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INFLUENCE OF THE PROCESSES OF STEAM-THERMAL CRYOGENIC TREATMENT AND MECHANOLYSIS ON BIOPOLYMERS AND BIOLOGICALLY ACTIVE SUBSTANCES IN THE COURSE OF OBTAINING HEALTH PROMOTING NANOPRODUCTS

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Вивчено вплив процесів паротермічної кріообробки та механолізу при дрібнодисперсному подрібненні на біополімери та біологічно активні речовини (БАР) плодів і овочів при отриманні оздоровчих нанопродуктів. Встановлено, що при дії указаних процесів відбувається активація пектинових речовин, більш повне вилучення із сировини (в 4,5…7,3 раз) із прихованої форми, і трансформація у розчинну форму. Розкрито механізм даних процесів, розроблено рекомендації створення оздоровчих нанопродуктів

Ключові слова: неферментативний каталіз, механоліз, паротермічна обробка, кріообробка, нанокомплекси, гетерополісахаридів, пектинові речовини

Изучено влияние процессов паротермической криообработки и механолиза на биополимеры и биологически активные вещества (БАВ) плодов и овощей при получении оздоровительных нанопродуктов. Установлено, что при действии указанных процессов происходит активация пектиновых веществ, их более полное извлечение (в 4,5…7,3 раза) из скрытой формы и трансформация в растворимую форму. Раскрыт механизм данных процессов, разработаны рекомендации создания оздоровительных нанопродуктов

Ключевые слова: неферментативный катализ, механолиз, паротермическая обработка, криообработка, нанокомплексы гетерополисахаридов, пектиновые вещества

1. Introduction

The relevance of development of technology of health products with prebiotic properties and high content of BAS is predetermined by the necessity of solving the global problem of immune deficit of the population [1]. The reasons for decreased immunity of the population in most countries of the world include deterioration of ecological situation on the Earth, disbalance and a 50 % deficit of basic food products (milk, meat, fish, fruits and berries) in nutrition. In addition, there is a 50 % deficit of BAS that promote immunity: vitamins, carotene, minerals, proteins, and prebiotics – non-digestible food components (in particular, pectin, cellulose, inulin, etc.) [2, 3]. Therefore, in the leading countries of the world, functional health-promoting foods have become widely used [4]. Promising raw material for obtaining health-promoting products are traditional fruits, berries, vegetables, which are high in cellulose, pectin and bioflavonoids [5]. Pectic substances and cellulose are prebiotics, which promote development of healthy microflora of the intestine. In addition, they have detoxication properties, help clean up the human organism from slags and various types of toxic substances contained in food [6]. Existence in fruit, berries, vegetables of bioflavonoids (quercetin, rutin, ursolic acid and others) that have immunomodulating, antioxidant, anti-tumor and detoxication properties also contributes to obtaining health promoting products that contribute to strengthening of immunity.

That is why it is relevant to apply the methods of deep processing of pectin-containing vegetable raw materials to puree, which allow the transformation of hardly soluble substances and BAS into an easily-digestible form. It is also important to develop the technology of health-promoting products with prebiotic properties and high content of BAS [1].

2. Literature review and problem statement

Difficulties during treatment and consumption of fresh fruits, berries and vegetables are associated with the fact that a considerable part of molecules of pectic substances, bioflavonoids, vitamins, carotenoids and others are in the inactive form, bound in nanocomplexes with other biopolymers and BARS. That is why they almost are not absorbed by human organism [7]. In this regard, it is difficult to extract them in soluble form in the course of processing of raw materials and during consumption in the stomach of humans. It is known that fresh fruit, berries and vegetables are assimilated by the human body only by 30...40 % [8].

This research is aimed at solving the problem of deficit in Ukraine of natural plant pectin-containing additives that are at the same time carriers of prebiotics, vitamins and other bioactive substances and are in the easily assimilable form [9]. The demand for the latter during production of food products in Ukraine is about 1 million tons per year [10]. Today in Ukraine there is no national production of pectin and high quality natural additives in the form of powders, purees and pastes from raw pectin-containing materials that are both prebiotics and BAS carriers [2, 3]. Such additives are necessary for making healthy products. Analysis of scientific literature for the last 10 years showed that nowadays in international practice there are two main methods of intensification of pectic substances during deep treatment of pectin-containing fruits and vegetables [11, 12]. The first and the most common method is treatment of raw material by pectolytic and cytolytic enzyme preparations [4]. The second and more promising method is cryogenic treatment of raw materials with the use of liquid and gaseous nitrogen [13]. Periodic literature contains information on influence of different kinds of pre-treatment of pectin-containing vegetable raw materials on nutrients and pectic substances [14]. Taking one of the kinds of pectin-containing raw material (tomato) as an example, the authors proposed the method of increasing molecular weight of pectin and its partial transition into a soluble form. The method is based on the use of intensive homogenization of high pressure [15]. But in scientific literature there is not sufficient information on the influence of cryogenic low temperatures during freezing and grinding on the quality of raw materials, BAS, biopolymers, and it is rather controversial. This area of technology has been insufficiently explored [7].

There are also no systematized data on the influence of other methods of pre-treatment on the changes in pectic and biologically active substances, transition of pectic substances to a soluble form. There are scattered details of the impact of heat, infrared, and microwave treatment on certain types of pectin-containing raw material [14]. For one type of pectin-containing vegetable raw materials (tomatoes), it was found that the use of intense homogenization of high pressure leads to a decrease in molecular weight of pectic substances and their partial transition into a soluble form [15]. But this method of pretreatment did not find its application in technology of obtaining pectin-containing additives.

It should be noted that the traditional methods of treatment of vegetable raw materials lead to a significant loss of vitamins and other BAS, biopolymers and incomplete use of the biological potential of raw materials [7]. In this regard, in today's international practice, it is relevant to develop high technologies, in particular nanotechnologies, which can make treatment of food raw materials more efficient, save and extract valuable target components – BAS and nutrients. Introduction of resource-saving processes, development of waste-free technologies and less energy-intensive processes is promising as well.

In the present research, while obtaining finely-dispersed additives from fruit, berries and vegetables, it was proposed to use as innovation the integrated effect of the two processes on pectin-containing raw material. In particular, the processes of steam-thermal treatment (or cryogenic freezing) and non-enzymatic catalysis – mechanolysis of nanoassociates and nanocomplexes of high-molecular biopolymers (heteropolysaccharides, proteins, etc.) were proposed. The authors obtained finely dispersed additives from fruit and vegetable raw materials (in the form of puree) with qualitatively new, compared with the original raw materials, consumer properties, which cannot be obtained by using traditional methods. Based on additives, a wide range of natural products for healthy eating (fillings for pastry, nanobeverages, nanosorbents, etc.) was developed.

3. The aim and objectives of the study

The aim of present research is to study the impact of processes of steam-thermal, cryotreatment and mechanolysis on activation and extraction of biopolymers of difficultly soluble pectins and BAS from the hidden form, bound in nanocomplexes with other biopolymers, to the free form when obtaining health-promoting nanoproducts.

To accomplish the set goal, the following tasks must be solved:

– to substantiate scientifically parameters of activation and extraction of pectin from the hidden bound form to the soluble form when obtaining frozen and thermally processed finely dispersed puree from fruits and vegetables with the use of processes of non-enzymatic catalysis;

– to identify and explore the biologically active complex of the main BAS and pectins of fresh fruit and vegetables (in particular, black currant, apricots, apples, lemons with peel, pumpkin, and spinach);

– to compare the quality of finely dispersed puree (thermally processed and frozen) with fresh fruit and vegetable raw materials and puree – analogues by content of the main BAS (low molecular phenolic compounds, polyphenols, β-carotene, L-ascorbic acid), prebiotic substances (soluble pectin, cellulose) and proteins.

4. Materials and methods of research

4. 1. Materials and equipment used in the experimental research

The research was conducted at Kharkiv State University of Food and Trade, KSUFT, Ukraine) on the basis of scientific research laboratory “Innovative cryo- and nanotechnologies of herbal additives and health promoting products” at the Department of Technology of Processing of Fruits, Vegetables and Milk. The study was performed using modern equipment for cryogenic freezing, available at the Department of KSUFT – program cryogenic “shock” freezer, in which liquid nitrogen was used as refrigerant and inert medium. In this case, the temperature in the freezer was lower than –60 °C. Fruit and vegetables were frozen at various high rates to different temperatures of the product. Low-temperature grinder (SIRMAN, Italy) was used for grinding.

Materials and methods of the study, as well as procedures for determining the indicators of the examined samples are given in paper [16].

5. Results of the study of the impact of processes of steam-thermal cryotreatment and mechanolysis on biopolymers and BAS of fruits, berries and vegetables

The main task while developing finely dispersed additives from fruit, berries and vegetables is to maximally extract difficultly soluble pectic substances and BAS from raw materials and transform them to a soluble form. The difficulties are caused by the fact that these substances are in nanocomplexes with other polysaccharides, proteins, etc.

It was found and scientifically substantiated that under integrated influence of steam-thermal or cryotreatment and finely dispersed grinding on vegetable raw material there occurs the activation of non-soluble nanocomplexes of heteropolysaccharides (in particular, pectin) with other biopolymers due to thermo-cryo- and mechanodestruction. This leads to their release from hidden, bound forms to the free state, which is 4.5…4.8 times higher than in the original raw material during cryotreatment, and is 3.6…3.9 times larger during thermal treatment and finely-dispersed grinding (Table 1). It was also found that during cryogenic freezing of fruits and vegetables, there occurs the cryodestruction of nanocomplexes of biopolymers and release of general pectin, which is 1.5…2.0 times higher than in the original raw materials (Table 1). It was also established that during steam-thermal treatment of fruits and vegetables in a steam-convective oven for 10 minutes, there is complete extraction of general pectin, which is 1.4…2.0 times larger than in the original raw material (Table 1).

Table 1

Influence of cryofreezing, steam-thermal treatment and non-enzymatic catalysis on the transformation of hardly soluble pectin to the soluble form

Raw material	Total amount of pectic substances		Protopectin		Soluble pectin		Organic acids	
	%	% of original	%	% of original	%	% of original	%	% of original
Fresh black currants	1.6	100.0	0.6	100.0	0.8	100.0	6.2	100.0
Frozen black currants	3.0	187.5	1.0	166.0	1.6	200.0	7.0	112.0
Frozen finely dispersed puree from black currant	7.4	462.5	1.6	266.6	4.9	612.5	9.6	154.8
Thermally treated black currant	2.9	184.3	0.9	153.1	1.5	187.5	7.2	116.4
Thermally treated finely dispersed puree from black currant	6.9	435.2	1.5	257.9	4.2	525.0	8.8	143.7
Fresh spinach	1.3	100.0	0.5	100.0	0.7	100.0	0.6	100.0
Frozen spinach	2.1	161.5	0.9	180.0	1.3	185.7	0.8	133.0
Frozen finely dispersed puree from spinach	5.9	454.5	1.0	200.0	5.1	728.5	1.0	166.6
Fresh apricot	1.6	100.0	0.6	100.0	0.8	100.0	1.0	100.0
Frozen apricot	2.4	150.0	1.0	166.6	1.2	150.0	1.2	120.0
Frozen finely dispersed puree from apricot	7.2	450.0	1.9	316.6	5.1	637.6	1.5	150.0
Thermally treated apricot	2.3	144.0	1.0	166.6	1.1	140.2	1.3	130.6
Thermally treated finely dispersed puree from apricot	5.8	362.5	1.6	266.6	4.1	512.5	1.4	140.0
Fresh pumpkin	1.0	100.0	0.3	100.0	0.7	100.0	0.6	100.0
Frozen pumpkin	1.8	150.0	0.7	166.6	1.1	150.0	0.8	120.0
Frozen nanopuree from pumpkin	4.5	450.0	0.6	200.0	5.2	650.0	1.0	166.6
Thermally treated pumpkin	2.0	200.0	0.6	200.0	1.4	200.0	0.7	112.0
Thermally treated finely dispersed puree from pumpkin	4.4	440.0	0.7	220.0	3.1	430.0	0.9	153.0
Fresh apple (of Semerenko variety)	1.5	100.0	0.7	100.0	0.8	100.0	0.8	100.0
Frozen apple	2.5	166.6	1.1	157.2	1.4	175.0	1.1	137.5
Frozen finely dispersed puree from apple	7.2	480.0	2.1	300.0	5.1	637.5	1.4	175.2
Thermally processed apple	2.3	153.3	1.0	144.0	1.3	162.5	1.2	150.0
Thermally treated finely dispersed puree from apple	5.9	393.3	1.2	171.4	4.8	600.0	1.3	162.5
Fresh lemon with peel	1.8	100.0	0.9	100.0	0.9	100.0	10.5	100.0
Fresh lemon fruit with peel	3.6	200.0	1.4	155.5	1.8	200.0	12.5	119.0
Frozen finely dispersed puree from lemon with peel	7.8	433.3	2.0	222.0	5.2	577.7	15.6	148.5

In addition, it was found that during thermal treatment and cryogenic finely dispersed grinding, pectic substances are ruined to individual monomers. Thus, during finely dispersed grinding of fruit and berries that were steam-thermally treated, weight fraction of soluble pectin increases by 5.1...6.0 times in comparison with the original raw material, and during cryogenic treatment and finely dispersed grinding, it increases by 6.1...7.3 times (Fig. 1). This indicates that hardly soluble protopectin is destroyed and transformed in soluble form. It is shown that a considerable part of pectin in nanopuree is in a soluble form (up to 70 %), which contributes to enhancing gel properties of the obtained puree from fruit, berries and vegetables (Table 1, Fig. 1).

Similar patterns also occur during the same treatment of all fruits and vegetables that are given in the present paper (Table 1, Fig. 1).

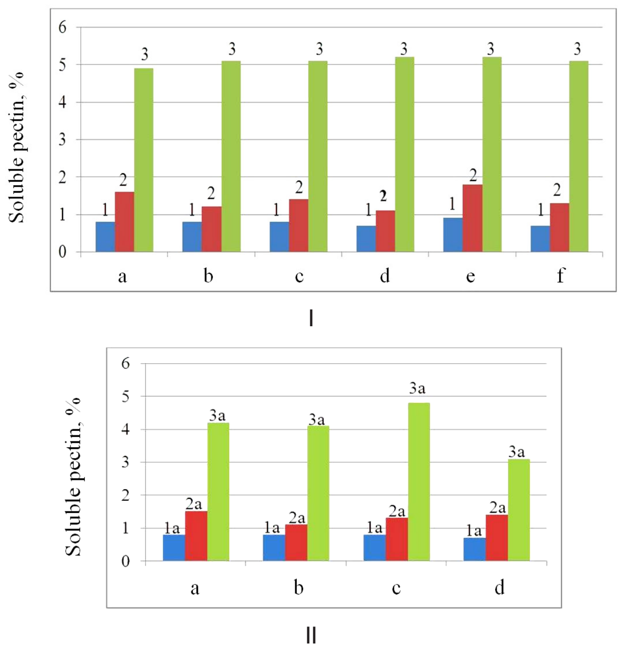

Fig. 1. Influence of freezing (I) (or steam-thermal treatment (II)) and mechanolysis during finely dispersed grinding of fruits and vegetables on extraction and destruction of insoluble pectic substances to individual monomers into soluble form, where: a – black currant, b – apricot, c – pumpkin, d – apple, e – lemon, f – spinach; 1 – fresh fruits and vegetables; 2 – frozen; 3 – frozen and finely dispersed ground, 1a – fresh fruits and vegetables; 2a – steam-thermally treated; 3a – steam-thermally ground and finely dispersed ground, a – black currant; b – apricot; c – apple; d – pumpkin; e – lemon with peels; f – spinach

Thus, it was shown that during freezing and fine grinding of vegetable raw materials, there occurs a more complete extraction of non-soluble pectin from the bound state with macromolecules of other polysaccharides, proteins and mineral substances to the free active form. An increase is by 4.5...4.8 times compared with fresh raw material. In addition, during steam-thermal treatment and fine grinding, we established a similar increase by 3.6...3.9 times compared with original raw material. Simultaneously, there occurs non-enzymatic catalysis of hardly soluble pectin to separate monomers, that is, they are transformed into a soluble easily digestible form. Similar patterns were also obtained during freezing and low-temperature grinding of all objects of the study.

The mechanism of this process is associated with thermodestruction, mechano- and cryodestruction, which lead to the destruction of complex nanocomplexes and pectic substances, released from the hidden form, into soluble easily assimilable form (Fig. 2).

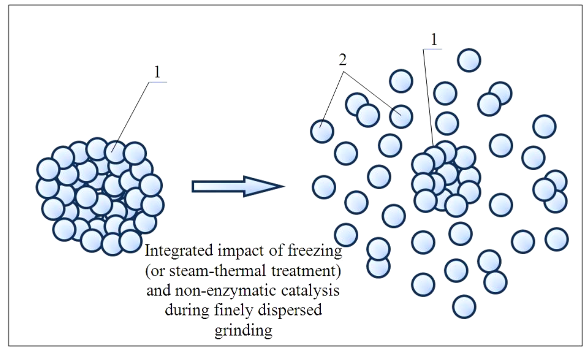

Fig. 2. Schematic of mechanism of integrated impact of freezing (or steam-thermal treatment) and mechanolysis at finely dispersed grinding during processing of fruits and vegetables on a molecule of biopolymer of hardly soluble pectin of heteropolysaccharide with the separation of monomers of galacturonic acid and transformation into easily assimilated form, where: 1 – biopolymer of pectin; 2 – galacturonic acid

In this case, there occurs non-enzymatic catalysis – mechanolysis, mechanocracking (destruction) of hydrogen and ionic bonds in nanocomplexes and in biopolymers themselves. Simultaneously, there is the transformation (destruction) of protopectin to individual monomers – galacturonic acid. This is indicated by a significant increase in organic acids (by 30...40 %) during thermal treatment or freezing relative to the original raw materials, and by 50...70 % – when obtaining nanopuree (frozen or thermally treated).

The mechanism of the specified processes was proved while comparing the IR-spectra of the frozen finely dispersed puree from fruit raw material (apples and apricots) and fresh original raw material. It was shown that in the range of frequencies from 3,200 to 3,650 cm^{-1}, spectra intensity decreases. This region of frequencies is characteristic of valence fluctuations of OH functional groups, involved in the formation of intramolecular and intermolecular hydrogen bonds. Such bonds are included in the composition of free and bound moisture, complexes of biopolymers – BAS (in particular, pectic substances), biopolymers (in particular, phenolic compounds, tannins, sugars, etc.). The obtained results of spectroscopic study indicate destruction of intermolecular and intramolecular hydrogen bonds, destruction of nanocomplexes of biopolymers (in particular, pectin substances) with other biopolymers and low-molecular BAS. In addition, this indicates disaggregation and mechanolysis of biopolymers or associates and nanocomplexes into separate monomers.

The study also included the exploration of biologically active complex of basic BAS and prebiotic substances (pectin, cellulose, and protein) of fresh fruit, vegetables, used in the present work. The following BAS were selected as the criteria: low-molecular and high-molecular phenolic compounds, β-carotene, L-ascorbic acid, pectic substances, cellulose, and protein.

Analysis of obtained experimental data regarding the BAS content in fruits and vegetables indicates that they contain the largest amount of low-molecular phenolic compounds that are represented by hydroxycinnamic acids and are calculated by chlorogenic acid in the amount from 280 to 680 mg per 100 g (depending on the type of raw materials) (Table 2). They also contain a significant amount of flavanol glycosides (in particular, rutin) – from 55 mg per 100 g to 160 mg per 100 g, and polyphenolic tannins – from 185 mg per 100 g to 540 mg per 100 g (depending on the type of fruit).

It was shown that in yellow-orange fruits, apricot, pumpkin, the mass fraction of β-carotene varied from 9.2 to 9.6 mg per 100 g. All fruits and vegetables contain L-ascorbic acid in amount from 45 mg per 100 g in apricots to 265 mg per 100 g of berries of black currant. All fruits contain prebiotic substances, including pectic substances in amounts ranging from 1.4 % to 6.5 % depending on the type of raw material and cellulose, ranging from 1.1 % to 1.9 %. The amount of protein in fruits, berries and vegetables ranged from 1.2 % to 2.5 %. The specified BAS complex, which is contained in fruits, berries, vegetables that were examined in the present paper contributes to the strengthening of blood vessels of the heart and the brain, the immune system due to the antioxidant, detoxicating, antibacterial and anti-tumor effect on the human organism.

We compared quality of the new finely dispersed additives in the form of puree from fruits, berries, vegetables with original raw materials and analogues by the content of BAS. It was shown that the new additives are distinguished by high BAS content (low molecular phenolic compounds, tannins, β-carotene, L-ascorbic acid, soluble pectin). It was established that in the finely dispersed frozen and thermally treated puree from the examined raw materials the mass fraction of BAR was, respectively, higher by 1.5...4.0 times and by 1.5...3.0 times than in the fresh raw materials (Table 2).

Thus, the quality of finely dispersed puree exceeds the quality of the original raw materials and substantially surpasses the quality of purees-analogues. Compared with fresh (original) raw material, the puree-analogues, obtained using traditional methods of thermal treatment of raw materials and grinding, are different from the new puree by significant losses of BAS (by 20... 80 %).

Based on experimental research, nanotechnology of frozen finely dispersed additives from fruit, berries and vegetables was developed. The new technology differs from the traditional one by the use of high rate and lower final temperature of product freezing (–32...–35 °C) due to the use of liquid or gaseous nitrogen. In addition, it differs by the use of finely dispersed grinding to particles, the dimensions of which are significantly smaller than traditional ones. The new types of additives are stored at temperature of –18 °C for 12 months without loss of vitamins and other BAS. Rational parameters of technology (for each of the indicated kind of raw materials separately) were experimentally determined and substantiated, technological schemes were developed, the equipment was chosen and the project of ND (TU) was designed, testing under production conditions was carried out.

Table 2

Comparative characteristic of BAS (L-ascorbic acid, β-carotene, phenolic compounds) and prebiotic substances (pectin, cellulose) in fresh fruit and vegetables and in the frozen nanostructured puree made from them

Product	Mass fraction, mg per 100 g					Mass fraction, g per 100 g			
	phenolic compounds (by chlorogenic acid)	flavanol glycosides (by rutin)	polyphenols-tannins	β-carotene	L-ascorbic acid	protein	Total amount of pectic substances	cellulose	total sugar
Fresh apple	520.1±27.0	156.3±12.3	354.0±8.2	0.1±0.05	56.3±2.6	1.9±0.2	1.5±0.1	1.7±0.1	7.6±0.1
Frozen nanopuree from apple	870.2±17.3	264.2±17.3	643.0±12.3	0.2±0.05	108.2±10.3	2.4±0.3	7.2±1.0	1.5±0.1	9.8±0.2
Steam-thermally treated puree from apple	620.2±10.2	80.3±5.4	470.3±5.4	0.2±0.05	94.2±1.2	2.3±0.1	5.9±0.6	1.5±0.1	9.7±0.2
Fresh lemon	340.1±10.5	70.6±5.2	290.1±4.8	0.2±0.05	68.2±3.4	2.5±0.1	1.8±0.2	2.6±0.2	10.5±1.0
Frozen nanopuree from lemon with peels	740±12.5	150.0±4.8	480.0±10.5	0.4±0.05	132.4±5.2	3.0±0.1	7.8±1.0	2.1±0.1	12.5±1.8
Fresh apricot	250.2±7.7	55.6±2.5	185.4±12.0	9.2±1.6	45.1±3.6	1.5±0.1	1.4±0.1	1.1±0.1	7.5±0.5
Frozen nanopuree from apricot	420.6±10.5	101.2±5.4	302.6±12.6	30.2±2.6	125.2±10.2	1.8±0.1	7.2±0.2	1.0±0.1	8.9±0.6
Steam-thermally treated puree from apricot	300.4±14.1	70.2±3.8	250.3±4.2	25.8±2.9	57.6±2.6	1.8±0.2	5.8±0.5	1.0±0.2	8.8±0.5
Fresh black currant	680.3±17.4	145.5±12.4	542.0±20.4	4.5±0.5	265.0±20.4	1.2±0.1	1.6±0.1	2.5±0.3	8.0±0.5
Frozen nanopuree from black currant	990. ±25.4	250.8±13.3	984.2±24.3	13.5±0.8	610.4±25.3	1.5±0.2	7.4±0.5	2.3±0.2	10.2±0.8
Fresh pumpkin	180.3±11.6	56.6±2.3	210.2±4.8	9.6±0.5	18.2±0.1	1.6±0.1	1.0±0.3	1.4±0.6	7.5±0.5
Frozen nanopuree from pumpkin	332.1±15.2	108.0±4.4	390.1±6.7	40.2±2.5	39.4±0.5	2.2±0.1	4.5±0.5	1.0±0.4	8.9±0.7
Thermally treated nanopuree from pumpkin	280.5±10.4	84.2±4.8	325.4±7.3	30.2±2.8	29.6±1.3	1.7±0.1	3.6±0.4	1.0±0.3	8.9±0.4
Fresh spinach	280.6±6.4	95.2±5.6	350.0±3.4	6.2±0.1	50.4±4.0	2.5±0.1	0.7±0.05	1.9±0.1	6.8±0.5
Frozen nanopuree from spinach	536.2±18.2	180.1±4.5	590.2±5.2	20.8±0.2	142.5±5.5	3.4±0.1	5.1±0.4	1.3±0.1	7.9±0.7

6. Discussion of results of examining the influence of processes of steam-thermal treatment, cryotreatment and mechanolysis on biopolymers and BAS of fruits, berries and vegetables

The present study addresses the impact of processes of steam-thermal or cryogenic treatment of pectin-containing vegetable raw materials and non-enzymatic catalysis, mechanolysis at finely dispersed grinding, on biopolymers and biologically active substances. It was shown that integrated influence of the indicated processes on vegetable raw materials leads to the activation of hardly soluble nanocomplexes of pectic substances with other biopolymers due to the processes of thermo-, cryo- and mechanodestruction.

The obtained results were used when designing a nanotechnology of health promoting nanoproducts (particularly, puree). The new technology makes it possible, in the process of treatment of pectin-containing vegetable raw materials, to better extract hardly soluble substances (cellulose, pectin, inulin, etc.), which have prebiotic properties, and transform them into the easily assimilable form.

The benefit of this research is that we established the possibility of releasing pectic substances from the hidden bound form to the free state. In comparison with the original (fresh) raw material, mass fraction of pectic substances increases by 4.5...4.8 times at cryofreezing and finely dispersed grinding and by 3.6...3.9 times at steam-thermal treatment and finely dispersed grinding. In addition, we established better extraction of general pectin at cryofreezing (by 1.5...2.0 times) and at steam-thermal treatment (by 1.4...2.0 times), as well as the destruction of pectic substances to separate monomers.

An increase in the mass fraction of soluble pectin was established, by 5.1...6.0 times and by 6.1...7.3 times at steam- and cryotreatment, respectively. The mechanism of these processes was revealed. It is explained by partial destruction and transformation of up to 70 % of non-soluble protopectin into a soluble form. This contributes to an increase in gel properties of the new purees from fruit, berries and vegetables compared with the analogues. In addition, the obtained purees differ by a considerable content of BAS with healthful effect that also have color and aromatic properties.

We designed recommendations regarding the use of nanostructured finely dispersed purees from fruit, berries, and vegetables in the composition of products for healthy eating with a record content of natural BAS. A wide range of nanobeverages, nanosorbents, dairy-vegetable cocktails, fillings for confectionery and extruded products, cottage cheese desserts, bakery products, snacks – falafels, creams, was developed. The new types of products are designed to be used at large and small food enterprises, restaurant businesses, trade and for individual nutrition.

Using obtained nanopurees from fruit and vegetable raw materials, the products for healthy eating were developed, in particular fillings for confectionery products "PanCake" and extruded products, which within the frameworks of 2 state-funded programs were implemented into production (Confectionery company "Lisova kazka" Kharkov, Ukraine). Vitaminized healthy juice nanobeverages and nanosorbents were developed and manufactured under production conditions in NVF "KRIAS" and NVF "HPK". Testing of new products under industrial conditions confirms the feasibility of producing frozen fruit and vegetable nanoadditives and health promoting products with their use.

A promising direction for continuation of the research is development of new kinds of additives in the form of powders from different kinds of vegetable raw materials based of the obtained finely dispersed purees. It is essential to determine the impact of types of drying on conservation of BAS, pectic substances, physical and chemical, structural-mechanical, and microbiological processes when obtaining powders depending on the type of original raw materials. Based on the obtained powders, enriched with natural BAS, dyes, fragrances, structure formers, it is planned to develop a wide range of products for special purposes, including products for the ATO zone, polar explorers, astronauts, submariners, tourists, etc.

7. Conclusions

1. It was found and scientifically substantiated that during the integrated influence of steam-thermal (or cryo-) treatment and finely dispersed grinding on fruits and vegetables, activation of non-soluble nanocomplexes of heteropolysaccharides (in particular, pectin) with other biopolymers occurs. Activation occurs due to processes of thermo-, cryo- and mechanodestruction. This leads to a release of mass fraction of pectic substances from the hidden, bound forms into free condition and its increase by 4.5...4.8 times and by 3.6...3.9 times during cryo- (or steam-thermal) treatment and finely dispersed grinding, respectively, in comparison with the original raw materials. Simultaneously, non-enzymatic catalysis of 70 % of non-soluble pectic substances to individual monomers, that is, transformation into the soluble in easily assimilable form, occurs.

2. It was established that fruits (black currants, apricots, lemons, apples) and vegetables (spinach, pumpkin) contain a large amount of BAS. Depending on the kind of original raw materials, the amount in 100 g is: low molecular phenolic compounds (in particular, hydroxycinnamic acids – 280...680 mg, flavanol glycosides (including rutin) – 55...160 mg, polyphenols – 185...540 mg. It was also shown that all fruits and vegetables contain from 45 to 265 mg per 100 g of L-ascorbic acid, depending on the type of raw material, and carotene-containing fruits contain β-carotene in amount from 9.2 to 9.8 mg per 100 g. This is almost two daily norms of β-carotene for a human body. It was demonstrated that all fruits and vegetables contain prebiotic substances (pectin, cellulose, protein). BAS and prebiotic substances give medical-prophylactic properties.

3. It was found that in comparison with fresh raw material, mass fraction of BAS in finely dispersed frozen and thermally treated puree from the studied raw materials (black currants, apricots, lemons, apples, spinach, pumpkin) increased. An increase is by 1.5...4.0 times and by 1.5...3.0 times, respectively. The quality of the obtained new kinds of finely dispersed puree surpasses the known analogues by content of BAS and technological characteristics. New kinds of puree are in nanodimensional, easily assimilable form.

4. With application of new types of finely dispersed additives, a wide range of products for healthy eating with a record content of natural BAS was developed. New kinds of nanobeverages, nanosorbents, dairy-vegetable cocktails, fillings for confectionery and extruded products, cottage cheese desserts, bakery products, snacks, such as falafels, creams, etc., were developed. New additives were recommended for using at large and small food enterprises, institutions of restaurant business, trade, and for individual nutritional needs.

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