INNOVATIVE METHOD OF MANUFACTURING FUNCTIONAL ORGANIC SEMI-FINISHED PRODUCTS OF A HIGH STAGE OF READINESS ON THE BASIS OF LOW-TEMPERATURE HEAT AND MASS EXCHANGE EQUIPMENT

Andrii Zahorulko[1]
Aleksey Zagorulko[2]

DOI: https://doi.org/10.30525/978-9934-26-241-8-2

Abstract. One of the main tasks of the food industry is the full provision of consumer cooperatives with high-quality functional food products, one of the main sources of production of which is fruit and berry raw materials. To create an assortment of such products, it is necessary to search for innovative measures to intensify heat and mass transfer processes for the production of high-quality products. The aim of the study is a scientific and practical substantiation of the effectiveness of using the developed innovative method for the production of organic functional semi-finished products of a high degree of readiness with a wide range of uses in the processing, manufacturing and pharmaceutical industries through the use of modern low-temperature heat and mass transfer equipment. The implementation of the aim will allow not only to expand the range of food products with a balanced content of physiologically functional ingredients, but also to create a resource-efficient technical complex for the production of such products. To select the optimal recipe for blending fruit and berry raw materials into functional products with predictable structural and mechanical properties and color formation, a reasonable analysis of the initial properties of fruit and vegetable raw materials was carried out: Jerusalem artichoke, chokeberry, sea buckthorn, beetroot, pumpkin. As a result, a technological process was developed for the production of blended functional fruit and berry concentrated and dried

[1] PhD, Associate Professor Department of Equipment and Engineering of Processing and Food Production, State Biotechnological University, Ukraine
[2] PhD, Associate Professor Department of Equipment and Engineering of Processing and Food Production, State Biotechnological University, Ukraine

products with the optimal prescription content of fruit and vegetable puree components: Jerusalem artichoke – 20%, black chokeberry – 20%, sea buckthorn – 25%, beetroot – 20% and pumpkin. The developed technology is distinguished by the use of gentle temperature conditions during concentration and drying, which occur on the developed rotary evaporator and thermoradiation drum dryer using a flexible film resistive radiant electric heater for heating. The developed equipment provides a gentle processing mode of 45…60 °C, which contributes to the production of high-quality semi-finished products with maximum preservation of physiologically functional ingredients. The obtained technology for the production of fruit and vegetable semi-finished products of a high degree of readiness will expand the range of functional products of high quality for health purposes.

1. Introduction

The priority direction of the food industry is the production of functionally health-improving products based on organic raw materials, which will make it possible to obtain semi-finished products of a high degree of readiness and a wide range of food products based on them [1–2]. The production of an appropriate range of food products with therapeutic and prophylactic properties of natural origin will contribute to the formation of a high-quality diet for the population, which will minimize the negative impact of environmental factors, chronic and acquired diseases, pandemics, etc. [3–5]. In addition, the use of highly prepared natural semi-finished products in food formulations will reduce the use of synthetic sweeteners, colors, flavors, etc.

An important direction of European countries is the development of farming enterprises aimed at growing an organic plant raw material base using innovative domestic agricultural technologies. It is relevant to grow and use our own raw material plant base (berries, fruits, vegetables, etc.), forming the prerequisites for the development of processing and manufacturing enterprises for the production of natural functional semi-finished products of a high degree of readiness [6–7]. A feature of semi-finished products of a high degree of readiness is, in addition to the original organoleptic properties due to the blending of various raw materials, also natural therapeutic and prophylactic properties.

Cultivation and processing of our own organic raw material base necessitates the introduction of modern innovative technological and hardware trends for resource-efficient processing. Ensuring resource-efficient processing of organic raw materials will allow maximum preservation of the initial natural properties of raw materials. Confirming the relevance of research aimed at finding innovative hardware and technological solutions for resource-efficient processing of organic raw materials using gentle and modern technologies. Ensuring the formation of innovative trends in the development of the latest resource-efficient processes implemented on low-temperature rational equipment, which is characterized by a uniform distribution of thermal energy and the use of secondary energy. Thus, it will allow to obtain high-quality and technological processing of organic raw materials into semi-finished products of a high degree of readiness, which will be characterized by the properties of independent products and at the same time functional additives in the formulations of various products.

In the production of semi-finished products of a high degree of readiness with subsequent use in processing and food industries, hotel and restaurant complexes, a rational selection of plant materials is necessary, based on determining its initial content of physiologically functional ingredients [8].

The deterioration of the ecological situation against the backdrop of modern pandemics leads to the emergence of chronic diseases and ailments, which largely induces the need to increase the level of consumption of high-quality natural food products with an immunomodulating effect. In turn, for high-quality processing of vegetable raw materials, it is necessary to introduce resource-efficient equipment using low-temperature processing modes. The consumption of organic plant raw materials is in great demand due to its natural properties, which ensure the fight against adverse factors that affect the formation of immunity. The value of organic food is emphasized by the content of a significant amount of nutrients and biologically active substances necessary for the functioning of human systems and organs by stabilizing the immune component.

The climatic conditions of many countries of the world, in particular, Ukraine, are favorable for the formation of competitive vegetable and fruit growing, thereby replenishing the range of semi-finished products of a high degree of use by obtaining a variety of textures.

2. Justification of the use of organic raw materials taking into account the physical and chemical composition for the production of functional semi-finished products

The industry ensures the implementation of the processing of organic raw materials (vegetables, fruits, berries, etc.) on various hardware and technological complexes. This raw material has an individual physical and chemical composition and is useful in the production of food due to a variety of natural elements necessary for the formation and maintenance of strong human immunity [9]. For example, organic vegetable fruit and vegetable raw materials on average contain dry matter approximately: 91...94%, including 16...32% protein, 30...55% fat, 3...14% sugar.

The introduction of organic semi-finished products of a high degree of readiness into the formulations of various food products, obtained from natural fruit and vegetable and berry raw materials, will increase the nutritional value, and also impart functional and therapeutic and prophylactic properties. At the same time, it should be noted that the current trends in food production, specializing in the processing of organic raw materials, are aimed at improving the hardware and technological components. This will ensure resource-efficient processing of raw materials in terms of placement in local places of its collection. An innovative approach to the optimal combination of hardware and technology components will ensure the competitiveness of the resulting vegetable semi-finished products of a high degree of readiness, which will reduce the market cost and increase the nutritional value of the resulting products. An important stage in the production of semi-finished products of a high degree of readiness is the resource-efficient production of paste-like and dried products, taking into account the existing instrumental shortcomings and modern instrumental and technological needs that form the production of high-quality products.

The raw material base of Ukraine has a significant fruit, berry and vegetable potential, among vegetables it is: Jerusalem artichoke, beetroot, carrots, pumpkins and others. Blackberry, cranberry, black chokeberry, agruz, black currant, currant, etc. are characterized by a wide range of use among fruit and berry raw materials. The natural raw material base is characterized by a significant content of food and biological ingredients with a wide functional and preventive effect.

Fruit and vegetable raw materials are characterized by a significant content of biologically active substances, taking into account the ingredients, depending on the variety. In general, 100 g of raw materials contain: 270...760 mg of phenolic compounds, 50...150 mg of flavonol glycosides, 195–620 mg of polyphenols, from 45 to 265 mg of L-ascorbic acid, from 9.2 to 9.8 mg of β-carotene, as well as pectin, cellulose, protein, etc.

In the world, vegetables occupy up to 5%, but their importance for consumers can hardly be overestimated, since this is actually the main consumer product, as of 2021, Ukraine is among the top five vegetable producers, emphasizing the relevance of the formation of resource-efficient processing complexes. Rational consumption of vegetables in the daily diet prevents the development of chronic and acquired diseases, provides the body with important organic macro- and microelements, including: vitamins of different groups, minerals, etc.

Vegetables have indigestible carbohydrates (dietary fiber, etc.), which act as regulators of food rations and should be 20...35% of the daily intake, depending on the way a person lives [10–11]. This ensures the normalization of the immune life cycle, in particular the formation of beneficial intestinal microflora and the removal of harmful ingredients from the body, reducing cholesterol.

For example, for the majority of the population, Jerusalem artichoke is familiar as a decorative flower that adorns a summer cottage, but not everyone knows about its nutritional, cosmetic and medicinal characteristics. In particular, Jerusalem artichoke is a perennial crop, which in many countries is valued above the tuber. Jerusalem artichoke has the ability to grow in almost any conditions. Thanks to powerful roots that can withstand drought and winter frosts, it does not require additional top dressing and easily tolerates high soil moisture [12].

Jerusalem artichoke potatoes have a significant content of vitamins and minerals, among them: proteins, iron, fiber, essential amino acids, organic acids and pectin. Jerusalem artichoke is especially useful for people with diabetes. It is rich in inulin, a natural analogue of insulin, and regular consumption in raw or fried form significantly reduces sugar levels [12].

Doctors advise to consume Jerusalem artichoke for diseases: gout, kidney disease, anemia, salt deposition. The use of Jerusalem artichoke provides: restoration of intestinal microflora and metabolic disorders; normalization of pressure; increase in hemoglobin; decrease in sugar levels; strengthening the heart and blood vessels; improvement of the pancreas and elimination of heartburn [12].

Due to the high concentration of inulin and fiber, Jerusalem artichoke has powerful antitoxic properties, effectively cleansing the body of salts of heavy metals, radionuclides, toxins and «bad» cholesterol [12].

According to the spectrum of use, Jerusalem artichoke is a universal raw material, it can be consumed raw, getting the maximum amount of nutrients, while it must be peeled. Jerusalem artichoke has a pleasant, sweetish, slightly nutty taste, partially reminiscent of a head of white cabbage, turnip or chestnut, in structure it is juicy, tender and slightly sweeter than potatoes. Jerusalem artichoke can be fried, boiled, marinated, used to prepare a variety of dishes (especially a good vegetable soup of broccoli, sweet peppers and celery), mashed potatoes, roasts, fillings for pies and even compotes. It is also possible to produce Jerusalem artichoke powder with its subsequent use in baking bread, or for preparing a drink that tastes like coffee [12].

Beetroot has medicinal and dietary properties, due to its chemical composition: sugar 7.5...10.0%, fiber 0.7...0.9%, nitrogenous substances 1.3...3.5%, minerals (ash) 0.8…1.0%. The calorie content of table beetroot is 39.9 kcal, it contains (per 100 g): water – 86.0, proteins – 1.5, fats – 0.1, carbohydrates – 8.8, mono- and disaccharides – 8.7, starch – 0.1, dietary fiber – 2.5, organic acids – 0.1, ash – 1.0. The vitamin composition of beetroot is valuable, (mg/100 g): A – 0.01, B1 – 0.02, B2 – 0.04, B3 – 0.1, B6 – 0.07, B9 – 13.0, C – 10.0, E – 0.1, PP – 0.2. Beetroot are also rich in minerals (mg / 100 g): Fe – 1.4, K – 288.0, Ca – 37.0, Mg – 22.0, Na – 46.0, P – 43.0, Cl – 43.0, B – 280.0, I – 7.0, Mn – 660.0, Cu – 140.0, F – 20.0, Zn – 425.0 and others [13]. Beetroot contains the most iodine among all vegetables, so it is widely used for the prevention and treatment of thyroid disease. It has a positive effect on the functioning of the kidneys and liver, normalizes the activity of the gastrointestinal tract. Diabetics value beetroot for their high zinc content, which increases the duration of insulin action. Beetroot improves memory in atherosclerosis, is used to treat neurosis, insomnia, anemia and hypertension, removes toxins and heavy metals from the body. Unlike other vegetables, even when boiled, it retains its beneficial properties to a large extent due to the persistence of flavonoids that have anticancer effects [14].

Pumpkin is one of the most valuable and nutritious fruits, which combines both a dietary product and a medicine. Pumpkin contains a unique complex of vitamins and minerals, perfectly absorbed by the body. The interesting thing is that pumpkin can be stored for a year at room temperature, and at the same time its beneficial properties are only getting better. It is recommended for use by all people, regardless of age, gender and health status, since it contains a significant amount of substances necessary for the normal functioning of our body. In addition to water, its composition includes nitrogenous and protein substances, organic acids, fiber, starch, carotene, glucose, fructose, sucrose, salts of copper, phosphorus, iron, zinc, as well as vitamins A, B_1, B_2, C in sufficient quantities, D, E, PP and more rare T and K. So all these ingredients found in baked, boiled and raw pumpkin are simply undeniable benefits [15].

Pumpkin is rich in dietary fiber – pectin, fiber, hemicelluloses, which adsorb and remove xenobiotics from the body, especially heavy metals and radionuclides. β-carotene and other carotenoids give pumpkin the greatest value, causing its yellow or orange flesh color. In terms of the content of β-carotene, it exceeds other vegetables (14.0–35.0 mg/100 g) and has a low energy value (28 kcal/100 g), so it is included in most diets [15]. Pumpkin has a high content of pectin substances, which have good structure-forming properties, making it possible to implement a high-quality blending process.

In Ukraine, the fruits of chokeberry are known as a vitamin remedy for strengthening the body and keeping it in good shape, especially during viral epidemics, for people who were in difficult situations (emotional, physical and stressful) or lived in areas with poor ecology. Introducing aronia into the diet is necessary for diseases associated with hypertension, atherosclerosis, rheumatism, various allergic reactions, measles, scarlet fever, iodine deficiency, capillary fragility, colds, etc.

The main active ingredients of chokeberry are phenolic compounds, terpenoids and carbohydrates, including: phenolcarboxylic acids and their derivatives: chlorogenic; neochlorogenic; coffee; catechins; anthocyanidins: cyanidin, malvidin, peonidin, pelargonidin and their glycosides; flavanone hesperidin. Flavonols: rutin, quercetin; tannins; carbohydrates and related compounds: sugars – up to 10%: glucose, rhamnose, fructose, sucrose, galactose; pectin substances – up to 2.5%; alcohol sorbitol; organic acids – 0.8%: malic, citric, succinic, quinic, n-sorbic. Vitamins: ascorbic acid – up to

167 mg%, carotenoids – 4.4...5.6 mg%, folic acid (vitamin B, C), nicotinic acid (vitamin PP) – 0.2...0.7 mg%, phylloquinone (vitamin K_1), riboflavin (vitamin B_2), tocopherols (vitamin E); nitrogen-containing compounds: amino acids – 220 mg%; amygdalin; fatty acids: oleic, linoleic, palmitic and others; macro- and microelements: K, Ca, Fe, Mg, P, Mn, Cu, Zn, Mo, Se [16].

The fruits also have hypotensive, antispasmodic, anti-inflammatory, antimicrobial, capillary-strengthening, diuretic and choleretic properties, and have a noticeable activating effect on the hemostasis system. Apply 50-100 g 3 times a day for 10-30 days for the prevention of P-vitamin deficiency, treatment of stage I and II arterial hypertension, various pathological disorders in the blood coagulation system, in particular hemorrhagic diathesis, capillary toxicosis and bleeding of various origins. Aronia is effective in atherosclerosis, diabetes mellitus, anacid gastritis, glomerulonephritis, hepatitis, radiation injury, allergic condition, disorders caused by the use of anticoagulants [17].

For example, sea buckthorn, which has long been known as a medicinal plant, takes its rightful place in the list of the most healing crops in the world. It is difficult to find other fruits containing the same amount of natural vitamins as sea buckthorn berries [18].

Sea buckthorn is unique in that it contains provitamins and almost all the main fat-soluble and water-soluble vitamins, glucose and fructose, which are well absorbed by the body. According to the content of fatty oil, sea buckthorn is the leader among all fruit and berry plants. Sea buckthorn is a rare product that heals a person from many diseases, and at the same time plays the role of a prophylactic against serious diseases [18].

Sea buckthorn is used in the treatment of diseases that lead to beriberi, and the uniqueness of the fruit lies in the fact that fatty oil is contained not only in the seeds, but also in the pulp, and the fruit pulp oil is of the greatest value. In total, sea buckthorn berries contain 109 biologically active components, of which 106 are contained in oil [18].

Fresh berries contain a lot of ascorbic acid (up to 300 mg per 100 grams). Sea buckthorn is also rich in vitamins B, P, E, provitamin A and folic acid. Trace elements: iron, manganese, magnesium, sulfur, boron, aluminum, titanium and silicon. Also valuable is the oil of the plant, which is contained in the seeds of the fruit. It should be noted that, despite conservation, it will retain all the useful properties [18].

Sea buckthorn oil has antibacterial properties. It perfectly heals wounds and minor damage to the mucous membranes and skin. It can be used both externally and internally. The oil improves lipid metabolism and increases the protein content in the liver, and also provokes regenerative processes in damaged tissues (including liver cells after alcohol intoxication). Sea buckthorn is also useful for the prevention of atherosclerosis, which is especially important for the elderly [18].

Thus, the production of semi-finished products of a high degree of readiness from fruit and vegetable raw materials through its careful selection and subsequent blending, taking into account the initial properties, will make it possible to provide the population with this product evenly throughout the year and create reserves. Semi-finished products can be made in the form of pastes and powders, which are the basis or a high-quality natural additive with various physiologically functional ingredients, structure formers and color enhancers of food products [19].

An important stage in the production of pastes is the concentration of pureed raw materials until the mass fraction of solids reaches 25–45% [20]. The traditional method of concentration takes place in batch evaporators, the duration of which in most evaporators can take from 60 to 400 minutes, due to which there is a significant loss of physiologically functional ingredients. Therefore, it is for the concentration process that it is necessary to improve and introduce efficient equipment, the use of which will ensure the production of high-quality semi-finished products through the use of an uninterrupted processing process and gentle temperature regimes with a simultaneous reduction in the duration of heat treatment [21].

An important feature in the production of paste-like semi-finished products is the consideration of their structural and mechanical properties using the results obtained in the calculations of technological equipment, and especially when introducing a prescription mixture as a component of structure formation in confectionery products, in particular, marmalade products.

Simultaneously with pasty semi-finished products from fruit and berry raw materials, the demand for powdered products also increases, the production technology of which is characterized by a greater degree of dehydration and is very similar. The paste is produced by thickening mashed vegetable purees to solids content of up to 25…60%. A powdered semi-finished product is obtained by subsequent dehydration, additional drying of the concentrated paste to the final moisture content, after which grinding is performed to obtain the required dispersion and packaging in a sealed container [22–23].

The existing methods for drying powdered semi-finished products, as a rule, have one important drawback, which is the use of high temperatures, which leads to the loss of physiologically functional ingredients of the feedstock. This is also one of the reasons for the introduction of new innovative methods and appropriate equipment, the use of which will create conditions for the production of high-quality powdered semi-finished products with minimal resource costs [24].

To date, the method of thermoradiation processing of natural raw materials using infrared energy of various range waves is gaining wide use. The use of infrared radiation as one of the methods for processing natural raw materials ensures the use of 98% of the supplied thermal energy directly to the natural component of the raw material, providing a high coefficient of performance (COP) of the technological process and simplicity of equipment, unlike other known drying methods.

Drying by thermal radiation is carried out in the field of IR radiation and allows, compared with convective drying, to significantly intensify the process due to an increase in the heat flux density on the surface of the product and the penetration of rays deep into the dried raw material [25]. More often, thermal radiation drying is combined with other methods to intensify the process.

The analysis of the presented materials confirms the relevance of research on improving the methods for the production of semi-finished products from vegetable raw materials by reducing the temperature of concentration and drying in the range of – 45...65 °C, which will improve the quality indicators of the obtained semi-finished products and confectionery products based on them. The possibility of obtaining the final powdered semi-finished product after drying the pre-thickened fruit and vegetable pastes will reduce the volume of the final product by an average of 5-6 times, which will ensure their compactness, reduce the cost of packaging and transportability with the possibility of long-term storage.

The creation of various confectionery products based on or with the addition of semi-finished fruit and berry semi-finished products is a promising task of purposefully creating preventive health products and expanding the range. For the development of this direction in Ukraine there is enough raw material base and scientific potential.

In view of the above analytical information, it is possible to make a preliminary conclusion that the use of our own raw organic plant base will make it possible to obtain semi-finished products of a high degree of readiness with acquired functional and therapeutic and prophylactic properties. However, it is necessary to ensure rational blending for the formation of daily consumption rates and resource-efficient processing of raw materials with maximum preservation of useful substances, noting the relevance of research in this direction.

The analysis of the available equipment and technological complexes for the processing of vegetable raw materials into organic semi-finished products of a high degree of readiness requires the introduction of modern resource-efficient technologies with simultaneous low-temperature processing and the provision of energy-saving complexes.

Therefore, it is possible to form general trends to ensure resource-efficient processing of organic raw materials into semi-finished products of a high degree of readiness in the following form:

– improvement of the method for the production of semi-finished products of a high degree of readiness with the selection of a rational content of the components of raw materials for blending and the determination of their rheological and organoleptic properties;

– improvement of hardware and technological components based on the use of a modern film-like radiant type electric heater and the proposal of complexes for the use of secondary thermal energy;

– improvement of the apparatus for concentrating blended purees based on a rotary-film evaporator with the determination of the effectiveness of the proposed solutions;

– improvement of the drum dryer design with determination of its efficiency;

– determination of the influence of the amount of blending organic semi-finished product on the resulting functional and physiological properties of confectionery products using the example of marshmallow.

3. Development of a method for the production of functional organic semi-finished products of a high degree of readiness

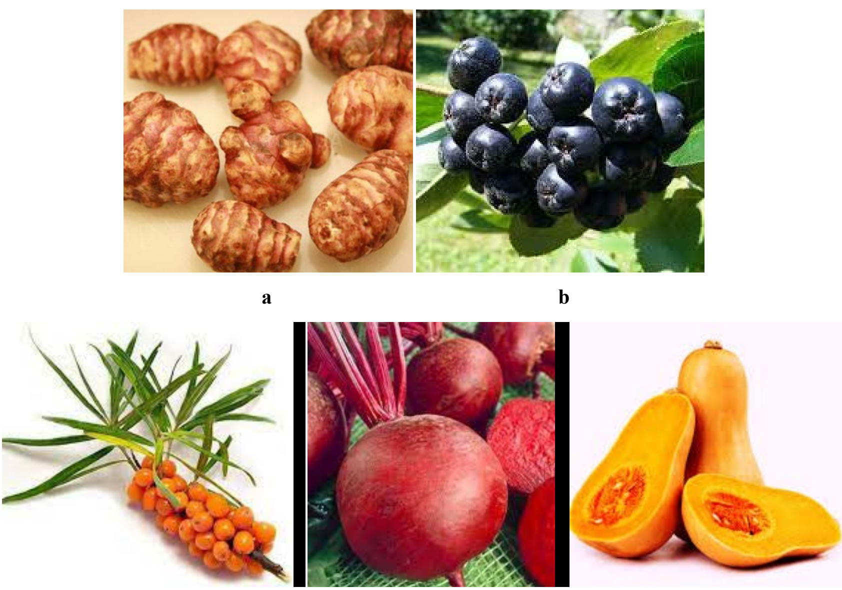
To improve the conditions for processing plant raw materials into semi-finished products of a high degree of readiness, it is necessary to re-equip enterprises with efficient and reliable equipment with high productivity, streamline organization of processing of raw materials, which will largely eliminate spoilage and loss of physiologically functional ingredients (PFI) due to low temperatures and conditions for their processing. Focusing on the need to develop new methods for the production of multi-component vegetable semi-finished products of a high degree of readiness with high organoleptic characteristics, nutritional and biological value, low cost and high profitability. Multi-component fruit and vegetable semi-finished products in a pasty state make it possible to provide the population with high-quality products with a high content of biologically active substances throughout the year and create stocks. On the one hand, these semi-finished products are a source of physiologically functional ingredients, and on the other hand, they can act as structure formers and improve the color of food products [26].

Consideration and systematization of the review of literary sources indicates that the main part of the produced fruit and vegetable pastes is one- or two-component. These semi-finished products have a significant drawback, namely, an insignificant amount and uniformity of organic acids, vitamins, and minerals. In addition, their organoleptic characteristics such as color, aroma and taste are not sufficiently pronounced and aesthetically unattractive. One of the ways to solve this issue is to expand the range of pasty semi-finished products produced by blending several types of plant raw materials, which will provide the product with all groups of physiologically functional ingredients with a significant content to ensure their therapeutic and prophylactic properties.

For scientific and practical testing of research on the intensification of the method of production of functional semi-finished products of a high degree of readiness, a growing domestic organic raw material base within the Kharkiv region was used. The selection of organic raw materials for prescription blends was carried out through a rationally substantiated selection of components with a high content of functionally physiological ingredients and original taste and organoleptic properties. As an example, it is proposed to carry out the following blending of organic raw materials: Jerusalem artichoke (Helianthus tuberosus l. varieties), black chokeberry (Aronia melanocarpa varieties), sea buckthorn (Solnechnaya varieties), beetroot (Delicatesnaya varieties) and pumpkin (Dolya varieties), the appearance of the components is shown in Figure 1.

After the choice of organic raw materials, a rational prescription ratio of blended fruit and vegetable samples was proposed experimentally (Table 1).

The cupping of organic raw materials according to the various content of the components makes it possible to obtain the necessary structural and mechanical properties, original organoleptic and competitive functional physiological content of organic substances. Any properties obtained during blending were compared with the control – apple paste (Table 1) when comparing 100 g blends in five repetitions. The study of changes in the structural and mechanical parameters of fruit blends during experimental



a b

c d e

Figure 1. Appearance of prototypes: a – jerusalem artichoke; b – black chokeberry; c – sea buckthorn; d – beetroot; e – pumpkin

and analytical studies was determined by a rotational viscometer Reotest-2 (Germany) in a cylindrical measuring device according to Kuet.

The process of blending fruit and berry organic components was implemented according to the predicted innovative method, taking into account the previously proposed recipe ratio (Table 1) under the conditions of using resource-efficient low-temperature heat and mass transfer equipment.

Table 1

Recipe ratio of components during blending

Recipe composition	Blended composition		
	A	B	C
Jerusalem artichoke	40	30	20
Black chokeberry	10	15	20
Sea buckthorn	15	20	25
Beetroot	10	15	20
Pumpkin	25	20	15

According to the proposed method (Figure 2), the fruits of chokeberry and sea buckthorn, beetroot and pumpkins were separately sent to the washing machines, after which they entered the inspection tapes.

The blanched raw material was loaded into a wiping machine with a variable hole diameter of 0.3–0.6 mm for subsequent direction for separate blanching with steam or water for 2.5...8 minutes. Rubbing waste (peel, seeds and pulp residues) was additionally subjected to boiling for 3–7 minutes, while the ratio of the mass of the peel and seeds with pulp to the mass of water is 1:0.5–1:0.7 and sent for repeated wiping.

After wiping, the obtained components of the puree are blended and thoroughly mixed to a homogeneous consistency with a previously wiped mass of the skin and seeds of these fruits and berries. The docked puree is heated at a temperature of 45–50 °C and sent for film vacuum concentration to an improved rotary evaporator, boiling for 55…95 s at a temperature of t = 55…60 °C, providing solids content of 40…45%. The resulting blended paste concentrate, in accordance with technological needs, is sent to a filling machine, followed by pasteurization, labeling and sale.

It should be noted that an innovative method for the production of functional organic semi-finished products of a high degree of readiness

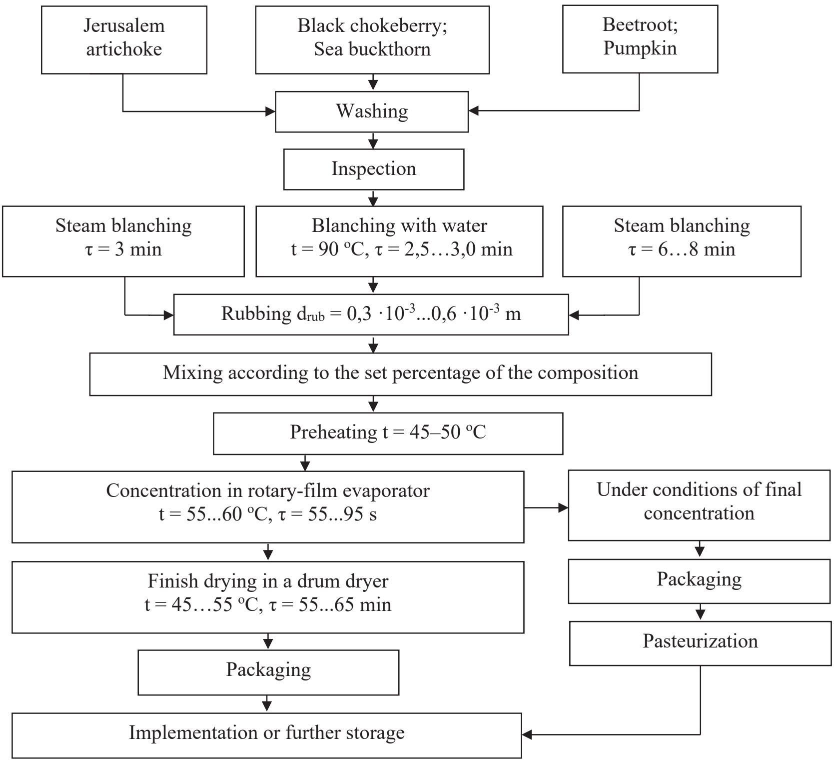


Figure 2. Method for the production of functional organic semi-finished products of a high degree of readiness

allows simultaneously obtaining powdered fractional semi-finished products. In this case, the pre-boiled blended paste is fed to the final drying in an improved thermo-radiation drum dryer, undergoing heat treatment at a temperature of 45...55 °C for 55...65 minutes, providing a final moisture content of 3...6%.

For the qualitative selection of technological equipment, in particular for the concentration and subsequent drying of organic raw materials into semi-finished products of a high degree of readiness, the rheological properties of blended fruit and vegetable purees were determined according to recipe ratios (Table 1 and Table 2).

Table 2

Structural and mechanical properties of fruit and vegetable purees in accordance with recipe ratios

Recipe composition	Blended composition		
	A	B	C
Jerusalem artichoke	40	30	20
Black chokeberry	10	15	20
Sea buckthorn	15	20	25
Beetroot	10	15	20
Pumpkin	25	20	15
Limiting shear stress, q_0:			
50 °C	32	25	22
60 °C	23	17	13
70 °C	15	12	5
Effective viscosity, η_{ef}:			
50 °C	21	18	16
60 °C	14	10	8
70 °C	11	8	5

Data analysis in Table 2 shows a decrease in the structural and mechanical properties of blended organic purees when the temperature changes within 50...70 °C, the effective viscosity varies in the range from 21...5 Pa·s, and the limiting shear stress from 32...5 Pa.

Therefore, a rationally justified selection of the recipe ratio of components makes it possible to obtain paste-like semi-finished products of a controlled structural-mechanical consistency that do not require the additional use of various thickeners.

The duration of concentration of organic purees can be reduced by preheating the puree and depends on the film-forming capacity of the apparatus. Taking into account the physical and chemical properties of organic raw materials, the optimal design of the film-forming element is a hinged blade with a stabilizing reflective surface.

For a qualitative assessment of the resulting blended system, changes in the structural and mechanical parameters of pasty concentrates were determined, allowing further calculations of pipelines and working units of apparatuses for the manufacture of low-temperature innovative heat and mass transfer equipment.

Obtaining the dependence of the effective viscosity on the displacement rate of blends of concentrated pastes in accordance with the recipe ratio (Table 1) and the proposed production method (Figure 2) is shown in Figures 2, 3. The initial value of effective viscosity for the undamaged structure of samples of paste compositions is (Pa·s): 1 – 391; 2 – 538; 3 – 585 and control – 183, respectively, characterized by the structure of solid-like non-ideally plastic bodies.

There is an increase in effective viscosity for all three blended compositions compared to the control – apple paste by 30...62%, which is explained by the high content of pectin in Jerusalem artichoke and other selected components.

The highest effective viscosity index of 585 Pa·s is characterized by the composition of the blend – B with the prescription content of the components: Jerusalem artichoke – 20%, chokeberry – 20%, sea buckthorn – 25%, beetroot – 20% and pumpkin – 15%.

To implement resource-efficient processing of organic plant raw materials, in most cases, concentration is used, which requires the

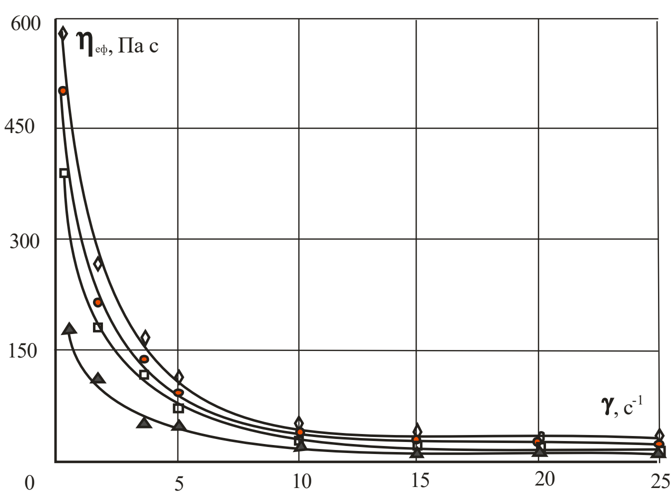


Figure 3. Full rheological curve of blended pastes at t=20 ˚C, CP 40%: ▲ – apple paste; ■ – composition A; ● – composition B; ♦ – composition C

introduction of modern engineering and design, including the possibility of using secondary energy for production needs. Emphasizing the feasibility of research to determine the provision of resource-efficient concentration of organic raw materials, a model design of a rotary-film evaporator was designed (Figure 4, [27]). A rotor 3 with fixed hinged blades is installed along the axis of the vertical body of the rotary-film

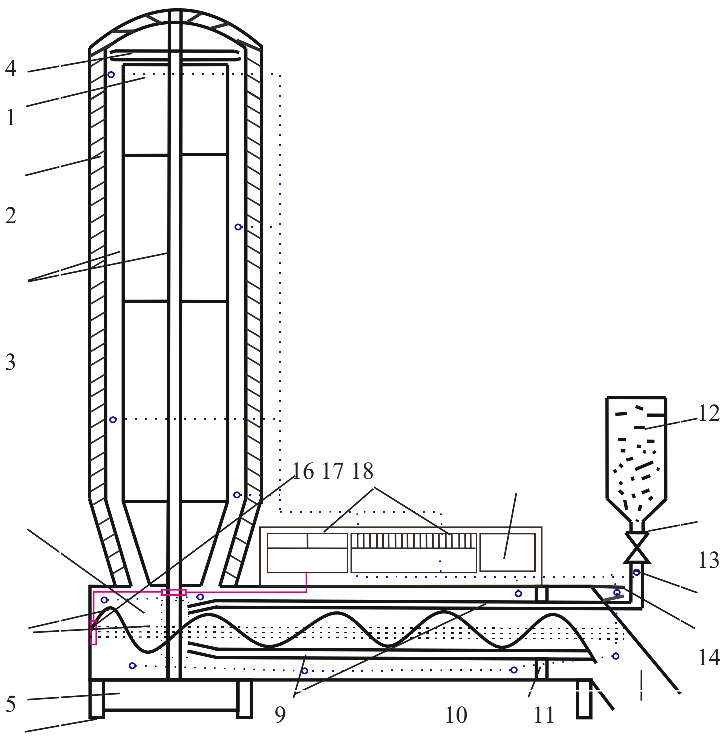


Figure 4. Scheme of the model design of the rotary-film evaporator (RFE):
1 – RFE; 2 – film-like resistive radiant electric heater (FRREH [28]); 3 – rotor with hinged blades; 4 – switchgear; 5 – separating space; 6 – unloading auger; 7 – electric motor with worm gear; 8 – legs; 9 – spiral supercharger puree; 10 – exhaust fans; 11 – fitting for unloading concentrated paste; 12 – container with blended puree; 13 – volume flow meter; 14 – thermocouples; 15 – branch pipe for the removal of secondary air (condensate); 16 – frequency meter; 17 – measuring set K-525 (Ukraine); 18 – microcontroller ATMega-07PI

evaporator, the rotation of which is carried out by an electric motor with a worm gear 7.

RFE vacuuming is provided by a centralized vacuum supply by connecting it to the secondary air outlet 15 (condensate). Pre-prepared blends of fruit and vegetable prototypes enter the RFE from tank 12 under control conditions by adjusting the automated valve 13. The product passes through the helical puree blower 9, thereby preheated by the energy of the condensate and enters the internal pipeline mounted in 4. After that, it moves with hinged blades along the heated surface of the RFE to the separating space 5, in which the separation of the condensate component after concentration from the volume of boiled blended paste is realized.

Temperature control is carried out by thermocouples 14 located at the main technological positions of concentration and is controlled by a microcontroller 18. The speed of the rotor and screw is controlled by frequency sensors 16. The resulting blended organic paste enters the unloading screw 6 and is removed from the apparatus for further sale.

The dependence of the distribution of the product K on the consumption of cupped organic puree at the temperature of concentration on the working surface of the RPV was experimentally determined: Δ – 50 °C; □ – 60 °C; ○ – 70 °C (Figure 5).

These dependences allow obtaining information about the piercing of the concentration process at the minimum consumption of raw materials (W=0.15...0.65 ml/s), underloading of the apparatus is observed under the conditions of the minimum thickness of the product on the RFE working surface, which can lead to burning. With an increase in flow rate to 1.9...2.5 ml/s, the concentration of raw materials was observed with prolonged heating and minimal evaporation. It has been established that the rational consumption of raw materials during concentration is 0.75...1.85 ml/s, which ensures an optimal change in the rate of the initial parameter K.

The obtained results of the study made it possible to identify the area of effective management of the process of concentrating fruit and vegetable purees in the RFE ($K_{min}=V_{con}/V_{out}=0.190$; $K_{max}=V_{con}/V_{out}=0.725$). Concentration was carried out from the initial content of organic puree CP = 8...16% to the final content CP = 40...45% with a surface load of 0.042...0.120 kg/m^{2}s. The relative error in measuring the degree

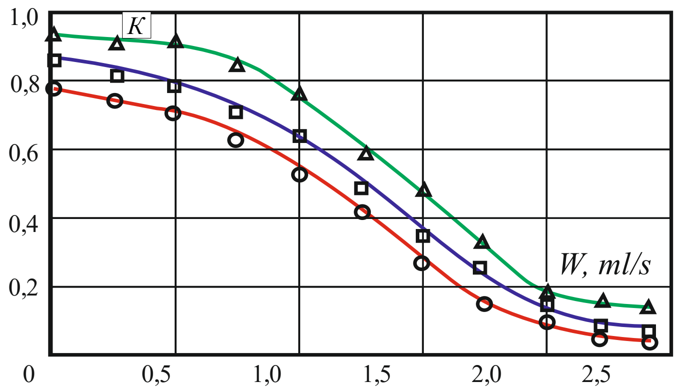


Figure 5. The dependence of the distribution of the product K on the consumption of blended puree at the temperature of the RFE working surface: Δ – 50 ° C; □ – 60 °C; ○ – 70 °C

of distribution K(W), taking into account the error in measuring the consumption of puree and condensate, respectively, of the above-mentioned surface heating temperature, is within 2...3%.

Ensuring the rational concentration of organic raw materials depends on the correctness of the calculation and determination of the heat transfer coefficient, subject to the choice of the average temperature of the test samples n. In particular, these are the temperature data obtained from thermocouples at the moment of film formation of the puree and at the exit of the concentrated paste. In addition, it is necessary to determine the temperature of the heating wall on the product side (temperature of the electric heater FRREH) and the temperature difference of the wall.

Guided by the basic methods of calculation, taking into account the variable temperature parameters and the consumption of puree, it is possible to determine the heat absorbed by the raw material and the heat transfer coefficient, namely:

– heat absorbed by the raw material during concentration:

$$Q_n=Gc(t_{n\,вих}-t_{n\,вх})+rG_{конд}, \quad (1)$$

where G – the mass flow rate of the product, kg/s; c – the specific heat capacity of the product; t_{nout} – the temperature of the concentrated product;

t_{nin} – the temperature of the inlet puree; r – the latent heat of vaporization, J/kg; G_{cond} – mass flow rate of condensate, kg/s; J/(kg·K);

– coefficient of heat transfer from the heating surface to the concentrated raw material:

$$\bar{\alpha} = \frac{Q_n}{\pi D L \Delta t_n}, \qquad (2)$$

where Q_n – the heat absorbed by the raw material during concentration; D – the inner diameter of the concentration chamber, m; L – the height of the concentration chamber, m; Δt_n – temperature difference, K.

It should be noted that the high-quality implementation of concentration processes depends on the rational selection of the criterion equation, which allows taking into account all the nuances of the heat and mass transfer process. Thus, the coefficient of heat transfer, when concentrating in a rotary film evaporator in the rouge mode of raw materials undergoing heat treatment, taking into account its physico-chemical and thermophysical properties. The component of convective heat exchange has the form of the quantitative value of the Prandtl criterion and the modified Reynolds criterion during vacuum boiling of the welded raw material, and the Grashof criterion takes into account the components of free-forced convection.

At the very front, the vertical execution of the RPV working chamber taking into account gravitational conditions and the formation of the film flow of the experimental raw material with hinged blades, namely its flow down the working heating surface during centrifugal movement with simultaneous evaporation due to boiling in a vacuum. It requires the use of three types of numerical parameters of the Reynolds criterion equation to take into account the velocities of raw materials obtained in the RPV: circumferential, axial, and boiling, taking into account the cutting angle of the hinged blades and the degree of its immersion in the experimental raw materials undergoing concentration.

The criterial equation of the process of concentration of organic raw materials in the sewage treatment plant also includes the Grazhoff centrifugal criterion, but Grahhoff's gravitational criterion can be neglected, since the film flow greatly complicates thermal convection. During the shearing of a film-like flow moving along a vertical working chamber and cut by hinged blades, a wave-like nature of the experimental surface is formed, which has a significant effect on the features of the hydraulic movement of the film.

Approbation of the RPV was carried out under the conditions of using blended organic puree under the conditions of the design features of the model design of the device. Namely: diameter – D=0,03 m; consumption of raw materials – G=1,35·10^{-3} kg/s. Specific heat of vaporization r = 2,35·10^{6} J/kg, heat flux density – q = 1,40·10^{4} W/m^{2} and organic raw materials – ρ = 1200 Pa·s, Prandtl number – Pr = 1,83·10^{4} and the frequency of rotation of the rotor with hinged blades n=1,14 c^{-1}.

To determine the influence of concentration, the value of the evaporated moisture of organic raw materials was taken into account, and in particular: the vapor density, volume expansion coefficient and surface tension were chosen from the amount of water in the state of saturated vapor (100 ºC): ρ_p = 5,96·10^{-1} kg/m^{3}; β = 7,13·10^{-4} 1/K and σ=5,85·10^{-2} N/m. Under these conditions, the indicators of the thickness of the film and the speed of its rotation (δ_k, v_k) were equal in size and amounted to: δ = 1,85·10^{-3} n i υ_{films} = 5,48·10^{-3} m/s. Due to the high viscosity of blended organic raw materials entering the concentration, the components of the Grashof number, and therefore the expression: GrPr, are minimized, indicating the absence of the influence of free convection on the heat transfer, and therefore it can be neglected under these conditions.

The vertical geometric RPV chamber will be characterized by a geometric criterion that will take into account the geometry of the area of convective heat exchange, taking into account the influence of the hinged blade on the hydrodynamics of the film flow. In addition, the length of the hinged blade and reflective surface to the length of the circle of the vertical working chamber is taken into account, taking into account the number of hinged blades along the length of the working chamber. And taking into account the geometric properties of the improved design of the rotary-film evaporator and mathematical processing of experimental data, the criterion equation of the process of concentration of organic raw materials was obtained:

$$Nu = 5,731 \cdot \mathrm{Re}_{ц}^{0,046}\, \mathrm{Pr}_{r}^{0,269} \left(\frac{\upsilon_{кип}}{\upsilon}\right)^{0,187} \left(\frac{\upsilon_{пл}}{\upsilon}\right)^{0,224} \mathit{П}_{г}^{\;0,0358} \qquad (3)$$

Approbation of the model design of a rotary-film evaporator was carried out on the process of concentrating blended fruit and vegetable purees based on Jerusalem artichoke, chokeberry, sea buckthorn, beet and pumpkin in accordance with the proposed recipe ratios. The studies were

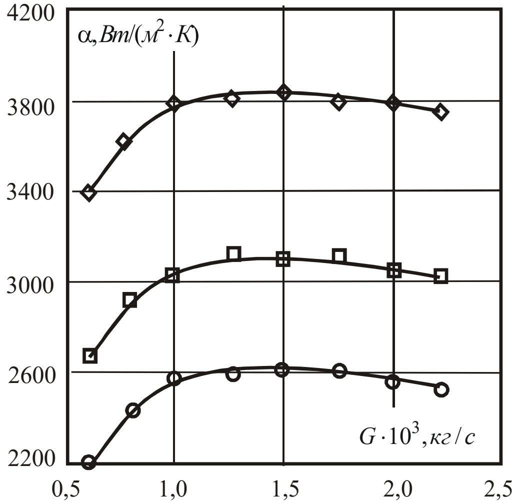


Figure 6. Dependence of the heat transfer coefficient on the consumption of organic puree when concentrating with a hinged blade: ○ – n=0.3 s^{-1}; □ – n=0.6 s^{-1}; ◊ – n=1.6 s^{-1}

carried out in fivefold repetition for the completeness of the reflection of the technological process. The results of experimental studies to determine the RFE heat transfer characteristics depending on the puree consumption and the rotor speed are shown in Figure 6.

The influence on the heat transfer coefficient when concentrating organic blended fruit and vegetable purees of the raw material consumption index was confirmed (Figure 6). The nature of the line of curves is explained by the movement of the surface layers of raw materials by delicate hinged blades under the conditions of flowing down of the near-wall layers by the heating surface, thereby reducing the heat transfer coefficient. With an increase in the consumption of organic puree raw materials, when moving with a hinged blade, a nose wave is created in which certain layers of the raw materials do not contact the heating surface, reducing the degree of evaporation, increasing the heating duration and reducing the heat transfer coefficient.

At a speed of rotation of the hinged blades of 1.6 s^{-1}, the heat transfer coefficient is 3845 W/(m^2·K), after which it gradually decreases its value.

The increase in the value of the intensity of heat transfer at the maximum consumption of raw materials actually stops, characterizing the rational mode of concentration of organic puree and efficient work on moving under the conditions of using hinged blades. The main difficulty in determining and controlling the heat transfer coefficient is the stabilization of the rotation of the hinged blades due to the load by the volume of raw materials supplied for concentration; it was to minimize the error that the structural and mechanical properties of organic blends were previously determined. The data obtained made it possible to determine that at the concentration temperature t = 55...60 °C for 55...95 s, the rational rotation frequency is in the range from 0.3 to 1.7 s^{-1}, providing the dry matter content at the level 40…45%.

To confirm the effectiveness of using the model design of a rotary-film evaporator in practice, by scaling and mathematical-practical modeling, a comparison was made of the RFE technical properties with a traditional vacuum evaporator (Table 3).

The model design of the rotary-film evaporator provides a 2-fold reduction in the specific energy consumption for heating the volume of a unit of product compared to a traditional vacuum evaporator: RFE – 547 kJ/kg, vacuum evaporator (1090 kJ/kg, Table 3). This is due to a decrease in the weight properties of the RFE, for example, due to the elimination of heating networks, while simultaneously reducing the duration of film concentration, increasing the efficiency of the process and the technological line for the production of semi-finished products of a high degree as a whole.

An organoleptic evaluation of the obtained blended organic paste-like semi-finished products obtained in the model design of a rotary-film evaporator was also carried out (Table 4). The expert commission of the State Biotechnological University (Ukraine, Kharkiv) found that, in terms of organoleptic properties, blend B has the best performance with: prescription ratio of components: Jerusalem artichoke – 20%, aronia chokeberry – 20%, sea buckthorn – 25%, beetroot – 20% and pumpkin – 15%.

Heating of the working chamber of FRREH and creation of a lower separating space with screw unloading of concentrated blended organic paste. The RFE is characterized by preheating the puree by a secondary steam at 9–15 °C when the puree passes through the spiral heat exchanger (Figure 4, item 9).

Table 3

Comparative characteristics of a model rotary-film evaporator in comparison with a traditional vacuum evaporator

Index	Vacuum evaporator	Rotary-film evaporator
Unit weight	m=1520 kg	m=74 kg
Unit heating	$Q_{heating}=m1c_c(t_4–t_3)+m_2c_c(t_2–t_1)=$ $=620·0.48·(143–80)+900·0.48·(65–25)=$ $=18748+17280=36028$ kJ	$Q_{heating}=mc_c(t_2–t_1)=$ $=74·0.48(65–25)=1405$ kJ
To heat and boil product	$Q_{pr}=mc(t_k–t_n)+rm_{cond}=$ $=1500·3.7·(65–25)+2350·600=$ 1632000 kJ	$Q_{pr}=Gc(t_k–t_n)+rG_{cond}=$ $=3700·0.025·(65–35)+2350·103·0{,}0052=$ 15318 Дж/с (55045 kJ)
Total amount of consumed energy	Q=1635608 kJ	Q=56581 kJ
Specific consumption	q_{pr}=Q/m=1635608/1.500= =1090 kJ/kg	q_{pr}=Q/G=15328/0.025= =547 kJ/kg
Treatment duration	$T_{VVA}=Q/F·k·Δt=1635608/3{,}7·1454·78=3897$ s	$T_{RPE}=L_{an}/\upsilon_{пл}=1{,}5/0{,}19=73$ s

Table 4

Organoleptic evaluation of blended organic pasty semi-finished products

Indicator	Characteristics of the blended composition		
	A	B	C
Appearance	Homogeneous mashed pasty mass		
Taste and smell	Pleasant harmonious taste and smell of Jerusalem artichoke, sea buckthorn and pumpkin	The smell and taste of beetroot is too strong; pronounced sea buckthorn	The pronounced taste and smell of Jerusalem artichoke and sea buckthorn, pumpkin and beetroot are almost not felt
Color	reddish purple	reddish purple	reddish purple
Consistency	Pasty, easy to form, does not spread when laid out on a flat surface		

To obtain a powder from a concentrated organic paste, it is proposed to implement final drying with giving the product a certain fractionation. The drying process itself, despite the significant energy and metal consumption, is in great demand if it is necessary to reduce the volume of feedstock with maximum preservation of quality, depending on the method of heat supply. Ensuring the production of functional organic semi-finished products of a high degree of readiness with a wide range of uses will provide competitive advantages and allow the creation of rational food rations. These products are also necessary for people in extreme conditions, in particular military personnel and doctors. Thus, creating the need for the implementation of innovative engineering and technological solutions to find innovative ways to intensify drying processes based on low-temperature conditions and taking into account the rheological properties of blended pastes from organic raw materials. Providing resource-efficient processing of organic pasta and high quality of semi-finished products of a high degree of readiness, and providing products with fractionation will expand the competitiveness and range of use in the processing and food industries.

One of the topical areas is the search for innovative engineering solutions to improve the model design of a drum dryer for the final drying of a blended organic paste pre-concentrated in a rotary-film evaporator to obtain fractionated dried semi-finished products. This can be implemented by intensifying the method of heat supply, qualitative analysis of technological parameters (applying a layer of raw materials, controlling the thickness, the degree of pressing it and cutting off the dried layer), forming hardware and technological competitiveness.

A model design of a drum dryer for final drying of a pre-concentrated blended organic paste is shown in Figure 7 [29].

The operation of the apparatus is as follows: blended organic paste pre-concentrated in a rotary-film evaporator to a content of 40...45% CP. It comes with the help of a pressure pump 1 to a coil blower 2, located in the interior of the dryer drum 3, located on the drive shaft 4. The shaft 4 is installed in the bearing compartments 5, providing a counterclockwise rotational movement of the dryer drum 3 from the gear motor.

The heating of the working surface of the drying drum 3, together with preliminary drying, is carried out by a film-like resistive electric heater of the radiant type 8. FRREH is placed on the inner surfaces of the drying drum 3 and the housing with heat-insulating material 9, and the design of the apparatus is mounted on racks 10.

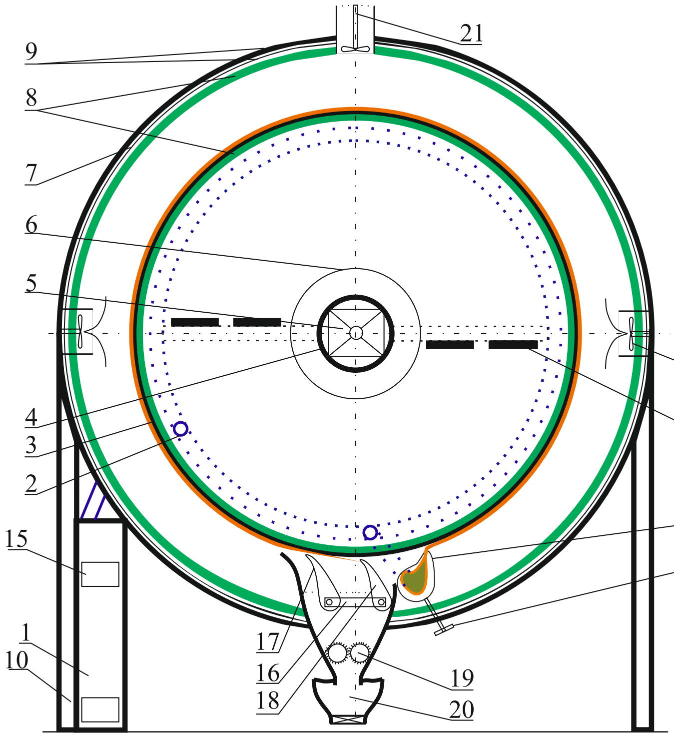


Figure 7. Scheme of the model design of a drum dryer for the final drying of blended organic paste pre-concentrated in a rotary-film evaporator:
1 – pressure pump; 2 – coil supercharger; 3 – drying drum; 4 – drive shaft of the drying drum; 5 – bearing compartments; 6 – motor-reducer; 7 – drying chamber; 8 – film-like electric heater of the radiating type (FRREH); 9 – case with heat-insulating material; 10 – racks; 11 – superchargers; 12 – Peltier elements; 13 – distribution and spreading pin; 14 – mechanism for adjusting the thickness of the applied layer; 15 – three-position regulator; 16 – pressure plate; 17 – cutting blades; 18 – fluoroplastic guides; 19 – fractional rollers; 20 – unloading capacity; 21 – exhaust fan

In accordance with the developed method for the production of functional organic semi-finished products of a high degree of readiness, final drying is carried out at a temperature of 45...55 ° C, for 55...65 minutes, providing a final moisture content of 3...6%.

The intake of air from the environment is carried out with the help of blowers 11, which have filter elements in their design to prevent unclean air from entering the working chamber. The operation of blowers 11 is autonomous due to the conversion of secondary thermal energy by Peltier elements 12 into a low-voltage supply voltage (at a temperature of 45...55 °C in the working chamber 10...45 W).

The application of pre-concentrated paste is controlled by a distributing-spreading trunnion 13, one of the ends of which is connected to a serpentine supercharger 2, and the trunnion itself is pulled apart symmetrically to the horizontal surface of the drying drum 3. The thickness of the raw material layer 3 is adjusted by the control mechanism 1 is set by a three-position regulator 15. One of the main requirements of the drum dryer is the drying of raw materials in one revolution of the drum 3, which will be characterized by ensuring the final moisture content of the dried semi-finished product at the level of 3...6%. Air is removed from the roller chamber from the working chamber of the drum dryer by exhaust fans 21.

Cutting the dried layer of the blended semi-finished product is carried out by blades 17 mounted on a pressure plate. The blades have fluoroplastic guides 18 to prevent possible sticking of the cut particles of raw materials, making it difficult to clean the apparatus. After cutting, the raw material falls under the action of gravity onto fractional rollers 19, which give it a certain size fraction, followed by unloading into a container 20.

The kinetics of moisture content of blended organic fruit and vegetable paste with a content of 40% CP (blend – B) at a temperature of 55°C, an air flow speed of 0.2 m/s to a final content of 5% CP in a drum dryer model was determined. The study was carried out with a change in the thickness of the layer of application of the blended paste within 5:10:15 mm (Figure 8).

Analysis of the kinetics of moisture content of blended organic fruit and vegetable paste with a content of 40% cf. set the duration of the drying process in the drum dryer. With a thickness of 15 mm it is 75 minutes, with a thickness of 10 mm it is 60 minutes, and with a thickness of 5 mm,

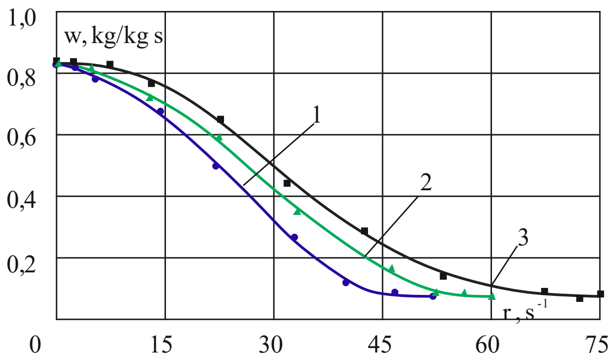


Figure 8. Kinetics of moisture content of blended organic paste with a content of 40% CP when dried in a drum dryer with a layer thickness of raw materials: 1 – 5 mm; 2 – 10 mm; 3 – 15 mm

respectively, 56 minutes (drying was started without the blower turned on, Figure 7, item 11).

After drying, the obtained semi-finished products of a high degree of readiness were examined for changes in their color formation, thereby analyzing the effect of heat treatment and the proposed engineering and technological solutions on the final color (quality).

To determine changes in the blending of organic raw materials, a study was made of the formation of color formation in multicomponent fruit and vegetable pastes and dried powder fractions under low-temperature treatment during concentration and drying. This will allow assessing the quality of the hardware-technological complex for the production of functional organic semi-finished products of a high degree of readiness based on the proposed low-temperature heat and mass transfer equipment. The analysis of color formation was carried out using modern computer technologies based on the study of high-quality photographs at any technological stages of production, followed by processing in free programs for processing the resulting digital images (ColorPix, Colors 2.2, etc.). For example, the processing of a photograph of a prototype using Photoshop is carried out in accordance with the CIE in the RGB color mode, which allows real-time determination of variable color formation properties.

For approbation, the determination of color formation of dried blended compositions of organic pastes made according to the recipe (Table 1) and the proposed method for the production of functional organic semi-finished products of a high degree of readiness (Figure 2) was carried out.

As a result of experimental and practical testing of blended compositions, their color indicators of organic pastes and dried fractions based on them were obtained (Table 5). An analysis of the obtained indicators of color purity and brightness of prototypes of blended pastes from organic raw materials is characterized by the minimum values of blend A – 35.8% with a tone purity of 76.2%. Compositions B and C are characterized by brightness values: 34.5 and 37.2 with a tone purity of 65.2 and 78.4% (Table 2), and according to the visual perception of color, all samples had a reddish-orange color.

Table 5

Color indicators of experimental blends of organic raw materials

Composition	**Color purity**	**Brightness**	**Visual color of test samples**
	P, %	**T, %**	
Blended pastes			
A	76.2	35,8	reddish-orange
B	65.2	34,5	reddish-orange
C	78.4	37,2	red-orange
Dried fraction based on blended paste			
A	33.8	31.5	bluish-purple
B	35.9	32.4	red
C	34.2	33.7	bluish-red

The brightness of the experimental sample of the dried fraction based on blended paste A is 31.5%, characterized by a bluish-purple color with a tone purity of 33.8%. Dried blends B and C, respectively, brightness: 32.4 and 33.7%. Blend B has a tone purity of 35.9% with a red color, and blend C is characterized by a bluish-red color with a tone purity of 34.2% (Table 2).

Comparing the obtained approbation data of color changes of blended pasty compositions and dried fractions based on them, taking into account the values of color purity and brightness. There is a decrease in color purity actually by half due to the final drying of pasty blends to a powder fraction, and a change in brightness in the range from 2 to 5%.

The qualification expert commission of the State Biotechnological University (Kharkiv, Ukraine) carried out an organoleptic evaluation of the obtained dried fractions based on blended pastes according to the current methodology of the European Organization for Food Quality Control (Table 6). In accordance with the expert evaluation of prototypes of dried fractions based on blended pastes, the best performance is characterized by composition B, containing 20% Jerusalem artichoke, 20% chokeberry, 25% sea buckthorn, 20% beet and 15% pumpkin. Other dried fractions (blends A and C) have attractive organoleptic characteristics, the choice of consumers should also be taken into account.

Table 6

The results of the assessment by the expert commission of dried fractions based on blended pastes

Samples of dried fractions	Quality indicators, score					Overall score, point
	External appearance	Consistence	Color	Taste	Scent	
A	9	13	9	10	5	46
B	9	12	7	8	4	40
C	10	14	9	9	5	47
Control (dried paste based on apple, pumpkin and blueberry)	9	14	8	9	5	45

The obtained approbation research data made it possible to establish color formation during prescription blending and heat and mass transfer low-temperature processing of organic raw materials. The given color data of blended experimental compositions of pastes and dried fractions based on them confirm the effectiveness of using the method for the production of functional organic semi-finished products of a high degree of readiness with maximum preservation of the natural properties of raw materials at all stages of production. The color change during the concentration of blended compositions from reddish-orange to bluish-purple after final drying in the IR field is explained by their maximum dehydration and long-term heat treatment (concentration + drying). The selected innovative computer method for determining changes in color formation provides an assessment in virtually real time at any point in the technological operation, thereby allowing to track the effect of heat treatment regardless of the amount. One of the limitations of the color evaluation method is the need to use high-quality photographic equipment, although today these costs are minimal compared to the costs of ensuring the release of competitive products. And ease of use allows implementation in various technological processes.

To analyze the effect of the obtained blended organic semi-finished product, studies were carried out to determine the resulting functional and physiological properties of confectionery products using marshmallow as an example. In the course of the research, the recipe ratio of the components during blending was used, shown in Table 1. The classic marshmallow manufacturing technology consists of preparing raw materials, creating an agar-sugar-treacle syrup, mixing the marshmallow mass, forming with structure formation and drying, followed by sprinkling with powdered sugar.

It was proposed to replace applesauce in the classic marshmallow recipe, taking into account the determination of changing structural-mechanical and organoleptic properties, as well as to determine the resulting functional-physiological content.

Applesauce was replaced with blended paste with the following ratio: 25%, 50%, 75% and 100%, followed by determination of their structural and mechanical parameters (Figure 9). Marshmallow without impurities was chosen as a control. Analyzing Figure 9, it can be argued that the viscosity changes with the displacement rate under the conditions of introducing blended pastes into the classic marshmallow recipe in different percentages.

Experimental samples of marshmallow mass are characterized by the following properties of dynamic viscosity η_{ef}, Pa·s, replacement: 25% – 725, 50% – 731, 75% – 902 and 100% – 1083, respectively, and control – 415.

Also, the color formation of marshmallow experimental masses was determined when blended paste with a variable percentage is added to the classic marshmallow recipe (the control is the classic marshmallow mass, Table 7).

The control is characterized by a wavelength of 512.4 nm at a color frequency of 26.3% with a characteristic white color. For a 25% replacement of applesauce with blended paste, the color purity is 32.5% and corresponds to a creamy white segment at a wavelength of 535.4 nm. At 50% applesauce substitution, the sample is characterized by a segment with a dominant wavelength of 581.6 nm. For the sample with 75% replacement, the

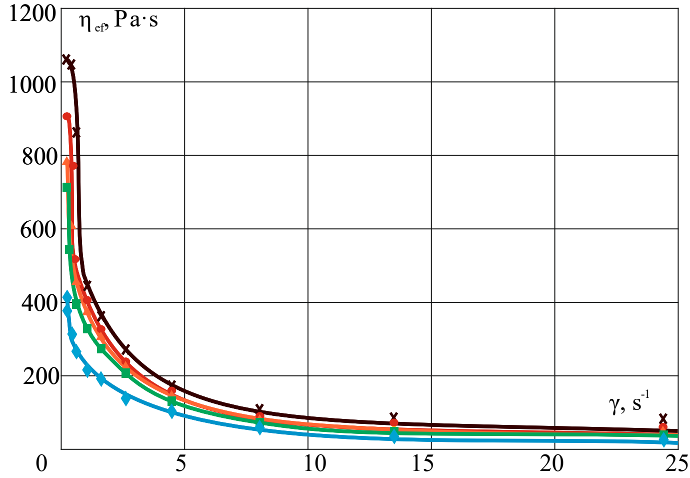


Figure 9. Rheological curve of marshmallow masses, t=25 °C: ♦ – classic marshmallow; replacing applesauce with blended pasta, %: ■ – 25; ▲ – 50; ● – 75; ✕ – 100

wavelength is 589.8 nm, the brightness is 62.3% and corresponds to a hot pink tint. With 100% replacement of applesauce with blended paste, a rich red color is formed with a wavelength of 606.3 nm, a brightness of 67.7% and a purity of 74.1%.

Table 7

Change in color formation in experimental samples of marshmallow masses with the percentage replacement of applesauce (25; 50; 75%) with blended paste (Sr=0.05, n=5, p=0.95)

Experimental samples of marshmallow masses	Dominant wavelength	Brightness	Purity of color	Visual assessment of the color of the test samples
	λ_{nm}	T, %	P, %	
Control	512.4	45.6	26.3	white
25 %	535.4	50.3	32.5	creamy white shade
50 %	581.6	53.6	46.1	light creamy pink shade
75 %	589.8	62.3	70.3	bright pink
100 %	606.3	67.7	74.1	deep red

The addition of a blended organic paste to the classic marshmallow recipe ensures a change in color shade from white (25% replacement) to saturated red (100% full replacement of applesauce with a blend).

The most competitive prototype marshmallow was also determined, taking into account the optimal percentage of blended paste added to the recipe ratio (Table 8).

Table 8

Organoleptic evaluation of experimental samples of marshmallow and its physico-chemical properties

Indicator	**Control**	**Percentage of adding paste to the marshmallow recipe**			
		25 %	**50 %**	**75 %**	**100 %**
1	**2**	**3**	**4**	**5**	**6**
Color	white	creamy white shade	creamy white tint	bright pink	rich red
1	2	3	4	5	6
Taste and smell	Properties of the marshmallow product	Characteristic of a marshmallow product, the paste is practically not felt	Light smell and taste of the paste	Pronounced smell and taste of the paste	Excessive taste and pungent smell of the paste
Consistence	The structure is soft, breakable				
Structure	Properties of marshmallow products (homogeneous, foamy, uniform)				touching
Surface	Properties of marshmallow products				
Mass fraction of dry substances,%	81.5	82.3	84.4	84.9	85.4
Mass fraction of reducing substances, %	7.4	7.9	8.2	8.7	8.9
Density, kg/m³	491.0	514.3	519.0	528.3	534.0
Total acidity, degrees	6.7	6.9	7.4	7.9	9.2

Analyzing the obtained organoleptic properties, the change in the organoleptic and physico-chemical properties of marshmallow products is confirmed when blended organic paste is added to their classic recipe under conditions of partial and complete replacement of apple puree. When adding 25% blended paste to the classic recipe, a slight change in organoleptic and physico-chemical parameters is observed, forming a creamy-white segment. The introduction of blended paste into the recipe of marshmallow masses at the level of 50 and 75% ensures that they acquire a creamy white and bright pink section. 50% of blended pasta forms a slight smell and taste of blended pasta, and 75% – an affected smell and taste of blended pasta. A 100% replacement of applesauce with blended pasta has an excessive taste and pungent smell of blended paste, as well as properties for a marshmallow product.

For the production of functional organic semi-finished products of a high degree of readiness based on low-temperature heat and mass transfer equipment, a generalized hardware-technological scheme was selected (Figure 10).

The selection of equipment was carried out taking into account the proposed rational recipe ratio of components during blending (Table 1) and in accordance with the method of production of functional organic semi-finished products of a high degree of readiness (Figure 2).

The implementation of the main processes of heat and mass exchange is implemented on improved low-temperature equipment, which differs from analogues by reducing the duration of processing and gentle temperature regimes. Therefore, the developed method of production of functional organic semi-finished products of a high degree of readiness from organic raw materials corresponding to the proposed technological one in comparison with existing technologies ensures the preservation of natural value, increasing the efficiency of processing organic raw materials and indicators of resource efficiency. The proposed design and technological solutions will ensure that the final profile consumer receives a multifunctional, high-quality product of organic origin.

The implementation of the proposed innovative solutions in the processing and food industry, as well as in hotels and restaurants and even in the home, will lead to a positive impact on the social sphere of human society, which will be expressed in the provision of a wide range of use

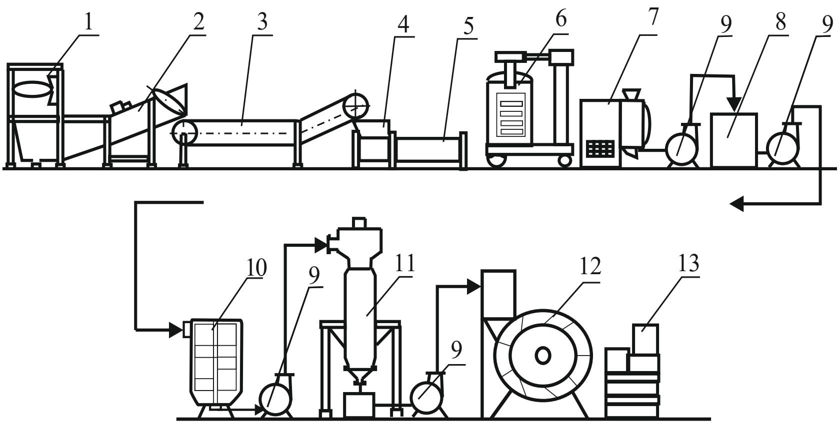


Figure 10. Principal hardware-technological line for the production of functional organic semi-finished products of a high degree of readiness:
1 – container tipper; 2 – a machine for washing organic raw materials; 3 – machine for inspection; 4 – conveyor; 5 – machine for preliminary cutting of organic raw materials; 6 – functional technological capacity; 7 – apparatus for blanching; 8 – wiping two mesh machine; 9 – storage capacity; 10 – pump; 11 – heating container with a stirrer; 12 – rotary film evaporator; 13 – single drum IR dryer; 14 – packaging machine

of manufactured semi-finished products in the daily diet. Ensuring, at the same time, competitiveness and rational organic resistance to today's environmental factors.

The proposed method of production makes it possible to obtain functional organic semi-finished products of a high degree of readiness with a wide range of uses in processing and food industries, hotel and restaurant complexes. As functional additives of organic origin in the confectionery, dairy, bakery industries, as well as for cooking and drinks in restaurants and even at home. In addition, functional semi-finished products and products can be used to produce rations for people in extreme conditions, in particular military personnel and doctors. It should be noted that the effectiveness of the proposed technological method for the production of organic functional semi-finished products of a high degree of readiness is based on the use of previously developed low-temperature heat and mass transfer equipment, the effectiveness of which is also given.

4. Conclusions

A method has been developed for the production of functional organic semi-finished products of a high degree of readiness based on fruit and vegetable raw materials: Jerusalem artichoke, chokeberry, sea buckthorn, beet, pumpkin. The selection of the percentage of fruit and vegetable raw materials occurred on the basis of the initial content of pectin substances, vitamins, color formation of the resulting puree components. The structural-mechanical and organoleptic characteristics of fruit and vegetable paste-like semi-finished products were determined, which made it possible to identify the optimal prescription content of the components of fruit and vegetable puree: Jerusalem artichoke – 20%, black chokeberry – 20%, sea buckthorn – 25%, beetroot – 20%. The developed method is distinguished by film vacuum concentration on an improved rotary evaporator for 55...95 s at a temperature of t = 55...60 °C, providing solids content of 40...45%. Final drying takes place in an improved thermo-radiation drum dryer, undergoing heat treatment at a temperature of 45...55 °C for 55...65 minutes, providing a final moisture content of 3...6%. Such gentle processing modes provide high-quality semi-finished products with maximum preservation of physiologically functional ingredients.

To carry out the concentration process, a rotary-film evaporator with a lower location of the separating chamber has been improved, equipped with a screw unloading of the concentrated pasty product and preheating of the initial puree with secondary steam energy. The energy of the concentrated product and secondary steam preheats the puree fed to the machine by 8…10 °C. The apparatus is heated by using a flexible film resistive radiant electric heater with a heat-insulating outer surface, which makes it possible to eliminate the steam component of heat supply systems. It has been established that for concentration from the initial content of organic purees CP = 8...16% to the final content CP = 40...45%, the surface load is 0.042...0.120 kg/m^{2}s. Calculation confirmed the decrease in the specific energy consumption for heating the volume of a product unit: a rotary film evaporator – 547 kJ/kg with a processing time of 75 s compared to the base vacuum evaporator – 1090 kJ/kg, respectively, 1.08 hours.

The model design of a thermoradiation single-drum roller dryer has been improved, which is distinguished by a combined method of heat supply, the formation of a paste-like product layer with a thickness of 5 to 15 mm on the working surface of the roller, and the method of cutting the dried layer of raw materials. The dryer makes it possible to obtain a powdered fraction of a fruit and vegetable semi-finished product with a solids content of 3-5% of the content of 40% of the original paste at a low temperature of 55 °C. The duration of drying in a single-drum roller dryer of blended paste with a content of 40% CP at different thicknesses of the layer applied to the working surface of 15, 10 and 5 mm, which is 75, 60 and 56 minutes, respectively, was determined. The drying process was carried out at a temperature of 65°C and an air flow rate of 0.2 m/s to a final content of 5% CP. The obtained characteristics of the color configurations of the samples and the duration of their drying confirm the possibility of using an improved dryer to obtain high-quality vegetable semi-finished products of the dried fraction.

A study was made of the prescription mixture of marshmallow when introduced into its recipe with the replacement of applesauce with the developed fruit and vegetable paste. By determining the structural-mechanical, physico-chemical, color and orgonaleptic indicators, it was found that the best prototype marshmallow has 75% of the developed paste when it is replaced in the recipe with applesauce.

Obtaining a technology for the production of fruit and vegetable semi-finished products makes it possible to produce pastes and powders with a wide range of uses in various branches of food production in restaurant complexes and in everyday life, which are universal irreplaceable carriers of valuable substances of immunomodulating action.

References:

1. Funktsionalnye produkty pitaniya. Available at: http://www.cnshb.ru/news/vex_fpp.shtm
2. Munekata, P. E. S., Pérez-Álvarez, J. Á., Pateiro, M., Viuda-Matos, M., Fernández-López, J., Lorenzo, J. M. (2021) Satiety from healthier and functional foods. *Trends in Food Science & Technology*, 113, 397–410. DOI: https://doi.org/10.1016/j.tifs.2021.05.025
3. Pap, N., Fidelis, M., Azevedo, L., do Carmo, M. A. V., Wang, D., Mocan, A. et al. (2021) Berry polyphenols and human health: evidence of antioxidant, anti-inflammatory, microbiota modulation, and cell-protecting effects. *Current Opinion in Food Science*, 42, 167–186. DOI: https://doi.org/10.1016/j.cofs.2021.06.003
4. Misra, N. N., Koubaa, M., Roohinejad, S., Juliano, P., Alpas, H., Inácio, R. S. et al. (2017) Landmarks in the historical development of twenty first cen-

tury food processing technologies. *Food Research International*, 97, 318–339. DOI: https://doi.org/10.1016/j.foodres.2017.05.001

5. Marcus, J. B. (2013) Chapter 11 – Life Cycle Nutrition: Healthful Eating Throughout the Ages: Practical Applications for Nutrition, Food Science and Culinary Professionals. *Culinary Nutrition*, 475–543. DOI: https://doi.org/10.1016/b978-0-12-391882-6.00011-x

6. König, L. M., Renner, B. (2019) Boosting healthy food choices by meal colour variety: results from two experiments and a just-intime Ecological Momentary Intervention. *BMC Public Health*, 19 (1). DOI: https://doi.org/10.1186/s12889-019-7306-z

7. Bucher, T., van der Horst, K., Siegrist, M. (2013) Fruit for dessert. How people compose healthier meals. *Appetite*, 60, 74–80. DOI: https://doi.org/10.1016/j.appet.2012.10.003

8. Mykhailov, V., Zahorulko, A., Zagorulko, A., Liashenko, B., Dudnyk, S. (2021) Method for producing fruit paste using innovative equipment. *Acta Innovations*, 39, 15–21. DOI: https://doi.org/10.32933/actainnovations.39.2

9. De Laurentiis, V., Corrado, S., Sala, S. (2018) Quantifying household waste of fresh fruit and vegetables in the EU. *Waste Management*, 77, 238–251. DOI: https://doi.org/10.1016/j.wasman.2018.04.001

10. Antipov, S. T., Zhashkov, A. A. (2010) “Sovremennye tekhnologii pri poluchenii plodovo-yagodnykh poroshkov” [“Modern technologies in the production of fruit and berry powders”], vol. 16, no. 2, pp. 332–336.

11. Lian Huang, Li Ba, Xiaoyi Zhang, Shunlong Gong (April 2019) Re-understanding the antecedents of functional foods purchase: Mediating effect of purchase attitude and moderating effect of food neophobia. *Food Quality and Preference*, vol. 73, pp. 266–275.

12. Vse o topinambure. Available at: https://yesfrukt.com/ru/blog/vse-o-topinambure

13. Svekla – kalorijnost’ i himicheskij sostav. Available at: http://frs24.ru/himsostav/svekla/

14. Naukovci rekomenduyut: viroshchuemo buryak stolovij. Available at: https://www.udau.edu.ua/ua/other-news/viroshhuvannya-buryaku-stolovogo.html

15. Garbuz – cinnij diєtichnij produkt z likuval’nimi vlastivostyami. Available at: https://kitsman.city/articles/143616/garbuz-cinnij-diyetichnij-produkt-z-likuvalnimi-vlastivostyami

16. Cilyushchi vlastivosti aronії (chornoplidnoї gorobini). Available at: https://greenheal.com.ua/article/aroniya-chernoplodnaya-ili-ryabina

17. Aroniya chornoplidna. Available at: https://www.pharmencyclopedia.com.ua/article/2875/aroniya-chornoplidna

18. Oblipiha – unikalna za vmistom vitaminiv yagoda, yaka maє likuvalni vlastivosti. Available at: https://kitsman.city/articles/143618/oblipiha-unikalna-za-vmistom-vitaminiv-yagoda-yaka-maye-likuvalni-vlastivosti

19. Shazzo R. I., Ovcharova G. P. (2005) Produkty detskogo pitaniya iz rastitel’nogo i myasnogo syrya infrakrasnoj sushki. *Hranenie i pererabotka sel’hozsyrya*, no. 1, pp. 50–52.

20. Lian Huang, Li Ba, Xiaoyi Zhang, Shunlong Gong (April 2019) Re-understanding the antecedents of functional foods purchase: Mediating effect of purchase attitude and moderating effect of food neophobia. *Food Quality and Preference*, vol. 73, pp. 266–275.

21. Method of determining the strength of the multicomponent structure of plant pastes [Electronic resource]: Patent UA 83943 U, MPK G01N 30/00, A23L 1/06/ Cherevko A. I., Kiptela L. V., Zaharenko V. A., Zagorulko A. N.; assignee: Kharkiv State University of Food Technology and Trade. – № u201302710; filed 04.03.2013; published 10.10.2013, Bull. № 19. – 4 p.

22. Hnuchkyi plivkovyi rezystyvnyi elektronahrivach vyprominiuiuchoho typu [Electronic resource]: Patent UA 108041 U, MPK G05D 23/19, B01D 1/22, H05B 3/36 / Zagorulko A. M., Zagorulko O. Ye.; assignee: Kharkiv State University of Food Technology and Trade. – № u201600827; filed 02.02.2016; published 24.06.2016, Bull. № 12. – 4 p.

23. Tekhnologiya pishchekoncentratnogo proizvodstva: uchebnoe posobie (2012) / V. V. Vanshin, E. A. Vanshina; Orenburgskij gos. un-t. Orenburg: OGU, 180 s.

24. Kasabova, K., Zagorulko, A., Zahorulko, A., Shmatchenko, N., Simakova, O., Goriainova, I. et al. (2021) Improving pastille manufacturing technology using the developed multicomponent fruit and berry paste. *Eastern-European Journal of Enterprise Technologies*, 3 (11 (111)), 49–56. DOI: https://doi.org/10.15587/1729-4061.2021.231730

25. Pashniuk, L. O. (2012) Kharchova promyslovist Ukrainy: stan, tendentsii ta perspektyvy rozvytku. *Ekonomichnyi chasopys-XXI*, 9-10, 60–63. Available at: http://dspace.nbuv.gov.ua/bitstream/handle/123456789/48329/18-Pashniuk.pdf?sequence=1

26. Burkhatovna, A. A., Abelbaevich, B. T., Kulkeldievna, A. G., Rakhmedovna, Ch. E. (2015) Primenenie innovatsionnykh tekhnologii v proizvodstve muchnykh konditerskikh izdeliy. *Evraziyskiy Soyuz Uchenykh*, 11 (20).

27. Zahorulko, A., Zagorulko, A., Mykhailov, V., Ibaiev, E. (2021) Improved rotary film evaporator for concentrating organic fruit and berry puree. *Eastern-European Journal of Enterprise Technologies,* 4 (11 (112)), 92–98. DOI: https://doi.org/10.15587/1729-4061.2021.237948

28. Plivkopodibnij rezistivnij elektronagrivach viprominyuvalnogo tipu [Electronic resource]: Patent UA 149981 U, MPK H05B 3/36, B01D 1/22, G05D 23/19 / Zagorulko A. M., Zagorulko O. Ye.; assignee: Kharkiv State University of Food Technology and Trade. – № uu202102839; filed 28.05.2021; published 22.12.2021, Bull. № 51. – 4 p.

29. Cherevko, O., Mikhaylov, V., Zahorulko A., Zagorulko, A., & Gordienko, I. (2021) Development of a thermal-radiation single-drum roll dryer for concentrated food stuff. *Eastern-European Journal of Enterprise Technologies*, 1 (11 (109), 25–32. DOI: https://doi.org/10.15587/1729-4061.2021.224990