fig. 2. Rheological curve of fruit-and-berry puree at t=20 °C: ● – control (apple puree); ■ – composition 1; ▲ – composition 2; ◆ – composition 3

The above curves of pseudoplastic purees and pastes are described by equation (1):

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

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

γ is the shear speed, s^{-1};

m is the rate of destruction of the structure.

Fig. 2 shows the effective viscosity of the studied samples of fruit-and-berry puree depending on the rate of displacement. The effective viscosity index (Pa·s) of puree during the application of the shear moment is for prototypes according to the formulation ratio: 1 – 291; 2 – 358; 3 – 382; and control – 57, respectively. The prototypes of blended fruit-and-berry puree obtained using the developed technology have indicators of effective viscosity, which in comparison with the control (applesauce) differ by 5...6.7 times. This difference is due to the different solids content between controls (apple puree, 8...9 %) and prototypes of puree compositions, 16...17 %. A significant increase in the prototypes of compositions 1–3 of effective viscosity can also be explained by a greater number of pectin substances in the puree of the starting raw materials (Ziziphus jujuba, blueberries).

The dependence of effective viscosity on the rate of displacement of the studied samples of blended fruit-and-berry boiled pastes with a solids content of 30 % is shown in Fig. 3.

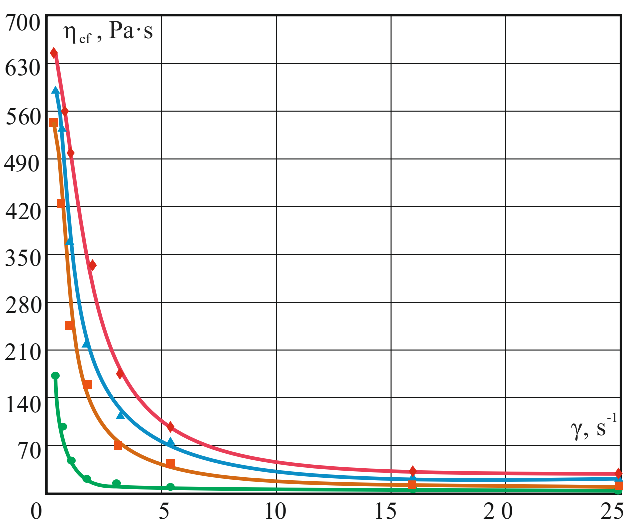

Fig. 3. Rheological curve of fruit-and-berry pastes at t=20 °C: ● – control (apple paste); ■ – composition 1; ▲ – composition 2; ◆ – composition 3

The effective viscosity (Pa·s) of pastes during the application of the shear moment is for experimental formulation samples: 1 – 543; 2 – 605; 3 – 634; and control – 176, respectively. The prototypes of fruit pastes obtained using the developed technology have indicators of effective viscosity, which, in comparison with the control (apple puree), increase by 3.08...3.6 times. The obtained structural and mechanical characteristics for purees and pastes in general indicate an improvement in the quality indicators of all prototypes in terms of strengthening their structure. This may be a prerequisite for reducing the number of structure-forming agents during the preparation of confectionery.

To determine the optimal percentage of raw material components in prototype pastes, their organoleptic assessment was carried out (Table 3).

Table 3

Organoleptic evaluation of prototypes of fruit-and-berry pastes

Indicator	Characteristics		
	Composition 1	Composition 2	Composition 3
Appearance	Homogeneous rubbed paste-like paste without extraneous inclusions		
Taste and smell	The smell and taste of blueberries are barely felt; pleasant – of apples and Ziziphus jujuba	Pleasant harmonious taste of blueberries, Ziziphus jujuba, and apples	Pronounced taste and smell of Ziziphus jujuba, pleasant – of blueberries, apple is almost not felt
Color	Pink-purple	Light burgundy purple	Bright maroon-purple
Consistency	Pasty, easy to spread and shape		

Our organoleptic studies of the experimental blend of composition 1 showed that the sample has a pleasant smell and a barely audible taste of blueberries, a pleasant Ziziphus jujuba, an apple is felt. Composition 2 has a pleasant harmonious taste of Ziziphus jujuba and blueberries, the apple is almost not felt, and blend 3 – more pronounced Ziziphus jujuba and blueberries. Increasing the content of Ziziphus jujuba gives a rich pleasant specific taste and smell. The color scheme of the first composition is not so bright, unlike the second, the third has a bright saturated color. The introduction of blueberries gives a specific sweet and sour taste, and in a small amount leads to a deterioration in the color gamut of the resulting paste. Comparing the obtained indicators of organoleptic evaluation and structural and mechanical characteristics, it was found that the best indicators are demonstrated by composition 3 with the formulation ratio of components: apple – 45 %; Ziziphus jujuba – 35 %; blueberries – 20 %, compared to compositions 1 and 2.

The content of physiologically functional ingredients of prototypes obtained according to the proposed formulation ratio and production technology (Table 4) in comparison with the control sample (apple paste) is determined.

The composition 3 obtained by the improved technology, compared to control, has a high content of dietary fiber, by 3.8 times, and vitamin C, by 2.25 times (Table 4). The content of low-molecular polyphenolic compounds (anthocyanins, leucoanthocyanins, catechins, and flavonoids) and tannins exceeds that of the apple paste. In addition, the resulting new functional pastes contain phytosterols. Such a composition of the developed functional paste indicates the feasibility of its use as an immunostimulant, and the content of phytosterols makes it possible to recommend a semi-finished product for creating products with cholesterol-lowering effect.

Table 4

Content of physiologically functional ingredients of pastes (per 100 g of product)

Substance	Measuring unit	Control, apple paste	Composition 1	Composition 2	Composition 3
Dry matter content		30±1.15	30±1.15	30±1.15	30±1.15
Food fibers	%	1.74±0.02	5.82±0.08	6.30±0.10	6.78±0.12
Organic acids recalculated for malic acid		0.52±0.01	0.87±0.05	0.95±0.05	1.09±0.05
Folic acid		0.60±0.01	1.2±0.05	1.8±0.05	2.4±0.05
Vitamin A	μg per 100 g	6.05±0.01	7.40±0.02	10.8±0.02	14.2±0.02
Vitamin K		1.05±0.01	3.86±0.02	5.79±0.02	7.72±0.02
Vitamin B_1		0.042±0.01	0.074±0.01	0.011±0.01	0.015±0.02
Vitamin B_2		0.042±0.01	0.0082±0.001	0.0013±0.001	0.0164±0.001
Vitamin B_3		0.31±0.005	0.54±0.005	0.67±0.005	0.81±0.005
Vitamin B_4	mg per 100 g	0.75±0.01	1.2±0.05	1.8±0.05	2.4±0.05
Vitamin B_5		0.01±0.001	0.03±0.001	0.04±0.001	0.05±0.001
Vitamin C		25.1±0.85	42.82±1.25	49.70±1.25	56.59±1.25
Vitamin E		–	0.1±0.001	0.17±0.001	0.20±0.0001
Low-molecular polyphenolic compounds	mg per 100 g	256±1.20	652.25±2.5	739.7±2.5	874.5±2.5
Tanning substances	%	0.06±0.01	0.18±0.01	0.21±0.01	0.27±0.01
Potassium		582.8±2.0	501.8±2.0	478.9±2.0	456.0±2.0
Calcium		33.5±1.15	32.5±1.15	32.0±1.15	31.5±1.15
Magnesium		18.5±0.05	17.9±0.05	17.6±0.05	17.5±0.05
Sodium	mg per 100 g	37.5±1.15	35.5±1.15	30.7±1.15	25.9±1.15
Phosphorus		18.5±0.05	14.5±0.05	13.8±0.05	16.1±0.05
Manganese		35.5±1.5	67.2±1.5	100.8±1.5	134.4±1.5
Phytosterols	mg per 1000 g	–	341.96±2.0	406.6±2.0	471.25±2.0
Active acidity	–	3.2±0.15	3.24±0.15	3.21±0.15	3.17±0.15

5. 2. Determining the effect of dispersion of blended compositions on the heat transfer coefficient during concentration

To establish optimal modes of heat treatment in the improved technology of production of functional pasty fruit-and-berry semi-finished products, in particular during concentration and pasteurization, it becomes necessary to calculate the dispersion (size) of the particles of the processed raw materials. The optimal implementation of the technological stage of grinding provides regulation of the dispersion of the semi-finished product, the impact on the qualitative nature of the interaction of the blended components and handling during heat treatment, storage and subsequent formation of food products based on it. The particle size of the developed functional blended fruit-and-berry puree during the determination of structural and mechanical characteristics was changed in the range from 0.1 to 2 mm. To change the particle size of the puree, the final size of the holes of the rubbing sieve was varied from 0.1 to 1.5 mm, while the DM content of the original puree after rubbing was 15...16 %. The structural and mechanical dependences on the particle size of the blended puree shown in Fig. 4 are characterized by a tendency to reduce the indicator of the limiting shear stress with a decrease in dispersion.

The prototypes presented are a dispersed system involving particles of pulp and cell sap. In the presence of large particles (1...1.5 mm) cell sap in suspension is not enough, which leads to the emergence of friction forces when applying shear forces and maximum values of the limiting shear stress equal to 167...242 Pa.

With a gradual decrease in the size of the particles, the amount of cell juice in the layer between the particles increases due to their destruction, this leads to a decrease in the shear stress. With a further decrease in the diameter of the particles, there is such a tendency to reach a value of 0.5 mm, after which the limiting shear stress practically does not change.

The resulting dependences (Fig. 4) show that in order to effectively conduct the process of concentration in the RFE and subsequent pasteurization in the stream, namely, intensive movement in a thin layer of the product film, it is rational to grind the starting raw materials to the particle size in the range from 0.1 to 0.5 mm (81...92 Pa). Such average particle sizes provide the formation of a stable movement of thinner films on the heat-transmitting surface of film devices, which significantly increases the heat transfer coefficient. In addition, the resulting structural and mechanical indicators will make it possible with greater accuracy to carry out calculations of hydromechanical and thermal processes.

To determine the changes in the heat transfer coefficient depending on the particle size of the blended fruit-and-berry puree, a study was conducted to determine the heat exchange characteristics of the RFE to establish the effect of the effective viscosity of fruit-and-berry puree, which is concentrated according to the technology. The process of concentration in RFE takes place from the content of dry substances of the puree of 16...17 % to the obtaining of the blended paste with the DM content of 28...30 %. To obtain prototypes of purees in the process of rubbing, their particle size was changed in the range of 0.1...1.5 mm, and the flow rate of the initial product was adjusted within $G \cdot 10^3 = 0.6...2.4$ kg/s. The rotational speed of the mixing element (rotary device RFE) was maintained at 1.6 s^{-1}.

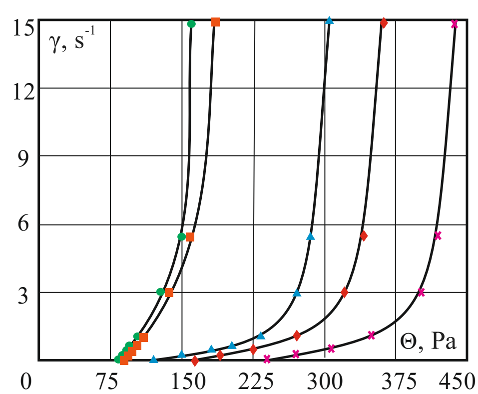

Fig. 4. The dependence of the shear rate on the particle size of the raw material (mm) t=20 °C: ● – 0,1; ■ – 0,5; ▲ – 0,8; ◆ – 1; × – 1,5

The results of the study of heat exchange indicators of RFE depending on the consumption of the product and the dispersion of the fruit-and-berry semi-finished product are shown in Fig. 5.

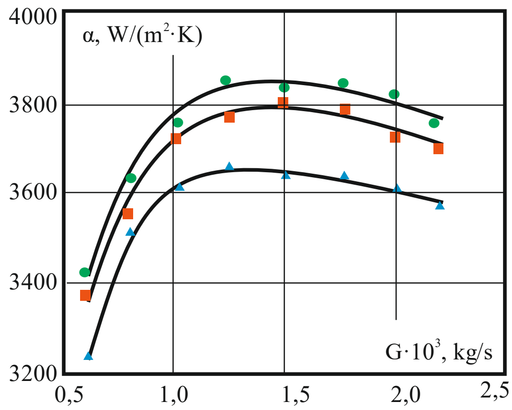

Fig. 5. The dependence of the heat transfer coefficient α on the consumption of the product G at the size of the puree particles, mm: ● – 0,5; ■ – 0,8; ▲ – 1,5

From the presented dependences, it was determined that the value of α when using puree with a particle size of 1.5 mm reaches a maximum heat transfer at a lower cost of raw materials. The nature of the curve indicates that the heat transfer coefficient is influenced by a change in the consumption of the product and, upon reaching the extreme, tends to decrease (Fig. 5). The decrease in the heat transfer coefficient after the extreme is explained by the fact that the blades of the mixing element are not pressed against the heat transfer surface due to the viscous friction forces of the raw material and stir only the surface layer of the product. The maximum values of the heat transfer coefficient for puree prototypes with a particle diameter of 0.5; 0,8; 1.5 mm, are equal to 3863; 3800; and 3646 (W/m^2K), respectively. The decrease after the maximum of the characteristic of the heat transfer coefficient is explained by the presence in this interval during mixing on the edge of the blade of a significant part of the product "nasal wave". Due to this, there is a decrease in the contact of the product with the heating surface, thereby the concentration process is less effective.

It is worth noting that the processed product wakes up, and as a result of this, the time the product stays on the surface that transfers heat decreases. The heating zone of the product increases under heavy loads, which leads to a decrease in the heat transfer coefficient. Thus, the value of the heat transfer coefficient during the concentration of the prototype of puree with a particle size of 0.5 mm has a higher rate, by 6 %, compared to the sample of puree in which the particle size is 1.5 mm. Thus, our results of heat exchange indicate that for more intensive concentration process, it is necessary to grind the starting raw materials to a particle size of 0.5 mm. These data fully confirm the results of studies of structural and mechanical characteristics when the diameter of the dispersed phase of fruit-and-berry puree changes.

6. Discussion of results of the production of functional fruit-and-berry paste using improved technology

To test the improved technology of production of functional pasty fruit-and-berry semi-finished products and further use in the production of special-purpose food products, plant raw materials with a high content of functional and physiological ingredients, immune-stimulating effect, and phytosterol content were selected. Namely, it is proposed to use: apple (Antonivka variety), Ziziphus jujuba (Ta-yang-tsao variety) and blueberries (Toro variety) with subsequent blending according to the recipe ratio (Table 2) for the enrichment of PFI and acquisition of competitive organoleptic and consumer properties.

A feature of the improved technology is the use of vacuum film concentration in a rotary film evaporator at gentle low-temperature parameters to the content of DM 30...32 % for 45...50 s at a temperature of 60...65 °C. In addition, to reduce the duration of heat treatment of plant materials and the viscosity of the original puree, it was preheated to 48...50 °C before concentration. In addition, it is proposed to pasteurize concentrated paste in a continuous way in a scraper heat exchanger at a temperature of 95...98 °C in the stream followed by packing in hermetic aseptic containers.

To organize a high-quality concentration process, the structural and mechanical indicators of purees and pastes obtained according to the formulation ratio (Table 2) in accordance with the improved technology were determined. The indicator of effective viscosity (Pa·s) of puree according to the recipe ratio is: 1 – 291; 2 – 358; 3 – 382, and in the control – 57, respectively, and therefore the viscosity of the samples is 5...6.7 times different from control (apple puree, Fig. 2). The effective viscosity (Pa·s, Fig. 3) of pastes for the proposed formulation ratios is: 1 – 543; 2 – 605; 3 – 634; and control – 176, respectively. The blends of fruit-and-berry pastes obtained using the developed technology have effective viscosity indicators of 3.08...3.6 times higher compared to control (apple paste). To confirm the choice of the optimal percentage of blends, their organoleptic assessment by an expert board was carried out (Table 3). It was established that composition 3 with a formulation ratio of components: apple – 45 %; Ziziphus jujuba – 35 %; blueberries – 20 % is characterized by better organoleptic indicators compared to other compositions. The content of physiologically functional ingredients of experimental blends obtained according to the proposed formulation ratio and improved technology for the production of functional pasty semi-finished products (Table 4) compared to control (apple paste) has also been determined. Our results confirm the advantage of the blended composition 3 compared to the control characterized by a high content of dietary fiber by 3.8 times, vitamin C by 2.25 times, and the presence of phytosterols by 471 mg per 1000 g (Table 4).

To establish the optimal modes of heat treatment in the improved technology of production of functional pasty fruit-and-berry semi-finished products when concentrating in RFE, structural and mechanical dependences on the particle size of the blended puree were determined (Fig. 4). It has been established that the presence of large particles (1...1.5 mm) – cell sap in suspension is not enough, which will ensure the occurrence of friction forces during the application of shear forces and the occurrence of maximum values of the limiting shear stress equal to 167...242 Pa. Effective concentration in RFE followed by pasteurization in the stream with intensive movement in a thin layer of the film of the product is rational when grinding the starting raw materials to a particle size of 0.1 to 0.5 mm (81...92 Pa). We also determined the change in the heat transfer coefficient depending on the particle size of the blended fruit-and-berry puree based on the predetermined heat exchange characteristics of the RFE to establish the effect of the effective viscosity of the fruit-and-berry puree, which is concentrated according to the technology. The process of concentration in RFE was implemented from the content of DM puree 16...17 %, and in the resulting blended paste to the content of DM – 28...30 %. From the presented dependences, it was determined that the value of α when using puree with a particle size of 1.5 mm reaches a maximum heat transfer at a lower cost of raw materials (Fig. 5). At the same time, the maximum values of the heat transfer coefficient for puree prototypes with a particle diameter of 0.5; 0.8; 1.5 mm are equal to 3863; 3800; and 3646 (W/m^2K), respectively. Thus, the value of the heat transfer coefficient during the concentration of the prototype of puree with a particle size of 0.5 mm has a higher rate by 6 % compared to the sample of puree in which the particle size is 1.5 mm. In addition, these data confirm the results of studies of structural and mechanical characteristics when the diameter of the dispersed phase of fruit-and-berry puree changes.

The relevance of our experimental and practical studies is confirmed by the approbation of the improved technology for the production of functional pasty fruit-and-berry semi-finished products. phytosterols, and as a result, immune-stimulating action. The proposed technology will make it possible in the future to use the obtained functional paste in the production of special-purpose food products, which will have a high content of functional and physiological ingredients, phytosterols, and as a result, immune-stimulating action. Thus, this will expand the competitive range of "healthy foods" by replacing raw materials with a low content of physiologically functional components with a multicomponent composition, to ensure a complete diet, including the military and doctors.

The advantages of the improved technology are the rational selection of fruit-and-berry blends with a significant content of PFI, the use of mild modes of concentration and subsequent pasteurization in the stream, which will ensure the preservation of natural properties and competitiveness of the equipment and technological complex. In addition, functional fruit and berry paste can be used as a natural raw material with a high content of low-molecular phenolic compounds, which will make it possible to abandon synthetic dyes and give new products original organoleptic properties.

It should be noted that despite some experience in adding blended pastes to a variety of foods to increase their health effect, it is necessary to determine the structure-forming properties to obtain the desired consistency. To study the effect of heat transfer of plant semi-finished products, simulation modeling is partially used [20], but in practice there are certain differences that require a quick response to obtain high quality and preserve the initial properties of raw materials. The resulting high-quality natural semi-finished products are widely introduced, in particular in innovative technologies for the production of confectionery [21], but require a clear definition of the mechanisms of structure formation when adding plant materials for the production of products enriched with PFI. Further research will be aimed at determining the regime parameters during pasteurization of the developed fruit-and-berry paste in a scraper heat exchanger. Development of recipes for food products for special purposes. In addition, it will be relevant to conduct research aimed at determining the timing and conditions of storage of paste.

7. Conclusions

1. The effective viscosity (Pa·s) of the mixtures of the original purees (DM 16...17 %) and prepared pastes (30...32 %) and an increase in the viscosity of pastes compared to puree was found, by 1.65...1.85 times. Our data indicate a strengthening of the structure of the resulting functional paste, which, compared to the control sample, has an effective viscosity of 3.6 times more. According to organoleptic quality indicators, paste 3 has an advantage (45 % apple; 35 % Ziziphus jujuba; 20 % blueberries), which is characterized by a 3.8-fold higher content of dietary fiber, vitamin C by 2.25 times, low-molecular polyphenolic compounds and tannins. In addition, the paste contains phytosterols, which indicates the feasibility of its use as an immunostimulant and recommend it for the creation of products with cholesterol-lowering effect.

2. The influence of dispersion of blended compositions on their structural and mechanical parameters and the heat transfer coefficient in RFE during concentration has been determined. It was established that in order to effectively conduct the process of concentration in the RFE and subsequent pasteurization in the SHE, it is rational to grind purees to a particle size within 0.1...0.5 mm. It was found that the heat transfer coefficient when concentrating prototypes with a particle size of 0.5 mm has a higher indicator by 6 % compared to the sample of puree in which the particle size is 1.5 mm. Thus, as a result of our research, the technology of production of functional fruit-and-berry paste with a rational selection of components (45 % of apple; 35 % of Ziziphus jujuba; 20 % of blueberries) was improved. A feature of the technology is vacuum film concentration of paste in RFE under gentle modes (60...65 °C) to the content of DM 30...32 % for 45...50 s and subsequent pasteurization in a scraper heat exchanger at a temperature of 95...98 °C followed by packing.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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