UDC 664.788.3
DOI: 10.15587/1729-4061.2023.290584

DEVELOPMENT OF BUCKWHEAT GROATS PRODUCTION TECHNOLOGY USING PLASMA-CHEMICALLY ACTIVATED AQUEOUS SOLUTIONS

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 *

Ivan Haliasnyi
PhD
Department of Restaurant, Hotel and Tourist Business
Ukrainian Engineering Pedagogics Academy
Universitetska str., 16, Kharkiv, Ukraine, 61003

Tatiana Gavrish
PhD, Associate Professor, Head of Department
Department of Technology of Bakery and Confectionery**

Aliona Dikhtyar
PhD, Associate Professor
Department of Food Technology in the Restaurant Industry**

Svitlana Andrieieva
PhD, Associate Professor
Department of Food Technology in the Restaurant Industry**

Nataliia Didukh
PhD
Department of Horticulture and Storage of Plant Products**

Iryna Balandina
PhD
Department of Tourism and Hospitality***

Larysa Obolentseva
Doctor of Economic Sciences
Department of Tourism and Hospitality***

Nataliia Hirenko
PhD, Senior Lecturer
Department of Production Technologies and Professional Education
Luhansk Taras Shevchenko National University
Kovalia str., 3, Poltava, Ukraine, 36014
*Dnipro State Agrarian and Economic University
Sergiy Yefremov str., 25, Dnipro, Ukraine, 49600
**State Biotechnological University
Alchevskikh str., 44, Kharkiv, Ukraine, 61002
***O. M. Beketov National University of Urban Economy in Kharkiv
Marshal Bazhanov str., 17, Kharkiv, Ukraine, 61002

The result of the conducted research is the development of a technology for the production of buckwheat groats using plasma-chemically activated aqueous solutions. The research object was buckwheat grain. An urgent technological problem is the preservation of biologically valuable components of buckwheat during technological operations and optimization of the existing technology for the production of buckwheat groats. The expediency of using plasma-chemically activated aqueous solutions as an intensifier of the technological process of production of buckwheat groats and an effective groats disinfectant has been experimentally proven. It is shown that the use of plasma-chemical activation of technological solutions allows reducing the temperature and accelerating the course of hydrothermal treatment of buckwheat grain. The composition of buckwheat grain as a raw material was analyzed. The obtained buckwheat groats were studied separately. A reduction in tempering time from 6–10 to 2 h and a decrease in the optimal moistening temperature from 60 to 40 °C were recorded. This allows preserving a number of biologically important components in buckwheat grain. The groats yield increases from 68 to 74 %, i. e. by 1.9–6.0 %. The preservation of the maximum number of amino acids is observed, namely, 7.7 % more than in the control. That is, only 2 % is lost during technological processing, instead of 9.7 % in the control sample. The vitamin composition also remains stable and almost does not decrease in terms of B_1, B_2, B_3, B_4, B_5, B_6, K, E, PP, P. In addition, plasma-chemically activated solutions qualitatively disinfect grain raw materials during processing, which has a positive effect on further storage of buckwheat groats.

The technology can be applied in the industrial production of high-quality buckwheat groats. The developed technology will receive special attention in the production of ecologically clean cereal products that are not contaminated with pathogenic microflora

Keywords: plasma-chemical activation, aqueous solutions, hydrothermal treatment, buckwheat groats, amino acids, disinfectant

Received date 12.09.2023
Accepted date 14.11.2023
Published date 28.12.2023

***How to Cite**: Kovalova, O., Vasylieva, N., Haliasnyi, I., Gavrish, T., Dikhtyar, A., Andrieieva, S., Didukh, N., Balandina, I., Obolentseva, L., Hirenko, N. (2023). Development of buckwheat groats production technology using plasma-chemically activated aqueous solutions. Eastern-European Journal of Enterprise Technologies, 6 (11 (126)), 59–72. doi: https://doi.org/10.15587/1729-4061.2023.290584*

1. Introduction

Buckwheat is a food crop with a global production of 1.9 million tons. Asia has the largest acreage of buckwheat, but its production is growing not only in Asia, but also in Europe [1]. Buckwheat (Fagopyrum esculentum), a highly nutritious pseudocereal rich in biologically active compounds, is mainly cultivated in Central and Eastern

Europe [2]. It should be noted that there is a positive trend towards increased production and industrial processing of buckwheat for food purposes in America and some African countries. The top 5 buckwheat producers include Russia, China, Ukraine, France and Poland. In particular, China and Russia account for 64 % of the total world production of buckwheat and its processing products [1, 3]. The high demand for healthy food has increased the global demand for buckwheat and its processing products, namely, buckwheat groats. Buckwheat is consumed in the form of flour, groats, noodles.

The world grain market is dominated by ordinary buckwheat, but the production and processing of Tatar buckwheat are developing. Modern technologies for hulling and grinding buckwheat grain are being developed. Buckwheat and its processing products are becoming more accessible to consumers, and the production of buckwheat products and beverages in the industry is growing rapidly around the world [3].

The choice of buckwheat dishes in the world gastronomy is becoming more and more noticeable. Buckwheat holidays, buckwheat goodies days, buckwheat cuisine weeks, buckwheat cooking competitions are held. Healthy eating trends contribute to the growing popularity of buckwheat and buckwheat groats in everyday use. Gluten-, sugar- and lactose-free products, such as buckwheat groats, are becoming a food hit [4].

Since the problem of useful and healthy food is currently global, highly nutritious buckwheat groats can find wide use among different segments of the population. Moreover, they can be used for people of different ages and with different physical activity. In addition, it is appropriate to include buckwheat groats in the diet of people with chronic diseases.

A promising direction for the cereal industry is the development of progressive innovative technologies for the production of various buckwheat groats. Cereal grain processing products occupy a leading place in the diet of modern people. They are suppliers of complex carbohydrates, proteins, vitamins, macro- and microelements and other valuable substances to the human body [5]. Buckwheat has great potential as a food ingredient, especially for the functional food industry [6]. Buckwheat groats contain high-nutritional protein, dietary fiber, resistant starch, rutin, D-chiroinosit, vitamins and minerals.

Buckwheat and cereals from it are traditional foods that are widely used all over the world. Buckwheat grain contains nutritious components in high quantities and can become the basis for creating a whole range of functional food products [7]. Buckwheat processing products are a source of protein, vitamins B (B_1, B_2, B_3), P, PP, E [8]. Various parts of the buckwheat plant, including seeds (grain), contain rutin, from which vitamin R is obtained. The buckwheat kernel has a high content of elements such as potassium, magnesium, phosphorus, iron, copper, and iodine. Buckwheat grain is a carrier of essential amino acids. In this respect buckwheat is inferior only to products of animal origin based on meat and milk. Which in modern social realities are economically inaccessible to consumers and less profitable for production for food enterprises [9].

Buckwheat is traditionally processed into buckwheat groats, an extremely important and useful food product [10]. The yield of groats during buckwheat processing ranges from 62 % or more, depending on the specifics of the technology, but it is possible to achieve a yield of 70–72 % by implementing modern, innovative grain processing technologies. The maximum groats yield in buckwheat grain is 74–76 %, depending on its quality, so the technological prospect is to obtain a higher groats yield [10]. There are many different technologies for producing buckwheat groats, each of them has disadvantages and advantages, but the search for innovative technological solutions continues.

Improvement of the technological process of buckwheat groats production is designed to preserve the nutritional value of the finished product as much as possible. The selection of rational modes of hydrothermal treatment of buckwheat grain allows preserving its valuable nutritional properties. In hydrothermal treatment, grain moistening and tempering operations are widely used. These operations are used in the hydrothermal treatment of grain of various crops, but it is in buckwheat production that they have found wide application.

The study of the features of the buckwheat grain moistening process arouses the interest of a wide range of researchers, processors and representatives of the scientific and technological community. The study of moisture distribution in buckwheat grain during moistening is of increased interest.

Hydrothermal treatment includes a number of operations that improve the consumer qualities of buckwheat groats. These include taste and nutritional qualities, namely, appearance, increased stability during storage. In the process of hydrothermal treatment, deep biochemical changes also occur, which causes not only changes in the chemical composition, but also in the structural and mechanical properties of the grain.

A promising direction is the development of an innovative technology for the production of buckwheat groats. In order to improve hydrothermal treatment, it is rational to introduce progressive treatment modes and wetting agents.

2. Literature review and problem statement

Currently, the population's needs for new food products, characterized by ecological purity and health-improving properties, are growing [11]. One of these products is buckwheat groats obtained from buckwheat grain. When growing buckwheat, chemical fertilizers are not used, which makes it environmentally friendly [12]. Due to the valuable composition of buckwheat grain, a wide range of products containing this cereal appeared on the market. Processes used during buckwheat processing can cause changes in valuable components, which affects their nutritional properties [13]. Buckwheat groats are a good source of bioactive components [14, 15].

They are good for health due to the content of ree sistant starch, mineral elements, proteins, phenolic substances, flavonoids. These substances prevent a number of chronic human diseases, including hypertension, obesity, cardiovascular diseases, and gallstone formation [16, 17].

The most important process affecting the quality of the product obtained during processing buckwheat into groats is hulling – the separation of films (outer shells) from grain [18]. There are differences in the chemical composition of buckwheat groats obtained by different hulling techu nologies, based on hulling raw or pre-processed grain [19]. Hulling of hydrothermally treated grain is one of the traditional methods of buckwheat processing in Europe and some parts of China and Japan [20]. During the hydrothermal treatment of buckwheat grain, part of the rutin turns into quercetin, a product of rutin breakdown [21]. Hydrothermal treatment with appropriate modes can increase the level of rutin in buckwheat groats [22]. Hydrothermal treatment processes significantly decrease the content of phenolic compounds, especially those that consumed the largest volumes of water [23]. An unresolved problem is to optimize the regulation of grain moisture and treatment temperature in order to preserve the biological value of the product.

Hydrothermal treatment can also have a positive effect on the finished product. The effect of hydrothermal treatment on the antioxidant potential of buckwheat products was noted. This is due to the formation of new antioxidants during the Maillard reaction after hydrothermal treatment of cereal grains [24, 25]. However, during hydrothermal treatment, a certain interaction between polyphenols and proteins occurs, which further reduces protein digestion [26]. Therefore, the optimization of the course of biochemical transformations during technological processing remains an unresolved problem.

Hydrothermal treatment of buckwheat grain is a mandatory technological operation in the production of instant buckwheat groats. Hydrothermal treatment can include additional operations, such as enzymolysis, ultrasonic treatment, microwave treatment, or steam explosion [27]. Hydrothermal treatment aims to create optimal conditions for separating rough shells from the kernel. As a rule, the production of buckwheat groats at cereal factories includes the following stages: heating, steaming, drying and cooling of grain. Disadvantages of the technological process lead to the loss of buckwheat kernels and biologically valuable grain components. Therefore, improving the technological process by moistening buckwheat grain before steaming will have a positive effect on preserving the kernel integrity after hulling.

Hydrothermal treatment of buckwheat grain is aimed at improving the indicators of hulling, grinding and nutritional properties of groats. The effect of two hydrothermal processes, namely steaming and soaking in boiling water of different durations, on buckwheat properties has already been evaluated [28]. An unresolved issue is that high temperatures in the process of hydrothermal treatment negatively affect the amino acid and vitamin composition of the product. To preserve the high content of amino acids, it is desirable to minimize exposure to high temperatures. Therefore, the selection of low-temperature hydrothermal treatment modes remains an unresolved issue.

The physico-chemical and textural properties of buckwheat starch can vary during moisture and heat treatment [29]. The influence of hydrothermal treatment on the components of buckwheat grain continues to be actively studied. Heat treatment with moisture reduces the swelling ability, solubility and oil absorption capacity of buckwheat starch. It also increases its water absorption capacity [30]. The selection of optimal modes can improve the thermal stability of buckwheat starch [31]. The preservation of the basic qualities of buckwheat grain components remains an unresolved issue.

The process of preparing buckwheat grain and improving its quality before processing occurs by thoroughly cleaning the grain material from foreign impurities followed by hydrothermal treatment. As a result of such processing, complex physico-chemical processes occur in the grain, which cause changes in the technological properties of grain raw materials and create optimal conditions for processing buckwheat grain into a finished food product.

As a rule, classic hydrothermal treatment consists of the following stages: heating of grain raw materials, moistening, tempering, steaming, drying and cooling. Thus, hydrothermal treatment allows changing the technological properties of raw materials by reducing the strength of buckwheat grain shells and increasing the strength of the kernel. Also, such processing helps to increase the utilization rate of buckwheat kernels and can improve the consumer properties and nutritional value of the finished product. The long duration of the steaming process remains an unsolved problem, which leads to a decrease in the protein content in the finished product [32]. Increased hydrophobicity of prolamins and glutelins is observed during heat and moisture treatment with a low heating temperature and short heat treatment time for raw materials with a high protein content. Therefore, reducing the time of this technological operation will improve the quality of buckwheat groats by preserving the high-protein composition [33].

In the process of hydrothermal treatment, the use of microwave radiation treatment is proposed [34]. The finished product demonstrated high water absorption capacity and improved ability to form stable emulsions. However, the problem of preserving the biological value of cereal products remains unresolved.

An important technological aspect is to obtain the maximum groats yield and reduce waste. Buckwheat waste is rich in bioactive components such as antioxidants and saccharides [35].

An option to overcome the relevant difficulties can be to use plasma-chemical technologies in the food industry. This is the approach used in [36], so plasma-chemical technologies have recently had various uses in the food industry. They are used for wastewater treatment in food production [37], in the production of microgreens and highly nutritious cereal seedlings [38]. They are also used as antiseptic agents in the food industry, for example, in the form of antiseptic ice when storing meat and fish [39]. Special attention of scientists is drawn to the study of the effect of plasma-chemical activation on the course of processes in various plant materials. However, studies of their impact on the technological process of buckwheat groats production have not been carried out before.

Plasma-chemical activation of water and aqueous solutions allows using a number of properties of water without its chemicalization by foreign chemicals [40]. During water activation, processes are implemented that contribute to changing the reactogenic properties of aqueous solutions. Thus, the properties of activated water that arise after plasma-chemical treatment can be rationally used in various areas of innovative food technologies. Water and aqueous solutions activated under the action of non-equilibrium contact plasma have antiseptic and antibacterial properties [41]. Plasma-chemically activated water is a cluster structure and can exhibit new properties that were little studied before, but are of considerable interest from a practical point of view [42]. Activated water has a specific composition, the most easily detectable are hydrogen peroxides and peroxide compounds, excited particles and radicals. These components play an important role in oxidation-reduction processes, and also accelerate the transport of moisture into grain material, correct biochemical transformations in grains of various cultures [43]. Plasma-chemical activation partially changes the structure of water. Water clusters are actively crushed under the action of cold contact plasma. This leads to the effect of more active transport of such crushed particles through the membranes and shells of grain during its soaking and further processing [43]. The clusters contain microparticles of hydrogen peroxide, which when in contact with food raw materials are able to form active oxygen and water [44]. This, accordingly, can correct biochemical transformations in grain during technological processing.

If we compare the technology of plasma-chemical activation of water with other grain processing technologies, we can note its chemical safety. This can be explained by the fact that its active components are decomposed during technological processing and the finished product does not contain any foreign chemical impurities [43]. The shortcomings of the technology include the lack of large-scale industrial use of plasma-chemically activated aqueous solutions.

All this allows us to state that it is appropriate to carry out research on the use of activated aqueous solutions in the process of hydrothermal treatment of buckwheat grain. This will make it possible to improve the existing technologies for the production of highly valuable buckwheat groats and obtain a high-quality and chemically pure, highly nutritious food product. Therefore, it is promising to conduct a study on the selection of processing modes and the use of plasma-chemically activated aqueous solutions in the process of hydrothermal treatment of buckwheat grain, which can improve the process of buckwheat processing into highly nutritious cereal products. In the future, this will allow us to improve the existing technologies of processing grain into cereals and obtain high-quality and chemically pure, highly nutritious cereal products.

3. The aim and objectives of the study

The aim of the study is to develop a technology for the production of buckwheat groats using plasma-chemically activated aqueous solutions. This will make it possible to optimize the technological process of buckwheat groats production and improve the nutritional qualities of the finished product.

To achieve the aim, the following objectives must be accomplished:

– to study changes in the moisture content of buckwheat grain during moistening and tempering;

– to investigate the yield of buckwheat groats;

– to investigate the amino acid and vitamin composition of buckwheat groats;

– to investigate the microbiological parameters of buckwheat groats;

– to develop a flowsheet for the production of buckwheat groats using plasma-chemically activated aqueous solutions.

4. Research materials and methods

4. 1. Research object and hypothesis

The research object is buckwheat grain.

Plasma-chemically activated aqueous solutions were chosen for the research. These solutions are already used in various food technologies [39–41], but it is promising to expand the scope of this innovative technology for processing technological solutions.

The main hypothesis of the research is the improvement of the hydrothermal treatment of buckwheat grain and the increase of the yield of buckwheat groats using plasma-chemically activated aqueous solutions. Plasma-chemically activated aqueous solutions were used as an intensifier of the technological process of moistening and tempering of buckwheat grain.

Plasma-chemically activated aqueous solutions were obtained in the Specialized Laboratory of Plasma Processing of Process Solutions of Food Industries of the Dnipro State Agrarian and Economic University and KNP-TECHNOLOGY Research and Production Enterprise LLC (Dnipro, Ukraine). The research was carried out on the basis of the research 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. Researched materials and equipment used in the experiment

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

Activation of water for the hydrothermal treatment of buckwheat, namely, for the moistening process, was carried out using the technology of plasma-chemical activation of aqueous solutions [41, 44]. For this purpose, a laboratory setup for plasma-chemical activation of aqueous solutions was used [40]. The laboratory analog of an industrial installation is a three-arc plasma-chemical installation and consists of a reactor, anodes, cathode, reflux condenser, power source, and vacuum pump. Plasma-chemically activated aqueous solutions were produced to moisten buckwheat grain, the characteristics of which are shown in Table 1. The concentration of hydrogen peroxide in activated water was determined by iodometry.

Table 1

Characteristics of water activated by contact non-equilibrium plasma

Experiment	Water	Activation time, min.	Concentration of hydrogen peroxide, mg/l
1 (control)	Tap	–	–
2	Activated	5	100
3	Activated	7	200
4	Activated	10	300
5	Activated	20	400
6	Activated	25	500
7	Activated	30	600
8	Activated	60	700

The duration of the activation process ranged from 5 to 60 minutes, accordingly solutions were obtained in which the concentration of the active substance (hydrogen peroxide) in the process water varied from 100 to 700 mg/l. Longer activation time does not give the desired effect due to increased energy consumption and slower accumulation of the active component. According to the indicated peroxide concentrations, the following research groups were formed:

1 – control (ordinary mains water was used for sample processing);

2 – plasma-chemically activated water (H_2O_2 concentration 100 mg/l);

3 – plasma-chemically activated water (H_2O_2 200 mg/l);

4 – plasma-chemically activated water (H_2O_2 300 mg/l);

5 – plasma-chemically activated water (H_2O_2 400 mg/l);

6 – plasma-chemically activated water (H_2O_2 500 mg/l);

7 – plasma-chemically activated water (H_2O_2 600 mg/l);

8 – plasma-chemically activated water (H_2O_2 700 mg/l).

4. 2. 2. Selection of raw materials for the production of buckwheat groats and features of hydrothermal treatment of buckwheat grain

Buckwheat grain was chosen as the raw material for the production of buckwheat groats. The studied grain had the characteristics shown in Table 2.

Table 2

Physico-chemical indicators of buckwheat grain

Indicator	Mass fraction, %
Moisture content	12.0±1.02
Protein	13.2±0.89
Carbohydrates	58.4±2.84
Dietary fiber	12.3±1.15
Fats	1.9±0.09
Ash content	2.1±0.11

The technological process is carried out as follows: hydrothermal treatment includes grain heating, moistening with plasma-chemically activated aqueous solutions up to 18–22 %, steaming, low-temperature drying, high-temperature drying, cooling. Intensive moistening was carried out by mixing the grain with sprayed activated solutions, which were fed into the auger under pressure using nozzles. So, a screw mixer and a tempering hopper were used, the tempering time was 5–15 min., which ensured the required moistening level of grain raw materials.

The grain cleaned of foreign impurities enters the heating hopper, then into the moistening auger, to which plasma-chemically activated aqueous solutions from the industrial activation plant are fed by nozzles. The peroxide content in the activated aqueous solutions is 100–700 mg/l. As a result of contact of buckwheat grain with activated solutions and uniform mixing, active absorption of the activated solution by buckwheat grain occurs. For uniform moistening of the grain material, it is sent to the tempering hopper. The moisture content before steaming is 18–22 %, the optimum is 20 %. The grain with this moisture content was sent to the steamer, after which it was dried in two stages in a low-temperature dryer, then in a high-temperature dryer and sent for processing. After hydrothermal treatment, the grain was sent for sorting. A feature of buckwheat processing is its separation into six size fractions before hulling. Next, the grain was sent to hulling, so under the action of the working bodies of hulling machines in the gap between the roller and decks, buckwheat grain undergoes complex deformation, as a result of which shells are separated from kernels.

4. 3. Methods of determining the properties of samples

4. 3. 1. Method of determining the moisture content of buckwheat grain during moistening and tempering

In the course of the research, the moisture content was recorded every hour, during 10 hours of the tempering process. Determination was carried out by drying buckwheat grain by a standard method, namely, using a drying cabinet. The control was carried out using a SuperPro automatic moisture meter (Manufacturer: SUPERTECH AGROLINE AGROELECTRONICS, Denmark).

Econometric modeling with regression-correlation analysis was used in the study to analyze the relationships between explained dependent variables and explanatory independent factors [45].

Classic linear econometric regression models from N factors X_i, i=1...N, have the following form:

$$Y=A0+A1\times X1+...AN\times XN,$$

where the numerical coefficients $A0$, $A1$, ..., AN are calculated by the least squares method based on sample actual data from M observations.

The ability of the model to explain changes in Y due to changes in factors Xi, i=1...N, is estimated by the coefficient of determination R^2, which should be as close as possible to 1. The reliability of the predictive regression conclusions is checked by the Fisher's test, which, if the condition is met:

$$R^2/(1-R^2)\times df2/df1>F(\alpha, df1, df2),$$

confirms the conclusion about the statistical significance of the model with a given level of significance α, degrees of freedom $df1=N$ and $df2=M-N-1$ and the corresponding critical value of the Fisher's test $F(\alpha, df1, df2)$. Factor analysis involves the application of the two-tailed Student's test, which, if the condition is met:

$$|Ai/\mathbf{s}i|=|T(Xi)|>T(\alpha, df),$$

confirms the conclusion about the statistical significance of the factor Xi with a standard error **s**i of the coefficient Ai, given level of significance α, degree of freedom $df=M-N-1$ and the corresponding critical value of the Student's test $T(\alpha, df)$.

In order to quantitatively analyze the dynamics of experimental indicators, the index transformation of sample data of the experiment and control (Ci) with the initial raw material as a base (Bi) was applied. The calculation formula for indices Ii based on a sample of N observations had the following form:

$$Ii=Ci/Bi,\ i=1...N.$$

Comparison of the experimental and control indices was carried out using descriptive statistical indicators of the average index Imean, minimum index Imin, maximum index Imax, and range of variation ΔI [45], where:

$$I\text{mean}=\Sigma_{i=1...N}Ii/N,$$

$$I\text{min}=\text{min}_{i=1...N}Ii,$$

$$I\text{max}=\text{max}_{i=1...N}Ii,$$

$$\Delta I=I\text{max}-I\text{min}.$$

Therefore, the analysis of dependencies between explained dependent variables and explanatory independent factors in the study was carried out by means of econometric modeling with regression-correlation analysis.

4. 3. 2. Methods of studying the yield of buckwheat groats

The resulting product consists of groats and crushed grain. Groats are buckwheat kernels, freed from shells, not ground, which do not pass through a 1.6×20 mm sieve. Crushed grain is the particles of kernels split during processing, which pass through a metal woven sieve No. 08. When assessing the quality of buckwheat varieties, preference is given to those with large, even grain.

The shells are separated by short-term clamping and shearing. This process is carried out in an LVS-1 roller deck device with a sickle-shaped working area and a regular gap between the roller and the deck. The size of the working gap depends on the grain size of the processed fraction and should be 0.1 mm smaller than the hole diameter of the sieve, by screening through which the processed grain fraction was obtained. Hulling is carried out by fraction, starting with the largest one. Hulling products from the working area fall into the guide oscillating tray, on which they are self-sorted, as a result of which films and flour are concentrated mainly in the upper layer. In a layered state, the products enter the expansion chamber, where, under the action of an upward air current, the chaff and flour are sucked out and sent to the sedimentation chamber, and the kernels and unhulled grains fall into the collector. The effectiveness of buckwheat hulling on LVS-1 varies widely depending on fraction size. After hulling, the weight consists of a mixture of hulled and unhulled grains, so processing is carried out with an intermediate selection of kernels. Unhulled buckwheat grains are selected from the groats and smaller hulling products by sorting on sieves with holes 0.2–0.3 mm smaller than the diameter of the sieve holes that characterize the size of this fraction. At the same time, the unhulled grains are tailings, and the groats and crushed grain are outsiftings. Hulled kernels are separated after each pass of the fraction through the roller deck machine, and unhulled kernels are sent for reprocessing; to hull each fraction, it is necessary to make from 3 to 15 passes. In each fraction, a few unhulled grains are allowed to remain, which are joined to the next fraction for hulling. After hulling the smallest fraction of the weight, unprocessed rudiac remains (feed waste), the amount of which should not exceed 1 %.

4. 3. 3. Methods of determining the amino acid and vitamin composition of buckwheat groats

The analysis of the amino acid content in buckwheat groats was carried out by ion-exchange liquid column chromatography on a T339 automatic amino acid analyzer, manufactured in the Czech Republic, Prague.

The vitamin composition of germinated flax seeds was also determined using ion-exchange liquid column chromatography and other standard methods [11].

4. 3. 4. Methods of determining the microbiological indicators of buckwheat

The total microbial count (QMAFAnM) was determined by the classical method of inoculation on agarized nutrient media, followed by incubation of the cultures and counting of cultivated microbial colonies. The microbiological indicators of buckwheat were determined by standard methods according to DSTU 8446:2015 Food products. Methods of determining the number of mesophilic aerobic and facultative anaerobic microorganisms.

5. Results of studies of indicators of the technological process of buckwheat groats production

5. 1. Study of changes in the moisture content of buckwheat grain during moistening and tempering

To optimize the hydrothermal treatment of buckwheat grain before steaming, it was moistened with plasma-chemically activated aqueous solutions with a peroxide concentration of 100–700 mg/l. In the future, this will allow increasing the mass fraction of buckwheat groats at the optimal level of increasing labor and energy costs and maintaining the minimum product cost.

The influence of the degree of moistening of buckwheat grain with activated aqueous solutions on further technological characteristics was studied. Buckwheat grain had an initial moisture content of 12 %, and was moistened to a moisture content of 20 % or more. The results are given in Table 3.

Analyzing the results shown in Table 3, it should be noted that the study of the effect of activated solutions on tempering time was carried out under the established modes. Namely, the water temperature ranged from 10 to 60 °C (with a corresponding step of 10 °C), the tempering time varied from 2 to 10 h. Thus, the buckwheat grain reached the desired moisture level in the control sample at a temperature of 60 °C after 6 hours. When using plasma-chemically activated aqueous solutions, a similar result was obtained at a temperature of 20 °C. If we consider a temperature of 40 °C, then the desired moisture level was achieved in 2 hours, which will significantly speed up the technological process. If necessary, the temperature can be lowered to 30 °C, but the process will last 4 hours. Therefore, the optimal temperature of the tempering process using plasma-chemically activated aqueous solutions should be considered exactly 40 °C.

As described in the research methodology, econometric modeling [45] based on sample data in Table 3 made it possible to obtain a linear three-factor (N=3) regression. With the explained dependent variable Y relative to the moisture content of buckwheat grain when moistened and tempered, %, and explanatory independent variables:

$X1$ – the temperature of the plasma-chemically activated aqueous solution, °C,

$X2$ – the concentration of hydrogen peroxide in the buckwheat grain moistening solution, mg/l,

$X3$ – tempering time, h.

The calculations carried out using the MS Excel spreadsheet processor tools on a data set of M=240 observations given in Table 3 resulted in a regression of the form:

$$Y=12.661+0.073X1+0.005X2+0.426X3. \quad (1)$$

With the coefficient of determination R^2=0.976, it can explain 97.6 % of changes in the values. Namely, the moisture content of buckwheat grain due to changes in the temperature of the plasma-chemically activated aqueous solution, the concentration of hydrogen peroxide in it during buckwheat grain moistening, and tempering time. At the level of significance α=0.01 and degrees of freedom $df1=N=3$ and $df2=M-N-1=240-3-1=236$, the Fisher's test condition is met:

$$R^2/(1-R^2)\times df2/df1=3225.740>3.866=F(\alpha, df1, df2).$$

Table 3

Buckwheat grain moisture content during moistening and tempering, %

Experiment	Tempering time, h					
	0	2	4	6	8	10
t=10 °C						
1 (control)	12.0	13.7	14.9	15.8	16.7	17.1
2	12.0	14.3	15.6	16.3	17.1	18.4
3	12.0	14.9	16.1	17.4	18.3	19.0
4	12.0	15.0	16.5	17.6	18.9	19.5
5	12.0	15.3	16.9	18.1	19.2	20.1
6	12.0	16.1	17.3	18.6	19.4	20.5
7	12.0	16.9	17.6	18.9	19.7	21.0
8	12.0	17.4	18.2	19.1	20.1	21.9
t=20 °C						
1 (control)	12.0	14.8	15.5	16.3	17.4	18.2
2	12.0	15.6	16.1	17.5	18.3	19.3
3	12.0	15.8	17.2	18.1	19.1	20.1
4	12.0	16.9	17.6	18.7	19.8	20.4
5	12.0	17.0	17.8	19.3	20.1	21.2
6	12.0	17.5	18.7	19.2	20.5	21.5
7	12.0	18.1	18.9	19.6	20.8	21.9
8	12.0	19.0	19.4	20.3	21.3	22.0
t=30 °C						
1 (control)	12.0	15.1	16.4	17.2	18.3	18.8
2	12.0	16.2	17.3	18.1	19.4	19.9
3	12.0	16.7	17.8	18.4	19.5	20.7
4	12.0	17.3	18.1	18.9	20.1	20.9
5	12.0	18.1	18.7	19.8	20.6	21.5
6	12.0	18.4	19.3	20.1	20.9	21.6
7	12.0	19.1	20.1	20.7	21.2	21.9
8	12.0	19.5	20.3	21.4	22.1	23.2
t=40 °C						
1 (control)	12.0	15.8	16.9	17.5	19.1	19.7
2	12.0	17.5	17.9	18.8	19.5	20.4
3	12.0	17.9	18.5	18.8	20.3	20.9
4	12.0	18.5	18.9	19.9	20.6	21.3
5	12.0	18.9	19.4	20.2	21.0	21.6
6	12.0	19.3	20.0	20.3	21.1	21.8
7	12.0	19.8	20.5	21.3	21.8	22.4
8	12.0	20.1*	20.6	21.8	22.4	23.5
t=50 °C						
1 (control)	12.0	16.9	17.7	18.6	20.0	20.2
2	12.0	17.8	18.3	19.5	20.4	20.7
3	12.0	18.3	19.5	19.8	20.6	21.8
4	12.0	19.6	19.9	20.5	21.2	21.9
5	12.0	19.9	20.2	20.8	21.3	22.4
6	12.0	20.4	21.1	21.6	22.5	22.8
7	12.0	20.7	21.3	21.8	22.7	23.1
8	12.0	20.9	21.4	22.5	23.2	23.8
t=60 °C						
1 (control)	12.0	17.8	19.3	20.1*	20.0	20.2
2	12.0	18.5	19.3	20.2	21.1	21.9
3	12.0	19.1	19.9	20.7	21.3	22.5
4	12.0	19.9	20.3	21.1	21.9	22.8
5	12.0	20.2	21.1	21.6	22.4	23.9
6	12.0	20.8	21.6	22.3	22.9	24.0
7	12.0	21.2	21.8	22.6	23.5	24.2
8	12.0	21.8	22.5	22.9	23.7	24.8

*Note: * – samples tested for amino acid content*

Thus, model (1) provides a prediction accuracy of more than 99 %.

The moisture content of buckwheat grain undergoes co-directional changes with changes in the values of model factors (1). Namely, the positive regression coefficients (1) report that:

– an increase/decrease in the temperature of the plasma-chemically activated aqueous solution by 1 °C results in an increase/decrease in the moisture content of buckwheat grain by 0.073 p.p. (or 0.73 % in response to temperature changes by a step of 10 °C);

– an increase/decrease in hydrogen peroxide concentration in the moistening solution by 1 mg/l leads to an increase/decrease in the moisture content of the processed buckwheat grain. So, by 0.005 p.p., or 0.5 % in response to changes in hydrogen peroxide concentration by a step of 100 mg/l;

– an increase/decrease in moistening time by 1 hour results in an increase/decrease in the moisture content of buckwheat grain by 0.426 p.p.

All these coefficients have a reliability of more than 99 %, because they meet the conditions of the Student's test at the level of significance α=0.01 and degree of freedom $df = M-N-1=240-3-1=236$, namely:

$$|T(X1)|=58.361>2.597=T(\alpha, df),$$

$$|T(X2)|=55.861>2.597=T(\alpha, df),$$

$$|T(X3)|=56.131>2.597=T(\alpha, df).$$

The conducted statistical analysis allowed us to prove that model (1) can be applied in determining the optimal technological parameters of moistening buckwheat grain with activated aqueous solutions. For example, if there are certain requirements for the temperature regime and the speed of reaching the target moisture content. Namely, according to formula (1), it is calculated that in 1 hour it is possible to reach a maximum moisture content of buckwheat grain of 20 % at a temperature of 60 °C. Accordingly, the minimum possible hydrogen peroxide concentration of 480.17 mg/l in the solution or at a hydrogen peroxide concentration of 700 mg/l with the minimum possible temperature of 44.32 °C.

5. 2. Study of the yield of buckwheat groats

The effectiveness of the proposed hydrothermal treatment technology was evaluated based on the mass fraction of whole kernels after hulling (Table 4). For the study, samples that underwent tempering at a temperature of 40 °C were taken.

Analyzing the results shown in Table 4, it can be concluded that the proposed technology will increase the mass fraction of whole kernels by 1.9–6 % compared to the classical technology (control). This is due to the use of plasma-chemically activated aqueous solutions for moistening buckwheat grain. Activated solutions qualitatively change the technological properties of grain material, namely, they weaken the bond between the shell and the kernel, which contributes to better hulling of buckwheat grain.

According to the research methodology, econometric modeling was carried out [45] based on sample data from Table 4. To determine the effect of the explanatory independent variable X in relation to the concentration of hydrogen peroxide in the buckwheat grain moistening solution, mg/l, on the 3 explanatory dependent variables about product yield, namely:

$Y1$ – groats, %,

$Y2$ – crushed grain, %,

$Y3$ – feed flour, %.

Table 4

Yield of buckwheat groats when using plasma-chemically activated aqueous solutions, %

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Product yield, %		
			groats	crushed grain	feed flour
1 (control)	Tap	–	68.0	0.8	1.2
2	Activated	100	69.9	0.7	1.0
3	Activated	200	70.1	0.7	0.9
4	Activated	300	70.3	0.6	0.7
5	Activated	400	71.1	0.5	0.5
6	Activated	500	72.5	0.4	0.4
7	Activated	600	73.2	0.3	0.1
8	Activated	700	74.0	0.2	0.1

The calculations carried out using the MS Excel spreadsheet tools on a data set of M=8 observations presented in Table 4 made it possible to obtain regressions of the form:

$$Y1=68.367+0.0079X, \quad (2)$$

$$Y2=0.825-0.0009X, \quad (3)$$

$$Y3=1.917-0.0017X. \quad (4)$$

Regression graphs are shown in Fig. 1. The coefficients of determination R^2 of regressions (2)–(4) are 0.959, 0.980, 0.984, respectively. They indicate that the hydrogen peroxide concentration in plasma-chemically activated aqueous solutions for moistening buckwheat grain determines 95.9 %, 98 % and 98.4 % of the yield of groats, crushed grain and feed flour. Econometric models (2)–(4) have a prediction reliability of more than 99 % under the conditions of the Fisher's test at the significance level α=0.01 and degrees of freedom $df1=N=1$ and $df2=M-N-1=8-1-1=6$ according to:

$$F(Y1)=139.050>13.745=F(\alpha, df1, df2),$$

$$F(Y2)=288>13.745=F(\alpha, df1, df2),$$

$$F(Y3)=369.191>13.745=F(\alpha, df1, df2).$$

All slope coefficients in models (2)–(4) have a reliability of more than 99 %, because they fulfill the conditions of the Student's test at the level of significance α=0.01 and degree of freedom $df=M-N-1=8-1-1=6$, namely:

$$|T(Y1)|=11.792>3.707=T(\alpha, df),$$

$$|T(Y2)|=16.971>3.707=T(\alpha, df),$$

$$|T(Y3)|=19.214>3.707=T(\alpha, df).$$

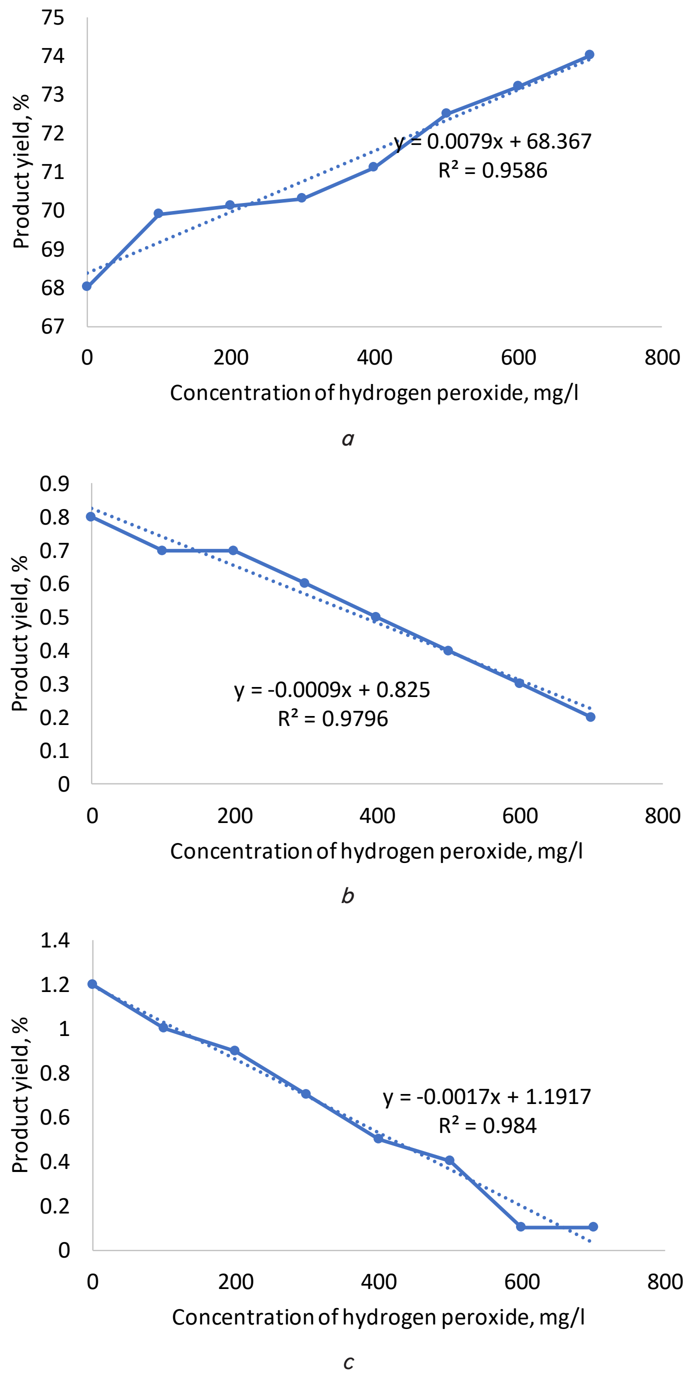

Fig. 1. Graphs of econometric models (1)–(3): *a* – groats; *b* – crushed grain; *c* – feed flour

Therefore, the positive slope coefficient of the regression (2) indicates that an increase/decrease in hydrogen peroxide concentration in the buckwheat grain moistening solution by 1 mg/l also increases/decreases the groats yield by 0.0079 p.p. or 0.79 % in response to changes in the hydrogen peroxide concentration by a step of 100 mg/l. However, according to the negative slope coefficients of regressions (3) and (4), an increase/decrease in hydrogen peroxide concentration in the buckwheat grain moistening solution by 1 mg/l reduces/increases the yield of crushed grain and feed flour, respectively, by 0.0009 p.p. and 0.0017 p.p. (or –0.09 % and –0.17 % in response to changes in hydrogen peroxide concentration by a step of 100 mg/l).

5. 3. Study of the amino acid and vitamin composition of buckwheat groats

The results of studies of the amino acid composition are shown in Table 5. Experiments were conducted for samples that reached a moisture content of 20 % in the shortest possible time, both in the control and in the experiment.

Table 5

Amino acid content in buckwheat, % of total protein

Amino acid	Indicator, % of total protein		
	buckwheat grain	control (buckwheat groats)	experiment (buckwheat groats)
Lysine	5.0	4.5	4.9
Histidine	3.8	3.2	3.6
Arginine	10.3	8.4	10.2
Aspartic acid	9.0	8.7	9.0
Threonine	3.2	3.0	3.1
Serin	4.7	4.1	4.5
Glutamic acid	19.6	19.1	19.4
Proline	6.1	4.1	5.9
Glycine	5.8	5.5	5.7
Alanine	4.1	3.9	4.0
Valine	4.0	3.4	3.9
Methionine	1.2	1.0	1.1
Isoleucine	2.6	2.1	2.4
Leucine	5.2	4.8	5.1
Tyrosine	3.1	2.7	3.0
Phenylalanine	3.6	3.1	3.5
Total content	91.3	81.6	89.3

Table 5 shows the results of analyzing the content of individual amino acids in the studied samples. Special attention should be paid to the experiment with buckwheat groats obtained using plasma-chemically activated aqueous solutions. In the experimental sample, the total amino acid content is 7.7 % higher than in the control. Compared to the basic amount of amino acids in buckwheat grain, only 2 % was lost during processing, which allows us to talk about the preservation of the original beneficial properties of highly valuable raw materials.

According to the research methodology, for the quantitative analysis of the dynamics of amino acid content, according to Table 5, the indices $I1$ of the decrease in the amino acid content $C1$ in the control (buckwheat groats) relative to the base B in buckwheat grain, as well as the indices $I2$ of the change in the amino acids content $C2$ in the experiment (buckwheat groats) relative to the same base B in buckwheat grain, were calculated, i.e.:

$I1=C1/B$, $I2=C2/B$.

Table 6 contains clear evidence that buckwheat groats in the experiment by all indicators lose less amino acids than the control and are more attractive in terms of nutritional qualities.

An important stage of research on the quality of buckwheat groats is the analysis of changes in the vitamin composition. In the process of classic hydrothermal treatment, the vitamin content in buckwheat groats is reduced as a result of temperature. Studies of groats during the research are given in Table 7.

Table 6

Index dynamics of amino acids in buckwheat groats

Index	Control	Experiment
average Imean	0.877	0.968
minimum Imin	0.672	0.917
maximum Imax	0.974	1.000
range of variation ΔI	0.302	0.083

Table 7

Vitamin content in buckwheat groats, mg/100 g of product

Vitamin	Initial raw material (buckwheat grain)	Control sample (standard hydrothermal treatment)	Experimental sample (hydrothermal treatment using plasma-chemically activated aqueous solutions)
Vitamin B_1	0.41	0.21	0.39
Vitamin B_2	0.19	0.10	0.18
Vitamin B_3	6.01	2.75	5.93
Vitamin B_4	53.90	26.7	52.8
Vitamin B_5	0.45	0.21	0.43
Vitamin B_6	0.30	0.18	0.28
Vitamin K	0.007	0.004	0.006
Vitamin E	5.81	3.31	5.77
Vitamin PP	4.22	2.15	4.01
Vitamin P	36.1	21.3	34.2

Analyzing the data in Table 7, it should be noted that the amount of vitamins in the experimental material was greater than in the control. According to the research methodology, for the quantitative analysis of the dynamics of vitamin content, according to Table 7, the indices $I1$ of the reduction in the vitamin content $C1$ in the control sample after standard hydrothermal treatment relative to the base B in the initial raw material of buckwheat grain were calculated. As well as the indices $I2$ of the change in the vitamin content $C2$ in the experimental sample after hydrothermal treatment using plasma-chemically activated aqueous solutions relative to the same base B in the initial raw material in buckwheat grain, i. e.:

$I1=C1/B$, $I2=C2/B$.

Table 8 contains clear evidence that buckwheat groats in the experiment by all indicators lose less vitamins than the control, which indicates the advantage of hydrothermal treatment technology using plasma-chemically activated aqueous solutions.

Table 8

Index dynamics of vitamins in buckwheat groats

Index	Control	Experiment
average Imean	0.523	0.950
minimum Imin	0.458	0.857
maximum Imax	0.600	0.993
range of variation ΔI	0.142	0.136

Analyzing the results shown in Tables 7, 8, it should be noted that with standard hydrothermal treatment, significant vitamin losses are observed. When using activated aqueous solutions as a moistening agent, the tempering temperature decreases and, as a result, we see a fairly high level of vitamin preservation in buckwheat groats.

5. 4. Study of the microbiological indicators of buckwheat groats

To determine the storage duration of buckwheat groats produced using plasma-chemically activated aqueous solutions, microbiological studies were conducted. The results are given in Table 9.

Table 9

Changes in the microbiological parameters of buckwheat groats during storage ((n=5, p≥0.95)

Groups of microorganisms	Sample	Storage period, months						
		0	2	4	6	8	10	12
QMAFAnM, thousand CFU/g	Control	2.4	2.7	2.2	1.9	1.6	1.5	1.4
	Experiment	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Fungi, thousand CFU/g	Control	1.1	1.7	1.8	2.1	2.4	2.5	2.6
	Experiment	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Escherichia coli bacteria (E. coli), in 0.1 g of the product	Control	0.00	0.04	0.10	0.11	0.14	0.12	0.12
	Experiment	Not found						

Table 9 shows the results of a microbiological study of buckwheat groats. It should be noted that no pathogenic microflora was detected in the experimental samples immediately after production. However, during storage and partial contamination of the product with microorganisms, there is still a significant decrease in the amount of microflora when using plasma-chemically activated aqueous solutions.

5. 5. Development of a flowsheet for the production of germinated flax seeds using plasma-chemically activated aqueous solutions

For the future industrial implementation of the proposed technology, a flowsheet for the production of buckwheat groats using plasma-chemically activated aqueous solutions has been developed (Fig. 2).

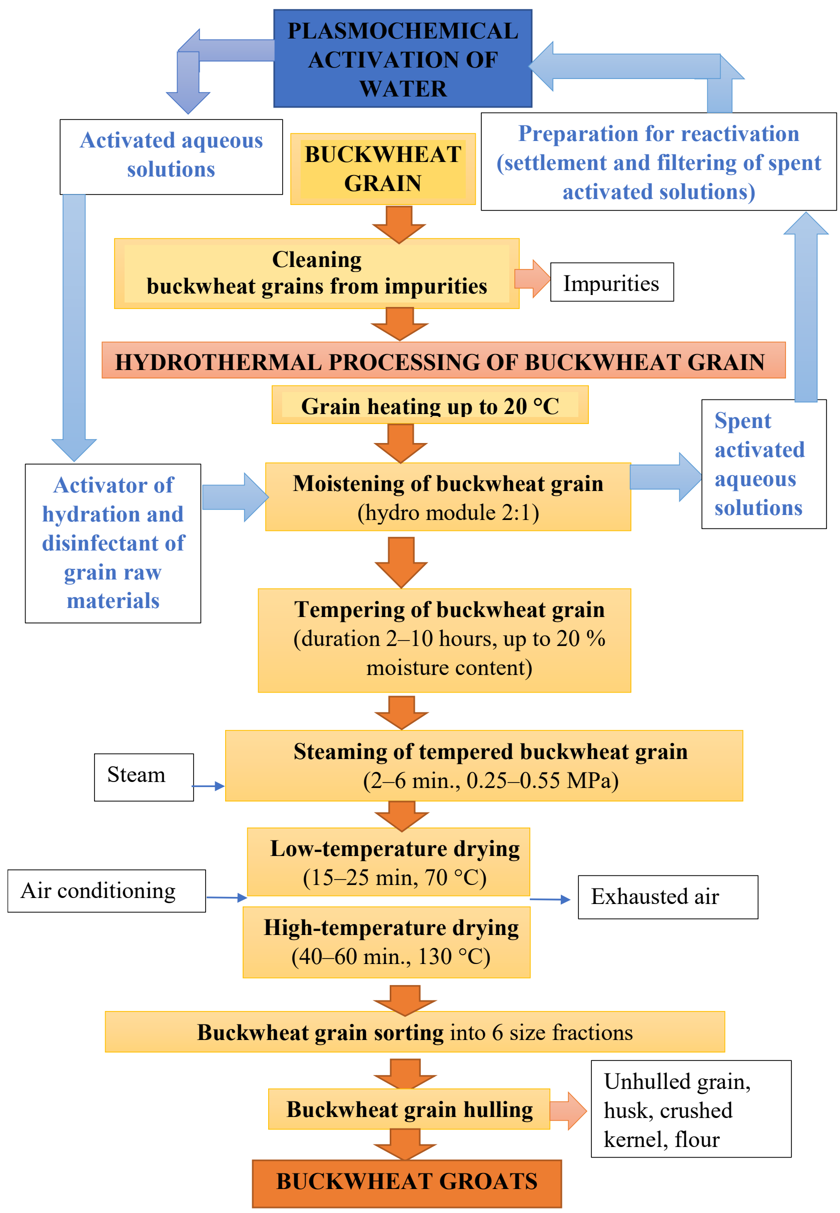

Fig. 2. Flowsheet for the production of buckwheat groats using plasma-chemically activated aqueous solutions

The flowsheet for the production of buckwheat groats using plasma-chemically activated aqueous solutions shown in Fig. 2 gives a comprehensive idea of the course of the technological process taking into account the proposed innovative component.

6. Discussion of the results of the study of buckwheat groats production technology

The analysis of the obtained results (Table 3) allows us to note that plasma-chemically activated aqueous solutions have a significant effect on tempering time. Thus, the buckwheat grain reached the desired moisture level in the control sample at a temperature of 60 °C after 6 hours. When using plasma-chemically activated aqueous solutions, a similar result was obtained in 6 hours at a temperature of 20 °C. If we consider a temperature of 40 °C, the desired moisture level was achieved in 2 hours, which will significantly speed up the technological process. If necessary, the temperature can be lowered to 30 °C, but the process will last 4 hours. Therefore, the optimal temperature of the tempering process using plasma-chemically activated aqueous solutions should be considered exactly 40 °C.

The rapid saturation of buckwheat grain with moisture is explained by the fact that plasma-chemically activated aqueous solutions can actively diffuse into the grain. The chaotic movement of ions in plasma-chemically activated water makes it possible to accelerate the diffusion of water into the flaxseed due to a more active influx of charged particles to the surface of the raw material [43, 44]. This is explained by the small-cluster structure of activated water, which seeps well into the pores and microcracks of the grain. Thus, buckwheat grain has a capillary-porous structure, and as a result of hydrothermal treatment involving activated aqueous solutions, the kernel surface, i.e. the seed coat, is subject to the greatest changes. With such processing, the grain gains moisture and increases in its linear dimensions and volume, which leads to deformation of the kernel and changes on its surface. It should be noted that preliminary high-quality moistening of buckwheat grain with plasma-chemically activated aqueous solutions can increase the mass fraction of whole kernels and the total yield of the finished product. Thus, when grains are moistened, the kernel surface and the shell can be deformed, especially if the moistening process is very intense. It is desirable to increase the integrity of the buckwheat kernel when using activated moistening solutions, which is associated with a weakening of the bond between the shell and the kernel.

Moisture content significantly affects the structural, mechanical and technological properties of grain. An increase in the moisture content of the buckwheat kernel leads to a decrease in hardness and an increase in plastic deformation, which the kernel can undergo before destruction, including during grain hulling. Therefore, for intensive moistening of buckwheat grain, plasma-chemically activated aqueous solutions were used, which can intensify the process of moisture transport to the grain material.

After examining the yield of buckwheat grain (Table 4), it can be concluded that the proposed technology will increase the mass fraction of whole kernels by 1.9–6 % compared to the classical technology (control). So, activated solutions qualitatively change the technological properties of the grain material, namely, they weaken the bond between the shell and the kernel. During moistening buckwheat grain, intensive movement of moisture to the grain was observed. This leads to the swelling of proteins and a decrease in the number of cavities between starch grains. As a result, the porous and loose structure of buckwheat endosperm becomes denser and increases in size. This leads to the deformation of the surface microstructure of both the kernel and shells. Deformation of the surfaces leads to the occurrence of internal stress, due to the difference between the expansion of the kernel and shell of buckwheat grain, as well as to a weakening of the bond between them. This makes the hulling process more efficient, contributing to the qualitative separation of the shell from the kernel. At the same time, the intensification of moistening using activated solutions only strengthens this effect.

Buckwheat grain proteins are sensitive to high-temperature processing, as they contain a significant part of the water-salt fraction. Therefore, with an increase in the temperature of the technological process, a general decrease in the amino acid content can be observed due to protein denaturation. When heated, the protein macromolecule usually loses its native state. Hydrothermal treatment of buckwheat grain, namely the high temperature of the process, can destroy amino acids, which reduces the amount of amino acids in buckwheat groats. Analyzing the amino acid composition, it should be noted that the number of amino acids in the experimental samples increases. As a rule, the reason for the decrease in the amino acid content as a result of hydrothermal treatment is the formation of non-hydrolyzable complexes with other compounds, for example, melanoidins. Since the total process temperature is reduced, it is logical to maximize the preservation of the amount of amino acids in samples where the temperature of hydrothermal treatment was lower. So, in the experimental sample, the total content of amino acids is 7.7 % higher than in the control. Compared to the basic amount of amino acids in buckwheat grain, only 2 % was lost during processing, against 9.7 % in the control, which suggests preserving the original beneficial properties of highly valuable raw materials. Comparing the obtained results with the results of other researchers [7], it should be noted that the original amino acid composition of the raw material is significantly preserved, which is a positive technological result.

The analysis of the vitamin composition of buckwheat groats (Table 7) showed that the amount of B vitamins in the experimental material was 35–54 % higher than in the control. The content of vitamin K changed insignificantly. There was 43 % more vitamin E in the experimental samples than in the control and 46 % more vitamin PP. A significant preservation of rutin was noted, it is more in the experimental samples by 38 %. Comparing the obtained results with the results of other researchers [7, 16], the expected preservation of the vitamin composition when using lower temperatures of hydrothermal treatment should be noted.

All grains, including buckwheat, contain microorganisms on their surface, in particular, pathogenic ones. It is known that plasma-chemically activated aqueous solutions have a disinfecting effect [37–40]. Therefore, it is advisable to use them in the fight against microbiological contamination of food raw materials.

The microbiological state of buckwheat groats was studied. Analyzing the data in Table 9, it should be noted that immediately after the production of buckwheat groats, no pathogenic microflora was detected in them. However, during storage and partial contamination of the product with microorganisms, there is still a significant decrease in the amount of microflora when using plasma-chemically activated aqueous solutions. It should be noted that a decrease in the amount of mesophilic microflora during 12 months of storage occurs due to the death of bacteria of the genus Pseudomonas herbicola, as well as lactic acid bacteria. Buckwheat groats obtained using plasma-chemically activated aqueous solutions contained a minimum amount of microorganisms, which did not change during the long-term storage of groats. Thus, the value of QMAFAnM was kept at the level of 0.01 thousand CFU/g.

The presence of mold microflora, which has a significant impact on the quality of food products, was also investigated [46, 47]. The amount of mold, including representatives of the genera Candidas, Penicillium, Aspergillus, was not detected immediately after production, but insemination occurred during storage. However, it should be noted that the amount of mold remained unchanged throughout storage, which indicates a stable microbiological state of the product.

After storing the product for 12 months, the amount of mold in groats obtained using plasma-chemically activated aqueous solutions is minimum. Accordingly, it was 260 times smaller than the control, which indicates the prospects of using plasma-chemically activated aqueous solutions for the disinfection of raw materials and further stability of the product.

It was found that the optimal disinfecting effect for buckwheat grain is shown by solutions with an activator concentration of 700 mg/l. At this concentration, buckwheat groats contained almost no microorganisms. Due to their specific composition, plasma-chemically activated aqueous solutions have a long-lasting disinfecting effect.

For the industrial implementation of the presented technology, a flowsheet for the production of buckwheat groats using plasma-chemically activated aqueous solutions has been developed (Fig. 2). In addition to classic technological operations, it includes moistening of buckwheat grain with plasma-chemically activated aqueous solutions. Activated solutions are used at the stage of hydrothermal treatment of buckwheat and do not require significant changes in improving the production line of buckwheat groats. Spent activated aqueous solutions are settled, filtered and sent for repeated plasma-chemical activation. Such a closed cycle of water use when applying the technology of plasma-chemical activation of aqueous solutions can significantly save water resources [37].

The results of studies of the technological process parameters and changes in the composition of buckwheat groats allow improving the existing technologies for the production of buckwheat groats.

The shortcomings of the research include the lack of data on changes in the content of albumins and globulins, as well as fatty acids in buckwheat groats. These data are planned to be obtained in the continuation of research on the technology of buckwheat groats production using plasma-chemically activated aqueous solutions.

The limitations of this study can be related to providing sufficient quantities of plasma-chemically activated aqueous solutions to industrial enterprises. However, now this issue is being resolved, as KNP-TECHNOLOGY Research and Production Enterprise LLC is actively working on the implementation of the project for mass production of plasma-chemical industrial installations. And this, in turn, will expand the prospects and opportunities for providing the food processing industry with activated technological solutions.

The prospect of the research consists in the development of technologies for the production of other types of cereals.

7. Conclusions

1. Changes in the moisture content of buckwheat grain during moistening and tempering using plasma-chemically activated aqueous solutions were studied. It was found that the optimum temperature of the tempering process using plasma-chemically activated aqueous solutions should be considered precisely 40 °C, for 2 hours, with a peroxide concentration of 700 mg/l.

2. The yield of buckwheat groats was studied, so using activated solutions (peroxide concentration of 700 mg/l) will increase the mass fraction of whole kernels by a maximum of 6 % compared to the classical technology.

3. The study of the amino acid composition of buckwheat groats showed that the total content of amino acids is 7.7 % higher than the control, losses during hydrothermal treatment amounted to only 2 %, against 9.7 % in the control. The vitamin composition of buckwheat groats was studied. The vitamin composition also remains stable and almost does not decrease in terms of B_1, B_2, B_3, B_4, B_5, B_6, K, E, PP, P, compared to buckwheat grain. Compared to the control, it is 35–54 % higher.

4. Studies of the microbiological indicators of buckwheat groats showed that immediately after the production of buckwheat groats, no pathogenic microflora was detected in them. During storage, the amount of microflora changed insignificantly and was associated with its entry into the product from the external environment.

5. A flowsheet for the production of buckwheat groats has been developed, the feature of which is the introduction of plasma-chemical activation of aqueous solutions into the technological process.

Conflict of interest

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

Financing

The study was conducted without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

References

1. Kim, S. J., Sohn, H. B., Suh, J. T., Kim, G. H., Hong, S. Y., Chang, D. C. et al. (2017). Domestic and Overseas Status of Buckwheat Production and Future Trends. Journal of the Korean Society of International Agricultue, 29 (3), 226–233. doi: https://doi.org/10.12719/ksia.2017.29.3.226
2. Lu, L., Murphy, K., Baik, B. (2013). Genotypic Variation in Nutritional Composition of Buckwheat Groats and Husks. Cereal Chemistry, 90 (2), 132–137. doi: https://doi.org/10.1094/cchem-07-12-0090-r
3. Suvorova, G Zhou, M. (2018). Distribution of Cultivated Buckwheat Resources in the World. Buckwheat Germplasm in the World, 21–35. doi: https://doi.org/10.1016/b978-0-12-811006-5.00003-3
4. Vombergar, B., Tašner, L., Horvat, M., Vorih, S., Pem, N., Golob, S., Kovač, T. (2022). Buckwheat – Challenges in nutrition and technology / Ajda – izzivi v tehnologiji in prehrani. Fagopyrum, 39 (2), 33–42. doi: https://doi.org/10.3986/fag0026
5. Gong, X., An, Q., Le, L., Geng, F., Jiang, L., Yan, J. et al. (2020). Prospects of cereal protein-derived bioactive peptides: Sources, bioactivities diversity, and production. Critical Reviews in Food Science and Nutrition, 62 (11), 2855–2871. doi: https://doi.org/10.1080/10408398.2020.1860897
6. Wijngaard, H. H., Arendt, E. K. (2006). Buckwheat. Cereal Chemistry, 83 (4), 391–401. doi: https://doi.org/10.1094/cc-83-0391
7. Ikeda, K. (2002). Buckwheat composition, chemistry, and processing. Advances in Food and Nutrition Research, 395–434. doi: https://doi.org/10.1016/s1043-4526(02)44008-9
8. Giménez-Bastida, J., Piskuła, M., Zieliński, H. (2015). Recent Advances in Processing and Development of Buckwheat Derived Bakery and Non-Bakery Products – a Review. Polish Journal of Food and Nutrition Sciences, 65 (1), 9–20. doi: https://doi.org/10.1515/pjfns-2015-0005
9. Vasylieva, N. (2017). Economic Aspects of Food Security in Ukrainian Meat and Milk Clusters. Agris On-Line Papers in Economics and Informatics, 9 (3), 81–92. doi: https://doi.org/10.7160/aol.2017.090308
10. Kovalova, O. S. (2022). Innovatsiyna tekhnolohiya vyrobnytstva hrechanoi krupy. The 14th International scientific and practical conference “Modern stages of scientific research development”. Prague, 453–460. Available at: https://isg-konf.com/wp-content/uploads/2022/12/Modern-stages-of-scientific-research-development.pdf
11. Kovaliova, O., Tchoursinov, Y., Kalyna, V., Koshulko, V., Kunitsia, E., Chernukha, A. et al. (2020). Identification of patterns in the production of a biologically-active component for food products. Eastern-European Journal of Enterprise Technologies, 2 (11 (104)), 61–68. doi: https://doi.org/10.15587/1729-4061.2020.200026
12. Zhygynov, D. A., Soc, S. M., Drozdov, A. Y. (2016). Production and quality of buckwheat products. Grain Products and Mixed Fodder’s, 64 (4), 22–25. doi: https://doi.org/10.15673/gpmf.v64i4.263
13. Worobiej, E., Piecyk, M., Perzyna, G., Turos, J. (2017). Effect of processing and thermally treating buckwheat grains on nutrients. Zywnosc Nauka Technologia Jakosc/Food Science Technology Quality, 24, 60–73. doi: https://doi.org/10.15193/zntj/2017/112/198
14. Chen, X.-W., Luo, D.-Y., Chen, Y.-J., Wang, J.-M., Guo, J., Yang, X.-Q. (2019). Dry fractionation of surface abrasion for polyphenol-enriched buckwheat protein combined with hydrothermal treatment. Food Chemistry, 285, 414–422. doi: https://doi.org/10.1016/j.foodchem.2019.01.182
15. Plumier, B., Kenar, J. A., Felker, F. C., Winkler-Moser, J., Singh, M., Byars, J. A., Liu, S. X. (2023). Effect of subcritical water flash release processing on buckwheat flour properties. Journal of the Science of Food and Agriculture, 103 (4), 2088–2097. doi: https://doi.org/10.1002/jsfa.12399
16. Luthar, Z., Golob, A., Germ, M., Vombergar, B., Kreft, I. (2021). Tartary Buckwheat in Human Nutrition. Plants, 10 (4), 700. doi: https://doi.org/10.3390/plants10040700
17. Christa, K., Soral-Śmietana, M. (2008). Buckwheat grains and buckwheat products - nutritional and prophylactic value of their components - a review. Czech Journal of Food Sciences, 26 (3), 153–162. doi: https://doi.org/10.17221/1602-cjfs
18. Dmitriev, A., Ziganshin, B., Khaliullin, D., Aleshkin, A. (2020). Study of efficiency of peeling machine with variable deck. Engineering for Rural Development. doi: https://doi.org/10.22616/erdev.2020.19.tf249
19. Kreft, I., Golob, A., Vombergar, B., Germ, M. (2023). Tartary Buckwheat Grain as a Source of Bioactive Compounds in Husked Groats. Plants, 12 (5), 1122. doi: https://doi.org/10.3390/plants12051122
20. Germ, M., Árvay, J., Vollmannová, A., Tóth, T., Kreft, I., Golob, A. (2020). Hydrothermal Treatments Affecting the Concentration of Neochlorogenic Acid in Dough of Tartary Buckwheat. Agriculture, 10 (12), 601. doi: https://doi.org/10.3390/agriculture10120601
21. Lukšič, L., Árvay, J., Vollmannová, A., Tóth, T., Škrabanja, V., Trček, J. et al. (2016). Hydrothermal treatment of Tartary buckwheat grain hinders the transformation of rutin to quercetin. Journal of Cereal Science, 72, 131–134. doi: https://doi.org/10.1016/j.jcs.2016.10.009
22. Oh, M., Oh, I., Jeong, S., Lee, S. (2019). Optical, rheological, thermal, and microstructural elucidation of rutin enrichment in Tartary buckwheat flour by hydrothermal treatments. Food Chemistry, 300, 125193. doi: https://doi.org/10.1016/j.foodchem.2019.125193
23. Filipiak-Florkiewicz, A., Florkiewicz, A. (2016). Effect of hydrothermal treatment on content of nutrients and bioactive components in groats and rice. Zywnosc. Nauka. Technologia. Jakosc/Food. Science Technology. Quality, 6. Available at: http://journal.pttz.org/wp-content/uploads/2017/03/06_Filipiak-Florkiewicz.pdf

24. Zieliński, H., Achremowicz, B., Przygodzka, M. (2012). Antioxidants in cereal grains. Zywnosc.Nauka.Technologia.Jakosc/Food.Science.Technology.Quality. doi: https://doi.org/10.15193/zntj/2012/80/005-026
25. Zielinska, D., Szawara-Nowak, D., Zielinski, H. (2007). Comparison of Spectrophotometric and Electrochemical Methods for the Evaluation of the Antioxidant Capacity of Buckwheat Products after Hydrothermal Treatment. Journal of Agricultural and Food Chemistry, 55 (15), 6124–6131. doi: https://doi.org/10.1021/jf071046f
26. Skrabanja, V., Lærke, H. N., Kreft, I. (2000). Protein-polyphenol interactions and in vivo digestibility of buckwheat groat proteins. Pflügers Archiv - European Journal of Physiology, 440 (S1), R129–R131. doi: https://doi.org/10.1007/s004240000033
27. Liu, X., Wang, L., Li, C., Li, X., Kumrungsee, T., Zhai, X., Zhou, Z., Cao, R. (2023). The modification of buckwheat polyphenols by different pretreatments and complexation, and its application in oat flour model. Food Bioscience, 56, 103133. doi: https://doi.org/10.1016/j.fbio.2023.103133
28. Roy, M., Dutta, H., Jaganmohan, R., Choudhury, M., Kumar, N., Kumar, A. (2019). Effect of steam parboiling and hot soaking treatments on milling yield, physical, physicochemical, bioactive and digestibility properties of buckwheat (Fagopyrum esculentum L.). Journal of Food Science and Technology, 56 (7), 3524–3533. doi: https://doi.org/10.1007/s13197-019-03849-9
29. Liu, H., Lv, M., Peng, Q., Shan, F., Wang, M. (2015). Physicochemical and textural properties of tartary buckwheat starch after heat–moisture treatment at different moisture levels. Starch - St rke, 67 (3-4), 276–284. doi: https://doi.org/10.1002/star.201400143
30. Sindhu, R., Devi, A., Khatkar, B. S. (2019). Physicochemical, thermal and structural properties of heat moisture treated common buckwheat starches. Journal of Food Science and Technology, 56 (5), 2480–2489. doi: https://doi.org/10.1007/s13197-019-03725-6
31. Liu, H., Guo, X., Li, W., Wang, X., lv, M., Peng, Q., Wang, M. (2015). Changes in physicochemical properties and in vitro digestibility of common buckwheat starch by heat-moisture treatment and annealing. Carbohydrate Polymers, 132, 237–244. doi: https://doi.org/10.1016/j.carbpol.2015.06.071
32. Amudha Senthil, S. P. (2015). Effect of Hydrothermal Treatment on the Nutritional and Functional Properties of Husked and Dehusked Buckwheat. Journal of Food Processing & Technology, 06 (07). doi: https://doi.org/10.4172/2157-7110.1000461
33. Collar, C. (2017). Significance of heat-moisture treatment conditions on the pasting and gelling behaviour of various starch-rich cereal and pseudocereal flours. Food Science and Technology International, 23 (7), 623–636. doi: https://doi.org/10.1177/1082013217714671
34. Vicente, A., Villanueva, M., Caballero, P. A., Muñoz, J. M., Ronda, F. (2023). Buckwheat grains treated with microwave radiation: Impact on the techno-functional, thermal, structural, and rheological properties of flour. Food Hydrocolloids, 137, 108328. doi: https://doi.org/10.1016/j.foodhyd.2022.108328
35. Yuan, Y., Shimizu, N., Li, F., Magaña, J., Li, X. (2023). Buckwheat waste depolymerization using a subcritical ethanol solution for extraction of bioactive components: from the laboratory to pilot scale. Journal of Environmental Chemical Engineering, 11 (3), 109807. doi: https://doi.org/10.1016/j.jece.2023.109807
36. Kovaliova, O., Pivovarov, O., Koshulko, V. (2020). Study of hydrothermal treatment of dried malt with plasmochemically activated aqueous solutions. Food Science and Technology, 14 (3). doi: https://doi.org/10.15673/fst.v14i3.1799
37. Kovaliova, O., Pivovarov, O., Kalyna, V., Tchoursinov, Y., Kunitsia, E., Chernukha, A. et al. (2020). Implementation of the plasmochemical activation of technological solutions in the process of ecologization of malt production. Eastern-European Journal of Enterprise Technologies, 5 (10 (107)), 26–35. doi: https://doi.org/10.15587/1729-4061.2020.215160
38. Pivovarov, O., Kovaliova, O., Koshulko, V. (2020). Effect of plasmochemically activated aqueous solution on process of food sprouts production. Ukrainian Food Journal, 9 (3), 576–587. doi: https://doi.org/10.24263/2304-974x-2020-9-3-7
39. Pivovarov, O., Kovalova, O., Koshulko, V., Aleksandrova, A. (2022). Study of use of antiseptic ice of plasma-chemically activated aqueous solutions for the storage of food raw materials. Food Science and Technology, 15 (4). doi: https://doi.org/10.15673/fst.v15i4.2260
40. Pivovarov, O., Kovalova, O., Koshulko, V. (2022). Disinfection of marketable eggs by plasma-chemically activated aqueous solutions. Food Science and Technology, 16 (1). doi: https://doi.org/10.15673/fst.v16i1.2289
41. Pivovarov, O., Kovaliova, O., Koshulko, V. (2022). Effect of plasma-chemically activated aqueous solutions on the process of disinfection of food production equipment. Food Science and Technology, 16 (3). doi: https://doi.org/10.15673/fst.v16i3.2392
42. Kovaliova, O., Pivovarov, O., Vasylieva, N., Koshulko, V. (2023). Obtaining of rice malt with the use of plasma-chemically activated aqueous solutions. Food science and technology, 16 (4). doi: https://doi.org/10.15673/fst.v16i4.2542
43. Kovalova, O., Vasylieva, N., Stankevych, S., Zabrodina, I., Haliasnyi, I., Gontar, T. et al. (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
44. Kovaliova, O., Vasylieva, N., Stankevych, S., Zabrodina, I., Mandych, O., Hontar, T. et al. (2023). Development of a technology for the production of germinated flaxseed using plasma-chemically activated aqueous solutions. Eastern-European Journal of Enterprise Technologies, 4 (11 (124)), 6–19. doi: https://doi.org/10.15587/1729-4061.2023.284810
45. Greene, W. (2003). Econometric Analysis. Prentice Hall, 1026. Available at: http://surl.li/mcvrp
46. Pivovarov, O., Kovaliova, O. (2019). Features of grain germination with the use of aqueous solutions of fruit acids. Food Science and Technology, 13 (1). doi: https://doi.org/10.15673/fst.v13i1.1334
47. Pivovarov, O., Kovaliova, O., Khromenko, T., Shuliakevych, Z. (2017). Features of obtaining malt with use of aqueous solutions of organic acids. Food Science and Technology, 11 (4). doi: https://doi.org/10.15673/fst.v11i4.728