UDC 663.432:663.437:641.8
DOI: 10.15587/1729-4061.2023.275548

DETERMINING THE EFFECT OF PLASMOCHEMICALLY ACTIVATED AQUEOUS SOLUTIONS ON THE BIOACTIVATION PROCESS OF SEA BUCKTHORN SEEDS

Olena Kovalova
Corresponding author
PhD, Associate Professor
Department of Food Technologies*
E-mail: livre@i.ua
Natalia Vasylieva
Doctor of Economic Sciences, Professor
Department of Information Systems and Technology*
Serhii Stankevych
PhD
Department of Zoology, Entomology, Phytopathology, Integrated Plant Protection and Quarantine named after B. M. Litvinova**
Inna Zabrodina
PhD
Department of Zoology, Entomology, Phytopathology, Integrated Plant Protection and Quarantine named after B. M. Litvinova**
Ivan Haliasnyi
PhD***
Tatiana Gontar
PhD***
Oleh Kotliar
PhD
Department of Food Technology in the Restaurant Industry**
Tatiana Gavrish
PhD, Associate Professor, Head of Department
Department of Bakery and Confectionery Technology**
Michael Gill
Doctor of Agricultural Sciences, Professor
Department of Biotechnology and Bioengineering
Mykolayiv National Agrarian University
Heorhiya Honhadze str., 9, Mykolayiv, Ukraine, 54008
Olena Karatieieva
PhD, Associate Professor
Department of Biotechnology and Bioengineering
Mykolayiv National Agrarian University
Heorhiya Honhadze str., 9, Mykolayiv, Ukraine, 54008
*Dnipro State Agrarian and Economic University
Sergiy Yefremov str., 25, Dnipro, Ukraine, 49600
**State Biotechnological University
Alchevskykh str., 44, Kharkiv, Ukraine, 61002
***Department of Restaurant, Hotel and Tourist Business
Ukrainian Engineering Pedagogics Academy
Universitetska str., 16, Kharkiv, Ukraine, 61003

The studies revealed the regularities of obtaining bioactivated sea buckthorn seeds using plasma-chemically activated aqueous solutions during germination. Sea buckthorn seeds were chosen as the research object. Plasma-chemically activated aqueous solutions were used to activate the germination process. This made it possible to solve the problem of processing waste from the production of sea buckthorn oil, and also contributed to obtaining a high-quality component of food products.

Experimental studies have proven the effectiveness of using plasma-chemically activated aqueous solutions as effective intensifiers and disinfectants for the process of bioactivation of sea buckthorn seeds. It is shown that their use intensifies the germination of sea buckthorn seeds, contributes to a more active accumulation of biologically valuable components in the seeds. Plasma-chemically activated aqueous solutions with a peroxide concentration of 300–700 mg/l were used. An increase in the geometric parameters of seeds, namely length by 8.5–14.9 % and width by 3.7–14.8 %, was recorded. The germination energy increased by 5–13 % and germination capacity by 5–14 %. The composition of sea buckthorn seeds, both derived raw material and bioactivated, was investigated. Studies have shown that bioactivated seeds contain an increased amount of highly valuable substances. The protein content increased by 4 % compared to sea buckthorn seeds and by 1.7 % compared to the control. The lipid content increased by 2 and 1.1 %. An increase in the content of vitamins was noted: B1, B2, C, A, E, R. The amount of amino acids increased by 9–13 % compared to the control, and compared to the original raw material – by 1.5–3.5 times. In addition, plasma-chemically activated aqueous solutions effectively disinfected the raw material.

The presented technology can be used in the food processing industry

Keywords: processing of sea buckthorn seeds, plasma-chemical activation, aqueous solutions, germinated seeds, biologically active substances

Received date 03.01.2023
Accepted date 09.03.2023
Published date 28.04.2023

***How to Cite**: Kovalova, O., Vasylieva, N., Stankevych, S., Zabrodina, I., Haliasnyi, I., Gontar, T., Kotliar, O., Gavrish, T., Gill, M., Karatieieva, O. (2023). Determining the effect of plasmochemically activated aqueous solutions on the bioactivation process of sea buckthorn seeds. Eastern-European Journal of Enterprise Technologies, 2 (11 (122)), 99–111. doi: https://doi.org/10.15587/1729-4061.2023.275548*

1. Introduction

The problem of providing consumers with highly nutritious and useful food products enriched with plant components is of great importance, it is an integral part of forming a living space for the full existence of a modern person.

There is a constant search for biologically valuable ingredients that could qualitatively enrich food products with the maximum amount of vital components and biologically active substances. The daily diet of a wide range of consumers has undergone a number of negative changes in recent years, and such dynamics are stable to this day. So, consumers give preference to food products that contain many different harmful components, which harms health. The result of an unbalanced diet is an increase in the number of people with various chronic diseases.

Sea buckthorn is an important source of high-quality and biologically valuable plant material. This is a universal plant, the components of which are widely used, both for pharmaceutical and food purposes. It is a valuable source of biologically active food components. Raw materials from sea buckthorn are processed using both traditional technologies and the latest technological solutions, which allows improving the processing process and reducing the amount of waste. As a rule, oil is obtained from sea buckthorn, and the secondary raw material is seeds, which can become a product with high biological potential when processed.

The main sources of valuable sea buckthorn products are berries, pulp juice and seeds. After squeezing the juice, the pulp remains, the main component of which is seeds. Sea buckthorn pulp is not always subject to technological processing, but it is advisable to convert the seeds into oil and obtain by-products from it. Traditionally, sea buckthorn seeds are processed into oil, but the search for waste-free technological solutions or technological techniques that will minimize production waste remains interesting.

A promising direction for processing sea buckthorn seeds is germination for further use in food. Bioactivation by germination of sea buckthorn seeds is an innovative method of processing waste after obtaining juice from sea buckthorn berries. In the modern food industry, the priority is to increase the biological and nutritional value of food products by introducing germinated seeds of various crops into the recipe. Sprouted seeds contain an increased amount of nutrients that have a harmonious effect on the human body, as they are of natural plant origin and have a balanced composition. In the future, such components can bring significant benefits to the consumer body, for example, being part of popular and widespread food products.

The relevance of research lies in the development of technology for obtaining bioactivated sea buckthorn seeds. This technology will have scientific value, both for processing secondary plant raw materials and for creating new healthy food products, since the obtained germinated sea buckthorn seeds can become an irreplaceable and highly nutritious component of useful food. All this will not only expand the range of high-quality food products, but also improve their nutritional properties.

2. Literature review and problem statement

The works [1–3] provide a large number of research results devoted to the study of the beneficial properties of sea buckthorn and its processing products. It has been shown that sea buckthorn (Hippophae rhamnoides L.) is a valuable multipurpose plant that is widely grown in Asia, Europe and Canada. The importance of this species is expected to increase in the future due to its high environmental friendliness and biological characteristics that make this plant suitable for many types of land, including arid areas [2]. The exceptional value of sea buckthorn is manifested in the presence of both lipophilic antioxidants (mainly carotenoids and tocopherols) and hydrophilic antioxidants (flavonoids, tannins, phenol carboxylic acids, ascorbic acid) in extremely high quantities. Some of the essential nutrients, namely lipids, have an optimal fatty acid composition that has a positive effect on consumer health. In addition, sea buckthorn contains such substances as sugars, sugar derivatives, fiber, organic acids, proteins, amino acids and mineral elements. But in [1], the increase of biologically active substances in raw materials remains an unresolved problem. Thus, it was noted [3] that sea buckthorn has a unique nutritional composition with vitamins (A, C, D, E, F, K, P and B), 18 free amino acids and a unique profile of unsaturated fatty acids, which makes this berry a plant source of omega-7 fatty acids. The components of sea buckthorn have various biological properties: antioxidant, immunomodulatory, anticarcinogenic, hepatoprotective, cardioprotective, antiatherogenic and radioprotective. Sea buckthorn is consumed in its natural form, but its industrial processing and preparation of various products from it is rational.

In addition, it is an urgent issue to ensure food production with vegetable raw materials, which can be used specifically to enrich food with useful substances.

In the food industry, it is advisable to use sea buckthorn to enrich products, improve their properties and saturate them with valuable food components. The work [4] gives the results of the study of food raw materials obtained from sea buckthorn. The main value is the fruit, although sometimes the leaves are used to make sea buckthorn tea. The two main sources of valuable products are berries, juice from the pulp and seeds in the form of individual seeds from each berry. The juice is used as a nutritious drink with a high content of useful substances and a very high content of vitamin C and carotene. It may contain an oil phase entrapped by suspended solids or residual oil. The pulp remaining after the juice is removed allows for the extraction of the "buckthorn yellow" pigment, which can potentially be used as a food dye. The seeds are a source of components that have light-absorbing and softening properties. So, the seeds of sea buckthorn berries contain a lot of fatty acids and fat-soluble vitamins. Extracts are made from sea buckthorn seeds, which are excellent against various intestinal diseases. Sea buckthorn seed processing products are used as ingredients of cosmetic and phytopharmaceutical preparations or preparations to protect the skin from UV rays. However, as a rule, sea buckthorn seeds become production waste.

An important aspect is the therapeutic value of using sea buckthorn processing products as food [5]. Both seeds and soft parts (pulp and skin) of berries are rich in lipids. The oils extracted from the two fractions differ in their fatty acid composition, and both contain large amounts of fat-soluble vitamins and plant sterols. The composition of raw materials varies depending on the origin and time of berry collection and the method of oil extraction. Experiments were conducted on the use of sea buckthorn in the treatment of cardiovascular diseases [6], a significant cardioprotective effect and a positive therapeutic effect on the cardiovascular system were noted. It suppresses platelet activation (especially platelet aggregation), helps reduce cholesterol concentration and normalize blood pressure, and also provides an antioxidant effect. In addition, sea buckthorn has antibacterial and antiviral properties. The leaves and fruits of the plant, as well as its oils, are sources of many biologically active substances, including vitamins (A, C and E), unsaturated fatty acids, phenolic compounds, especially flavonoids, and phytosterols, which have a positive effect on the cardiovascular system [6]. Phytocomponents have recently been considered as factors that play a significant role in the prevention of major chronic human diseases. Numerous phytocompounds affect the processes of metabolism and elimination of contaminants that are carcinogens and mutagens [7]. In addition, sea buckthorn flavone has demonstrated antiplatelet potential, including antiadhesive activity [8].

In order to increase the nutritional value, it is advisable to use berries, leaves, seeds or pulp of sea buckthorn, since the oil contains many bioactive compounds. The results of these studies are given in [9], so sea buckthorn oil is a rich source of natural antioxidants, such as ascorbic acid, tocopherols, carotenoids, flavonoids. It also contains proteins, vitamins (especially vitamin C), minerals, lipids (mainly unsaturated fatty acids), sugars, organic acids and phytosterols. Animal and human studies show that sea buckthorn can have various beneficial properties and effects: cardioprotective, antiatherogenic, antioxidant, immunomodulatory, antibacterial, antiviral, healing and anti-inflammatory [10]. Also, sea buckthorn oil improves blood circulation, helps saturate the skin with oxygen, removes excess toxins from the body and easily penetrates the epidermis. Since gamma-linolenic acid turns into prostaglandins inside the skin, sea buckthorn oil protects against infections, prevents allergies, eliminates inflammation and inhibits aging processes [11]. The expediency of using sea buckthorn in feeding people and animals has been noted, but the issue of using sea buckthorn raw materials in the food industry remains urgent for many scientists.

It should be noted that having a high nutritional value and a valuable source of natural antioxidants, sea buckthorn can be used as a source of nutraceuticals, as well as a functional food [12]. After analyzing the literature [13], it should be noted that in the modern conditions of meat production, one of the priority areas of the meat processing industry is making products with improved consumer properties. To fulfill this task, it is necessary to introduce physiologically functional ingredients of plant origin into industrial circulation, which will provide the body with nutrients and expand the range of functional nutrition. The issue of partial replacement of raw materials of animal origin with flour from germinated sea buckthorn seeds as a functional ingredient in the production of sausage products is considered. The improvement of the functional and technological properties of experimental minced sausage products based on sea buckthorn flour has been proven. The consumption of such sausage products allows us to consider them as food products with fundamentally new functional properties that would meet modern requirements for food products. In addition, sea buckthorn processing products are widely used in the production of beverages such as smoothies [14].

The question arises of what components of sea buckthorn seeds can be used to enrich food products. Thus, after obtaining sea buckthorn juice, 8–12 % of pulp remains, of which about 10 % are seeds. A fat fraction is obtained from sea buckthorn juice and seeds by extraction with a chloroform-menthol mixture. For pharmacological purposes, sea buckthorn oil is obtained by extracting the pulp with refined vegetable oil. The highest oil yield is obtained by the extraction of dry pulp with n-hexane. The oil content of sea buckthorn pulp ranges from 2 to 14 % depending on the method of production, i.e. the yield will be 86–98 % [15]. Residues after pulp processing are used for animal feed. Therefore, it will be appropriate to diversify the methods of processing sea buckthorn seeds in order to use them in food production. Germination of seeds after obtaining juice from sea buckthorn will allow you to obtain a natural plant filler for food products of various purposes.

However, the problem of providing industrial production with such important components as germinated sea buckthorn seeds immediately arises. All this allows us to state that it is appropriate to conduct a study on the development of a new intensive technology for obtaining germinated seeds, which could ensure an increased demand of food industry enterprises for biologically active components of natural origin [16].

The production of germinated sea buckthorn seeds using intensive and environmentally friendly technology is promising. The literature [17–21] provides various methods to intensify germination. The main methods used in the process of intensification of grain germination are: biotechnological, chemical, physical, physicochemical, complex and others [17]. Thus, the most common methods to intensify germination include stratification of sea buckthorn seeds with H_2SO_4 solution, activation with gibberellic acid, and ultrasound treatment of soaked seeds.

Plasma chemical technologies have been widely used in the grain processing industry in recent years.

Activation of water and aqueous solutions by plasma chemical treatment is the first step towards using the properties of water without its forced chemization by foreign chemicals [22]. So, all the processes that occur during activation take place directly in the water without adding any chemicals. The reactogenic properties of activated water are of increased interest to scientists, since the properties of water that arise after activation can become a starting point in the development of a new direction of nanotechnology [23]. Water activated by contact non-equilibrium plasma has antiseptic and antibacterial properties [24]. However, it should be noted that such water, which is a cluster structure after plasma treatment, may exhibit some new properties that were little studied before, but which are of interest from a practical point of view [25]. The resulting activated water has a specific composition. The reaction products that determine the reactivity of such water are the most easily detectable. First of all, this concerns hydrogen peroxide and superoxide compounds, excited particles and radicals, which play an important role in redox processes [22]. It should also be noted that such water after plasma treatment can exhibit some new properties that were previously little studied, for example, to speed up the transport of moisture into the grain material, correct biochemical transformations in the seed material. A special role in this case is assigned to the study of the effect of activated water on the technological parameters of some processes in food, biochemical and biotechnological industries.

When it comes to final components in water and aqueous solutions after non-equilibrium contact plasma treatment, they can be represented as a mixture of hydrogen peroxide, superoxide components, and active radicals and particles [24]. But their quantitative characteristics (mcg and ppm) are such that they cannot harm human health in any way. The peculiarity of the action of such components lies in several directions. First, if you follow the process of grain raw material processing, very useful processes appear that are aimed at intensifying seed dehumidification [24]. This is due to changes in the water structure itself. Water clusters are actively crushed under the action of contact plasma, there is an effect of faster penetration of such crushed clusters through the seed membranes and shells [22]. Such clusters contain microparticles of hydrogen peroxide, which, upon contact with raw materials, can form active oxygen and water [24]. Therefore, microparticles of hydrogen peroxide have a positive effect on seed raw materials, acting as a stimulator of biochemical transformations to activate the germination process [23].

It is extremely important to select an intensifier of germination (bioactivation) of sea buckthorn seeds, which would allow obtaining high-quality and chemically pure grain raw materials. Among the many intensifiers (stimulators) of the germination process, plasma-chemically activated aqueous solutions were chosen for research. In the future, such solutions will be a useful addition to the technology of obtaining biologically active sea buckthorn seeds. It should be noted that they are already used to obtain brewing malt [24], but it remains interesting for scientists to expand the range of technological application of the selected intensifier of biological processes. All this allows us to state that it is appropriate to conduct research on obtaining bioactivated sea buckthorn seeds using plasma-chemically activated aqueous solutions as an intensifier of biochemical processes.

3. The aim and objectives of the study

The aim of the study is to identify the influence of plasma-chemically activated aqueous solutions on the technological process of industrial production of a biologically active component, namely germinated (bioactivated) sea buckthorn seeds, which would become part of the recipes of healthy food. This can provide food enterprises with a sufficient amount of bioactivated plant raw materials to make products of increased nutritional value.

To achieve the aim, the following objectives were set:

– to investigate the dynamics of changes in the geometric parameters of sea buckthorn seeds;

– to investigate the energy and germination capacity of sea buckthorn seeds;

– to investigate the chemical composition, content of amino acids and vitamins;

– to investigate the microbiological state of sea buckthorn seeds.

4. Research materials and methods

4. 1. Research object and hypothesis

Sea buckthorn seeds obtained from the production of sea buckthorn juice were chosen as the object of the study.

As a germination intensifier, plasma-chemically activated aqueous solutions were used. The main research hypothesis was the possibility to obtain biologically valuable material during the germination of sea buckthorn seeds for food purposes.

The preparation of plasma-chemically activated aqueous solutions was carried out on the basis of the Specialized Laboratory of Plasma Processing of Technological Solutions of Food Industries. The research was carried out on the basis of the Scientific and Production Laboratory for Determining the Quality of Grain and Grain Products, Department of Food Technologies, Dnipro State Agrarian and Economic University (Ukraine).

4. 2. Research materials and equipment used in the experiment

4. 2. 1. Preparation of plasma-chemically activated aqueous solutions

Studies of the germination (bioactivation) process were carried out using plasma-chemically activated aqueous solutions as a germination intensifier.

Activation of water for moistening sea buckthorn grain was carried out using a laboratory plasma-chemical installation (Fig. 1) [23]. Tap water was activated in low-pressure plasma discharges with a voltage of 1000–1200 V and a current of 30.0–200.0 mA. With the subsequent transition as the electrical conductivity increases to the contact non-equilibrium plasma mode with parameters: voltage from 400 to 600 V and current up to 150 mA [25]. The content (concentration) of hydrogen peroxide in the activated water was determined by iodometry.

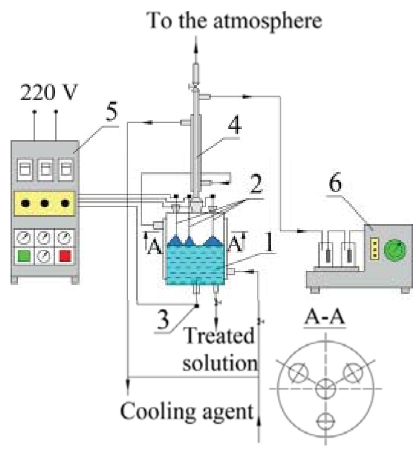

Fig. 1. Diagram of a laboratory three-arc plasma-chemical installation [23]: 1 — reactor; 2 — anodes; 3 — cathode; 4 — backflow condenser; 5 — power source; 6 — vacuum pump

The characteristics of plasma-chemically activated aqueous solutions used for soaking sea buckthorn seeds are given in Table 1.

Table 1

Characteristics of aqueous solutions activated by contact non-equilibrium plasma

Experiment	Water	Activation time, min.	Concentration of hydrogen peroxide, mg/l
1 (control)	tap water	–	–
2	activated	10	300
3	activated	20	400
2	activated	30	600
4	activated	40	650
5	activated	60	700

Table 1 shows fixed indicators of peroxide concentration in plasma-chemically activated water samples. The concentration of peroxides ranged from 300 to 700 mg/l, and the activation time lasted from 10 to 60 minutes.

4. 2. 2. Selection of raw materials for germination and features of obtaining germinated sea buckthorn seeds

Seeds of the sea buckthorn species *Hippophae rhamnoides L.* were chosen as the raw material for germination. This is a secondary raw material in the industrial processing of sea buckthorn, namely in the production of juice and sea buckthorn oil from it. Such raw materials contain water- and fat-soluble biologically active substances that have not found their wide industrial use. It was found that 10 to 25 % of the raw material is lost during processing with waste [19]. After obtaining sea buckthorn juice by squeezing, the pulp remains, the main component of which is undamaged sea buckthorn seeds (approximately 10 %).

In laboratory conditions, sea buckthorn juice is separated from the berries, the pulp remains. Accordingly, the juice is used for its intended purpose, and the resulting mass of berry seeds, pulp and skin is dried in a drying cabinet at a temperature not higher than +45 °C, with occasional stirring. The dried pulp is rubbed in palms, separating the seeds from the dry remains of the berry pulp. The resulting cleaned sea buckthorn seeds are germinated.

Seeds were germinated in a laboratory malt house, which is a set of plastic containers covered with a layer of filter paper and moistened with plasma-chemically activated aqueous solutions, with the characteristics given in Table 1.

The seed material was treated with activated aqueous solutions as follows: the prepared bioactivation material was saturated with a plasma-chemically activated solution with a given concentration of peroxides (from 300 to 700 mg/l) in two stages. Pre-soaking was carried out for 4 hours at a temperature of 18–20 °C. At the end of the period, the solution was drained, and the seeds were kept for 18 hours without liquid access. The intermediate separation of the soaking liquid is carried out in order to prevent acidification of the samples. The ambient temperature was maintained within 18–20 °C, the samples were periodically stirred and moistened as they dried. The separated soaking liquid is filtered and reactivated for purification purposes, since plasma-chemical activation of aqueous solutions is one of the technologies for treating malt wastewater [22]. In re-soaking, plasma-chemically activated solutions of similar concentration were used. Air-water soaking was carried out for 48 hours until the seeds were completely saturated with the activated solution. The water duty of the process of soaking sea buckthorn seeds is 3, that is, 3 parts of activated water solutions are used for 1 part of sea buckthorn seeds.

Germination (bioactivation) was carried out for 3–15 days at a temperature of 17–21 °C, periodically moistening and stirring the seed layer with a height of no more than 45–55 mm in order to evenly distribute the liquid and prevent mass clumping. The wide range of germination time is explained by the significant hardness of sea buckthorn shells, which causes a longer process of moisture transport into the seed. As a result, a longer germination time is desirable compared to traditional crops. The duration of germination affects the accumulation of biologically active substances. When the ridge overgrows, useful components of bioactive seeds can undergo changes as a result of complex biochemical transformations. Therefore, it is important to monitor the state of the ridge, that is, when monitoring the state of germinating seeds, the sprout length should not exceed 75 % of the seed length.

The final stage of the process is the further processing of bioactivated sea buckthorn seeds, namely, cooling, grinding or drying, depending on the technological need.

After germination, the moisture content of the material is 46–48 %. Seed drying was carried out in a laboratory dryer under the following conditions: up to 30 % humidity at a temperature of up to 40 °C; up to 10 % – at elevated temperatures from 40 to 70 °C; up to 6 % – at a temperature of 70–85 °C. The total drying time of the material was 24 hours.

The proposed technology used conventional grinding of bioactivated seeds on a Miller-350 laboratory mill. However, it is advisable to use cryogenic grinding. This method is optimal for preserving biologically active substances in plant raw materials.

4. 3. Methods of determining sample properties

4. 3. 1. Methods of determining the dynamics of changes in the geometric parameters of sea buckthorn seeds

In the course of research, geometric indicators were recorded, namely the length and width of seeds after soaking in plasma-chemically activated aqueous solutions at the initial stage of germination. The parameters were recorded in a sample of 50 seeds.

4. 3. 2. Methods of determining the germination energy and capacity of sea buckthorn seeds

Five analytical groups of 500 pieces each were selected for research on sea buckthorn seeds.

The germination capacity and energy were determined in order to find the number of seeds capable of forming normally developed seedlings. Simultaneously with the capacity, the germination energy of seeds was determined, which characterizes the speed and friendliness of their germination. The germination capacity and energy were expressed as a percentage of normally germinated seeds to the total number. Standard methods were used to determine the germination energy and capacity. 72 hours after the end of grain soaking, the germination energy of the seed material was determined, after 120 hours – the germination capacity. These indicators were expressed as % of the total number of seeds in the sample. The effectiveness of the selected growth intensifier (plasma-chemically activated solutions) was compared with the control, which was sea buckthorn seeds that were not subjected to any physical or chemical treatment. All experiments were repeated five times.

4. 3. 3. Methods of determining the chemical composition, content of amino acids and vitamins in germinated sea buckthorn seeds

The protein content in seeds was determined by the Kjeldahl method. The method includes several main stages: sample preparation, mineralization, distillation and titration.

Determination of fat content (according to Rushkovsky). The method is based on the principle of determining the fat content from the defatted residue. Portions of dried and ground material are placed in filter paper bags and extracted with diethyl ether in a Soxhlet apparatus until complete degreasing. The amount of extracted fat is calculated by the difference between the initial weight and the weight of the defatted residue.

The liquid chromatography method was used to determine the carbohydrate content.

Determination of crude fiber content. Crude fiber includes: pure fiber, part of hemicellulose, lignin, cutin, some protein substances and ash elements. The sample is treated with sulfuric acid, alkali, alcohol and ether, after which the plant residue is weighed.

The mass fraction of pectin substances was determined by the weight calcium-pectin method.

The mass fraction of starch was determined by the Ewers polarimetric method. It is based on starch hydrolysis with dilute hydrochloric acid, precipitation of protein substances and determination of the rotation angle of polarized light using a polarimeter.

Total sugar and reducing sugars were determined by the ferricyanide method. The method is based on the oxidation of reducing sugars with an alkaline solution of potassium ferric oxide, followed by measurement of the oxidizer color intensity with a photoelectrocolorimeter.

To determine the biological value, an analysis of the content of amino acids in sea buckthorn seeds was carried out. For this purpose, the method of ion-exchange liquid column chromatography on a T339 automatic amino acid analyzer, manufactured in the Czech Republic, Prague was used. The vitamin composition of seedlings was also determined using ion-exchange liquid column chromatography and other standard methods.

4. 3. 4. Methods of studying the microbiological state of sea buckthorn seeds

The number of aerobic and facultatively anaerobic microorganisms (KMAFAnM), or the total microbial number, was determined. This indicator includes various taxonomic groups of microorganisms – bacteria, yeast, molds. The KMAFAnM indicator was determined by the classical method by sowing in agarized nutrient media, incubating the cultures and counting the resulting colonies [23].

5. Results of studies of indicators of the technological process of obtaining bioactivated sea buckthorn seeds

5. 1. Study of the dynamics of changes in the geometric parameters of sea buckthorn seeds

The rate of absorption of plasma-chemically activated aqueous solutions by sea buckthorn seeds can be monitored by recording changes in the geometric parameters of the seeds. The results of the studies are given in Table 2.

Table 2

Dynamics of changes in the geometric parameters of sea buckthorn seeds

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Geometric parameters, mm	
			length	width
1 (control)	tap water	–	4.7	2.7
2	activated	300	5.1	2.8
3	activated	400	5.2	2.9
2	activated	600	5.4	3.0
4	activated	650	5.3	3.1
5	activated	700	5.2	2.9

The geometric parameters of the seeds – length and width, increase in comparison with the control to the maximum at the concentration of peroxides in the solution of 600–650 mg/l, which is evidence of positive dynamics in germinating seeds. So, the length increases from 8.5 to 14.9 %, and the width from 3.7 to 14.8 %. These results show how actively the seed swells when soaked. That is, the faster the seed is saturated with moisture and accordingly swells (geometric parameters will increase), the more actively hydrolytic enzymes will work and, accordingly, germination will begin.

5. 2. Research on the germination energy and capacity of sea buckthorn seeds

The main indicators of germinated seeds and the quality of bioactivation of seed raw materials are the germination energy and capacity of sea buckthorn seeds (Table 3). Through preliminary analysis, the concentrations of peroxides in plasma-chemically activated solutions were selected, which showed the maximum increase of these parameters, the results of the studies are shown in Table 3. At the same time, the selected concentrations of peroxides in the activated solutions did not damage the seeds during the experiments and did not cause a change in the organoleptic properties of the finished product.

Increased germination activity in the test samples compared to the control is noted, which indicates the possibility of using plasma-chemically activated aqueous solutions in order to intensify the process of bioactivation of sea buckthorn seeds. Plasma-chemically activated aqueous solutions intensify the process of seed germination to varying degrees, but the effect of increased germination energy and capacity is present when using any concentration of peroxides in activated solutions. This allows us to talk about the positive dynamics of the influence of the selected intensifier on the technological process of obtaining bioactivated sea buckthorn seeds.

Table 3

Germination energy and capacity of sea buckthorn seed when using plasma-chemically activated aqueous solutions

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Germination rates, %	
			energy	capacity
1 (control)	tap water	–	80	86
2	activated	300	85	91
3	activated	400	87	95
2	activated	600	90	98
4	activated	650	93	100
5	activated	700	91	97

The germination energy and capacity of sea buckthorn seeds are significantly increased when using plasma-chemically activated aqueous solutions, the effect of a positive change in the indicator ranges from 5 to 14 %. Therefore, the duration of the germination process is 4–5 days when using plasma-chemically activated solutions, as evidenced by 100 % germination of seeds on the 5th day of the process. In the control, full germination was achieved on the 10th day of germination. So the time of the process of sea buckthorn seed germination was reduced by 2 times.

Calculations were made to substantiate the consistency of the advantages of the experimental samples based on a set of four indicators. Geometric parameters of length and width and indicators of germination energy and capacity of sea buckthorn seeds were used when using plasma-chemically activated aqueous solutions. For this purpose, the Friedman test based on the Kendall's W concordance coefficient with related ranks was applied. The concordance coefficient was calculated by the formula:

$$W=\frac{\left(12\cdot\sum_i\left(S_jR_{ij}\right)^2-3\cdot M^2\cdot N\cdot(N+1)^2\right)}{\left(M^2\cdot\left(N^3-N\right)-M\cdot S_k\left(t_k^3-t_k\right)\right)}, \quad (1)$$

where M is the number of evaluation indicators;

N is the number of samples;

R_{ij} denotes the rank of sample i by the evaluation indicator j, i=1, .., N, j=1, .., M;

t_k denotes the length of the group k with related (same) ranks.

The hypothesis about the inconsistency of the evaluation indicators regarding the quality of the studied samples was canceled on the basis of inequality:

$$M\times(N-1)\times W>X^2(\alpha; N-1), \quad (2)$$

where $X^2(\alpha; N-1)$ is the critical Pearson's Chi-square value with significance level α and N–1 degrees of freedom.

When performing calculations in (1), M=4, N=6. As the analyzed data R_{ij}, the ranks of the indicators from Table 2, 3 were taken, located in Table 4 with two groups of related ranks $t_1=t_2=2$.

Table 4

Ranked indicators of sea buckthorn seeds when using plasma-chemically activated aqueous solutions

Experiment	Geometric parameters, rank		Germination indicators, rank		Cumulative rank assessment
	length	width	energy	capacity	
1 (control)	6	6	6	6	24
2	5	5	5	5	20
3	3.5	3.5	4	4	15
4	1	2	3	2	8
5	2	1	1	1	5
6	3.5	3.5	2	3	12

Based on inequality (2) with a typical level of significance α=0.05:

$$18.696=4\times(6-1)\times0.935>X^2(0.05; 6-1)=11.071,$$

a conclusion was made about the existence of consistency among the considered geometric parameters of length and width and indicators of germination energy and capacity of sea buckthorn seeds. Therefore, according to the total ranking from Table 4, among the plasma-chemically activated aqueous solutions, test sample 5 with a hydrogen peroxide concentration of 650 mg/l was the best.

5. 3. Study of the chemical composition, content of amino acids and vitamins in germinated (bioactivated) sea buckthorn seeds

An important stage of research is to determine the composition of bioactivated sea buckthorn seeds. For a deeper analysis of bioactivated seeds, samples were selected that showed the best effect in previous experiments, namely, those treated with plasma-chemically activated solutions with a peroxide concentration of 650 mg/l. The main components included in their composition are listed in Table 5.

Table 5

Change in the chemical composition of sea buckthorn seeds when using plasma-chemically activated aqueous solutions, %

Indicator	Raw materials (ungerminated sea buckthorn seeds)	Control (seeds germinated without adding activator)	Experiment (seeds germinated using plasma-chemically activated aqueous solutions)
Proteins	26.1	28.4	30.1
Lipids	15.2	16.1	17.2
Carbohydrates	27.1	25.4	24.8
Cellulose	19.2	16.3	14.3
Pectin	3.7	3.8	3.9
Starch	2.6	1.9	1.1
Mono- and disaccharides	1.6	3.4	5.5

Analyzing Table 5, it can be stated that the germinated sea buckthorn seeds obtained using plasma-chemically activated aqueous solutions have an increased content of important substances. They differ from the control by the increased content of protein, easily digestible carbohydrates, free fatty acids, and pectin. This makes bioactivated seeds particularly valuable in human nutrition.

To test the hypothesis about the preservation of the relative proportions of the chemical composition of sea buckthorn seeds compared to the raw material, the t-test for sample means with different variances was applied [35]. The test statistic was calculated by the formula:

$$t=(M1-M2)/(S1/N1+S2/N2)^{0.5}, \quad (3)$$

where $N1$ and $N2$ are the size of the first and second samples, consisting of elements $\Delta1_i$, i=1, ..., $N1$, $\Delta2_j$, j=1, ..., $N2$, respectively;

$M1$ and $M2$ denote the mean sample values, i. e.:

$$M1=(\Sigma_i\,\Delta1_i)/N1,\ M2=(\Sigma_j\,\Delta2_j)/N2, \quad (4)$$

$S1$ and $S2$ denote the unadjusted (corrected) sample variances, i. e.:

$$S1=\Sigma_i\,(\Delta1_i-M1)^2/(N1-1),\ S2=\Sigma_j\,(\Delta2_j-M2)^2/(N2-1). \quad (5)$$

The hypothesis about the difference in sample means was rejected on the basis of inequality:

$$t\leq t(\alpha; df), \quad (6)$$

where $t(\alpha; df)$ is the critical value of the Student's t-distribution with the level of significance α and degrees of freedom df found by the formula:

$$df=(S1/N1+S2/N2)^2/((S1/N1)^2/(N2-1)+(S2/N2)^2/(N1-1)). \quad (7)$$

When performing calculations in (3)–(5), (7), $N1=N2=7$. The change in the chemical composition of the control and test samples of sea buckthorn seeds relative to the raw material is shown in Table 6 as modules of the difference between the parameters of the control and raw material ($\Delta 1_i$) and the test and raw material ($\Delta 2_j$).

Table 6

Change in the chemical composition of treated sea buckthorn seeds relative to the raw material, %

Indicator	$\Delta 1_i$	$\Delta 2_j$
Proteins	2.3	4
Lipids	0.9	2
Carbohydrates	1.7	2.3
Cellulose	2.9	4.9
Pectin	0.1	0.2
Starch	0.7	1.5
Mono- and disaccharides	1.8	3.9

Based on inequality (6) with a typical level of significance α=0.05:

$$1.658=t\leq t(0.05;\ 10)=2.228,$$

it was concluded that the relative proportions of the chemical composition of the sea buckthorn seeds of the control and experimental samples were preserved, which is evidence of the inviolability of the natural qualities observed in the sea buckthorn raw material.

The average vitamin composition of bioactivated sea buckthorn seeds is given in Table 7.

Table 7

Average vitamin composition of seedlings, mg %

Vitamin	Raw materials (ungerminated sea buckthorn seeds)	Control (seeds germinated without adding activator)	Experiment (seeds germinated using plasma-chemically activated aqueous solutions)
B_1 (thiamine)	1.05	1.64	1.82
B_2 (riboflavin)	0.27	0.37	0.52
C (ascorbic acid)	6.72	7.54	8.25
A (retinol)	4.31	4.62	4.88
E (tocopherol)	83.91	86.73	89.12
P (rutin), %	1.47	1.98	2.23

The increased content of vitamins (Table 7) also indicates the importance of using sea buckthorn seeds in food in order to balance the diet and enrich it with a vitamin complex contained in bioactivated sea buckthorn seeds.

To test the hypothesis about the preservation of the relative proportions of the vitamin composition of sea buckthorn seedlings compared to the raw material, Dixon's Q-test for outliers [36] and t-test for sample means with distinct variances, presented by formulas (3)–(7), were used. The test statistic of Dixon's Q-test for outliers was calculated by the formula

$$Q=(\Delta_2-\Delta_1)/(\Delta_N-\Delta_1), \quad (8)$$

where N denotes the sample size, Δ_q – ordered sample elements from the maximum Δ_1 to the minimum Δ_N, q=1, .., N.

The hypothesis that Δ_1 belongs to the sample of the remaining elements was canceled on the basis of inequality

$$Q>Q(\alpha;\ N), \quad (9)$$

where $Q(\alpha;\ N)$ is the critical value of the Dixon Q-test for outliers with a significance level α and N degrees of freedom.

The change in the vitamin composition of sea buckthorn seedlings of the control and experimental samples relative to the raw material is shown in Table 8 as the modules of the difference between the parameters of the control and raw material ($\Delta 1_i$) and the test and raw material ($\Delta 2_j$).

Table 8

Change in the vitamin composition of treated sea buckthorn seedlings relative to the raw material, mg %

Vitamin	$\Delta 1_i$	$\Delta 2_j$
B_1 (thiamine)	0.59	0.77
B_2 (riboflavin)	0.1	0.25
C (ascorbic acid)	0.82	1.53
A (retinol)	0.31	0.57
E (tocopherol)	2.82	5.21
P (rutin)	0.51	0.76

Dixon's Q-test for outliers according to formulas (8) and (9) with a significance of α=0.05 found a special nature of changes in vitamin E (tocopherol) content in the control and experiment compared to the raw material, because:

$$0.735=(0.82-2.82)/(0.1-2.82)>Q(0.05;\ 6)=0.56,$$

and

$$0.742=(1.53-5.21)/(0.25-5.21)>Q(0.05;\ 6)=0.56.$$

Instead, the t-test for sample means with distinct variances according to formulas (3)–(7) with a typical significance level of α=0.05 for the rest of the vitamins resulted in inequality:

$$1.271=t\leq t(0.05;\ 6)=2.447,$$

which convinces of the preservation of the relative proportions of the vitamin composition of the bioactivated sea buckthorn seeds of the control and experimental samples and indicates the inviolability of the natural qualities observed in the sea buckthorn raw material according to these indicators.

Amino acid analysis was also performed to confirm the biological value of germinated sea buckthorn seeds. Amino acids important for the human body were found in sufficient quantities in the samples. When using plasma-chemically activated aqueous solutions, the content of amino acids increases, the results of the experiments are shown in Table 9.

Analyzing the data in Table 9, it can be argued that as a result of more intensive germination of sea buckthorn seeds, the accumulation of amino acids is more active. In the samples treated with plasma-chemically activated solutions, an increased content of amino acids is recorded, compared to the original raw material and the control sample by 150–350 % (Table 9). This is a confirmation of the hypothesis about the increased content of biologically active substances in the bioactivated material obtained from sea buckthorn seeds.

Table 9

Amino acid composition of bioactivated sea buckthorn seeds, mg/100 g

Amino acid	Raw materials (ungerminated sea buckthorn seeds)	Control (seeds germinated without adding activator)	Experiment (seeds germinated using plasma-chemically activated aqueous solutions)
Phenylalanine	0.93	1.84	2.41
Leucine+Isoleucine	1.82	6.93	8.25
Valin	1.45	2.41	2.93
Proline	0.587	0.722	0.877
Serin	3.18	2.11	2.18
Glycine	1.83	2.24	2.49

To test the hypothesis about the preservation of the relative proportions of the amino acid composition of bioactivated sea buckthorn seeds compared to the original raw material, the Dixon Q-test for outliers was applied. It is described by formulas (8) and (9). The t-test for sample means with different variances, represented by formulas (3)–(7), is also applied. The change in the amino acid composition of the bioactivated sea buckthorn seeds of the control and experimental samples relative to the raw material is shown in Table 10 as the modules of the difference between the parameters of the control and raw material ($\Delta 1_i$) and the test and raw material ($\Delta 2_j$).

Table 10

Change in the amino acid composition of bioactivated sea buckthorn seeds relative to the raw material, mg/100 g

Amino acid	$\Delta 1_i$	$\Delta 2_j$
Phenylalanine	0.91	1.48
Leucine+Isoleucine	5.11	6.43
Valin	0.96	1.48
Proline	0.135	0.29
Serin	1.07	1
Glycine	0.41	0.66

Dixon's Q-test for outliers according to formulas (8) and (9) with a significance of α=0.05 found a special nature of changes in the content of amino acids Leucine+Isoleucine in the control and experiment compared to the raw material, because:

$$0.812=(1.07-5.11)/(0.135-5.11)>Q(0.05; 6)=0.56,$$

and

$$0.806=(1.48-6.43)/(0.29-6.43)>Q(0.05; 6)=0.56.$$

Instead, the t-test for sample means with distinct variances according to formulas (3)–(7) with a typical significance level of α=0.05 for the remaining amino acids resulted in the following inequality:

$$0.969=t\leq t(0.05; 8)=2.306,$$

which convinces of the preservation of the relative proportions of the amino acid composition of the bioactivated sea buckthorn seeds of the control and experimental samples and indicates the inviolability of the natural qualities observed in the sea buckthorn raw material according to these indicators.

5. 4. Study of the microbiological state of germinated sea buckthorn seeds

An important problem in the bioactivation of seeds is the presence of microorganisms, especially pathogenic ones, on the surface of the seed material.

Most often, the germination process takes place in non-aseptic conditions. Microbes are found on seeds treated in such conditions, the presence of which is determined by the external environment during plant growth or seed storage. The conditions maintained during the germination process (heat, moisture) are most favorable for the microbes present on seeds, which multiply during the entire process. These microbes may have an undesirable effect on the bioactivation product, since it will not be thermally treated. This is explained by the fact that microorganisms are not only on the surface of the seeds, but also penetrate into the seed material, causing its deterioration. Therefore, the selection and use of a high-quality and non-harmful antiseptic preparation is a very important task aimed at improving the quality of the obtained bioactivated raw materials. The effect of plasma-chemically activated aqueous solutions (300–700 mg/l H_2O_2) on the microbiological state of sea buckthorn seeds is shown in Table 11.

Table 11

Study of the microbiological state of germinated sea buckthorn seeds (KMAFAnM)

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Standard KMAFAnM	Microorganisms in the test sample
1 (control)	tap water	–	$<5*10^4$	$5.1*10^7$
2	activated	300		$2.7*10^5$
3	activated	400		$1.4*10^2$
2	activated	600		<10
4	activated	650		–
5	activated	700		–

Local disinfecting properties of plasma-chemically activated aqueous solutions in relation to sea buckthorn seeds were investigated. The results of determining the total microbial number testify to the effectiveness of the proposed disinfectant. The number of microorganisms was determined by counting the colonies found on standard media. For non-traditional raw materials, including sea buckthorn seeds, the standard value of KMAFAnM is no more than $5*10^4$. Table 11 shows the change in the average number of microorganisms on the surface of germinated sea buckthorn seeds as a result of using plasma-chemically activated solutions of different concentrations. Disinfecting ability was more pronounced in samples with a higher peroxide concentration, at a concentration of 650 mg/l H_2O_2 the material surface had no microorganisms. This is explained by the fact that plasma-chemically activated aqueous solutions are able to qualitatively disinfect the surface of food raw materials.

6. Discussion of the results of research on the intensive technology of obtaining the biologically active component of food products

Having studied the change in the geometric parameters of sea buckthorn seeds when plasma-chemically activated aqueous solutions are used as a wetting agent, it should be noted that the geometric parameters undergo positive changes when using the proposed activator. Thus, the length increases from 8.5 to 14.9 %, and the width from 3.7 to 14.8 %, depending on the concentration of peroxides in the solution. Moreover, the concentration of peroxides in the activated solution within 600–650 mg/l is characterized by the optimal effect on the seeds (Table 2). The change in the geometric parameters of the seeds indicates the active transport of moisture into the seeds preceding the bioactivation processes in them. Moisture penetrating sea buckthorn seeds activates hydrolytic enzymes. Free moisture is able to ensure the transition of enzymes and nutrients into the solution and their migration to the embryo [25]. This creates favorable conditions for the penetration of enzymes into the endosperm, which are able to transform the reserve insoluble substances of the seeds into soluble and easily accessible forms, which are quickly absorbed by the embryo and serve as an impetus for the germination process. Comparing the obtained results with similar studies [20], it should be noted that in the proposed technology, a faster change in geometric parameters is noted, which confirms the active transport of solutions into the seeds. All this contributes to the increase of soluble substances and the reduction of insoluble substances. In the process of bioactivation, the sea buckthorn embryo is fed by the substances available to it, such as simple sugars, amino acids, and vitamins that can dissolve in aqueous solutions. Bioactivation of seed material is the process of moisture saturation of seeds, accompanied by the action of moisture, heat and air during the germination process. This process involves the transformation of high molecular weight substances into easily digestible forms. In addition, the accumulation of biologically active components continues. Bioactivation is often called enzymatic grain depolymerization or germination [23]. However, it should be noted that the purpose of germination is to obtain germinated grain (malt), and the purpose of industrial bioactivation of seeds is to obtain a grain product rich in biologically active substances. However, indicators such as germination energy and capacity, which are characteristic of malting, also play an important role in industrial bioactivation processes, since they confirm that the process of accumulation of biologically active components has been successfully launched.

Having studied the germination energy and capacity of sea buckthorn seeds when using plasma-chemically activated aqueous solutions, it should be noted that these indicators increase significantly, the effect of positive change varies from 5 to 14 %. Analyzing the data in Table 3, it should be noted that the germination energy increased by 5–13 %, germination capacity – by 5–14 %. Comparing the results with other studies [18], it can be noted that the use of activated solutions increased the given parameters by 3–5 % compared to similar intensive technologies. This is due to the fact that plasma-chemically activated aqueous solutions stimulate a number of biochemical processes in the grain, which are satellites of germination and serve as tools for the synthesis and accumulation of biologically active substances in seeds [23]. This allows you to enrich the seed material with useful substances and expand the functional properties of the finished product. Samples treated with plasma-chemically activated aqueous solutions with a peroxide concentration of 650 mg/l showed optimal results in the germination process.

Plasma-chemically activated aqueous solutions accelerate the flow of moisture and, as a result, nutrients from the endosperm to the embryo, stimulate its awakening to vital activity, which activate and significantly accelerate the process of accumulation of a number of enzymes [23]. It should be noted that when using water treated with non-equilibrium contact plasma, the transport of moisture into the grain is improved due to the fragmentation of water cluster structures at the molecular level [17]. Thus, the pattern is confirmed that the faster the process of water absorption and swelling of seeds (change in geometrical parameters), the more active the bioactivation processes. All this leads to changes in the composition of the material, so almost all components of sea buckthorn seeds undergo changes. Therefore, an important stage of research was determining the composition of bioactivated sea buckthorn seeds.

For a deeper analysis of bioactivated seeds, samples were selected that showed the best effect in previous experiments, namely, those treated with plasma-chemically activated solutions with a peroxide concentration of 650 mg/l.

Having studied the chemical composition of bioactivated sea buckthorn seeds (Table 5), it can be noted that bioactivated sea buckthorn seeds obtained using plasma-chemically activated aqueous solutions differ in their component composition. Namely, the increased content of protein (compared to sea buckthorn seeds by 4 % and compared to the control by 1.7 %), lipids (2 and 1.1 %), reduction of carbohydrates while increasing mono- and disaccharides. Analyzing the results obtained in other works [20], it can be noted that the studied indicators underwent positive changes when using the proposed activators and changed within the norm. The increase in proteins is especially important. All this makes the obtained product particularly valuable in human nutrition. The listed components play an important role in the formation of the future plant, so the more active the germination process is, the more components are involved in it.

In the process of activation of biological transformations, enzymes and biological substances are activated in the seeds, and components are synthesized that will form the basis of a new plant [17]. Under the action of enzymes, starch is hydrolyzed and the sugar content in the grain increases, the content of group B vitamins and the amount of vitamin E increase. The vitamin E activity of bioactivated grain is especially important for human nutrition. Vitamin E (tocopherol) protects unsaturated fatty acids of cell membranes from oxidation, participates in the exchange of proteins and carbohydrates, and improves the absorption of fats and vitamins A and D.

The change in the vitamin composition (Table 7) is explained by the activation of a number of biological processes in sea buckthorn seeds. An increase in the content of the following vitamins was noted: B1 (thiamine), B2 (riboflavin), C (ascorbic acid), both in comparison with the derived raw material (seeds) and with the control sample (germinated seeds). In comparison with other technologies of sea buckthorn seed germination [20], a constant increase in the vitamin content when using plasma-chemically activated aqueous solutions should be noted.

Also, in the course of research, increased amino acids were recorded, compared to the control sample by 3–19 % (Table 9). Positive accumulation dynamics was observed for the following amino acids: phenylalanine, leucine, isoleucine, valine, proline, serine. If we compare the indicators of sea buckthorn seeds and bioactivated seeds, the amount of amino acids increases during bioactivation from 1.5 to 3.5 times, which indicates the prospects of processing sea buckthorn seeds into biologically complete raw materials. Compared to the studies on the effects of other germination activators [17, 18, 21], a higher level of amino acid accumulation should be noted. This is due to the fact that the use of activated aqueous solutions increases proteolytic activity in seeds [23].

It is advisable to use bioactivated sea buckthorn seeds in the daily diet, especially during periods of vitamin deficiency and significant stress on the body of people of different age groups.

The use of plasma-chemically activated aqueous solutions in the technological process of bioactivation of sea buckthorn seeds will not have any limitations, since the presented activator is non-toxic. The study of the chemical composition of bioactivated sea buckthorn seeds gave positive results, since the studied material contains amino acid and vitamin complexes that can significantly improve the composition of food products, the components of which will be the raw materials obtained.

In addition, the study of the microbiological state of bioactivated sea buckthorn seeds confirmed the positive effect of plasma-chemically activated solutions on raw materials. Because at a concentration of 650 mg/l H_2O_2 in the solution, the surface of the material did not contain microorganisms at all, which is a positive result that indicates the microbiological safety of the finished product. Compared to other disinfectants for grain raw materials [18], plasma-chemically activated aqueous solutions completely disinfect the treated surface without leaving extraneous chemicals in the product [23]. It should be noted that plasma-chemically activated aqueous solutions are also able to inhibit pathogenic microflora, namely Escherichia coli group bacteria and moldy microflora [23–25].

The presented studies can become the basis for a new direction of processing technological waste from the process of obtaining sea buckthorn juice and oil, namely, the industrial production of bioactivated sea buckthorn seeds.

The technological result of the studies is obtaining a biologically active component of food products of universal purpose, which would become a useful and highly valuable component of health products.

The implementation of research results in the industrial production of germinated sea buckthorn seeds will reduce the technological process of seed bioactivation by 1.5–2 times, since an effective germination intensifier is used – plasma-chemically activated aqueous solutions.

The use of plasma-chemical activation makes it possible to disinfect and purify wastewater of food industries [22].

The finished product (bioactivated sea buckthorn seeds) is recommended to be used fresh. It will also be appropriate to use it as a component in the industrial production of food products.

In the food processing industry, it is appropriate to use dried and crushed germinated sea buckthorn seeds in the form of powder. Such a filler will have a positive effect on increasing the biological value of a wide range of food products.

Dried and crushed appropriately bioactivated sea buckthorn seeds will enrich confectionery, dairy, meat and fish products. In the future, it can become part of multi-component, universal fillers for various semi-finished products. As a biologically active component, it will be able to diversify a wide range of everyday dishes of modern consumers.

The limitations of research include the reproducibility of experiments at specialized enterprises, since for industrial processing of sea buckthorn seeds, a fairly significant amount of activated aqueous solutions is required. However, it should be noted that activated aqueous solutions can be produced industrially. Thus, the industrial version of the plasma-chemical plant can produce sufficient volumes of solutions of 1.5–2.0 m^3/hour. [17], which will satisfy the needs of the processing enterprise. The production cost of 1 m^3 of activated solutions is 1 cu [23]. Currently, the industrial production of activated aqueous solutions is carried out by Scientific and Production Enterprise “KNP-TECHNOLOGY” LLC, (Dnipro, Ukraine).

The development of the presented research will consist in the application of the biologically active component (bioactivated sea buckthorn seeds) in the recipes of various food products, as well as in the study of the composition of the obtained food products.

7. Conclusions

1. The change in the geometric parameters of sea buckthorn seeds when using plasma-chemically activated aqueous solutions as a wetting agent was studied. The length was found to increase by 8.5–14.9 %, and the width by 3.7–14.8 %.

2. The indicators of sea buckthorn seed germination when using plasma-chemically activated aqueous solutions were studied: the germination energy increased by 5–13 %, germination capacity – by 5–14 %.

3. The study of the chemical composition of germinated sea buckthorn seeds showed that it is a biologically active food component, as an increase in protein content by 1.7 % and lipids by 2 % was observed when plasma-chemically activated aqueous solutions were used. In addition, the content of mono- and disaccharides increases by 62 %. The amino acid composition increased by 3–19 % depending on the amino acid, and compared to the original raw material by 1.5–3.5 times. An increased amount of the following vitamins was found in the germinated seeds: B1, B2, C, A, E, P. The same can be said about the biological and nutritional value of bioactivated sea buckthorn seeds obtained by innovative technology.

4. The study of the microbiological state of the material showed the high-quality disinfecting effect of plasma-chemically activated solutions when processing sea buckthorn seeds. At a peroxide concentration of 650 mg/l, there are no microorganisms on the surface of bioactivated seeds.

Conflict of interest

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

Financing

The study was conducted without financial support.

Data availability

The manuscript has no associated data.

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