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DEVELOPMENT OF TECHNOLOGY FOR THE PRODUCTION OF ALL-PURPOSE BUCKWHEAT MALT USING PLASMOCHEMICALLY ACTIVATED AQUEOUS SOLUTIONS

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The result of the conducted research is the development of buckwheat malt production technology using plasma-chemically activated aqueous solutions. Buckwheat grain with high starch content became the object of research. The main technological problem is obtaining high-quality brewing malt suitable for the production of gluten-free beer. The expediency of using plasma-chemically activated aqueous solutions as an intensifier of the process of germination of buckwheat grains and an effective disinfectant of buckwheat malt has been experimentally proven. It is shown that the use of plasma chemical activation of technological solutions allows to speed up the process of moistening of buckwheat grain by more than 2 times. The energy and germination capacity of buckwheat grains, when using plasma-chemically activated aqueous solutions, underwent positive changes. The effect of increasing the energy of germination was from 8 to 14 %, and the ability to germinate was 2–9 %. The amylolytic activity of buckwheat malt was analyzed, an increase in amylolytic activity in the range of 30–77 units/g was noted. The extractability of buckwheat malt was investigated separately. This indicator increased by 2–9 % depending on the concentration of peroxides in the solution. The Kolbach index also increased by 2–10 %, which indicates an intensive course of proteolysis. The total amount of amino acids in the experimental samples increased by 619 mg/100 g. There was a significant decrease in the viscosity of the wort, which indicates the high solubility of the obtained buckwheat malt.

The technology can be applied in the industrial production of brewing malt and sprouted buckwheat grain of functional purpose. The developed buckwheat malting technology will receive priority in the production of environmentally friendly buckwheat malts of universal purpose that are not contaminated with pathogenic microflora

Keywords: buckwheat malt, plasma chemical activation, aqueous solutions, hydrogen peroxide, amino acids

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1. Introduction

Buckwheat is a traditional agricultural crop grown in Central and Eastern Europe and Asia. The main producers of edible buckwheat are China – about 42 % of the total world production, Ukraine produced about 10 % in the pre-war period. Buckwheat is also grown in Poland, Brazil, the USA, France, Japan and other countries. The world production of buckwheat food grain is equal to 1.9 million tons [1].

As a rule, buckwheat varieties belonging to the species Fagopyrum esculentum Moench – seed or common buckwheat – are grown commercially. Buckwheat fruits are represented by nuts, mostly trihedral in shape, with smooth edges and solid ribs, brown, black or gray in color. Buckwheat is a very nutritious pseudocereal crop [2]. It contains nutritionally useful food components and can become a valuable ingredient in the creation of functional products [3]. Products made from buckwheat are a valuable source of proteins, vitamins of group B (B_1, B_2, B_3), P, PP, E [4]. Buckwheat grain has a high content of elements important for human nutrition, such as K, Mg, P, Fe, Cu, I. Buckwheat is a carrier of amino acids, including essential ones [5].

Buckwheat is recognized as a good source of nutrients and, in combination with other health-promoting components, is attracting increasing attention as a potential functional food. Despite the high nutritional value of buckwheat, the variety of anti-nutritive properties makes it difficult to fully use its potential. However, during germination, the macromolecular profile is improved, including the reduction of anti-nutrient factors and the synthesis or release of bioactive substances. Thus, buckwheat germination can increase the content of peptides and free phenolic compounds, as well as antioxidant activity. This process contributes to a marked reduction in the concentration of a number of anti-nutritional components and affects the metabolomic profile with an overall improvement in nutritional characteristics. Therefore, buckwheat germination is widely used to improve the compositional properties of grain material. All this will contribute to the use of sprouted buckwheat as a high-quality ingredient in innovative products of industrial interest [6].

A promising direction is the development of innovative technology for the production of high-quality buckwheat malt of universal purpose. That is, sweetened buckwheat grain, which is advisable to use both in fermentation technologies (production of beer and kvass), and as an enricher of various health and dietary food products. In order to intensify and optimize the malting process, it is rational to introduce safe and highly effective germination intensifiers and disinfecting agents. In addition, an extremely important aspect is the selection of safe intensive germination methods that would not introduce extraneous chemical compounds into the finished product.

Therefore, research devoted to the development of the production technology of universal buckwheat malt should be considered relevant.

2. Literature review and problem statement

The urgent needs of the population for highly nutritious and useful food products are a technological problem of food enterprises [7]. Buckwheat grain processing products, namely buckwheat malt, can enrich the diet of a wide range of consumers. When growing buckwheat, as a rule, no dangerous chemicals are used, which makes its grain an ecologically clean raw material [8]. In terms of chemical composition, buckwheat grain is close to cereal crops, but it is unique in the ratio of different parts of the grain. The fractional composition of buckwheat protein is also special, it is almost completely devoid of prolamins, low in gluten and, conversely, high in globulins and albumins. So, thanks to these features, buckwheat is classified as a gluten-free culture and recommended for use in dietary nutrition. Therefore, the use of buckwheat as a raw material for the production of buckwheat malt, for its further use in the production of a variety of food products and beer, is promising and interesting from a scientific and production point of view. However, the issue of implementing new technological solutions in the buckwheat processing process remains unresolved.

Food products made from buckwheat and malt flour have attracted wide interest due to their high nutritional value with various health benefits, becoming increasingly popular [9]. Providing the industry with a sufficient amount of high-quality buckwheat malt remains an unresolved issue.

The germination process is a complex processing of grain raw materials, which provides a significant increase in nutritional value due to the bioavailability of a number of nutrients, in particular vitamins [10]. During the malting of buckwheat, 64 metabolites were identified. They include a wide range of polar components (amino acids, sugars, acids and phenolic compounds). And, accordingly, non-polar (methyl esters of fatty acids, free fatty acids, sterols). These components of buckwheat have a low molecular weight and quantity, but are valuable in nutrition [11]. The content of polar metabolites, such as sugars and amino acids, increases during buckwheat germination. Meanwhile, the contents of most non-polar metabolites, including fatty acid methyl esters, free fatty acids and sterols, change very little or remain constant [11]. Due to its excellent antioxidant properties, sprouted buckwheat can be a valuable component for functional food products. Buckwheat sprouts, which are used both fresh and steamed, are also widely used in food [12]. An unsolved issue is the provision of high-quality sprouted raw materials to the industry.

Highly nutritious couscous with a higher content of phenolic compounds (including rutin and quercetin) and pronounced antioxidant activity is prepared from sprouted buckwheat [13]. Gluten-free products based on buckwheat malt are currently popular worldwide (e.g. cookies) [14]. Gluten-free cookies made from rice flour and buckwheat malt showed significantly higher total phenolic and quercetin content [15]. Malted gluten-free buckwheat grain is a promising raw material for the production of fermented products. The effect of buckwheat malt as a delivery system for endogenous enzymes is being studied [16]. Buckwheat malt can be successfully used for the production of gluten-free fermented beverages or as an additive to fermented products, for example, in baking and confectionery [14]. However, there is a problem of low extractability of buckwheat malt, which prevents its wide use as a brewing raw material. This problem can be solved by adjusting the technology of malt production.

Beer is the most common alcoholic beverage in the world, but it is not suitable for celiac patients because its main ingredients, barley or wheat, contain gluten [17]. The recent boom in the production of gluten-free beer is due to the awareness of celiac disease and the significant increase in the volume of the market for gluten-free beer. Several strategies have been recognized as suitable procedures for gluten-free brewing: the use of gluten-free grains, non-grain sources such as sugar, syrups, and honey, and enzymatic and microbial treatment of barley wort to reduce gluten content to negligible levels [18]. Buckwheat malt is currently actively used for the production of gluten-free beer [19, 20]. New varieties of buckwheat beer are the result of the influence of a number of factors. For example, innovations in science and technology, changes in requirements for food consumption. As well as competition between producers, promotion of healthy, tasty and high-quality food. Manufacturers are looking for new solutions to obtain products that meet consumer requirements, authentic products of higher quality, with a characteristic taste and aroma [19]. The use of buckwheat malt increases the protein content in the wort, which is not observed when using other auxiliary substances, such beer subsequently has greater colloidal stability during storage [21]. Gluten-free malt is not sufficiently modified compared to traditional barley and wheat malt, but is potentially suitable as an adjuvant (especially buckwheat) [22]. Buckwheat has the potential to be used as a raw material for the production of gluten-free beer, as evidenced by studies of the physical and chemical parameters of buckwheat malt, according to the methods of the European Brewing Convention [23]. Hypersensitivity to gluten of a large population contributes to the expansion of the range of gluten-free products [24], which in the future will lead to an increased demand for buckwheat malt. Therefore, the production of gluten-free food products, including non-alcoholic beverages, is an unsolved problem [25]. This urgent task of the food industry is solved by providing manufacturers with high-quality raw materials, namely buckwheat malt.

Using the system of mass production of sprouted buckwheat, it is possible to provide the food industry with raw materials rich in linoleic acid, unsaturated fatty acids, free amino acids, rutin, quericitrin, chlorogenic acid, as well as vitamins B_1, B_6, C, E [26, 27]. Sprouted buckwheat grains are gaining popularity as functional food ingredients [28, 29]. However, the implementation of innovative buckwheat malting technologies is an unsolved task. Objective difficulties associated with the fact that the malting technology is dominated by classic technological trends. But, despite this, industrial demand prompts researchers to expand and modernize the technological process.

As a rule, malt extracts are produced from germinated buckwheat. Extracts of germinated Tatar buckwheat have regenerative capacity, high free radical absorption activity and superoxide anion absorption activity, which is an important function for the human body [30]. An important aspect of malting technology is the increased accumulation of sugars and amino acids [31]. The concentration and composition of simple sugars and free amino acids, as precursors of the Maillard reaction, change with grain germination [32]. Therefore, the maximum accumulation of these components is the goal of obtaining high-quality brewing malt. Selection of technological modes that will allow to increase the activity of enzymes remains an unsolved problem.

The use of sprouted buckwheat grain is currently a popular trend in the production of heat-treated products. This is due to the fact that the malting of buckwheat grain qualitatively changes the composition of sugars and amino acids and directly affects the course of the Maillard reaction [33]. And, as a result, the organoleptic properties of the finished product are improved [33]. But questions related to increased accumulation of amino acids in buckwheat malt remained unresolved. This problem can be solved by directed regulation of the course of the technological process.

In addition, buckwheat sprouts are used in food. The consumption of buckwheat sprouts in a person's daily diet is gradually increasing, and their health benefits are attracting the attention of many scientists. Young shoots are characterized by a high content of useful phytochemicals. Germination is an effective strategy that allows the manipulation of phytochemicals in seeds to enhance their health benefits [34]. However, this process is complex and sensitive to the influence of external factors.

Currently, buckwheat malt is proposed to be used for the production of soft drinks of plant origin. Sprouted buckwheat (Fagopyrum esculentum Moench.) can be used as a raw material for functional drinks, it has good potential for expanding the range of this category [35]. However, such raw materials contribute to an increase in the level of microbial contamination. Therefore, improving the safety of raw materials (buckwheat malt) is an unsolved problem. Food companies sell products with "sprouted", "activated" or "awakened" ingredients. The label implies that sprouting the grain improves health, but the process of "sprouting" consists of simply soaking in water, often at room temperature, followed by drying and further processing. Currently, the most widespread pathogenic microflora on malt is Salmonella bacteria [36]. Therefore, the development of a practical strategy for improving the safety of these products is a promising direction of research.

Sprouted grain can cause food poisoning, as inappropriate conditions can promote the development of pathogenic microorganisms on the surface of the grain [37]. As a result, heat-treated germinated grain is used in long-term storage products, the parameters of which depend on the initial content of bacteria. The preservation of biologically active substances in germinated buckwheat during high-temperature thermal processing remains an unsolved problem. There are various ways to reduce bacterial contamination of germinated grain, each with its own advantages and disadvantages. Disinfectants can be natural substances with antimicrobial properties, for example medicinal herbs. Currently, antimicrobial drugs that will allow high-quality disinfection of buckwheat grain are widely studied [37]. The food safety of the use of disinfectants in the processing industry remains an unsolved problem.

All over the world, germinated grains (malt) are used for the production of dietary products and consumed whole, ground or ground. Recent studies in the field of nutrition and epidemiology indicate that whole grains are beneficial to human health and, as a result, their consumption has increased significantly. Controlled germination is one of the effective methods of increasing the nutritional value of whole grains [38]. For the purpose of malt production, the term "controlled germination" is used in malting technology. This concept includes: soaking under carefully controlled conditions and germination accompanied by environmental exposure that triggers the plant's defense systems to produce and accumulate health-promoting bioactive compounds [38]. Basic are studies of conventional methods of germination control (germination time, temperature and oxygen), as well as the effect of these treatments on the nutritional value of germinated grain. An important aspect is also considering the prospects of using new forms of physical energy, such as ultrasound, high pressure, pulsed electric field), light and cold plasma. These forms of energy are being studied as new controlled germination stimulators. They also include the use of physico-chemical methods of processing solutions [39], for example, processing technological solutions with ultrasound and an electromagnetic field. However, such methods are technically complex and are not used on an industrial scale. But the use of cold plasma has found wider application [40]. Despite the complexity of the process, it is currently being improved and ways of industrial implementation are being sought. Their bioactivating effect is currently being studied [41]. Solutions treated with cold plasma exhibit interesting properties that may be useful in the processing industry, but they are currently poorly understood. The effect of cold plasma is also used in the production of special malts [42]. However, there is a technological problem related to the substantiation of the parameters of the plasma treatment of solutions.

Various chemical substances are used as stimulants [7]. In addition, natural intensifiers of the germination process, such as fruit acids, were widely used [43]. The use of these organic substances is promising, but they have a high cost. The use of organic acids of various origins [44] is currently practiced for leguminous crops. But the acidification of the environment has a negative effect on the future quality of malts. Chlorophyllipt and chicken eggshell extract [45] are interesting activators of the germination process. But they require a significant expenditure of labor resources for the implementation of the process. An unsolved problem is the expediency of using germination stimulators in industrial malting. However, the search for new, chemically safe intensifying agents continues.

Intensification of the technological process of malt production is a basic task in obtaining malted raw materials. An urgent problem is the rational management of the course of the technological process. In addition, it should be noted that the process of malting requires a large amount of resources such as mains water. Therefore, most technological solutions are aimed at speeding up the process, improving the quality of malt and reducing resources for the production of malt [46].

In the process of soaking grain raw materials, various germination activators are used. Buckwheat grain, like most grains, should also be treated with intensifying solutions in order to speed up malting.

An important technological aspect is obtaining maximally germinated buckwheat grain, the physical and chemical parameters of which will meet the requirements of brewing production. In addition, buckwheat malt must be mycobiologically clean, that is, the selection of an intensifying agent must be correlated with the selection of a high-quality disinfectant for the malting process.

An option for overcoming technological difficulties may be the use of plasma-chemical activation of aqueous solutions in the process of malting buckwheat. This innovative approach was used in the work [47]. Thus, plasma-chemical technologies have recently found various applications in the food industry. They are used for the purpose of wastewater treatment of malt enterprises [46], in the production of various microgreens and highly nutritious cereal seedlings [47]. Also, plasma chemically activated solutions are used as disinfectants in the food industry, namely, in the form of antiseptic ice when storing food raw materials [48]. This allows to increase the shelf life of raw materials of various origins. When processing the surfaces of food products with plasma-chemically activated aqueous solutions [49], surfaces are disinfected. Such processing allows to improve the microbiological state of raw materials and minimize the number of pathogenic microflora without changing the quality indicators of processed products. An important technological solution is processing of technological equipment with activated solutions [50]. This makes it possible to qualitatively disinfect technological surfaces for a long time. Special attention of modern scientists is drawn to the study of the influence of plasma chemical activation on the course of processes in grain material during its moistening and germination. However, studies of their influence on the technological process of buckwheat malt production have not been fully implemented before.

Plasma-chemical activation of water and aqueous solutions allows to use specific properties of water without contaminating it with toxic chemical compounds [51]. During the treatment of water with cold plasma, processes are implemented that contribute to changing the reactogenic properties of aqueous solutions [51]. Thus, the reactogenic properties of activated water, which arise after plasma chemical treatment, are widely used in various areas of the food industry. Mains water activated under the action of cold plasma has established antiseptic and antibacterial properties [50]. Activated water is a cluster structure and can exhibit functional properties that have been little studied before, but can be useful from a practical point of view [52]. Activated water contains hydrogen peroxides and peroxygen compounds, excited particles and radicals. These components take an active part in oxidation-reduction processes, and also intensify the transport of moisture into grain material, correct biochemical transformations in grains of various crops [47]. Cold plasma treatment partially changes the basic structure of water. Water clusters are crushed under the action of contact non-equilibrium plasma. This prompts the implementation of the process of active transport of crushed particles through the membranes and shells of the grain during its soaking and subsequent processing [47]. The clusters contain microparticles of hydrogen peroxide, which, upon contact with food raw materials, are capable of forming active oxygen and water [49]. These features of activated solutions can correct biochemical processes in buckwheat grains during soaking and germination.

The technology of plasma-chemical activation of water is ecological and if it is compared with other technologies of grain material processing, it can be noted that it is absolutely chemically safe. This is explained by the fact that its active components are decomposed during technological processing and the finished product does not contain any extraneous chemical impurities [41, 47]. Urgent technological problems include the lack of widespread industrial use of cold plasma at food enterprises.

All this allows to state that the implementation of research devoted to the use of activated aqueous solutions in the technological process of buckwheat malting is promising. This will allow expanding the raw material base for the production of gluten-free food products. Therefore, it is expedient from a technological point of view to carry out research devoted to the selection of optimal processing modes and the use of plasma-chemically activated aqueous solutions in the process of producing high-quality buckwheat malt. In the future, the implementation of the presented technology will allow the use of sprouted buckwheat as a component of dietary products aimed at people with gluten intolerance. In addition, the production of new functional products, in which the sprouted buckwheat grain itself will become an enrichment component, is interesting.

3. The aim and objectives of the study

The aim of the study is to develop a technology for the production of buckwheat malt using plasma-chemically activated aqueous solutions. This will make it possible to speed up the technological process of buckwheat malt production and expand the range of high-quality raw materials for the production of gluten-free drinks.

To achieve the set aim, it is necessary to solve the following objectives:

– to investigate changes in the moisture content of grain material during soaking;

– to investigate the energy and germination capacity of buckwheat;

– to investigate quality parameters of malt: amylolytic activity, extractability, Kolbach index, amino acid composition and wort viscosity indicators;

– to investigate the microbiological indicators of buckwheat malt;

– to develop a technological scheme for the production of buckwheat malt using plasma-chemically activated aqueous solutions.

4. Research materials and methods

4. 1. Object and research hypothesis

The object of research is the production of buckwheat malt.

Plasma-chemically activated aqueous solutions were chosen as an activator for conducting research on the buckwheat malting process. These solutions are already used in various food technologies, including in the malting process of various grain crops [47–50]. However, further implementation and more thorough research of the innovative technology of processing technological solutions is promising.

The main research hypothesis is the significant intensification of buckwheat germination and the improvement of the physico-chemical parameters of buckwheat malt through the use of plasma-chemically activated aqueous solutions. Such solutions were used as an intensifier and disinfectant of the technological process.

Aqueous solutions that were activated by cold non-equilibrium plasma were obtained in the Specialized Laboratory of Plasma Processing of Process Solutions of Food Industries of the Dnipro State Agrarian and Economic University and in the industrial conditions of the Scientific and Production Enterprise “KNP-TECHNOLOGY” 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 technological solutions for buckwheat germination was carried out according to a special technology of processing liquids with cold non-equilibrium plasma [41, 43]. A special laboratory setup for plasma-chemical activation of aqueous solutions of a generally accepted sample was used for the research [47]. The laboratory installation is an absolute analogue of the industrial one. This aspect makes it easier to conduct multistage studies with a large number of repetitions. It is represented by a three-arc plasma chemical installation and consists of a reactor, anodes, a cathode, a reflux condenser, a power source, and a vacuum pump [47–49]. Plasma-chemically activated aqueous solutions were prepared for sweetening buckwheat grain, the characteristics of which are given in the Table 1 [39]. Accordingly, the concentration of hydrogen peroxide in the activated water was determined by the iodometry method and the value was simultaneously fixed by the express method.

Table 1

Indicators of aqueous solutions treated with cold plasma

Experiment	Water	Activation time, min	Concentration of hydrogen peroxide, mg/l
1 (control)	water supply	–	–
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

Mains water was activated at the experimental laboratory installation within the time limits of 5–60 minutes. Solutions were produced in which the concentration of hydrogen peroxide varied from 100 to 700 mg/l. Longer and shorter activation in the process of research was determined as inappropriate. This conclusion was made based on the ratio of the effectiveness of the solutions and the energy intensity of the process [47]. The following research groups were formed:

1 – control (ordinary tap water was used to soak the grain);

2 – water treated with cold plasma (H_2O_2 concentration 100 mg/l);

3 – water treated with cold plasma (H_2O_2 200 mg/l);

4 – water treated with cold plasma (H_2O_2 300 mg/l);

5 – water treated with cold plasma ($H_2O_2$400 mg/l);

6 – water treated with cold plasma (H_2O_2 500 mg/l),

7 – water treated with cold plasma (H_2O_2 600 mg/l);

8 – water treated with cold plasma (H_2O_2 700 mg/l).

4. 2. 2. Selection of raw materials for the production of buckwheat malt and peculiarities of soaking and germination of buckwheat grains

Buckwheat grain was chosen as the raw material for the production of malt. Several widely distributed buckwheat varieties were analyzed.

The Slobozhanka variety was chosen for further research. This is due to the high starch content (74.4 %) and relatively low protein content (16.9 %), which is optimal for obtaining buckwheat malt with acceptable indicators for use in brewing.

The technological process is implemented according to the classic scheme of malting using a box-type laboratory malt house. First, the buckwheat is cleaned of impurities, the grain is washed and disinfected with plasma-chemically activated aqueous solutions, and the grain is soaked for a long time using a 3:1 hydromodule. The duration of soaking ranged from 2 to 4 days, until the grain material reached a moisture content of 47–48 %. Buckwheat was germinated for 3–5 days at a constant temperature of 17–18 °C. Buckwheat malt was dried at a temperature of 40–60 °C to a moisture content of 5–7 %. Next, the malt was cooled and crushed.

4. 3. Methods of determining indicators and properties of samples

4. 3. 1. The method of determining the humidity of buckwheat grain during the soaking process

In the process of research, the moisture content of the material was recorded every 12 hours at the stage of soaking buckwheat grains in plasma-chemically activated aqueous solutions. Soaking was implemented by the air-water method, with regular irrigation of the material as the surface dries. Determination of humidity was carried out by drying grain samples by a standard method using a drying cabinet. Control was carried out using an automatic SuperPro moisture meter (Manufacturer: SUPERTECH AGROLINE AGROELECTRONICS, Denmark).

4. 3. 2. Methodology for determining the energy and germination capacity of buckwheat grains

Energy and the ability to germinate are basic indicators for grain raw materials that are subject to malt germination. These indicators were determined according to generally accepted methods [47].

4. 3. 3. Methods of determining quality indicators of buckwheat malt

Determination of the amylolytic activity of buckwheat malt was carried out by the colorimetric method [53]. The extractability of the obtained buckwheat malt was determined by the standard method [53]. Kolbach index is an indicator of the degree of protein dissolution of malt, for its determination let's use the standard method [53], which is widely used in the brewing industry. The analysis of the content of amino acids in buckwheat malt was carried out by the method of ion-exchange liquid column chromatography on an automatic amino acid analyzer T339, manufactured in the Czech Republic, Prague. The viscosity of the wort was determined by the accelerated method with stirring according to DSTU 4282:2004. Brewing barley malt.

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

In the course of research, the total microbial count (KMAFAnM) was recorded by the classical method of inoculation on agarized nutrient media with subsequent incubation of the crops and counting of cultivated colonies of microorganisms. Microbiological indicators of buckwheat malt were determined according to standard methods according to DSTU 8446:2015 Food products. Methods of determining the number of mesophilic aerobic and facultative anaerobic microorganisms.

4. 3. 5. Methods of mathematical processing of experimental data

A combination of regression analysis and non-linear optimization methods was used to average and smooth out errors in measuring changes in the moisture content of grain material during soaking [54, 55]. For the mathematical formalization of buckwheat grain moisture dynamics, the data of each experiment were described by a cubic regression of the form:

$$Ycalc=A0+A1\times T+A2\times T^2+A3\times T^3, \quad (1)$$

where the numerical coefficients $A0$, $A1$, $A2$, $A3$ are to be found by the method of least squares by solving the optimization problem:

$$\Sigma_{i=1\ldots N}(Ycalc_i-Yfact_i)^2\to \min,$$

according to the known actual moisture indicators *Yfact* of the sample of size *N*. The assessment of the adequacy of the obtained regression with the actual data was carried out using the classical coefficient of determination R^2, which characterized the degree of dependence of the change in the moisture content of the buckwheat grain on the time of its soaking in plasma-chemically activated aqueous solutions with different concentrations of hydrogen peroxide.

Then, based on the cubic regressions created for the 8 analyzed experiments, models were calculated to minimize the soaking time of buckwheat grain to achieve the optimal moisture level of 48 %, i. e.:

$$T\to \min \text{ under the condition } Ycalc=A0+A1\times T+A2\times T^2+A3\times T^3=48. \quad (2)$$

The comparative analysis of the found answers aimed to confirm the hypothesis regarding the optimal concentration level of hydrogen peroxide in plasma chemically activated aqueous solutions, which was found experimentally.

To substantiate the conclusions about the nature of changes in the amino acid composition of buckwheat malt, clustering methods were used [56]. The relative indicators of the growth of the content of amino acids in the experiment ($X2$) compared to the control ($X1$) were analyzed:

$$\Delta X=(X2-X1)/X1. \quad (3)$$

For further grouping of amino acids in clusters with similar dynamics, a test for outliers was first carried out using the Dixon test. The test statistic Q was calculated according to the formula:

$$Q=(\Delta X_3-\Delta X_1)/(\Delta X_{M-2}-\Delta X_1), \quad (4)$$

where M ($14\leq M\leq 25$) is the sample size, Δ_q – ordered sample elements from the maximum Δ_1 to the minimum Δ_M, $q=1\ldots M$.

The hypothesis that ΔX_1 belongs to the sample from the remaining elements was canceled on the basis of the inequality:

$$Q>Q(\alpha;M), \quad (5)$$

where $Q(\alpha; M)$ is the critical value of the Dixon outlier test with a significance level α.

The number of clusters was calculated according to the square-root rule:

$$Ktotal=\lceil M^{0.5}\rceil. \quad (6)$$

It should be noted that some of the *Ktotal* clusters can be identified as outliers. The distribution of L, remaining in the sample, analyzed indicators of changes in the content of amino acids in the remaining clusters K with independent variable centers Cj, $j=1\ldots K$, was carried out based on the solution of a nonlinear optimization model:

$$\Sigma_{q=1\ldots L}\min_{j=1\ldots K}(\Delta X_q-C_j)^2\to \min. \quad (7)$$

The substantiation of the advantages of buckwheat malt obtained with the use of plasma-chemically activated aqueous solutions for the processing of raw materials was carried out. Applied unified relative deviations of biochemical indicators (B or D) from their fixed desired maximum ($\max B$) and minimum ($\min D$) values, i.e.:

$$\Delta B = 1 - B/\max B, \quad (8)$$

$$\Delta D = D/\min D - 1. \quad (9)$$

Further comparative analysis allows to illustrate the range of variation between biochemical indicators and to argue for the choice of the optimal concentration of hydrogen peroxide in plasma-chemically activated aqueous solutions when soaking buckwheat grains.

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

5. 1. Study of changes in the moisture content of grain material during soaking

To accelerate the start and further acceleration of the germination of buckwheat grain, it was soaked in plasma-chemically activated aqueous solutions with a concentration of peroxides of 100–700 mg/l. In the future, this will allow to accelerate the transport of moisture to the embryo and will give an impetus to the activation of the complex of hydrolytic enzymes.

The parameters of moistening of samples of grain material were studied in order to establish the optimal concentration of peroxides. The influence of the degree of moistening of buckwheat grains with activated aqueous solutions on the further process and dynamics of germination was analyzed. Buckwheat grain had an initial moisture content of 12 %, and was moistened to a moisture content of 48 %. The results are given in the Table 2.

Table 2

Buckwheat grain moisture during prolonged soaking, %

Experiment	Soaking time, hours								
	0	12	24	36	48	60	72	84	96
1 (control)	12.0	24.5	32.6	34.7	36.9	39.9	41.2	45.7	**48.4**
2	12.0	26.7	34.2	36.4	37.2	41.4	44.7	**47.9**	49.3
3	12.0	29.6	35.7	38.4	41.3	45.8	**48.3**	49.3	50.0
4	12.0	34.2	38.9	41.8	44.3	**48.1**	49.1	50.9	51.3
5	12.0	36.5	41.9	45.1	**48.0**	49.3	50.7	51.0	51.5
6	12.0	37.8	42.4	**48.9**	48.9	49.5	50.4	51.1	51.8
7	12.0	36.7	41.9	**48.2**	48.5	49.3	49.8	50.2	50.7
8	12.0	35.4	40.5	44.9	**48.0**	48.9	49.2	49.9	50.2

Analyzing the results presented in the Table 2, it should be noted that the study of the effect of activated solutions on the grain material was aimed at achieving the optimal humidity for germination, namely, 48 %. The temperature of the water during soaking was 17–18 °C, the time of wetting ranged from 12 to 96 hours. Thus, the buckwheat grain reached the desired moisture level after 96 hours. When using plasma chemically activated aqueous solutions, a similar result was obtained after 36 hours of hydration. The optimal concentration of peroxides in the solution to achieve the optimal humidity parameter of buckwheat grain was 500 mg/l.

To confirm the conclusions of the empirical data analysis, the mathematical calculations carried out using MS Excel and Google Sheets spreadsheet tools showed the following. Namely, in the Table 3 collected cubic regressions created according to formula (1), which mathematically formalize the moisture dynamics of buckwheat grain depending on the time of its soaking in plasma-chemically activated aqueous solutions with different concentrations of hydrogen peroxide.

Table 3

Regression models of moisture content of buckwheat grain during prolonged soaking

Experiment	Ycalc formula	R^2
1	$Ycalc = 16.33571 + 0.86901 \times T - 0{,}01215 \times T^2 + 0{,}00007 \times T^3$	0.987
2	$Ycalc = 21.66429 + 0.55879 \times T - 0{,}00542 \times T^2 + 0{,}00003 \times T^3$	0.976
3	$Ycalc = 25.40714 + 0.39475 \times T - 0{,}00031 \times T^2 - 0{,}00001 \times T^3$	0.992
4	$Ycalc = 30.02857 + 0.38057 \times T - 0{,}00126 \times T^2 - 0{,}000004 \times T^3$	0.995
5	$Ycalc = 29.86429 + 0.63518 \times T - 0{,}00657 \times T^2 - 0{,}00002 \times T^3$	0.999
6	$Ycalc = 28.29286 + 0.91171 \times T - 0{,}01285 \times T^2 - 0{,}00006 \times T^3$	0.972
7	$Ycalc = 26.71429 + 0.96200 \times T - 0{,}01343 \times T^2 - 0{,}00006 \times T^3$	0.981
8	$Ycalc = 27.20000 + 0.76567 \times T - 0{,}00883 \times T^2 - 0{,}00003 \times T^3$	0.997

High adequacy in the range from 97.2 % to 99.9 % made it possible to use the obtained cubic regressions. Which served to calculate the minimum soaking time of buckwheat grains in activated aqueous solutions with different concentrations of hydrogen peroxide until the moisture content reaches 48 %.

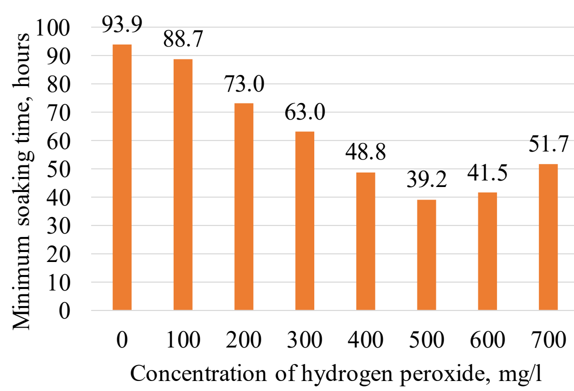

Fig. 1. Simulated minimum soaking time of buckwheat grain to a moisture content of 48 %

The answers obtained according to the method (2) were visualized by a bar chart in Fig. 1. Which, taking into account the errors of smoothing and averaging, convinces of the superiority of the activated aqueous solution with a concentration of hydrogen peroxide of 500 mg/l and confirms the experimental conclusion.

5. 2. Research on the energy and germination capacity of buckwheat grains

The main indicators of raw materials for obtaining high-quality malt are energy and the ability to germinate grain raw materials (Table 4). The concentrations of peroxides taken are identical to those used in the humidity study. Since it is important to establish a joint dynamics of achieving the necessary humidity and intensity of germination. Determination of the joint positive dynamics will help to choose the optimal parameters for the activation of aqueous solutions. It should be noted that the presented concentrations of peroxides in activated solutions did not damage buckwheat grain during the experiments and did not cause a change in the organoleptic properties of buckwheat malt.

Table 4

Energy and ability of buckwheat grain germination when using plasma-chemically activated aqueous solutions

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Germination rates, %	
			Energy	Ability
1 (control)	water supply	–	82	91
2	activated	100	90	94
3	activated	200	91	95
4	activated	300	92	96
5	activated	400	94	98
6	**activated**	**500**	**96**	**100**
7	activated	600	95	99
8	activated	700	94	98

The energy and germination capacity of buckwheat grains increases rapidly when using plasma-chemically activated aqueous solutions, the effect of increasing the germination energy was from 8 to 14 %, and the germination capacity was 2–9 %.

5. 3. Study of amylolytic activity, extractability, Kolbach index, amino acid composition of buckwheat malt and indicators of wort viscosity

The results of amylolytic activity studies are shown in Table 5.

Table 5

Amylolytic activity of buckwheat malt when using plasma-chemically activated aqueous solutions

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Amylolytic activity, units/g
1 (control)	water supply	–	371
2	activated	100	401
3	activated	200	419
4	activated	300	427
5	activated	400	435
6	**activated**	**500**	**448**
7	activated	600	435
8	activated	700	430

Analyzing the results given in the Table 5, it should be noted that the maximum amylolytic activity was observed in the samples that previously showed the maximum moisture and germination energy. This is a logical and expected result. The increase in amylolytic activity ranged from 30 to 77 units/g.

The next important indicator of malt's suitability for brewing is extractability. Extractivity is the sum of extractive substances of buckwheat malt, which, when mashed in a standard way, turn into a solution. Studies of this indicator are given in Table 6. In addition, in the Table 6 shows the results of the study of the Kolbach index. This indicator characterizes the degree of protein solubility.

Table 6

Extractivity and Kolbach index of buckwheat malt when using plasma-chemically activated aqueous solutions

Experiment	Concentration of hydrogen peroxide, mg/l	Malt extractivity, %	Kolbach index, %
1 (control)	–	39	29
2	100	40	32
3	200	42	34
4	300	45	36
5	400	47	37
6	**500**	**48**	**39**
7	600	49	38
8	700	46	35

The research results showed an increase in the extractability of buckwheat malt when using plasma-chemically activated aqueous solutions. Thus, this indicator increased by 2–9 %, depending on the concentration of peroxides. The Kolbach index also increased by 2–10 %, which indicates an intensive course of proteolysis.

The next stage was the study of the amino acid composition of buckwheat malt. The results are given in the Table 7. The experimental group with the maximum extractability and Kolbach index was selected for the study.

Table 7

Amino acid composition of buckwheat malt, mg/100 g of product

Amino acid	Malt		
	Control	Experiment	Change in the amount of amino acids
Lysine	939	980	+41 (4.4 %)
Histidine	220	271	+51 (2.3 %)
Arginine	811	893	+82 (10.1 %)
Aspartic acid	1,012	1,104	+92 (9.1 %)
Threonine	615	650	+35 (5.7 %)
Serin	504	543	+39 (7.7 %)
Glutamic acid	2,583	2,657	+74 (2.9 %)
Proline	507	525	+18 (3.6 %)
Glycine	945	991	+46 (4.9 %)
Alanine	572	587	+15 (2.6 %)
Valin	743	779	+36 (4.8 %)
Cysteine	198	205	+7 (3.5 %)
Methionine	201	208	+7 (3.5 %)
Isoleucine	654	668	+14 (2.1 %)
Leucine	1,136	1,152	+16 (1.4 %)
Tyrosine	243	251	+8 (3.3 %)
Phenylalanine	441	462	+21 (4.8 %)
Ornithine	60	64	+4 (6.7 %)
Tryptophan	184	197	+13 (7.1 %)
Sum	12,568	13,187	+619 (4.9 %)

Analyzing the results given in the Table 7, it should be noted that the number of amino acids in the experimental samples increases. All measurements of amino acids were tested three times in experiments, and the differences between the indicators were less than 1 %. In the experimental sample, the total amount of amino acids by 619 mg/100 g of the product is greater than the control.

To substantiate the common and distinctive features of changes in the composition of M=19 amino acids, described in the Table 7, mathematical calculations were carried out using MS Excel and Google Sheets spreadsheet tools. According to the method according to formula (3), the relative indicators of the increase in the content of amino acids ΔX in buckwheat malt were calculated. Dixon's emissions test (formulas (4), (5)) with a significance level of α=0.05 established the special nature of histidine's response to the use of plasma-chemically activated aqueous solutions, because:

$$Q=0.685>0.462=Q(0.05;\ 19).$$

The number of clusters for grouping amino acids according to formula (6) was $Ktotal$=5, and histidine was assigned as a separate cluster. The distribution of the remaining L=18 amino acids was carried out by calculating the centers of K=4 clusters in a nonlinear optimization model (7). The obtained answer is visualized by a histogram in Fig. 2.

8 amino acids, namely alanine, glutamic acid, isoleucine, leucine, methionine, proline, tyrosine, cysteine, which showed growth from 1.41 % to 3.55 %, were included in cluster 1 with an average increase of 2.86 %. Cluster 2 with an average increase of 4.91 % includes 5 amino acids, such as valine, glycine, lysine, threonine, phenylalanine, which were observed to increase from 4.37 % to 5.69 %. Cluster 3 with an average increase of 7.16 % includes 3 amino acids, including ornithine, serine, and tryptophan, which had an increase in content from 6.67 % to 7.74 %. Cluster 4 with an average increase of 9.60 % includes 2 amino acids – arginine and aspartic acid, the content of which increased, respectively, by 10.11 % to 9.09 %. Cluster 5 was assigned to histidine, which demonstrated the greatest sensitivity to plasma-chemically activated aqueous solutions with an increase of 23.18 %.

The next stage of the research was the determination of viscosity indicators of wort obtained from buckwheat malt. This indicator indicates the degree of cytolytic dissolution of malt. The recorded results are shown in the Table 8.

As expected, the test samples with high malt solubility had the lowest viscosity.

According to the described method of mathematical data processing, unified relative deviations of the indicators listed in the table were calculated 4–6, 8.

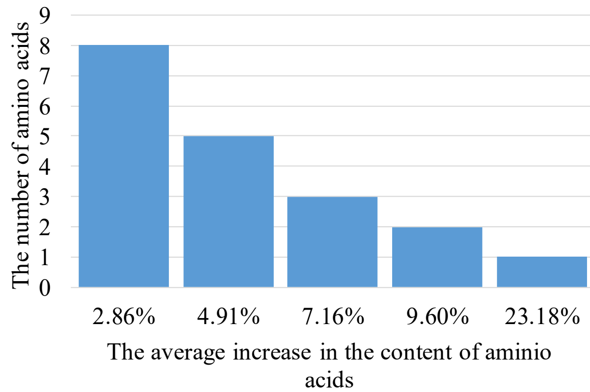

Fig. 2. Histogram of changes in the amino acid composition of buckwheat malt under the influence of plasma-chemically activated aqueous solutions

Table 8

Viscosity of wort obtained from buckwheat malt

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Viscosity of wort, mPa·s
1 (control)	water supply	–	2.1
2	activated	100	1.9
3	activated	200	1.6
4	activated	300	1.5
5	activated	400	1.4
6	**activated**	**500**	**1.2**
7	activated	600	1.3
8	activated	700	1.7

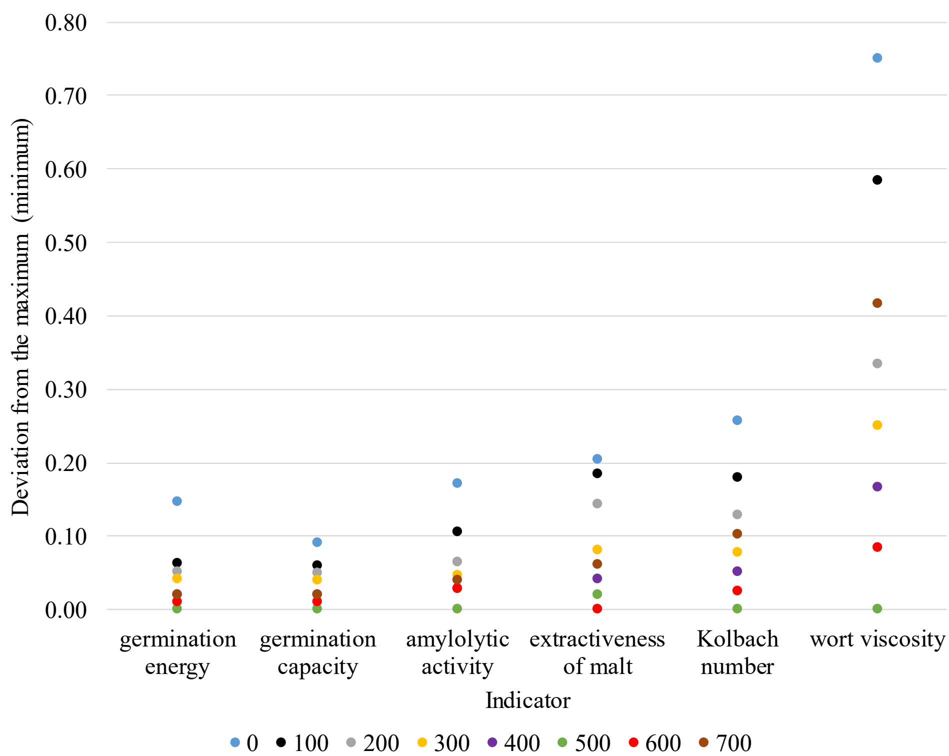

Fig. 3. Dynamics of indicators of buckwheat malt depending on the concentration of hydrogen peroxide from 0 to 700 mg/l

Visualization of calculations, presented by a dot diagram in Fig. 3, convinces that the most resistant to changes in the concentration of hydrogen peroxide were the energy and the ability to germinate (formula (8)). A gradual decrease in stability with an increase in the range of variation was recorded for indicators of amylolytic activity, extractability and Kolbach index of buckwheat malt (formula (8)). The viscosity of the wort was found to be most sensitive to the concentration of hydrogen peroxide (formula (9)). Finally, Fig. 3 clearly convinces that the optimal concentration of hydrogen peroxide in plasma-chemically activated aqueous solutions when soaking buckwheat grain is 500 mg/l, whose markers (green) illustrate the predominant achievement of the desired values of the selected biochemical indicators of buckwheat malt.

5. 4. Study of microbiological indicators of buckwheat malt

Malt microflora has a significant impact on the quality of beer. Therefore, the presence of pathogenic microorganisms on the surface of malt grain was investigated. The results are given in the Tables 9, 10.

Analyzing the data in the Tables 9, 10 it should be noted that plasma-chemically activated aqueous solutions suppress the microflora on the surface of malt grains, including fungal ones. And with a significant concentration of peroxides, buckwheat malt is qualitatively disinfected.

Table 9

Microbiological indicators of buckwheat malt (n=5, p≥0.95)

Groups of microorganisms	Sample	
KMAFAnM, thousand CFU/g	control	2.9
	experiment	not found
Mushrooms, thousand CFU/g	control	1.8
	experiment	not found
Escherichia coli bacteria (E. coli) in 0.1 g of the product	control	0.04
	experiment	not found

Table 10

Infection of buckwheat malt with fungal microflora ((n=5, p≥0.95)

Infection with fungal microflora	Concentration of peroxides in plasma chemically activated aqueous solutions, mg/l							
	0	100	200	300	400	500	600	700
Aspergillus	97	72	35	7	0	0	0	0
Alternaria	39	21	14	6	0	0	0	0
Penicillium	28	10	7	1	0	0	0	0
Fusarium	11	5	3	1	0	0	0	0
Mucor	35	21	15	7	0	0	0	0

5. 5. Development of a technological scheme for the production of buckwheat malt using plasma-chemically activated aqueous solutions

For the purpose of the future industrial implementation of the proposed technology, a technological scheme for the production of buckwheat malt using plasma-chemically activated aqueous solutions has been developed (Fig. 4).

The technological scheme for the production of buckwheat malt using plasma chemically activated aqueous solutions, shown in Fig. 4, allows to have a comprehensive idea of the course of the malting process of buckwheat grain, taking into account the presented innovative component.

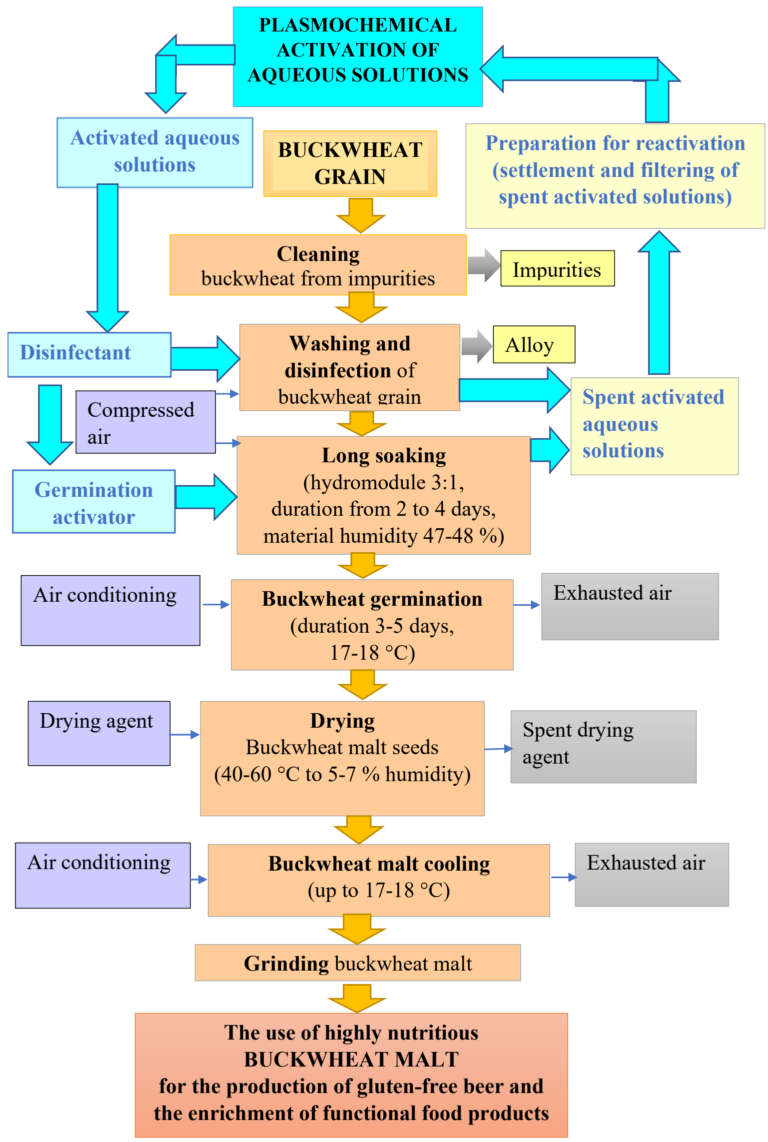

Fig. 4. Technological scheme of buckwheat malt production using plasma-chemically activated aqueous solutions

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

Analysis of the obtained results of the Table 2 allows to note that plasma chemically activated aqueous solutions have a significant effect on the duration of buckwheat soaking. Thus, the buckwheat grain reached the desired moisture level (48 %) in the control sample after 96 hours. When using plasma chemically activated aqueous solutions, a similar result was obtained in 36 hours at a concentration of peroxides of 500 mg/l.

The intensification of the process of moistening buckwheat grain is explained by the fact that plasma chemically activated aqueous solutions are able to defuse much more actively into the grain than ordinary water. The chaotic movement of ions in water treated with contact non-equilibrium plasma allows to accelerate the diffusion of moisture into the middle of the grain due to a more active inflow of charged particles to the surface of the studied raw material [47, 51]. This can be explained by the small-cluster structure of activated water, which seeps well into the pores and microcracks of the grain [39]. Thus, during the implementation of sorption processes, plasma-chemically activated aqueous solutions:

1) accelerate the diffusion of moisture into the grain;

2) growth inhibitors are leached from the flower membrane;

3) lead to the migration of charged particles into the middle of the grain;

4) ensure the effect of hydroperoxide radicals;

5) activate the splitting of the components of the endosperm of the buckwheat grain. It should be assumed that due to the presence of crushed cluster structures at the molecular level, the transport of moisture into the middle of the grain improves. Active hydration is the impetus for intensive germination and synthesis of hydrolytic enzymes.

The study of energy and the ability to germinate allows to predict how effectively the proposed activator acts on malting processes. The results are given in the Table 4 indicate that the energy and germination capacity of buckwheat grains increases rapidly when using plasma-chemically activated aqueous solutions. Let's note that the effect of increasing germination energy was from 8 to 14 %, and germination capacity was 2–9 %. Such dynamics of growth processes allows to talk about the effectiveness of the growth-stimulating effect of the proposed activator. Increased germination activity was noted in the test samples compared to the control, which indicates the prospect of using plasma-chemically activated aqueous solutions to intensify the buckwheat malting process. Plasma-chemically activated aqueous solutions intensify the germination process of buckwheat grains to varying degrees, however, the effect of positive dynamics of energy change and the ability to germinate is present when using any concentration of peroxides in activated solutions. So, it is possible to talk about the positive intensification dynamics of the influence of plasma-chemically activated solutions on the technological process of buckwheat malt production.

The first indicator was amylolytic activity, the results of its research are shown in the Table 5. Maximum amylolytic activity was observed in samples that previously showed maximum moisture and germination energy. This is a logical and expected result. The increase in amylolytic activity ranged from 30 to 77 units/g. Experimental data show that activated water has a positive effect on the degree of buckwheat soaking, and thereby leads to significant activation of amylolytic enzymes. Which in turn contribute to a deeper enzymatic hydrolysis of starch with the formation of simple sugars, which are important components of wort in brewing.

The extractability of buckwheat malt was studied (Table 6). This is the mass fraction of the extract in the dry substance of the malt, which is the sum of the extractive substances of the malt that pass into the solution during mashing. Extract yield is one of the main technochemical characteristics of malts. Compared to barley malt, buckwheat has a fairly low extractability. Therefore, increasing the extractability is an urgent problem, which will be solved by the intensification of the process of splitting the components of the grain. The research results showed an increase in the extractability of buckwheat malt when using plasma-chemically activated aqueous solutions. Thus, this indicator increased by 2–9 %, depending on the concentration of peroxides. Such a result is important for the brewing industry.

Kolbach index was also studied, it characterizes the degree of protein breakdown, is the ratio of soluble nitrogen to total, expressed as a percentage. This indicator reflects the efficiency of proteolysis that occurs during malting and wort preparation. Studies have shown an increase in this indicator by 2–10 % compared to the control, which indicates an intensive course of proteolysis.

The amino acid composition of buckwheat malt also showed a significant result. All investigated amino acids, when using plasma-chemically activated aqueous solutions in the process of sweetening, showed an increase. Analyzing the results given in the Table 7, it should be noted that the total amount of amino acids in the experimental sample is 619 % mg/100 g of product higher than the control. This allows to talk about the activation of proteolytic enzymes in the experimental samples, since amino acids are the result of active proteolysis in malt grain.

In addition, the viscosity of wort obtained from buckwheat malt was investigated. This indicator, as a rule, indicates the degree of cytolytic dissolution of malt. Buckwheat malt, as a rule, has increased viscosity, this is due to the presence of hemicelluloses and gum substances in buckwheat grains. Therefore, the reduction of this indicator is important for wort made from buckwheat malt. The increased viscosity is believed to be the result of underdissolving malt. It causes problems when filtering the wort, reduces the extraction of malt components and thus leads to a decrease in the yield of wort in the brewing compartment. The obtained results are shown in the Table 7. Thus, the viscosity of the wort decreased from 2.1 to 1.2 mPa·s. This is a significant technological result, as it indicates a high degree of dissolution of malt grains and the high quality of the obtained buckwheat malt.

Malts, including buckwheat, contain microorganisms on their surface, in particular, pathogenic ones. It is known that plasma chemically activated aqueous solutions have a disinfecting effect [47–50]. Therefore, it is advisable to use them in the fight against microbiological contamination of malt and beer.

The microbiological state of malt was studied. Analyzing the data in the Table 9, it should be noted that buckwheat malt obtained with the use of plasma-chemically activated aqueous solutions does not contain pathogenic microorganisms. The presence of fungal microflora, which has a significant impact on the quality of food products, was also investigated [47]. Mold, including representatives of the genera Aspergillus, Alternaria, Penicillium, Fusarium, Mucor, was not detected at a high concentration of peroxides in buckwheat malt. It was established that activated solutions with a concentration of peroxides of 500 mg/l or more have the optimal disinfecting effect for buckwheat malt. At this concentration, malt does not contain pathogenic microorganisms.

The industrial implementation of the presented malt production technology requires the development of a technological scheme for the production of buckwheat malt using plasma-chemically activated aqueous solutions. Such a scheme was created and tested in laboratory conditions (Fig. 2). It includes, in addition to classic technological operations, washing and soaking of buckwheat grains with plasma-chemically activated aqueous solutions. Activated solutions are used at the stage of washing and soaking buckwheat grains before germination and do not require significant changes in the improvement of the technological line for the production of buckwheat malt. Used activated aqueous solutions are settled, filtered and sent for repeated plasma chemical activation. Such a technological solution to the use of water when implementing the technology of plasma-chemical activation of aqueous solutions makes it possible to significantly save water resources [46]. The results of research into technological process parameters and changes in the composition of buckwheat malt make it possible to improve existing malting technologies.

The lack of data on the proteolytic activity of buckwheat malts should be attributed to the shortcomings of the research. These data are planned to be obtained during the continuation of research into the technology of buckwheat malt production using plasma-chemically activated aqueous solutions.

The limitations of this study may be related to the provision of processing enterprises with a sufficient number of plasma-chemically activated aqueous solutions. At this stage, this technical-technological problem is being solved, namely, Scientific and Production Enterprise "KNP-TECHNOLOGY" LLC is implementing a program of serial production of industrial plasma chemical installations. In the future, this aspect will make it possible to expand the possibilities of providing specialized food enterprises with technological solutions of a given quality. Therefore, plasma-chemical activation of technological solutions will become available to manufacturers, and this will allow a wider use of innovative technological methods of plasma-chemical processing of raw materials.

The perspective of the research consists in the development of the production technology of fermentable buckwheat malts.

7. Conclusions

1. Changes in the moisture content of grain material during soaking using plasma-chemically activated aqueous solutions were studied. It was established that the optimal soaking time is 36 hours at a concentration of peroxides in the solution of 500 mg/l.

2. The energy and ability to germinate buckwheat grains were studied, so when using activated solutions (concentration of peroxides 500 mg/l), the energy of germination increased by 14 %, and the ability to germinate increased by 9 %.

3. Qualitative indicators of buckwheat malt were studied. Amylolytic activity increased by 77 units/g; extractivity increased by 9 %; Kolbach index increased by 10 %; the total content of amino acids increased by an average of 619 mg/100 g. In addition, the viscosity of the wort decreased from 2.1 to 1.2 mPa·s.

4. Studies of microbiological indicators of buckwheat malt showed that no pathogenic microflora, including mold, was detected on its surface.

5. A technological scheme for the production of buckwheat malt 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 study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

Financing

The study was conducted without financial support.

Availability of data

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.

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