*The object of the study was oat malt production. The result of the presented study is the development of a technology for gluten-free oat malt production using cold plasma-treated technological solutions. The material for the study was oat grain. The main technological task is to obtain high-quality oat malt, which, in turn, will be suitable for producing gluten-free beverages and highly nutritious foods. The expediency of using cold plasma-treated aqueous solutions as an activator of the oat malting process and an effective disinfectant of the technological process and the finished product (oat malt) was experimentally proved. It was confirmed that using cold plasma-treated aqueous solutions can accelerate the oat germination process: the germination energy increased by 6–14 %; germination capacity by 2–10 %. The moisture content of oats when moistened increases by 6–37 %. Analysis of the amylolytic enzymatic activity showed a dynamic increase of 17.6 %. The result was the breakdown of carbohydrates. Thus, the amount of starch decreased by 2.4 %, fiber did not undergo significant changes, and the content of simple sugars increased by 2.3 %. The proteolytic activity of oat malt increased by 18.1 %. An increase in the amount of amino acids in the experimental samples was noted. The total amount of amino acids is 793 mg/100 g of product higher than in the control (i.e. by 3 %). There was also an increase in the content of vitamins B ($B_1$, $B_2$), as well as vitamin C, the content of which increased by 5.6 %. Disinfecting properties of cold plasma-treated aqueous solutions in relation to oat malt were noted.*

*The innovative technology of oat malt production can be implemented in the industrial production of gluten-free malts for the brewing industry and for producing gluten-free foods*

*Keywords: malting, oat malt, gluten-free product, plasma-chemical activation, hydrogen peroxide*

UDC 663.432:663.437
DOI: 10.15587/1729-4061.2024.311477

# DEVELOPMENT OF OAT MALT 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*
**Aliona Dikhtyar**
PhD, Associate Professor**
**Svitlana Andrieieva**
PhD, Associate Professor**
**Svitlana Omelchenko**
PhD, Associate Professor**
**Oleh Kotliar**
PhD**
**Andrii Kariyk**
Senior Lecturer
Department of Tourism and Hospitality
O. M. Beketov National University of Urban Economy in Kharkiv
Marshala Bazhanova str., 17, Kharkiv, Ukraine, 61002
**Serhii Rudakov**
PhD, Associate Professor
Department of Fire Prevention in Settlements***
**Serhii Harbuz**
PhD
Department of Supervisory and Preventive Activities***
**Liudmyla Onyshchenko**
PhD
Department of Livestock Production Technology
Mykolayiv National Agrarian University
Georgy Gongadze str., 9, Mykolayiv, Ukraine, 54008
*Dnipro State Agrarian and Economic University
Serhiya Yefremova str., 25, Dnipro, Ukraine, 49600
**Department of Food Technology in the Restaurant Industry
State Biotechnological University
Alchevskykh str., 44, Kharkiv, Ukraine, 61002
***National University of Civil Defence of Ukraine
Chernyshevska str., 94, Kharkiv, Ukraine, 61023

*Received date 02.07.2024*
*Accepted date 11.09.2024*
*Published date 30.10.2024*
***How to Cite:*** *Kovalova, O., Vasylieva, N., Dikhtyar, A., Andrieieva, S., Omelchenko, S., Kotliar, O., Kariyk, A., Rudakov, S., Harbuz, S., Onyshchenko, L. (2024). Development of oat malt production technology using plasma-chemically activated aqueous solutions. Eastern-European Journal of Enterprise Technologies, 5 (11 (131)), 80–91. https://doi.org/10.15587/1729-4061.2024.311477*

## 1. Introduction

Barley, rye and wheat are considered traditional cereals for producing high-quality malt. However, there are more and more individuals among consumers suffering from intolerance to gluten contained in these cereals. This is due to a significant limitation of the food range for this category of consumers, which affects the quality of life of such people. To expand the raw material base, numerous studies are being conducted on using a wide range of grain crops for malting,

which have a number of useful and unique properties. However, gluten-free raw materials are currently the priority and universal for food production. Gluten-free crops include oats and buckwheat and are recommended to be used in dietary nutrition for patients with gluten intolerance [1]. Oats have a high nutritional value. Oat proteins contain all the essential amino acids. Carbohydrates are represented by starch, a high content of non-starch polysaccharides, especially fiber. Oats also contain various vitamins and minerals. Compared to other cereals, oats have a number of useful properties: high content of essential amino acids in the protein, the presence of B vitamins, energy value. The amino acid composition of oats is much richer in a number of essential amino acids compared to rice and barley grain. Oats are a gluten-free grain raw material, which is due to a low content of the protein gluten fraction, so this raw material will be indispensable for consumers with gluten intolerance.

Industrial production of oat malt is based on innovative grain germination technologies, which are progressive for the malt industry. So, various germination intensifiers of universal application are widely used. Scientific research in this area is important, and the relevance of the topic is reflected in the development of oat malt production technology using cold plasma-treated technological solutions. The future scientific value of the technology lies in the development of innovative gluten-free oat malt technology and the implementation of innovative technological solutions in malt production.

## 2. Literature review and problem statement

Oats are a grain crop mainly used as animal feed and for malt production and brewing, respectively [2]. Studies have shown that eating oats-rich foods can reduce the risk of some chronic diseases. Although there is no absolute consensus, some of these benefits may be due to the presence of compounds such as phenolic compounds, vitamin E, and **b**-glucan in oats. A number of advantages were also associated with the lipid component (sterols, fatty acids), proteins and bioactive peptides of oats [2]. The paper [3] shows that oats are a rich source of soluble fiber, beta-glucan, phenolic compounds, as well as functional lipid and protein components, which can potentially help in the prevention and treatment of hypertension. Oat malt is also considered a delivery system for endogenous enzymes [4]. But there are still unresolved issues related to the availability of oat grain components for assimilation by the human body.

The main category of consumers of gluten-free raw materials, including oats, are people with diet-dependent diseases who need a gluten-free diet and groups of potential consumers of gluten-free beer [5]. The production of gluten-free malts for special beers for people suffering from celiac disease remains an unresolved problem. For the production of light beer, three different types of gluten-free cereals (oats, rice and corn) are used, grain mixtures show promising properties as additives to the raw material base of special brewing [6]. Using oat malt is also associated with the desire to add new characteristics to beer and improve the brewing process or reduce production costs [7]. However, using alternatives to classic malts can affect the quality of gluten-free beer and lead to some negative consequences [8]. Therefore, the production of gluten-free malts that could satisfy brewers by their technological indicators remains an unresolved problem.

The technology of malt production from oats is currently not widespread among scientists, as well as industrial maltsters. The reason for this may be difficulties associated with the production and further processing of such malt. An option to overcome the relevant difficulties can be an intensive method of grain bioactivation, namely intensive germination, which will lead to an improvement in technological parameters. This will increase the efficiency of managing the production and processing of grain and related food products [9]. The study also confirmed the hypothesis that the breakdown of carbohydrates during oat germination leads to a decrease in wort viscosity [10]. The oat malting process is currently used to improve the health properties and aroma of oats [11].

Oat malting is commonly carried out using enzyme preparations as intensifiers [12]. This can significantly improve the technological indicators of malt. Oat malt starch was found to react with water during the first nine hours of fermentation, producing large amounts of free sugars [12]. Therefore, correcting processes in the grain due to the action of enzymes is a promising direction. This is the approach applied in [13], suggesting the use of a cytolytic enzyme preparation as a stimulator of biochemical processes in oat grain. However, artificially introduced enzyme preparations make the production process much more expensive. Also, to improve the technological parameters of malt, the effect of high-intensity ultrasound is used as a pre-treatment in developing fermented oat drinks [14]. But there are still unresolved issues related to adjusting the technological parameters of oat malt for its wide use.

Currently, industrial processes of producing functional food with an increased β-glucan fraction are vulnerable due to high losses of energy and valuable nutrients, which requires new technological solutions. Oat malt is considered a raw material for producing β-glucan concentrates rich in protein, vitamins, and enzymes [15]. The process of malting cereals improves their antioxidant properties and increases their nutritional value. Oat malt can be successfully used for producing gluten-free fermented beverages, or as an additive to fermented products, for example, in confectionery baking [16]. Oat malt is widely used in breadmaking [17]. The nutritional characteristics of beverages made from oat malt obtained by a special technology are not inferior to dairy products, the production of which is now less economically attractive due to difficulties in obtaining dairy raw materials [18]. However, producing oat malts with directed technological properties remains an unresolved problem.

Currently, the factors influencing the germination process of oat grain and the accumulation of nutrients in it during malting are widely studied. So, studies on the effect of different oat grain moistening temperatures on the technological process were carried out. The results showed that the mass transfer constants increased with increasing temperature [19]. However, microbiological processes on the grain surface are an unresolved issue, since when the ambient temperature rises, pathogenic microflora accumulates. The effect of high-pressure carbon dioxide on the microbial quality and germination of oat grain was studied [20]. An unresolved problem is the influence of chemicals on oat germination rates, i.e. the microflora partially dies, and oats become unsuitable for malting.

Therefore, an important aspect is the introduction of oat germination intensifiers, which would be safe for consumers and effectively correct directed biochemical processes in the

grain. A way to overcome the relevant difficulties can be the use of various germination intensifiers in the process of soaking oats during malt production. The purpose of intensification is to obtain well-germinated oat grain, rich in biologically active components. It is also important to maintain the microbiological purity of the malting process.

An interesting option to overcome technological difficulties can be the use of cold plasma-treated aqueous solutions in the oat germination process. Such an innovative approach is presented in [21], so modern technologies of cold plasma treatment of technological solutions in the food industry have found quite promising applications. This is the approach used in [22], so cold plasma treatment is used for cleaning wastewater of food enterprises. However, using plasma-chemical technology in the production of food sprouts from seeds of various crops is more promising [23]. Currently, plasma-chemical technologies are used for grain conditioning in cereal production [24]. However, the main attention of scientists is drawn to the effect of plasma-chemical activation on the malting process of various crops [25]. Compared to intensifiers of natural origin [26], the presented technology is more effective. But there are still unresolved issues related to the influence of cold plasma on the oat malt production process.

All this suggests that it is advisable to conduct a study on using cold plasma-treated aqueous solutions in the technological process of oat germination for various purposes.

## 3. The aim and objectives of the study

The aim of the study is to develop an innovative technology for oat malt production using plasma-chemically activated aqueous solutions. The study will make it possible to speed up the technological process of oat malting and qualitatively expand the range of gluten-free grain raw materials for food and beverage production.

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

– to study the germination indicators and changes in the moisture content of oat grain during germination;

– to investigate the enzymatic activity in oats during germination, analyze the carbohydrate and amino acid composition of oat malt;

– to examine the vitamin composition of oat malt;

– to study the microbiological indicators of oats and oat malt;

– to develop a flow diagram of oat malt production using cold plasma-treated aqueous solutions.

## 4. Materials and methods

### 4. 1. Object and hypothesis of the study

The object of the study is oat malt production. To study the oat germination process, cold plasma-treated solutions were chosen as a germination stimulator. They are also called plasma-chemically activated aqueous solutions. They are already widely used in food technologies, including technologies of malt production from various grain crops [21, 25]. From a scientific point of view, further research and wider use of the presented technology in the germination of gluten-free grain raw materials, namely, oats, are interesting.

The working hypothesis of the study is the intensification of oat grain germination and enrichment of oat malt with biologically active components by applying the presented germination stimulator. Cold plasma-treated aqueous solutions were used as a grain moistening agent at all process stages.

Technological solutions were activated in the Specialized Laboratory of Plasma Processing of Technological Solutions of Food Industries of the Dnipro State Agrarian and Economic University and in the production conditions of the KNP-TECHNOLOGY Research and Production Enterprise LLC (Dnipro, Ukraine). The research was conducted 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. Materials and equipment used in the experiment

#### 4. 2. 1. Cold plasma treatment of aqueous solutions

Plasma-chemical activation of aqueous solutions for the oat germination process was carried out using a special technology of mains water treatment with cold non-equilibrium plasma [22]. To carry out research, a special laboratory-type plasma-chemical plant was used, being an absolute analog of an industrial plant for processing aqueous solutions [22]. Such a laboratory unit is represented by a three-arc plasma-chemical plant, consisting of a reactor, anodes, a cathode, a reflux condenser, a power source, and a vacuum pump [17]. For oat grain germination, technological solutions were prepared, the characteristics of which are given in Table 1. Hydrogen peroxide in the activated water was determined by iodometry, and the values were simultaneously recorded by the express method.

Table 1

Characteristics of cold plasma-activated technological solutions

| Experiment No. | Water | Activation time, min | Concentration of hydrogen peroxide in the aqueous solution, mg/l |
|---|---|---|---|
| 1 (control) | mains | – | – |
| 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 |

Accordingly, mains water activation was carried out at an experimental laboratory plant. The treatment time was regulated, varying from 5 to 60 minutes. The concentration of hydrogen peroxide in the activated solutions ranged from 100 to 700 mg/l (Table 1).

#### 4. 2. 2. Selection of raw materials for oat malt production and features of soaking and germination of oat grain

Oat grain was chosen as the raw material for malt production. The technological process was implemented by the classical malting technology using a box-type laboratory malt house. At the initial stage, oats were cleaned of impurities, washed and disinfected with activated water solutions. Oat soaking was implemented by the air-water method at a temperature of 16 °C until the moisture content reached

44–46 % using a 3:1 hydromodule. The soaking time was 48 hours, until the oats reached the moisture level necessary for germination. Oats were germinated for 5 days at a constant temperature of 14–18 °C, and stirred 2 times a day. Oat malt was dried at a temperature of 40–80 °C for 24 hours to a moisture content of 5 %.

**4. 3. Methods of determining the parameters and properties of samples**

**4. 3. 1. Method of studying the germination indicators and changes in the moisture content of oat grain during germination**

Germination energy and capacity are important technological indicators for oat grain intended for malt production. The presented indicators are determined by conventional methods.

The moisture content of oats was recorded every day during soaking and germination of oats using activated water solutions. When soaking grain material, the air-water method was used. Moisture monitoring was carried out by drying grain samples by a standard method using a drying cabinet.

**4. 3. 2. Methods of studying the enzymatic activity in oats during germination and analyzing the carbohydrate and amino acid composition**

The amylolytic activity was determined by the colorimetric method. To analyze the proteolytic activity, Anson's modification method was used.

To determine the carbohydrate composition, the polarimetric (Ewers) method for determination of starch content, conventional method for determination of crude fiber content in food products (DSTU ISO 5498:2004), and refractometric method for determination of sugars were used.

The amino acid content in oat malt was determined by ion-exchange liquid column chromatography on a T339 automatic amino acid analyzer, manufactured in the Czech Republic, Prague.

**4. 3. 3. Methods of studying the vitamin composition of oat malt**

Determination of vitamins $B_1$ and $B_2$ was carried out by the fluorimetric method, based on the release of bound forms of thiamine and riboflavin by acid and enzymatic hydrolysis. For vitamin C, the reversed-phase HPLC method with UV detection is used.

**4. 3. 4. Methods of determining the microbiological indicators of oat malt**

During microbiological studies, the total microbial count (QMAFAnM) was determined. The microbiological indicators of oat malt were determined by conventional methods according to DSTU 8446:2015 Food products. Methods for quantity determination of mesophilic aerobic and facultative anaerobic microorganisms.

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

To process the quantitative results of experiments, they were analyzed by a number of statistical methods [27], which gave the basis for formulating conclusions and recommendations as the results of the study.

First, the change in moisture content ($Y1$, %) during germination ($T$, days) of control and experimental oat grain was mathematically formalized by linear paired regressions with numerical coefficients $A0$ and $A1$ according to the formula:

$$Y1=A0+A1\times T. \quad (1)$$

The adequacy of regression (1) to the experimental data of a sample of $N$ observations was confirmed by the coefficient of determination $R^2$ and Fisher's test (Fregr) according to the inequality:

$$Fregr>Fcrit(\alpha; 2; N-2) \quad (2)$$

with the critical value $Fcrit(\alpha; 2; N-2)$ with the significance $\alpha$ and degrees of freedom 2 and $N-2$. The significance of the coefficient $A1$ as an indicator of the daily dynamics of oat grain moisture when comparing grain processing technologies was analyzed using the Student's test (*Tregr*). Moreover, the fulfillment of the inequality with the critical value $Tcrit(\alpha; N-2)$:

$$|Tregr|>Tcrit(\alpha; N-2) \quad (3)$$

meant the reliability of the coefficient $A1$ with a given significance $\alpha$ and degree of freedom $N-2$.

Second, the analysis of daily changes ($\Delta_i$, %) in the amylolytic and proteolytic activity of oats during germination for $M$ days was carried out using a sample of the dynamics of the experimental and control indicators ($Bi$, units/g) relative to the initial level of the zero day ($B0$, units/g), i. e.:

$$\Delta_i=((Bi-Bi-1)/B0-1)\times 100,\ i=1,...,M. \quad (4)$$

The corresponding mean changes $\Delta mean$ and standard deviations $\Delta st.dev$ became the basis for comparing the amylolytic and proteolytic activity of oats during germination by classical and experimental technologies using plasma-chemical activation.

Third, statistical analysis was used to compare the composition of germinated oats by K groups of amino acids in the experiment ($Di$, mg/100 g of product) and control ($Ci$, mg/100 g of product). For this, the absolute ($\Delta i^{abs}$, mg/100 g of product) and relative ($\Delta i^{rel}$, %) changes in each amino acid were considered according to the formulas:

$$\Delta i^{abs}=Di-Ci, \quad (5)$$

$$\Delta i^{rel}=(Di-Ci)/Ci\times 100. \quad (6)$$

The hypothesis about the special dynamics of certain amino acids in the groups was tested by Dixon's test ($Qcalc$). At the same time, in the group of $N$ amino acids, outliers with a significance level $\alpha$ were established when the inequality was fulfilled:

$$Q>Q(\alpha; N), \quad (7)$$

with the critical value $Q(\alpha; N)$.

The remaining $J$ amino acids after outlier exclusion were investigated for the advantages of using plasma-chemically activated technological solutions over classical technology. The conclusion about differences between the amino acid groups was confirmed by the one-factor ANOVA test (*Fanova*) with the critical value $Fcrit(\alpha; K-1; J-K)$ at a significance $\alpha$ and degrees of freedom $K-1$ and $J-K$ according to the inequality:

$$Fanova > Fcrit(\alpha; K-1; J-K). \quad (8)$$

Fourth, for changes in the vitamin composition of oat malt, mathematical formalization of the vitamin C content ($Y2$, μg/g) during germination ($T$, days) of control and experimental oats was carried out. The analysis was made using linear paired regressions with numerical coefficients $E0$ and $E1$ according to the formula:

$$Y2=E0+E1\times T. \quad (9)$$

To substantiate the adequacy of regressions (9), the coefficient of determination $R^2$ and Fisher's test (2) were used, while the Student's test (3) was the basis for concluding the significance of the coefficient $E1$, characterizing the daily dynamics of vitamin C content during the germination of control and experimental oats.

Fifth, contamination of oat malt with fungal microflora ($Y3$, units/sq.cm) depending on peroxide concentration ($X$, mg/l) in technological solutions is mathematically described by linear paired regressions with numerical coefficients $G0$ and $G1$ according to the formula:

$$Y3=G0+G1\times X. \quad (10)$$

As before, the adequacy of regressions (10) is substantiated by the coefficient of determination $R^2$ and Fisher's test (2). The significance of the coefficient $G1$ as a characteristic of the rate of reduction of oat malt contamination with fungal microflora was checked using the Student's test (3).

Calculations by the described methods were carried out using MS Excel and Google Sheets electronic spreadsheet tools.

## 5. Results of studies of the process indicators of oat malt production

### 5. 1. Study of the germination indicators and changes in the moisture content of oat grain during germination

The basic technological indicators of grain raw materials for malting are germination energy and capacity (Table 2). Oat raw materials with 100 % viability were selected, i. e. the maximum germination rate is set at 100 %.

Table 2

Oat germination rates when using cold plasma-treated solutions

| Experiment | Water | Concentration of hydrogen peroxide, mg/l | Germination rates, % | |
|---|---|---|---|---|
| | | | Energy | Capacity |
| 1 | mains | – | 82 | 90 |
| 2 | activated | 100 | 88 | 92 |
| 3 | activated | 200 | 90 | 95 |
| 4 | activated | 300 | 92 | 96 |
| 5 | activated | 400 | 94 | 97 |
| 6 | activated | 500 | 95 | 98 |
| 7 | activated | 600 | 96 | 100 |
| 8 | activated | 700 | 95 | 99 |

The oat grain germination rates increased when using cold plasma-treated solutions. The germination energy increased by 6–14 %, and germination capacity by 2–10 %, respectively.

Based on the maximum oat germination rates, the change in the moisture content of grain material during germination was analyzed. The experiment was conducted for two groups – the control group and the group with maximum germination rates (peroxide concentration of 600 mg/l). The results are shown in Fig. 1.

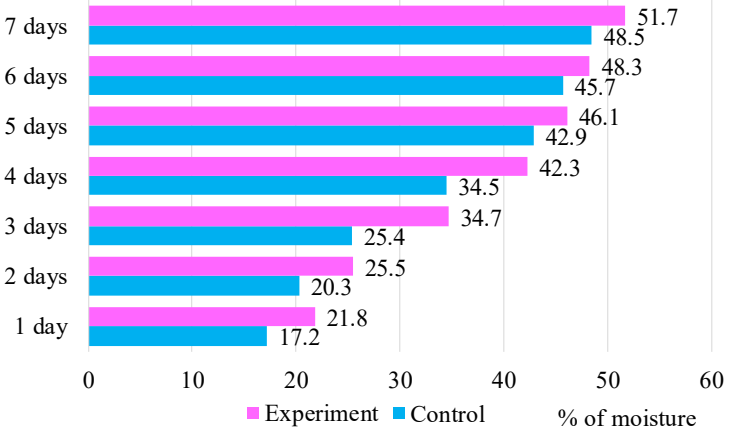


Fig. 1. Changes in the moisture content of oat grain during germination

The results of the analysis in Fig. 1 showed that the grain reached the optimal moisture content for the continuous germination of oat ridges on the 4th day of the technological process, which is a day faster than with classical technology (control). So, it is logical that on the 5th day the germination capacity reaches 100 %.

To compare the experimental and control technologies, a statistical analysis of the data in Fig. 1 was carried out, given that the initial moisture content of oat grain was 12 %. For this, linear paired regressions (1) were constructed for 2 samples of $N$=8 observations. As shown in Table 3, both regressions are adequate to the sample data due to high coefficients of determination $R^2$ and according to the Fisher's test (2) with a significance level $\alpha$=0.05 and $Fcrit(0.05; 1; 6)$=5.987.

Table 3

Dynamics of oat grain moisture content during germination

| Oat malt | Regression | $R^2$ | $Fregr$ | $Tregr$ | $A1$, % for 1 day |
|---|---|---|---|---|---|
| Control | $Y1=11.03+5.65T$ | 0.978 | 261.78 | 16.18 | 5.65 |
| Experiment | $Y1=15.31+5.71T$ | 0.962 | 149.88 | 12.24 | 5.71 |

Also, by the Student's test (3) with a significance level $\alpha$=0.05 and $Tcrit(0.05; 6)$=2.447, it was determined that the found coefficients $A1$ are reliable indicators for the daily increase in the oat grain moisture level during germination. Therefore, it is confirmed that the experimental technology (using plasma-chemical activation) accelerates moistening by 0.06 pp per day, compared to the control (by classical technology).

### 5. 2. Study of the enzymatic activity in oats during germination, analysis of the carbohydrate and amino acid composition

An important stage of the study is to determine the enzymatic activity of oat malt. So, the activity level of amylolytic and proteolytic enzymes is significant for future malt. The

first are responsible for starch breakdown into simple sugars, the second – for protein breakdown into amino acids. The analysis of amylolytic enzymatic activity is given in Table 4.

Table 4

Changes in the amylolytic activity of oats during germination, units/g

| Process stage | Oat malt | |
|---|---|---|
| | Control (classic technology) | Experiment (using plasma-chemical activation) |
| 0 day (oats) | 79.1 | 79.1 |
| 1 day | 101.4 | 120.2 |
| 2 day | 118.3 | 131.5 |
| 3 day | 123.5 | 142.0 |
| 4 day | 131.7 | 154.8 |
| 5 day | 142.3 | 168.4 |
| 6 day | 155.2 | 179.6 |
| 7 day | 167.4 | 190.3 |

The results of analyzing the amylolytic activity showed a dynamic increase during the entire germination process, so the increase of this indicator varied from 18.8 units/g on the first day of germination and reached a maximum of 25.1 units/g on the fifth day (i. e. by 17.6 %).

Now it is logical to analyze the biochemical complex affected by a group of amylolytic enzymes. During oat germination, significant biochemical transformations of the main oat grain components occur, especially the carbohydrate complex undergoes changes. Therefore, to reflect the main directions of biochemical processes, a study of changes in the carbohydrate composition of both oat grain and oat malt was conducted. The results are shown in Table 5.

Table 5

Changes in the carbohydrate composition of oats and oat malt, %

| Indicator | Oat | Oat malt | |
|---|---|---|---|
| | | Control (classic technology) | Experiment (using plasma-chemical activation) |
| Starch | 40.7±1.1 | 33.2±1.2 | 30.8±1.1 |
| Fiber | 10.4±0.6 | 10.2±0.5 | 10.0±0.1 |
| Mono- and disaccharides | 1.2±0.2 | 7.3±0.1 | 9.7±0.1 |

The results of analyzing the carbohydrate complex showed significant starch breakdown, namely, the amount of starch during germination decreased by 7.5 % (with classical technology) and by 9.9 % (when using cold plasma-treated solutions). That is, using the presented technology, it is possible to increase grain starch breakdown by 2.4 %. When examining the fiber content, a slight decrease (0.2–0.4 %) was noted. Simple sugars (mono- and disaccharides) had a tendency to increase, so they increased by 6.1 % with classical technology, and by 8.4 % with the intensive one.

The next step was to analyze the proteolytic activity of oats during germination, the main results are given in Table 6.

The results of analyzing the proteolytic activity showed a dynamic increase during the entire germination process, so the increase in this indicator varied from 10.1 units/g on the first day of germination and reached a maximum of 12.5 units/g on the fifth day (i.e. by 18.1 %). Increased proteolytic activity will increase the amino acid content in oat malt.

Table 6

Changes in the proteolytic activity of oats during germination, units/g

| Process stage | Oat malt | |
|---|---|---|
| | Control (classic technology) | Experiment (using plasma-chemical activation) |
| 0 day (oats) | 40.7 | 40.7 |
| 1 day | 45.3 | 55.4 |
| 2 day | 49.4 | 60.7 |
| 3 day | 56.2 | 68.1 |
| 4 day | 61.3 | 71.5 |
| 5 day | 69.0 | 81.5 |
| 6 day | 79.6 | 92.0 |
| 7 day | 89.3 | 99.7 |

A mathematical comparison of the amylolytic and proteolytic activity of oats during germination for $M$=7 days was carried out by the indicators $\Delta i$ calculated by formula (4) in Table 7.

Table 7

Dynamics of the amylolytic and proteolytic activity of oats during germination, %

| Day | Amylolytic activity | | Proteolytic activity | |
|---|---|---|---|---|
| | Control | Experiment | Control | Experiment |
| 1 | 28.2 | 52.0 | 11.3 | 36.1 |
| 2 | 21.4 | 14.3 | 10.1 | 13.0 |
| 3 | 6.6 | 13.3 | 16.7 | 18.2 |
| 4 | 10.4 | 16.2 | 12.5 | 8.4 |
| 5 | 13.4 | 17.2 | 18.9 | 24.6 |
| 6 | 16.3 | 14.2 | 26.0 | 25.8 |
| 7 | 15.4 | 13.5 | 23.8 | 18.9 |

The found values of $\Delta mean$ and $\Delta st.dev$ are visualized in Fig. 2, suggesting that the experimental technology in both cases stimulated a greater increase in activity, since 17.1 %<20.7 % and 15.9 %<20.1 %. The daily proteolytic activity was higher than the amylolytic activity in both the experiment and the control, i.e. 20.7 %>20.1 % and 17.1 %>15.9 %. At the same time, the amylolytic activity was more unstable than the proteolytic activity of oats in both classical and experimental germination technologies, as evidenced by the inequalities 6.6 %>5.8 % and 13.1 %>8.4 %.

A significant technological indicator of oat malt is the amino acid composition. Therefore, an important step is to analyze the amino acid composition of germinated oat grain. The results are given in Table 8. For the study, the malt obtained by classical technology and the experimental group with maximum germination energy and capacity were selected.

Analyzing the results given in Table 8, note that the amount of amino acids in the experimental samples increased. So, the total amount of amino acids is 793 mg/100 g of product higher than in the control (i.e. by 3 %). Statistical analysis of the amino acid composition of germinated oat grain was carried out for $K$=2 groups presented in Table 8. A comparison of the experiment and control was carried out in absolute and relative terms by the indicators $\Delta i^{abs}$ (5) and $\Delta i^{rel}$ (6) given in Tables 9, 10.

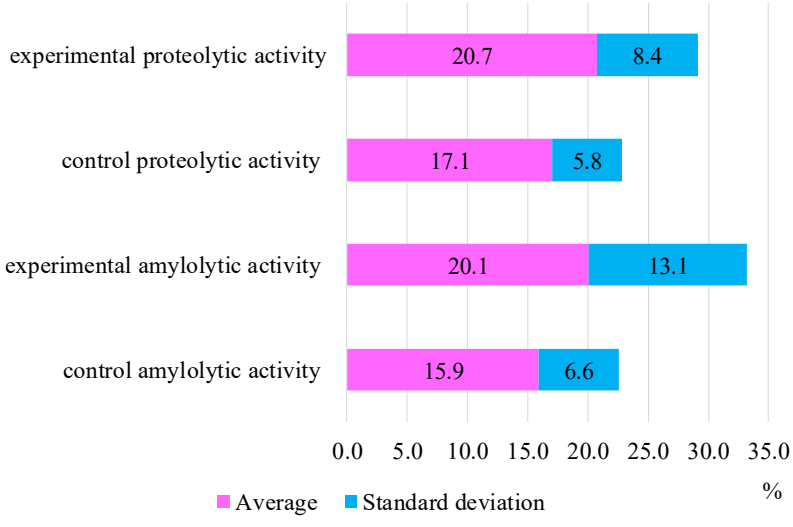


Fig. 2. Changes in the amylolytic and proteolytic activity of oats during germination

Table 8

Amino acid composition of germinated oats, mg/100 g of product

| Amino acid | Oat malt | |
|---|---|---|
| | control (classic technology) | experiment (using plasma-chemical activation) |
| Essential amino acids | | |
| Lysine | 491 | 576 |
| Threonine | 4,049 | 4,170 |
| Valine | 335 | 395 |
| Methionine | 25 | 36 |
| Isoleucine | 257 | 341 |
| Leucine | 630 | 659 |
| Phenylalanine | 482 | 524 |
| Non-essential amino acids | | |
| Histidine | 149 | 162 |
| Arginine | 5,231 | 5334 |
| Aspartic acid | 10,291 | 10,320 |
| Serine | 537 | 587 |
| Glutamic acid | 1,958 | 1,998 |
| Proline | 158 | 173 |
| Glycine | 479 | 497 |
| Alanine | 541 | 586 |
| Cystine | 134 | 159 |
| Tyrosine | 268 | 291 |
| Total | 26,015 | 26,808 |

Table 9

Dynamics of the essential amino acid composition of germinated oats

| Name | Diabs, mg/100 g of product | Direl, % |
|---|---|---|
| Lysine | 85 | 17.31 |
| Threonine | 121 | 2.99 |
| Valine | 60 | 17.91 |
| Methionine | 11 | 44.00 |
| Isoleucine | 84 | 32.68 |
| Leucine | 29 | 4.60 |
| Phenylalanine | 42 | 8.71 |

Table 10

Dynamics of the non-essential amino acid composition of germinated oats

| Name | $\Delta i^{abs}$, mg/100 g of product | $\Delta i^{rel}$, % |
|---|---|---|
| Histidine | 13 | 8.72 |
| Arginine | 103 | 1.97 |
| Aspartic acid | 29 | 0.28 |
| Serine | 50 | 9.31 |
| Glutamic acid | 40 | 2.04 |
| Proline | 15 | 9.49 |
| Glycine | 18 | 3.76 |
| Alanine | 45 | 8.32 |
| Cystine | 25 | 18.66 |
| Tyrosine | 23 | 8.58 |

Dixon's test revealed that in the group of $N$=10 non-essential amino acids, arginine is an outlier in absolute growth and cystine is an outlier in relative increase in content, confirming the corresponding inequalities (7) with a significance level $\alpha$=0.05:

$Q$=0.602>0.477=$Q$(0.05; 10)
and $Q$=0.549>0.477=$Q$(0.05; 10).

The remaining $J$=16 amino acids were analyzed by the one-factor ANOVA test (8) with a significance level $\alpha$=0.05. Based on the inequality:

6.003=*Fanova*>4.6=*Fcrit*(0.05; 1; 14),

it was concluded that the absolute average increase (61.714 mg/100 g of product) in essential amino acids was significantly higher than in non-essential amino acids (without arginine), which increased by an average of 28.667 mg/100 g of product. Similarly, based on the inequality:

5.749=*Fanova*>4.6=*Fcrit*(0.05; 1; 14)

it was concluded that the relative average increase (18.316 %) in essential amino acids was significantly higher than in non-essential amino acids (without cystine), which increased by an average of 5.831 %.

### 5. 3. Study of the vitamin composition of oat malt

An important step in studying the oat malt quality is to analyze changes in the vitamin composition during oat germination. So, oat grain has no vitamin C, but it is synthesized during germination and accumulated in the germinated grain. The results of the oat grain study are presented in Fig. 3. Analyzing the data in Fig. 3, we note that the amount of vitamin C in oat malt increased compared to the control. At the final germination stage, the amount of vitamin C was higher by 14 μg/g (5.6 %, respectively). After drying oat malt as a result of partial destruction of vitamin C, 190 μg/g remained in the control and 210 μg/g in the experimental sample. To compare the experimental and control technologies, a statistical analysis of the data in Fig. 3 was carried out, given that the vitamin C content in oat grain on the first day was 0 %. For this, linear paired regressions (9) were constructed for 2 samples of $N$=7 observations.

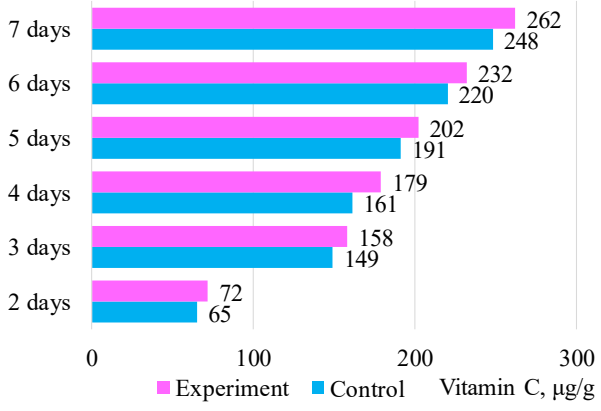


Fig. 3. Changes in vitamin C content during oat germination

As shown in Table 11, both regressions are adequate to sample data due to high coefficients of determination $R^2$ and according to the Fisher's test (2) with a significance level $\alpha$=0.05 and *Fcrit*(0.05; 1; 5)=6.608. Also, by the Student's test (3) with a significance level $\alpha$=0.05 and *Fcrit*(0.05; 5)=2.571, it was determined that the found coefficients *E*1 are reliable indicators for the daily increase in the vitamin C content in oat grain during germination. Therefore, it was confirmed that the experimental technology (using plasma-chemical activation) accelerates the synthesis and accumulation of vitamin C by 1.93 μg/g per day, compared to the control (using classical technology).

Table 11

Dynamics of vitamin C content during oat germination

| Vitamin C | Regression | $R^2$ | *Fregr* | *Tregr* | *E*1, μg/g for 1 day |
|---|---|---|---|---|---|
| control | *Y*2=–8.86+39.14*T* | 0.933 | 69.31 | 8.33 | 39.14 |
| experiment | *Y*2=–6.43+41.07*T* | 0.926 | 62.20 | 7.89 | 41.07 |

The content of B vitamins, namely $B_1$ and $B_2$, was also analyzed. The results are shown in Table 12.

Table 12

Vitamin composition of oat malt, mg/100 g of product

| Indicator | Oat malt | |
|---|---|---|
| | Control (classic technology) | Experiment (using plasma-chemical activation) |
| Vitamin $B_1$ (thiamine) | 0.22 | 0.34 |
| Vitamin $B_2$ (riboflavin) | 0.03 | 0.05 |

Analyzing the results given in Table 12, it should be noted that the content of B vitamins in the experimental samples increased by 55–67 %.

**5. 4. Study of the microbiological indicators of oats and oat malt**

Oat grain is highly contaminated with pathogenic microflora, so it is appropriate to study the disinfecting ability of plasma-chemically activated aqueous solutions. The microbiological state of oat malt affects the subsequent quality of finished products. Therefore, the microbiological state of oat malt was investigated. The results are shown in Tables 13, 14.

Analyzing the data given in Tables 13, 14, we note that solutions subjected to plasma-chemical activation reduce the microbial contamination of oat malt. So, the disinfecting effect of hydrogen peroxide present in the solutions made it possible to destroy even very resistant microbiota, namely, fungal. That is, the raw material is devoid of mold microflora of the genera Aspergillus, Alternaria, Penicillium, Fusarium, Mucor, which are very dangerous for consumers. And at a peroxide concentration of (500 mg/l of hydrogen peroxide), oat malt had no pathogenic microorganisms on its surface.

Table 13

Total microbiological indicators of oat malt ($n$=5, $p$≥0.95)

| Groups of microorganisms | Sample | |
|---|---|---|
| QMAFAnM, thousand CFU/g | Control | 4.7 |
| | Experiment | 0 |
| Fungi, thousand CFU/g | Control | 2.9 |
| | Experiment | 0 |
| Escherichia coli bacteria (E. coli), in 0.1 g of product | Control | 0.08 |
| | Experiment | 0 |

Table 14

Oat malt contamination with fungal microflora ($n$=5, $p$≥0.95), units/sq.cm

| Type of fungal microflora | Concentration of peroxides in technological solutions, mg/l | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | 400 | 500 | 600 | 700 |
| Aspergillus | 120 | 99 | 61 | 34 | 11 | 0 | 0 | 0 |
| Alternaria | 78 | 45 | 31 | 14 | 5 | 0 | 0 | 0 |
| Penicillium | 54 | 35 | 17 | 7 | 0 | 0 | 0 | 0 |
| Fusarium | 22 | 19 | 15 | 2 | 0 | 0 | 0 | 0 |
| Mucor | 46 | 25 | 15 | 10 | 2 | 0 | 0 | 0 |

Following the research methodology, according to the data in Table 14, linear paired regressions (10) were constructed for 5 samples of *N*=5 observations illustrating the reduction of oat malt contamination with fungal microflora depending on the peroxide concentration in cold plasma-treated solutions. As shown in Table 15, all regressions are adequate to sample data due to high coefficients of determination $R^2$ and according to the Fisher's test (2) with a significance level $\alpha$=0.05 and *Fcrit*(0.05; 1; 3)=10.128.

Table 15

Mathematical description of oat malt contamination dynamics

| Type of fungal microflora | Regression | $R^2$ | *Fregr* | *Tregr* | *G*1×100, units/sq.cm per 100 mg/l |
|---|---|---|---|---|---|
| Aspergillus | *Y*3=121.6–0.283*X* | 0.992 | 369.07 | –19.21 | –28.3 |
| Alternaria | *Y*3=70.0–0.177*X* | 0.948 | 54.55 | –7.39 | –17.7 |
| Penicillium | *Y*3=49.8–0.136*X* | 0.961 | 73.4 | –8.57 | –13.6 |
| Mucor | *Y*3=40.2–0.103*X* | 0.923 | 36.04 | –6.00 | –10.3 |
| Fusarium | *Y*3=23.8–0.061*X* | 0.927 | 38.36 | –6.19 | –6.1 |

Also, by the Student's test (3) with a significance level $\alpha$=0.05 and *Tcrit*(0.05; 3)=3.182, it was determined that the found *G*1 coefficients are reliable indicators for the daily decrease in oat malt contamination with fungal microflora. In addition, these indicators make it possible to rank its species by sensitivity to an increase in the peroxide concentration in cold plasma-treated solutions. Fig. 4 shows a comparison of the rate of reduction of oat malt contamination when using cold plasma-treated peroxide solutions.

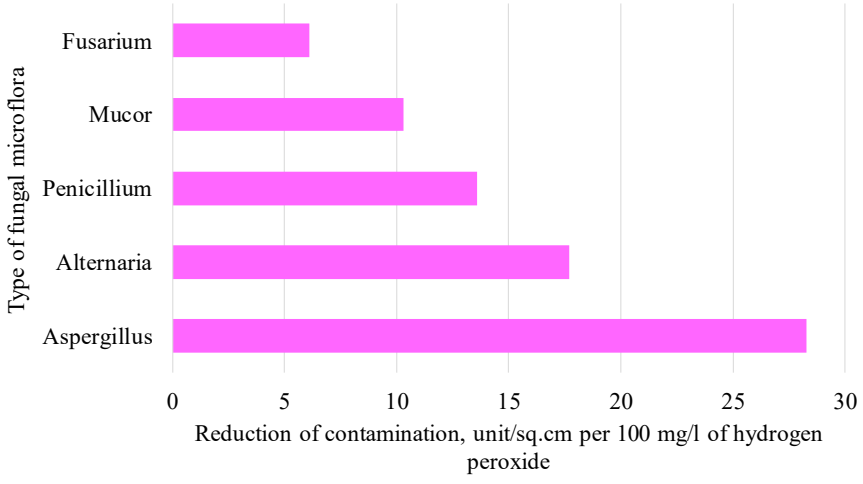


Fig. 4. Comparison of the rate of reduction of oat malt contamination when using cold plasma-treated peroxide solutions

As shown in Fig. 4, Aspergillus was the least resistant (–28.3 units/sq.cmwith an increase in the peroxide concentration by 100 mg/l), while Fusarium showed the greatest resistance (–6.1 units/sq.cm with an increase in the peroxide concentration by 100 mg/l).

### 5. 5. Development of a flow diagram of oat malt production using plasma-chemically activated aqueous solutions

To implement the presented technology in oat malt production, a flow diagram of oat malt production using plasma-chemically activated aqueous solutions was developed (Fig. 5).

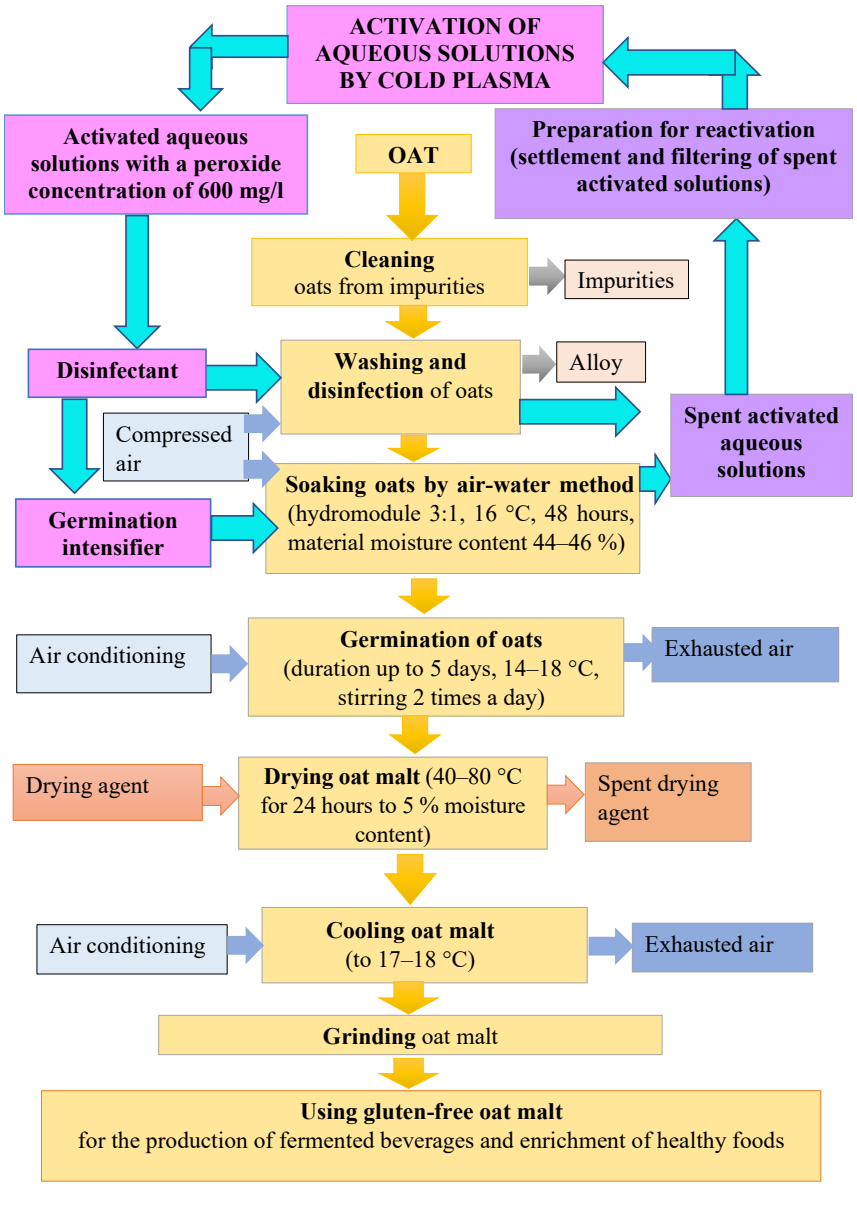


Fig. 5. Flow diagram of oat malt production using plasma-chemically activated aqueous solutions

The flow diagram of oat malt production using cold plasma-treated aqueous solutions shown in Fig. 5 gives a comprehensive idea of the oat germination process taking into account the use of the proposed germination intensifier.

## 6. Discussion of the results of the study of oat malt production technology

The analysis of the results obtained (Table 2) allows us to note that cold plasma-treated aqueous solutions significantly increase germination rates. The germination energy increased by 6–14 %, and germination capacity by 2–10 %, respectively. Achieving the required moisture content for germination occurs on the 4th day, i.e. compared to the control, it is accelerated by 1 day. Oat grain reaches these parameters at a peroxide concentration of 600 mg/l. Intensive moistening and germination are explained by the fact that activated aqueous solutions, due to their specific composition, can accelerate the natural diffusion of moisture into the oat grain [21].

Studies of biochemical transformations in oat grain also confirm the working hypothesis, namely, that all processes in the grain are intensified. The amylolytic activity increased by 17.6 % (Table 4), the amount of starch decreased by 2.4 %, fiber did not undergo significant changes, and the content of simple sugars increased by 2.3 % (Table 5). The proteolytic activity of oat malt increased by 18.1 %, and the total amount of amino acids increased by 3 %, so the total amount of amino acids in the experimental sample is 793 mg/100 g higher than in the control. That is, the increased activity of enzymes made it possible to maximally split complexes of substances and transfer them to an accessible, soluble state. This is an important result for oat malt, as it has a rather low basic enzymatic activity, resulting in low dissolution of grain components and low brewing quality of the malt. So, we can talk about obtaining higher quality oat malt with a well-dissolved carbohydrate and protein complex and a high content of dietary fiber, which is important for healthy nutrition.

Considering the results given in Fig. 3 and Table 12, it should be noted that the amount of B vitamins ($B_1$, $B_2$) increased, as well as vitamin C, the content of which increased by 5.6 %, indicating the high biological value of oat malt. This allows recommending the obtained grain product for wide consumption to prevent vitamin deficiency.

Oat grain contains many microorganisms on its surface, including pathogenic ones, and when moistened, they actively accumulate. Plasma-chemically activated aqueous solutions are known to have disinfectant properties [23–25]. Analyzing the data in Tables 13, 14, it is worth noting that oat malt treated with activated aqueous solutions with a peroxide concentration of 600 mg/l does not contain pathogenic microorganisms, including molds. That is, the malt will be absolutely safe for consumption.

The shortcomings of the study include the lack of data on the cytolytic activity of oat malt. These data are planned to be obtained in the future when continuing the presented study.

Concomitant limitations of the presented study may concern the provision of specialized production with technological solutions. However, the problem has been solved, since the KNP-TECHNOLOGY Research and Production Enterprise LLC is a manufacturer of plasma-chemically activated aqueous solutions. This will provide food enterprises with activated aqueous solutions and allow them to more widely implement innovative technological solutions for using plasma-chemical treatment of solutions in the food industry. The prospect of the research lies in developing a production technology for fermented oat malt.

## 7. Conclusions

1. The germination indicators and changes in the moisture content of oat grain during germination were studied. It was found that when using activated solutions (peroxide concentration of 600 mg/l), the germination energy increased by 14 %, and germination capacity by 10 %. The optimal moisture level for the beginning of germination was reached on the 4th day of the germination process.

2. The enzymatic activity in oats during germination was studied, the carbohydrate and amino acid composition of oat malt was analyzed. Thus, the amylolytic activity increased by 17.6 %, the amount of starch decreased by 2.4 %, and the content of simple sugars increased by 2.3 %. The proteolytic activity of oat malt increased by 18.1 %, and the total amount of amino acids by 3 %.

3. The study of the vitamin composition showed an increase in the content of B vitamins ($B_1$, $B_2$), as well as vitamin C, the content of which increased by 5.6 %.

4. Studies of the microbiological indicators of oat malt showed no pathogenic microflora, including mold, on the grain surface at a peroxide concentration in the solution of 600 mg/l.

5. A flow diagram of oat malt production using cold plasma-treated aqueous solutions was developed. A feature of the developed flow diagram was the use of activated solutions in the process of washing, disinfection and soaking of oat grain.

## 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. Kovalova, O., Vasylieva, N., Haliasnyi, I., Gavrish, T., Dikhtyar, A., Andrieieva, S. et al. (2024). Development of technology for the production of all-purpose buckwheat malt using plasmochemically activated aqueous solutions. Eastern-European Journal of Enterprise Technologies, 1 (11 (127)), 38–51. https://doi.org/10.15587/1729-4061.2024.298797
2. Gangopadhyay, N., Hossain, M., Rai, D., Brunton, N. (2015). A Review of Extraction and Analysis of Bioactives in Oat and Barley and Scope for Use of Novel Food Processing Technologies. Molecules, 20 (6), 10884–10909. https://doi.org/10.3390/molecules200610884
3. Bouchard, J., Valookaran, A. F., Aloud, B. M., Raj, P., Malunga, L. N., Thandapilly, S. J., Netticadan, T. (2022). Impact of oats in the prevention/management of hypertension. Food Chemistry, 381, 132198. https://doi.org/10.1016/j.foodchem.2022.132198
4. Ispiryan, L., Kuktaite, R., Zannini, E., Arendt, E. K. (2021). Fundamental study on changes in the FODMAP profile of cereals, pseudo-cereals, and pulses during the malting process. Food Chemistry, 343, 128549. https://doi.org/10.1016/j.foodchem.2020.128549
5. Gumienna, M., Górna, B. (2020). Gluten hypersensitivities and their impact on the production of gluten-free beer. European Food Research and Technology, 246 (11), 2147–2160. https://doi.org/10.1007/s00217-020-03579-9
6. Orhotohwo, O. L., Czipa, N., Kovács, B., Alexa, L. (2021). Impacts of the use of gluten-free cereals and spices on the quality parameters of beer. Journal of Microbiology, Biotechnology and Food Sciences, 11 (1), e3838. https://doi.org/10.15414/jmbfs.3838
7. Zdaniewicz, M., Pater, A., Knapik, A., Duliński, R. (2021). The effect of different oat (Avena sativa L) malt contents in a top-fermented beer recipe on the brewing process performance and product quality. Journal of Cereal Science, 101, 103301. https://doi.org/10.1016/j.jcs.2021.103301
8. Yang, D., Gao, X. (2020). Progress of the use of alternatives to malt in the production of gluten-free beer. Critical Reviews in Food Science and Nutrition, 62 (10), 2820–2835. https://doi.org/10.1080/10408398.2020.1859458
9. Bridges, A. R., Wrigley, C. W. (2016). Standardized Test Methods for Grains and Grain-Based Products. Encyclopedia of Food Grains, 300–307. https://doi.org/10.1016/b978-0-12-394437-5.00114-5
10. Blšáková, L., Gregor, T., Mešťánek, M., Hřivna, L., Kumbár, V. (2021). The Use of Unconventional Malts in Beer Production and Their Effect on the Wort Viscosity. Foods, 11 (1), 31. https://doi.org/10.3390/foods11010031
11. Gasiński, A., Kawa-Rygielska, J., Błażewicz, J., Leszczyńska, D. (2022). Malting procedure and its impact on the composition of volatiles and antioxidative potential of naked and covered oat varieties. Journal of Cereal Science, 107, 103537. https://doi.org/10.1016/j.jcs.2022.103537
12. Chusova, A. E., Zelenkova, A. V., Novikova, I. V., Zueva, N. V., Romanyuk, T. I., Kulneva, N. G. (2022). Bio-processing of oats to make malt. IOP Conference Series: Earth and Environmental Science, 1052 (1), 012005. https://doi.org/10.1088/1755-1315/1052/1/012005
13. Miller, Y. Yu., Kiseleva, T., Pomozova, V. (2024). Using non-traditional raw materials in the production of grain beverages. BIO Web of Conferences, 103, 00092. https://doi.org/10.1051/bioconf/202410300092
14. Herrera-Ponce, A. L., Salmeron-Ochoa, I., Rodriguez-Figueroa, J. C., Santellano-Estrada, E., Garcia-Galicia, I. A., Alarcon-Rojo, A. D. (2021). High-intensity ultrasound as pre-treatment in the development of fermented whey and oat beverages: effect on the fermentation, antioxidant activity and consumer acceptance. Journal of Food Science and Technology, 59 (2), 796–804. https://doi.org/10.1007/s13197-021-05074-9
15. Gematdinova, V. M., Kanarskiy, A. V., Kanarskaya, Z. A., Kruchina-Bogdanov, I. V. (2019). Production of β-glucan concentrate by oat germination. Chemistry of Plant Raw Material, 2, 231–237. https://doi.org/10.14258/jcprm.2019024251
16. Salamon, A., Kowalska, H., Ignaczak, A., Marzec, A., Kowalska, J., Szafrańska, A. (2023). Characteristics of Oat and Buckwheat Malt Grains for Use in the Production of Fermented Foods. Foods, 12 (20), 3747. https://doi.org/10.3390/foods12203747
17. Salamon, A., Kowalska, H., Stępniewska, S., Szafrańska, A. (2024). Evaluation of the Possibilities of Using Oat Malt in Wheat Breadmaking. Applied Sciences, 14 (10), 4101. https://doi.org/10.3390/app14104101
18. Vasylieva, N., Velychko, O. (2017). Development of the controlling system in the management of dairy clusters. Eastern-European Journal of Enterprise Technologies, 4 (3 (88)), 20–26. https://doi.org/10.15587/1729-4061.2017.108591
19. Anthero, A. G. S., Lima, J. M., Cleto, P. B., Jorge, L. M. M., Jorge, R. M. M. (2019). Modeling of maceration step of the oat (Avena sativa) malting process. Journal of Food Process Engineering, 42 (7). https://doi.org/10.1111/jfpe.13266
20. Fang, Y., Franke, C., Manthei, A., McMullen, L., Temelli, F., G nzle, M. G. (2021). Effects of high-pressure carbon dioxide on microbial quality and germination of cereal grains and beans. The Journal of Supercritical Fluids, 175, 105272. https://doi.org/10.1016/j.supflu.2021.105272
21. 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. https://doi.org/10.15587/1729-4061.2023.284810
22. 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. https://doi.org/10.15587/1729-4061.2020.215160
23. 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. https://doi.org/10.24263/2304-974x-2020-9-3-7

24. Kovalova, O., Vasylieva, N., Haliasnyi, I., Gavrish, T., Dikhtyar, A., Andrieieva, S. et al. (2023). Development of buckwheat groats production technology using plasma-chemically activated aqueous solutions. Eastern-European Journal of Enterprise Technologies, 6 (11 (126)), 59–72. https://doi.org/10.15587/1729-4061.2023.290584
25. 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. https://doi.org/10.15587/1729-4061.2023.275548
26. Kovalova, O., Vasylieva, N., Zhulinska, O., Balandina, I., Zhukova, L., Bezpal'ko, V. et al. (2024). Development of lentil malt production technology using plasma-chemically activated aqueous solutions. Technology and Equipment of Food Production, 4 (11 (130)), 76–86. https://doi.org/10.15587/1729-4061.2024.308298
27. Cetinkaya-Rundel, R., Hardin, J. (2021). Introduction to Modern Statistics. OpenIntro, 549.