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COMPREHENSIVE PROCESSING OF JERUSALEM ARTICHOKE TUBERS INTO FUNCTIONAL PRODUCTS

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Abstract. The paper presents an analysis of literary sources showing how important it is to expand the range of functional products and develop a technology for the comprehensive processing of Jerusalem artichoke tubers. In the experimental studies, standardised techniques were used. Using the Ishikawa diagram has allowed identifying the most significant cause-and-effect relationships of the main factors that influence the quality of healthy food based on the Jerusalem artichoke. The amino acid composition of tubers has been studied, and the limiting amino acid established. The main raw material has been tested for the content of heavy metals and nitrates. The possibility of excluding the peeling operation from the technology has been experimentally proved and confirmed by microbiological studies. To reduce the microbiological contamination of raw materials, we have studied the effect of ultra high frequency treatment at different processing modes. Technologies have been developed for processing the Jerusalem artichoke into succades and fermented products. In the succade technology, to reduce the mass fraction of sugar in the final product, a mixture of fructose and pectin was used for sprinkling. Drying was carried out until the moisture content in the finished succades was 14%. The parameters of Jerusalem artichoke fermentation process have been established: temperature 20°C, duration 10 days, the amount of the added starter 1% of the mass of the prepared raw material. The strain AH 11/16 of lactic acid bacteria *Lactobacillus plantarum* was used as the starter. The fermentation lasted till the amount of titratable acids accumulated was 0.8–0.9% of lactic acid. A flow chart of the comprehensive processing of Jerusalem artichoke tubers into functional food is added. The tasting of the samples developed have shown high organoleptic qualities of the final product. The technologies developed have been tested in restaurant facilities.

Keywords: Jerusalem artichoke, fermentation, succades, vegetable paste, amino acid composition, sensory characteristics.

Introduction. Formulation of the problem

Human health depends on how well the body is provided with the necessary nutrients (first of all with the essential ones) and energy. The main factors people's health depends on have long been established (Fig. 1) [1], though it is difficult to determine the effect of every individual factor, since they are all interrelated. The most important of them are healthy lifestyle and high-quality good nutrition. Thus, it has been determined that in more than 80% of cases, cardiovascular disease and type 2 diabetes mellitus can be prevented due to these very factors.

One of the main stages in developing various technological solutions for comprehensive processing of raw materials is selecting and giving reasons for functional ingredients that form new properties of a finished dish and have a positive physiological effect on the human body. At the present stage of food market development, the seven main types of functional ingredients are in use: dietary fibre, vitamins, minerals, polyunsaturated fatty acids, antioxidants, prebiotics, probiotics [2].

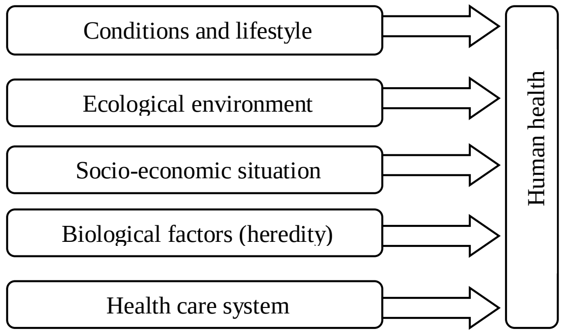

Fig. 1. Factors that effect on human health

Jerusalem artichoke tubers are an important source of biologically active ingredients. They contain such a prebiotic as inulin, pectin substances, polyphenolic compounds, amino acids, vitamins, and minerals. Besides, these tubers accumulate almost no heavy metals and nitrates [3,4]. That is why, comprehensive processing of this raw material into healthy food is a topical issue.

Analysis of recent research and publications

The range of functional foods on the market is growing every year, especially the production segment that uses inulin and oligofructose obtained from Jerusalem artichoke tubers [5,6]. There are technologies for dairy and sour-milk products [7], confectionery and bakery products [8-11], mayonnaise [12], chips [13], beverages [14], baby food [15], dry mixes and dietary supplements [16,17], where Jerusalem artichoke tubers are used. The medical and dietary properties of the Jerusalem artichoke tubers have been studied by scientists [18,19] who proved that they could be used to enrich people's diets and prevent some global diseases. The range of functional foods on the market is growing every year, especially the production segment that uses inulin and oligofructose obtained from Jerusalem artichoke tubers [5,6]. There are technologies for dairy and sour-milk products [7], confectionery and bakery products [8-11], mayonnaise [12], chips [13], beverages [14], baby food [15], dry mixes and dietary supplements [16,17], where Jerusalem artichoke tubers are used. The medical and dietary properties of the Jerusalem artichoke tubers have been studied by scientists [18,19] who proved that they could be used to enrich people's diets and prevent some global diseases.

The authors of the article [20] developed the technologies of paste and purée from Jerusalem artichoke with an addition of fruit and berry raw materials. The paste production technology includes the following technological operations: after hydromechanical treatment, the tubers are processed in a combi-steamer at the temperature 100°C and the humidity 100%, baked at 180°C, grated with the gelling juice formed, and reduced by boiling to a paste consistency. Black chokeberry, cowberry, and pumpkin were suggested as raw materials. Citric acid is added to mashed pumpkin and chokeberry to activate the sugar inversion and the formation of taste properties.

A technology of concentrated paste from Jerusalem artichoke was developed [21]. According to this technology, the Jerusalem artichoke purée to be concentrated was hydrolysed for 40 minutes at a 50°C using the enzyme preparation Rohapect DA6L in an amount of 0.1% of the purée weight. The enzyme preparation Rohapect DA6L belongs to combined pectinase-arabase preparations obtained from the specific cultures Aspergillus niger. After hydrolysis, the purée is concentrated at 55°C and under the pressure 10 kPa till the mass fraction of solids is 50–56%.

A number of works suggest using Jerusalem artichoke tubers in the meat processing industry. To enrich cooked sausages with inulin, the Jerusalem artichoke is introduced into minced meat in the form of purée, concentrated juice, and dry pomace [22]. In the recipe of moulded meat products, 10% of raw meat can be replaced by Jerusalem artichoke purée [23]. It is recommended that semi-processed minced meat products (cutlets) contain Jerusalem artichoke pomace (added in an amount of up to 15% of the main raw material) [24]. Such technological methods reduce the loss in the forcemeat mass during heat treatment and enrich products with inulin.

The results of the research [25] prove that the Jerusalem artichoke can be used in the technology of dry coffee substitute concentrates. This technology consists in drying the prepared raw materials with subsequent roasting. A coffee substitute from the Jerusalem artichoke is a gentler alternative to real coffee and can be used by people suffering from heart diseases, diabetes, and by children.

There is a method of processing Jerusalem artichoke tubers registered as Patent 2396030 RU. The method consists in washing the tubers, grinding them, covering with acidified water until the pH of the extraction mixture reaches 5–6.5, with the phase ratio 1:1, and extracting for 30–40 minutes. The extraction mixture should preliminarily undergo electrocontact heating to the temperature 55–65°C. The extract is sequentially passed through membranes with the retention thresholds 6–8 kDa and 0.8–2 kDa, with the low molecular weight fraction returning to the extraction stage. The remaining fractions are concentrated by reverse osmosis till the solids content is not more than 15%. The high molecular weight fraction concentrate is combined with meal to obtain a gelling concentrate, and the concentrate remaining in the form of an inulin-containing solution purified from the accompanying substances is photosterilised and packaged under aseptic conditions.

The scientists [26] have developed a technology for the production of juice and functional paste based on the Jerusalem artichoke and the quince. The technology is based on the comprehensive processing of these products and includes washing, peeling, crushing, and processing the crushed mass with 0.1% of NaCl to prevent darkening and pressing together. The resulting Jerusalem artichoke and quince juice is deaerated and heated. The pomace obtained after juice production are used to make paste.

Having analysed the main research directions, we have found none dealing with the comprehensive processing of Jerusalem artichoke tubers into beverages with probiotic and prebiotic properties, into fillings for desserts, and into healthy vegetable paste.

The purpose of the work is developing scientifically grounded technologies for the comprehensive processing of Jerusalem artichoke tubers into functional food products.

The objectives were as follows: to study and analyse the essential amino acid content of the raw materials that gives it a functional orientation; to study the quality parameters of the processed raw materials; to give scientific reasons for, and develop technological parameters of the comprehensive processing of the raw materials under study.

Research materials and methods

The research materials used in the research were the Jerusalem artichoke varieties Interes and Violet de Rennes, and lactic acid bacteria Lactobacillus strain lantarum of the strain AN 11/16.

The Jerusalem artichoke was UHF-treated with a Samsung microwave oven MC28H5013AK/BW with the maximum power 900W.

For the experimental studies, standardised methods were used: sampling according to State Standard (GOST) ISO 872-2002; sample preparation in accordance with GOST 7670-2014; mass fraction of mercury according to State Standard DSTU ISO 6637-2001; mass fraction of arsenic according to DSTU ISO 6634-2005; mass fraction of copper according to DSTU ISO 7952-2004; mass fraction of lead according to DSTU ISO 6633-2001; mass fraction of cadmium according to DSTU ISO 6561-2004; mass fraction of zinc according to DSTU ISO 6636-2005; mass fraction of nitrates according to DSTU 4948-2008; dry matter content in the semi-processed product according to GOST 4945-2008; mass fraction of titrated acids (in terms of malic and lactic acids) by the volumetric titration method according to DSTU EN 12147-2003; sensory evaluation according to GOST 6075-2009 (succades), GOST 7159-2010 (juice), GOST 3797-98 (vegetable paste); microbiological analysis in accordance with GOST 8051-2015 (sample preparation), in accordance with DSTU ISO 18593-2006 (determining the total contamination of raw materials); tryptophan mass fraction by the colorimetric method using alkaline hydrolysis [27]; mass fraction of methionine by the colourimetric method using enzymatic hydrolysis [27]. The mass fraction of other essential amino acids was determined by liquid chromatography, according to which a weighed portion of 20 mg of ground Jerusalem artichoke was subjected to acid hydrolysis, then evaporated, and dissolved in 0.5 n HCl. The prepared samples were analysed on a Hitachi L-8900 amino acid analyser. The analysis was performed according to the procedure [28].

Results of the research and their discussion

For comprehensive processing of raw materials into healthy food products, it is necessary to control the quality throughout the entire manufacturing process. In the restaurant sector, certain cooking conditions are created to preserve the biologically active substances of raw materials and give the product the desired organoleptic properties. The target quality level of the final product depends, first of all, on how clear the requirements are in the regulatory documents. The Ishikawa diagram (Fig. 2) helped analyse the main factors that form the quality of functional food based on the Jerusalem artichoke. The graphical method of research and determination of the most significant cause-and-effect relationships allows identifying the key links among various first-order factors [29]: raw materials, manufacturing technology and process conditions, equipment used, personnel's qualifications and the duration of the process.

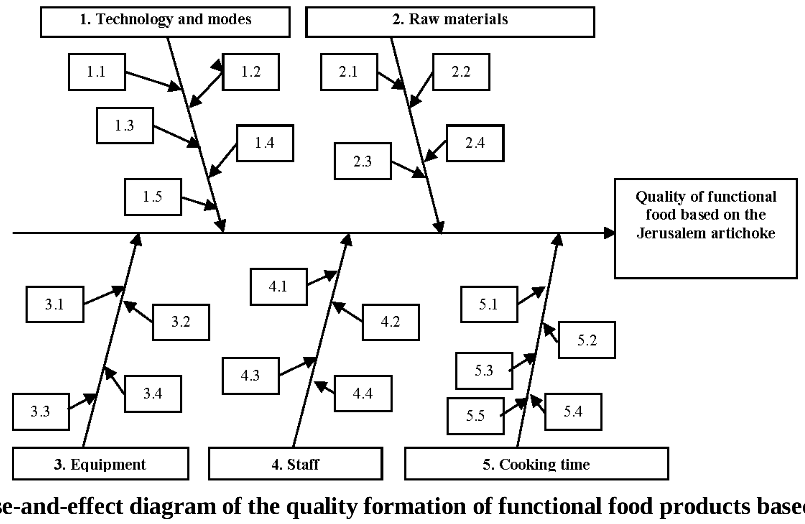

Fig. 2. Cause-and-effect diagram of the quality formation of functional food products based on the Jerusalem artichoke (Ishikawa diagram), the second-order factors:

1.1 – compliance with the formulation; 1.2 – sequence of adding the components; 1.3 – observing the dosage of the components; 1.4 – technological process parameters; 1.5 – sanitary conditions; 2.1 – quality of Jerusalem artichoke tubers; 2.2 – quality and type of the fermentation culture; 2.3 – quality of auxiliary raw materials; 2.4 – observing the storage conditions for raw materials; 3.1 – equipment of the enterprise; 3.2 – line productivity; 3.3 – serviceability of the equipment; 3.4 – presence of control points; 4.1 – staff's qualifications; 4.2 – employees' experience; 4.3 – staff's diligence; 4.4 – working conditions; 5.1 – timely preparation of components; 5.2 – promptness in taking orders (for restaurants), or the availability of a timeline (for sanatoria and health resorts) 5.3 – availability of fermented Jerusalem artichoke; 5.4 – availability of succades from Jerusalem artichoke, 5.5 – availability of auxiliary raw materials.

To improve the quality of healthy food based on the Jerusalem artichoke, it is necessary to take into account the effect of all factors in the technological process. According to Fig. 2, the first-order factors are followed by the second-order factors that are listed below the main ones with the corresponding code numbers. The second-order factors, which are specific when making succades and products from fermented Jerusalem artichoke determine the features of the technologies developed.

The cause-and-effect diagram shown in Fig. 2 makes it possible to track how various factors affect the quality of the final product. Besides, its quality and functionality depend on whether there is protein in the raw material and how complete it is.

The completeness of protein in the raw materials depends on the ratio of essential amino acids and the value of the amino acid score. So, Jerusalem artichoke tubers were studied for the content of essential amino acids (Table 1). In order to recommend the variety best suited for being processed into food, we have examined the two most common varieties in the Odessa region: Interes and Violet de Rennes.

According to Table 1, methionine is the limiting amino acid among the presented ones. This amino acid helps liver and kidney cells regenerate and is antioxidative. The methionine content is higher in the Interest variety, its amino acid score being by 5.6% higher than that of Violet de Rennes. Lysine of the Interes variety has been established to have the highest amino acid score, which is by 3.6% higher compared to that of the Violet de Rennes variety. Lysine is responsible for the growth of the body and stimulates mental performance. It has been determined that the variety Interes is richer in essential amino acids than the variety Violet de Rennes.

The product quality is determined primarily by the safety parameters. That is why the selected Jerusalem artichoke varieties have been examined for the presence of heavy metals and nitrates (Table 2).

Table 1 – The amino acid composition of Jerusalem artichoke tubers (n = 3, p ≥ 0.95)

Amino acid	Variety Interes		Variety Violet de Rennes		Recommendation of FAO/WHO, g/100g
	amino acid content, g/100 g	amino acid score, %	amino acid content, g/100 g	amino acid score, %	
Valine	4.0	80.0	3.8	76.0	5.0
Isoleucine	4.5	112.5	4.0	100.0	4.0
Leucine	7.0	100.0	7.0	100.0	7.0
Lysine	6.8	123.6	6.6	120	5.5
Methionine	2.4	68.5	2.2	62.9	3.5
Tryptophan	0.8	80.0	0.7	70.0	1.0
Threonine	3.8	95.0	3.5	87.5	4.0
Phenylalanine	4.6	76.7	4.5	75.0	6.0

Table 2 – Content of heavy metals and nitrates in Jerusalem artichoke tubers (n = 3, p ≥ 0.95)

Parameter	Admissible norm of a parameter in fresh vegetables, mg/kg, not exceeding	Variety of the Jerusalem artichoke	
		Interes	Violet de Rennes
Lead	0.3	not detected	not detected
Cadmium	0.02	not detected	not detected
Mercury	0.01	not detected	not detected
Copper	5.0	0.02	0.02
Zinc	10.0	2.3	2.5
Arsenic	0.2	not detected	not detected
Nitrates	80	45	52

The research results presented in Table 2 confirm the data from the literature [3,4] that Jerusalem artichoke tubers accumulate almost no heavy metals and nitrates. The nitrate content in the variety Interes is by 35 mg/kg lower than the permissible level, and for the Violet de Rennes variety, this parameter is by 28 mg/kg less than the daily norm.

According to the comprehensive processing plan for Jerusalem artichoke tubers, the following products are to be obtained: succades, juice from fermented Jerusalem artichoke, vegetable paste.

During the initial processing of tubers, the following operations are done: sorting, washing, peeling. Since Jerusalem artichoke tubers are irregular in shape, removing their jackets is quite a time-consuming process. It should be noted that industry has no equipment to do this technological operation properly, and the use of alkaline solutions does not allow obtaining a health-improving product even when it is thoroughly washed with water. Besides, after peeling, the tubers get dark-coloured due to oxidative reactions with the participation of the polyphenol oxidase enzyme in the presence of atmospheric oxygen, which in turn negatively affects the colour and phenolic compounds content in the final product.

To exclude this operation from the technology of comprehensive processing of the Jerusalem artichoke, ultra high frequency irradiation of tubers seems practical.

This will help reduce the total microbial contamination of the surface of raw materials and improve the diffuse processes during fermentation.

Several ways of how raw materials could be preliminarily prepared were considered: tubers unpeeled and washed; peeled and washed; unpeeled, washed, and UHF-irradiated in various modes. A total of 7 samples were examined: sample 1 – unpeeled and washed; sample 2 – peeled and washed; sample 3 – unpeeled, washed, and UHF-treated at 100W for 4 min; sample 4 – unpeeled, washed, and UHF-treated at 180W for 3.5 min; sample 5 – unpeeled, washed, and UHF-treated at 300W for 3 min; sample 6 – unpeeled, washed, and UHF-treated at 450 W for 2 min; sample 7 – unpeeled, washed, and UHF-treated at 600W for 1 min.

To study the total microbial contamination of the surface of the raw material, microbiological analysis of the samples was carried out. As the control, we used a sample of unpeeled tubers before washing, with the total surface contamination $2.15 \cdot 10^6$ (Fig. 3).

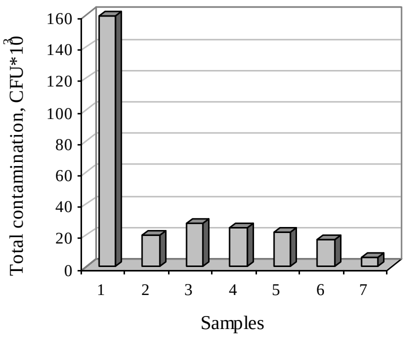

Fig. 3. Microbiological analysis of the surface of Jerusalem artichoke tubers

During the initial processing of tubers, the following operations are done: sorting, washing, peeling. Since Jerusalem artichoke tubers are irregular in shape, removing their jackets is quite a time-consuming process. It should be noted that industry has no equipment to do this technological operation properly, and the use of alkaline solutions does not allow obtaining a health-improving product even when it is thoroughly washed with water. Besides, after peeling, the tubers get dark-coloured due to oxidative reactions with the participation of the polyphenol oxidase enzyme in the presence of atmospheric oxygen, which in turn negatively affects the colour and phenolic compounds content in the final product.

The data obtained have shown that the least contaminated surface was that of the unpeeled and UHF-treated raw materials. The total microbial contamination of the surface of the raw materials treated with ultra high frequency radiation at 600W for 1 min is 358 times as low as that of the raw materials unpeeled before washing, and 3.3 times as low as that of the peeled and washed raw materials.

Based on the results of the microbiological studies, it is recommended to exclude the technological operation of peeling. This will make it possible to obtain a final product enriched with dietary fibre, including the fibre contained in the skin. A high fibre content in food slows down the passage of food along the gastrointestinal tract [30]. Prolonged digestion helps avoid a sharp increase in blood sugar after eating, and the body, in turn, is provided with energy gradually and for a longer time.

Prior to fermentation, Jerusalem artichoke tubers were washed, UHF-treated, and chopped into pieces sized 1×1×1 cm. Further, they were processed according to the technological scheme shown in Fig. 4. According to the technology developed of processing the Jerusalem artichoke into succades, prior to drying, they were sprinkled with a mixture of fructose and pectin in the ratio 1:1. This approach allowed us to reduce the mass fraction of sugar and provide the succades with certain taste properties. The succades were dried until their mass fraction of moisture was 14%.

In order to determine the optimal fermentation mode for Jerusalem artichoke tubers, we took into account the main factors effecting on the quality of the fermented semi-processed product and on the duration of the process: the temperature and the amount of fermentation agent introduced. It was experimentally established that to start fermentation, lactic acid bacteria *Lactobacillus plantarum*, strain AN 11/16, should be used. The following process parameters were established: the amount of lactic acid bacteria introduced as the fermentation starter was 1% of the weight of the prepared raw material, the temperature was 20°C, the duration of the process was 10 days until the total acidity of the product reached 0.8–0.9% [4].

The Jerusalem artichoke tubers were fermented in three stages. At the first stage, the release of cell sap and the intensive development of lactic acid bacteria were observed. The second fermentation stage was characterised by lactic acid accumulation. At the third stage, the sensory and physico-chemical parameters of product quality changed. The fermentation was carried out in absence of oxygen, since lactic acid bacteria are classified as facultative anaerobes, and most unwanted microorganisms behave as obligate aerobes.

From the fermented Jerusalem artichoke, according to the technology developed, juice and pomace were obtained. The pomace was mixed with the recipe components, boiled soft, grated, and reduced by boiling until the moisture content was 25%.

To determine the sensory qualities of the products developed, a taste test was carried out. Its results are presented in Table 3.

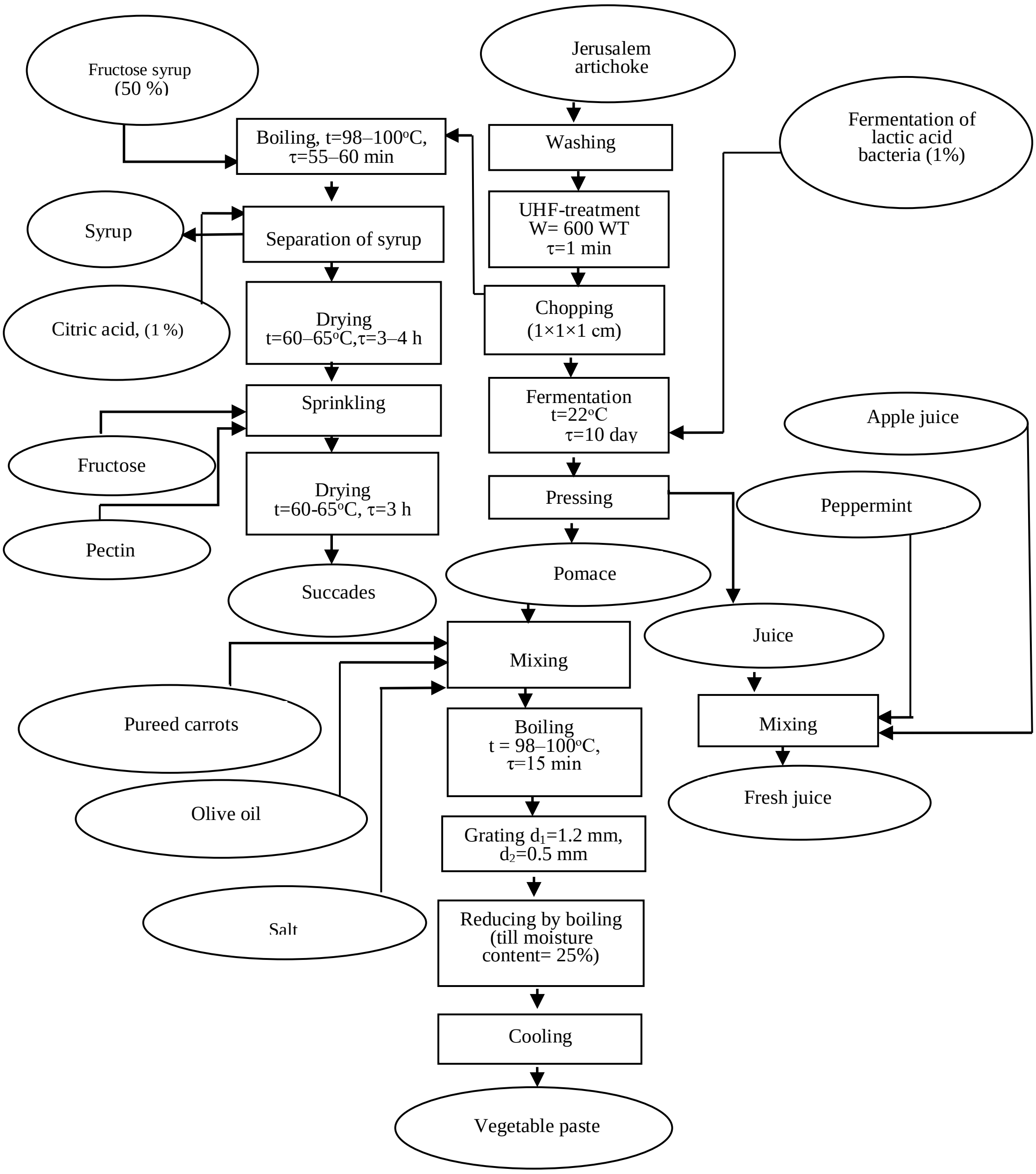

Fig. 4. Technological scheme of the comprehensive processing of Jerusalem artichoke tubers into functional food products

Table 3 – Organoleptic characteristics of the products developed

Parameter	Characteristic		
	Succades	**Juice**	**Vegetable paste**
Appearance	A flat surface, evenly sprinkled with a fructose and pectin mixture, no signs of spoilage (mould, fermentation).	A pulpless liquid, can have a slight sediment	Semi-fluid homogeneous structure, no foreign inclusions
Taste and smell	A pronounced caramel taste with a tinge of the Jerusalem artichoke taste.	Sweet and sour, without a foreign flavour, with a slight peppermint smell	Sweet and sour, without a foreign flavour, with a pleasant smell
Colour	Uniform throughout the product, yellow or light brown, translucent.	Uniform throughout the product, orange	Uniform throughout the product, yellow or light brown
Texture	Dense, crumbly, no moisture released when pressed	Liquid, without a pronounced sediment	Purée-like, homogeneous, no foreign inclusions

An organoleptic analysis allows quickly assessing the quality of a dish and detect violations of the recipe or of the production technology, so that measures can be quickly taken to correct the problems found. During the taste test, the quality of the product was evaluated by the following parameters: appearance, smell and taste, colour and texture. According to the results of the sensory evaluation, it can be stated that the products developed on the basis of the Jerusalem artichoke taste good.

The desserts, including candied Jerusalem artichoke, were practically tested in the restaurant facilities at the Kuyalnik sanatorium, at the trading companies TIRAS LLC and Epicentre LLC. Scientific and practical work to manufacture the test batches of fermented Jerusalem artichoke products was carried out at Helsfood LLC.

Conclusion

The advantages of manufacturing functional foods for restaurant facilities have been proved. The ultra high frequency irradiation of Jerusalem artichoke tubers allowed improving the organoleptic quality of the final products and shortening the technological cycle by eliminating the operation of peeling. The experimental studies conducted made it possible to select the strain AN 11/16 of lactic acid bacteria *Lactobacillus lantarum* as a fermentation starter and to establish the fermentation parameters: temperature 20°C, duration 10 days, the amount of starter 1% of the weight of Jerusalem artichoke prepared. It has been suggested to process tubers comprehensively into succades, fermented juice, and vegetable paste, which, according to the results of the tasting test, have high organoleptic qualities.

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КОМПЛЕКСНА ПЕРЕРОБКА ТОПІНАМБУРА У ФУНКЦІОНАЛЬНІ ХАРЧОВІ ПРОДУКТИ

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Анотація. У роботі представлено аналіз літературних джерел, що показує важливість розширення асортименту функціональних продуктів та актуальність розробки технології комплексної переробки бульб топінамбура. Для проведення експериментальних досліджень застосовували стандартизовані методики. За допомогою діаграми Ісікави визначено найвагоміші причинно-наслідкові взаємозв'язки основних чинників, що формують якість продукції здорового харчування на основі топінамбура. Проведено дослідження амінокислотного складу бульбоплодів та встановлено лімітуючу амінокислоту. Перевірено основну сировину на вміст важких металів та нітратів. Експериментально обґрунтовано та підтверджено мікробіологічними дослідженнями можливість виключення технологічної операції «очищення». Для зниження мікробіологічної забрудненості сировини вивчено вплив НВЧ-випромінювання при різних режимах обробки. Розроблено технології переробки топінамбура на цукати та ферментовану продукцію. У технології цукатів для обсипання використовували суміш фруктози та пектину з метою зменшення масової частки цукру у готовому продукті. Сушіння проводили до досягнення у готових цукатах масової частки вологи 14%. Встановлено параметри процесу ферментації топінамбура: температура – 20°С, тривалість 10 діб, кількість внесеної закваски 1% від маси підготовленої сировини. В якості закваски застосовували молочнокислі бактерії *Lactobacillus plantarum* штаму АН 11/16. Ферментацію проводили до накопичення титрованих кислот 0,8–0,9%, при перерахунку на молочну кислоту. Наведено принципову технологічну схему комплексного переробляння бульб топінамбура у функціональні харчові продукти. Проведено дегустацію розроблених зразків, яка показала високі органолептичні показники якості готової продукції. Розроблені технології апробовано у закладах ресторанного господарства.

Ключові слова: топінамбур, ферментація, цукати, овочева паста, амінокислотний склад, органолептичні показники.

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