UDC 663.432:663.437
DOI: 10.15587/1729-4061.2026.365166

DEVELOPMENT OF TECHNOLOGY FOR THE PRODUCTION OF CORN MALT USING PLASMOCHEMICALLY ACTIVATED AQUEOUS SOLUTIONS

Olena Kovalova
Corresponding author
Candidate of Technical Sciences, Associate Professor
Department of Food Technologies*
E-mail: livre@i.ua
ORCID: https://orcid.org/0000-0002-9508-2701
Natalia Vasylieva
Doctor of Economic Sciences, Professor
Department of Information Systems and Technologies*
ORCID: https://orcid.org/0000-0003-4100-0659
Tatiana Gontar
Candidate of Technical Sciences, Associate Professor
Department of Restaurant, Hotel and Tourist Business
Education and Research Institute "Ukrainian Engineering and Pedagogical Academy" of V.N. Karazin Kharkiv National University
Universytetska str., 16, Kharkiv, Ukraine, 61003
ORCID: https://orcid.org/0009-0007-1088-6764
Yana Svishchova
Candidate of Chemical Sciences, Associate Professor
Department of Agrochemistry**
ORCID: https://orcid.org/0000-0002-5358-8624
Oleg Kolontaievskyi
Candidate of Economic Sciences, Associate Professor***
ORCID: https://orcid.org/0000-0002-2210-739X
Anna Sokolenko
Candidate of Economic Sciences, Associate Professor***
Department of Tourism and Hospitality Management
O. M. Beketov National University of Urban Economy in Kharkiv
Chornoglazivska str., 17, Kharkiv, Ukraine, 61002
ORCID: https://orcid.org/0000-0002-9271-7118
Inna Zabrodina
Candidate of Agricultural Sciences, Associate Professor
Department of Zoology, Entomology, Phytopathology, Integrated Protection and Quarantine of Plants named after B. M. Litvynova**
ORCID: https://orcid.org/0000-0001-8122-9250
Serhii Stankevych
Candidate of Agricultural Sciences, Associate Professor
Department of Zoology, Entomology, Phytopathology, Integrated Protection and Quarantine of Plants named after B. M. Litvynova**
ORCID: https://orcid.org/0000-0002-8300-2591
Tetiana Novozhylova
Associate Professor
Department of Chemical Engineering and Environment Protection
National Technical University «Kharkiv Polytechnic Institute»
Kyrpychova str., 2, Kharkiv, Ukraine, 61002
ORCID: https://orcid.org/0000-0003-2551-6954
Maryna Ponomarova
Candidate of Economic Sciences, Associate Professor
UNESCO Department of Philosophy of Human Communication and Social and Humanitarian Disciplines**
ORCID: https://orcid.org/0000-0001-8463-821X
*Dnipro State Agrarian and Economic University
Serhiya Yefremova str., 25, Dnipro, Ukraine, 49600
**State Biotechnological University
Alchevsky str., 44, Kharkiv, Ukraine, 61002
***Department of Tourism and Hospitality Management
O. M. Beketov National University of Urban Economy in Kharkiv
Chornoglazivska str., 17, Kharkiv, Ukraine, 61002

The object of the study is the production of corn malt. The problem of developing an innovative technology for the production of high-quality and universal corn malt is being solved.

The rationality of using plasma-chemically activated solutions as an intensifier of corn grain malting, as well as a disinfectant agent in the implementation of the technological process and obtaining corn malt, has been experimentally proven. It has been established that the use of plasma-chemically activated aqueous solutions allows stimulating the process of soaking and germination of corn. The germination energy increased by 2–12%, the germination capacity by 2–9%. The moisture content of corn grain reached 42% 2.5 times faster. Monitoring of enzymatic activity showed a dynamic increase in the number of amylolytic enzymes by 2.8–3.4 times. The number of proteolytic enzymes increased from 19 units/g on the first day of germination and reached a maximum of 256 units/g on the fifth day. The total number of amino acids increased by 9.5%. An increase in the content of vitamins A, D, E, B_1 C was observed, the number of which increased by 14–25%. Technological characteristics of malt showed an increase in extractability by 5.7%, saccharification time decreased to 15 minutes, acidity decreased by 0.3 units, and the content of amine nitrogen increased by 52.7 mg/100 g. Stable disinfectant properties of solutions in relation to corn malt were noted. The results indicate the production of high-quality corn malt.

The presented technology can be used in the production of high-quality gluten-free corn malts. In addition, germinated corn has functional properties and can become a valuable component in the production of dietary gluten-free products.

The result of the study is the development of a technology for the production of corn malt using plasma-chemically activated aqueous solutions

Keywords: corn malt, plasma chemical activation, hydrogen peroxide, germination enhancer, sprouted corn

Received 25.03.2026
Received in revised form 08.06.2026
Accepted date 15.06.2026
Published date 30.06.2026

How to Cite: *Kovalova, O., Vasylieva, N., Gontar, T., Svishchova, Y., Kolontaievskyi, O., Sokolenko, A., Zabrodina, I., Stankevych, S., Novozhylova, T., Ponomarova, M. (2026). Development of technology for the production of corn malt using plasmochemically activated aqueous solutions. Eastern-European Journal of Enterprise Technologies, 3 (11 (141)), 85–98*
https://doi.org/10.15587/1729-4061.2026.365166

1. Introduction

Beer consumption is growing dynamically all over the world. In the fight for the consumer market, beer producers are forced to expand the range of their products and look for ways to reduce costs. Therefore, the search for a new raw material base and the use of innovative approaches to improve the quality of grain raw materials and finished beer is currently relevant. Corn is considered as a new raw material base.

Corn grain has a high starch content, and in recent years it has served as a promising raw material for the fermentation industry. Corn occupies a special place in brewing technology. In order to save barley malt, it is often replaced with unmalted materials, the most common are corn flour and corn grits. Corn has only begun to be widely used in the form of malt in recent years, so the features of its malting have not yet been studied and investigated in sufficient depth. An important technological aspect in corn malting is the development of new technological techniques that can affect product quality and reduce its cost. The environmental friendliness of food products is currently coming to the fore. The main technological concept is currently the safety of raw materials and the use of environmentally friendly technologies.

Malt is the main raw material for brewing, it is a source of extractive substances and hydrolytic enzymes, namely amylolytic and proteolytic. Corn malt is a promising raw material that can not only expand the range of beer, but also become an enriching component of many functional food products.

The technology of industrial production of corn malt includes soaking, germination of cleaned and sorted corn grain and drying of freshly germinated malt. The most important and responsible stage is the germination process, the purpose of which is to accumulate the maximum amount of active enzymes and dissolve the endosperm of the grain. The basic directions of improving the technology of obtaining corn malt are to accelerate the malting process and reduce losses during germination. In order to intensify the process and reduce losses of valuable grain components, as well as improve the quality of malt, various methods and techniques are used in the industry. However, the search for new technological solutions is actively being implemented by scientists, it is important to find technological solutions that will allow obtaining a high-quality, environmentally friendly and inexpensive product of universal purpose.

Industrial production of corn malt is currently based on the implementation of modern innovative approaches to the germination of grain raw materials, which are considered promising for the development of the malting industry. Technologies using universal germination stimulants and intensifiers are becoming especially widespread, capable of increasing the efficiency of malting, reducing the duration of the technological process and improving the quality characteristics of corn malt.

In this regard, scientific study aimed at improving the processes of corn malt production is of important practical and scientific importance. The relevance of this area is confirmed by the need to develop new technological solutions, in particular, corn malt production technology using plasma-chemically activated aqueous solutions. The scientific and practical value of such technology lies in creating an innovative method for producing gluten-free corn malt with improved technological and biochemical parameters, as well as introducing environmentally friendly solutions into the field of malt production.

2. Literature review and problem statement

In the work [1], corn is considered as a promising food raw material. Thus, corn (*Zea mays L.*) is one of the leading grain crops in the world and occupies an important place in the nutrition of the population. Of greatest interest to the food industry and dietetics are varieties of corn with a high content of amylose, protein and lipids, which are characterized by high nutritional and functional value [1]. Corn of numerous varieties has been widely used in the nutrition of the population in different countries of the world for a long time [2]. It is shown that the chemical composition of corn grain, as well as the molecular structure of its main components – starch, non-starch polysaccharides, proteins and fats – have been studied in detail and are associated with the physical properties of the product. As well as the level of bioavailability of nutrients and the physiological effect on the human body [1]. Particular attention is paid to corn flour and starch with a high content of amylose. Because their use affects postprandial glycemic and insulin responses, increases insulin sensitivity, appetite regulation and satiety, lipid metabolism processes and obesity prevention. In addition, such products have a positive effect on the condition of the large intestine and contribute to better absorption of minerals by the human body [1]. Corn is a good source of polyamines, i.e. different types of available corn products can be used to provide an amine profile according to specific nutritional needs [3]. However, issues related to the expansion of its use in the production of gluten-free fermented beverages remain unresolved. This may be due to difficulties associated with the lack of sufficient corn malt.

Corn is widely used in traditional Mexican fermented beverages [4], but there is no widespread use of this raw material in the world. A new approach to creating beer products is being developed among scientists, beer producers and consumers, which involves expanding the range of traditional brewing raw materials, and corn is the undisputed leader among such raw materials [5]. However, the problem of high-quality technological preparation of grain material for widespread use in the food industry remains unresolved. The reason for this may be the lack of clear requirements for the finished product and insufficient study of the technological process. The results of the studies presented show that malt from corn grain is a priority raw material for the food industry due to its high technological, nutritional and functional value. Corn malt is obtained by germinating corn grain with subsequent drying, as a result of which basic enzymatic processes are activated in the grain and, accordingly, significant changes in the biochemical composition occur [6]. It has been shown that the nutritional value of corn malt is due to the high content of proteins, carbohydrates, B vitamins, minerals and biologically active substances [7]. During the malting process, some of the complex substances are converted into simpler and more easily digestible forms, which increases the availability of nutritional components at the biological level and improves their digestibility by the human body [8]. Sprouting reduces the content of phytates and increases the bioavailability of minerals, i.e. makes corn grain more useful from a nutritional point of view [9]. The complex use of germination and extrusion contributes to an increase in the content of soluble dietary fiber, as well as such essential amino acids as lysine, methionine and tryptophan, while the amount of insoluble dietary fiber decreased [10]. However, issues related to the industrial adaptation of corn malting technology to large-scale production conditions remain unresolved. The reason for this may be the lack of rational solutions for the introduction of new technological lines. An option for overcoming these difficulties may be to develop malt technology that will be available for implementation at existing malting industry enterprises.

It has been shown that corn malt plays an important role in the technology of beverage and fermented food production. Due to the presence of amylolytic and proteolytic enzymes, it is able to realize the saccharification of starch, the breakdown of proteins into amino acids, and accordingly form the taste, aroma and color of fermented beverages [11]. However, the unsolved problem remains the maximum increase in enzymatic activity during malting, which would allow the maximum breakdown of complex substances of corn grain into simpler ones. And this, in turn, allowed to increase the extractivity of corn malt. The reason for this may be the lack of a clear understanding of the features of biochemical transformations in corn grain during germination. An option for overcoming the relevant difficulties may be the selection of stimulants that can activate enzymatic activity in corn grain.

Currently, the prevalence of celiac disease and gluten sensitivity has increased, which has led to an increase in demand for gluten-free products, such as beer. However, traditional beer contains gluten, which makes it unsafe for people with such diseases [11]. The results of the studies presented show that corn malt is widely used in the production of gluten-free beer, kvass, fermented beverages and other fermentation products [12]. Corn malt is of undeniable value for the development of innovative recipes for gluten-free food products. Thus, the simplest option for the production of gluten-free beer is the use of alternative gluten-free cereals. Since corn does not naturally contain gluten, it is rational to use products based on it in the diet of people with celiac disease and people following a gluten-free diet, and especially when creating gluten-free beer [13]. All these aspects expand the possibilities of using corn malt in the production of functional and specialized food products [14]. In addition to its nutritional and technological value, corn malt also has economic advantages. Corn is an affordable and widespread grain crop, which makes the production of such malt economically feasible. Its use is a priority area for the development of the craft brewing industry, the production of functional beverages, as well as innovative gluten-free food products [15]. However, issues related to the provision of corn malt to producers remain unresolved. The reason for this may be objective difficulties associated with the lack of sustainable production of this raw material. An option for overcoming these difficulties may be the development of a universal and economically viable technology that would interest producers.

Corn malt is a universal component of gluten-free food products. The results of the studies presented show that corn malt has already found wide application in the production of functional products. An important technological aspect is the production of gluten-free bread. For this purpose, both corn flour and corn malt are used [16]. Also, such raw materials are increasingly used for the production of gluten-free cookies [17]. It should also be noted its use in the production of gluten-free pasta [18]. Thus, it is possible to obtain kombucha without adding additional sugar by using sprouted corn as a component of tea drinks produced by the fermentation of malt grain extract [19]. The range of products that include corn malt is becoming increasingly wider. Ensuring the production of a sufficient amount of high-quality and environmentally friendly corn malt remains an unresolved problem. The reason for this may be the limited production of gluten-free food products. However, there is a pronounced dynamics of increasing the production of gluten-free products, and this will require significant volumes of gluten-free grain raw materials in the future.

The technology of corn malt production has not yet become widespread, neither in the scientific community nor among malting industry enterprises. An option for overcoming the relevant difficulties may be the industrial production of corn malt, which will provide brewers with accessible and high-quality raw materials. Currently, special attention is paid to the microbiological purity of raw materials and finished fermentation beverages [20]. However, the production of corn malts under aseptic conditions and without the use of chemical antiseptics remains an unresolved problem. All this gives reason to argue that it is advisable to conduct study devoted to the search for environmentally friendly antiseptics for the malting process.

Corn grain malting is usually carried out using various chemical preparations as an intensifying agent. However, manufacturers have increasingly begun to use innovative germination enhancers in combination with classical technology. Thus, in order to develop environmentally safe and sustainable nanotechnologies in the food industry, a simple, economically accessible and environmentally friendly method was proposed. Namely, the production of iron oxide nanoparticles using Moringa oleifera leaves and chitosan as a complex intensifier of the corn germination process [21]. The effect of UV-B radiation and $CaCl_2$ on increasing the content of carotenoids in germinated corn grains and on the malting process itself [22]. In addition, scientific work is being conducted to select optimal corn malting modes, which will optimize the process and obtain high-quality malt [23]. An option for overcoming the relevant difficulties may be the search for innovative technological solutions that will improve existing technologies. But the issues related to the creation and implementation of innovative and environmentally friendly technology for the industrial production of universal corn malt remain unresolved. The reason for this may be the difficulties associated with the significant chemicalization of the malting industry.

An industrially promising option for overcoming technological difficulties may be the use of plasma-chemically activated aqueous solutions in the process of corn malting. This new approach is presented in [24], i.e. modern technological methods of plasma-chemical treatment of aqueous solutions in the processing industry have found quite wide application. Plasma-chemical treatment of technological solutions is already actively used for wastewater treatment of food enterprises [24], as well as during the production of edible sprouts from grain and seed material of various types of agricultural crops [25]. Plasma-chemical methods are used in the processes of moistening grain raw materials during the production of cereal products [26]. However, the greatest interest of scientists is focused on studying the influence of plasma-chemical activation on the peculiarities of the malting process of various crops, including non-traditional ones. This approach was used in [27], which considers the influence of plasma-chemical activation on the germination of sea buckthorn seeds. The feasibility of using plasma-chemical activation in the production of various malts is scientifically substantiated, as this technology has already found its application in the production of buckwheat malt [28], oat malt [29], flax malt [30] and lentil malt [31]. However, the study of the influence of plasma-chemical treatment of technological solutions on the process of malting corn grain and obtaining germinated grain raw materials has not been previously investigated.

All this gives grounds to argue that it is advisable to conduct a study devoted to the development of innovative corn malt technology. Therefore, it can be considered promising to conduct a study on the use of plasma-chemically activated aqueous solutions in the technology of corn grain malting for various areas of practical use.

3. The aim and objectives of the study

The aim of the study is to develop an innovative technology for malting corn grain using plasma-chemically activated aqueous solutions. The implementation of the conducted study will make it possible to intensify the technological process of corn grain germination and significantly expand the range of high-quality gluten-free grain raw materials for the production of fermentation beverages and functional food products.

To achieve this aim, it is advisable to solve the following objectives:

– to investigate the germination and moisture indicators of corn grain during the germination process;

– to investigate the dynamics of amylolytic and proteolytic activity of corn malt, analyze the amino acid composition and vitamin content;

– to investigate the quality indicators of corn malt;

– to investigate the microbiological indicators of corn malt;

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

4. Materials and methods

4. 1. The object and hypothesis of the study

The object of the study is the production of corn malt. Plasma-chemically activated aqueous solutions were chosen as an intensifying agent for the germination process.

The working hypothesis of the presented studies is to increase the efficiency of corn grain germination and modify the composition of corn malt by enriching it with bioactive components under the action of plasma-chemically activated aqueous solutions.

The assumptions made are that the active components of the plasma-chemically activated solution are evenly distributed in the volume of the liquid and interact equally with the corn grain.

The simplifications made are that the composition and properties of plasma-chemically activated aqueous solutions are considered stable during their use.

At all stages of the technological process, aqueous solutions treated with cold plasma were used as an agent for moistening and disinfecting the grain material.

Activation of technological solutions was carried out on the basis of the Specialized Laboratory for Plasma Treatment of Technological Solutions of Food Production of the Dnipro State Agrarian and Economic University and in the production conditions of LLC “Scientific and Production Enterprise “KNP-TECHNOLOGY”, Dnipro, Ukraine. Basic study was carried out in the conditions of the scientific and production laboratory for determining the quality of grain and grain products and the educational laboratory of food biotechnology, Department of Food Technologies, Dnipro State Agrarian and Economic University, Ukraine.

4. 2. Materials and equipment used in the experiments

4. 2. 1. Plasma-chemical treatment of technological aqueous solutions

Plasma-chemical treatment of aqueous solutions for the implementation of the technological process of malting corn grain was carried out using a special technology for treating tap water in a plasma-chemical reactor [24]. Special equipment was used for the experiments, namely, a laboratory-type plasma-chemical installation, which is an indisputable analogue of an industrial installation for plasma-chemical treatment of water and aqueous solutions [24, 25]. The laboratory equipment is represented by a three-arc plasma-chemical installation and consists of a reactor, anodes, cathode, reflux condenser, power source, vacuum pump [24].

For the germination of corn grain, plasma-chemically activated technological solutions with the following parameters were prepared:

1) control (main water);

2) activated water, treatment time 10 min., H_2O_2 concentration 300 mg/l;

3) activated water, treatment time 15 min., H_2O_2 concentration 350 mg/l;

4) activated water, treatment time 20 min., H_2O_2 concentration 400 mg/l;

5) activated water, treatment time 25 min., H_2O_2 concentration 450 mg/l;

6) activated water, treatment time 30 min., H_2O_2 concentration 600 mg/l;

7) activated water, treatment time 40 min., H_2O_2 concentration 650 mg/l;

8) activated water, treatment time 60 min., H_2O_2 concentration 700 mg/l;

9) activated water, treatment time 80 min., H_2O_2 concentration 750 mg/l.

The hydrogen peroxide content in activated water was determined by iodometric analysis, and was additionally controlled using an express method.

In accordance with the specified modes, water activation was carried out on a laboratory experimental installation. The water treatment time was regulated accordingly within the range from 10 to 80 minutes. In activated solutions, the concentration of H_2O_2 ranged from 300 to 750 mg/l.

4. 2. 2. Selection of raw materials for the production of corn malt and features of soaking and germination of corn grain

The basic raw material for the production of corn malt was corn grain. The grain malting process was implemented according to classical technology using laboratory box-type malting machines. At the initial stage, the corn was cleaned of foreign impurities, washed and disinfected with activated aqueous solutions. Corn grain was moistened by soaking using an air-water method at a temperature of 16–18°C until a humidity of 42–48% was reached. Accordingly, the hydromodule of the technological process was 4:1. The soaking duration ranged from 30 to 80 hours until the corn reached the optimum grain moisture level for germination. The corn was germinated for 3–5 days at a constant temperature of 18–20°C, stirred 2 times a day. Drying of corn malt was carried out at a temperature of 20–65°C for 22–24 hours to a humidity of 5–6%.

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

4. 3. 1. Methodology for analyzing germination indicators and changes in corn grain moisture during the malting process

Energy and germination capacity are among the main technological indicators of corn grain used in the production of various types of malt. The determination of these indicators was carried out according to generally accepted methods.

The moisture content of corn grain was measured every 10 hours during the soaking and germination of corn using activated aqueous solutions. When soaking the grain material, the classic air-water method was used. Humidity monitoring was carried out by drying samples of grain material by the standard method using a drying cabinet and the experiment was duplicated using a grain moisture meter without grinding Wile-55 (Finland).

4. 3. 2. Methods for studying the dynamics of enzymatic activity of corn malt, analysis of amino acid composition and vitamin content

The amylolytic activity of freshly germinated corn malt was determined by a colorimetric method adapted based on the provisions of DSTU 8453:2015 “Enzyme preparations. Methods for determining amylolytic activity”. The activity of amylolytic enzymes was determined by the ability of enzymes to break down soluble starch to dextrins, which was recorded accordingly using iodine. The amount of enzyme that catalyzes the hydrolysis of 1 g of starch under standard conditions (temperature 30°C, pH 4.7–4.9) was taken as a unit of activity.

The proteolytic activity of corn malt was determined by the modified Anson method according to DSTU 8452:2015, which was adapted to the specifics of the raw material under study. Considering the high density of corn endosperm and the specific fractional composition of its proteins, the standard method was modified: additional stages of fine grinding of malt were introduced, and the temperature of enzyme extraction was increased to 55–60°C to ensure their maximum transition into solution and complete inactivation of associated inhibitors.

The content of amino acids in corn malt was determined by ion-exchange liquid column chromatography using an automatic amino acid analyzer T339 (Prague, Czech Republic).

The quantitative determination of vitamin A was carried out by the Carr-Price method using antimony trichloride ($SbCl_3$). The content of vitamin D was determined by a colorimetric method based on its interaction with antimony trichloride. For the determination of vitamin E, a colorimetric method for the determination of tocopherols using nitric acid was used. The content of vitamin B_1 was determined by a fluorimetric method based on the release of bound forms of thiamine by acid and enzymatic hydrolysis. The method of reversed-phase high-performance liquid chromatography (HPLC) with UV detection was used to determine vitamin C.

4. 3. 3. Methods of the study of qualitative indicators of corn malt

The determination of technological indicators of corn malt was carried out in accordance with standard methods. Extractivity characterizes the amount of soluble substances that pass into the wort during mashing (determined by the standard congress method). The saccharification time was determined by the reaction with iodine and it shows the rate of starch cleavage. Acidity (pH) was determined by the potentiometric method to assess the active acidity of the wort. The content of amine nitrogen was determined by titrimetric methods, since it characterizes the provision of the wort with compounds necessary for yeast nutrition. Detailed methods of performing the analyses and the corresponding calculation formulas are given in the profile standard DSTU 4282:2018 “Barley malt for brewing. General technical conditions”.

4. 3. 4. Methods for determining microbiological indicators of corn malt

During microbiological studies, the total microbial count (KMAFAnM) was determined. The assessment of microbiological indicators of corn malt was carried out using generally accepted methods in accordance with the requirements of DSTU 8446:2015 “Food products. Methods for determining the number of mesophilic aerobic and facultative anaerobic microorganisms”.

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

The methodological basis of the data processing was the methods of correlation-regression and variance analysis. In particular, the methods of constructing linear and quadratic regressions with checking their adequacy and assessing elasticity were applied; one-factor and two-factor ANOVA method without repetitions for comparing mean values in groups based on the Fisher criterion; Student’s statistical criterion for establishing the reliability of differences between two related samples [32–34]. The selected mathematical apparatus made it possible to quantitatively substantiate the conclusions of the study.

To substantiate the dependences of germination energy and germination ability of corn grain on the activation time and concentration of H_2O_2, polynomial regressions of the form

$$Y = A_0 + A_1 \cdot X + A_2 \cdot X^2. \tag{1}$$

Their numerical coefficients A_0, A_1, and A_2 were found by the least squares method on the sample data of the regressand Y_i and the regressor X_i, $i = 1, \ldots, I$. The adequacy of the created regressions was assessed by the coefficient of determination R^2. The obtained mathematical approximation allowed to calculate the smoothed maximum value of the effective characteristic $Y_{\max}$, which is achieved at $X = X_{\max}$, namely

$$X_{\max} = -A_1 / (2 \cdot A_2),\; Y_{\max} = A_0 + A_1 \cdot X_{\max} + A_2 \cdot X_{\max}^2. \tag{2}$$

For the mathematical processing of data on the amylolytic and proteolytic activity of corn malt, a two-factor analysis of variance without repetitions was used, which was applied alternately to the experiment and control. It was assumed that the considered temperature and time factors had, respectively, M and N gradations, from where the sample observations were denoted as U_{mn}, $m = 1, \ldots, M$, $n = 1, \ldots, N$. The average values over the entire sample, along the rows with gradations of the first factor and along the columns with gradations of the second factor were calculated by the following formulas:

$$\overline{U} = \sum_{m=1,\ldots,M} \sum_{n-1,\ldots,N} U_{mn},$$

$$\overline{U1_m} = \sum\nolimits_{m=1,\dots,M} U_{mn} / N,\ m = 1,..,M,$$

$$\overline{U2_n} = \sum\nolimits_{n=1,\dots,N} U_{mn} / M,\ n = 1,..,N. \tag{3}$$

Testing the influence of the gradations of the first factor consisted in comparing the calculated value of F1

$$F1 = \frac{N(N-1)\sum\nolimits_{m=1,\dots,M}\left(\overline{U1_m} - \overline{U}\right)^2}{\sum\nolimits_{m=1,\dots,M}\sum\nolimits_{n-1,\dots,N}\left(U_{mn} - \overline{U1_m} - \overline{U2_n} + \overline{U}\right)^2}, \tag{4}$$

with critical value $F(\alpha; M-1; (N-1)(M-1))$ with significance level a and degrees of freedom $M-1$ and $(N-1)(M-1)$.

Testing the influence of the gradations of the second factor consisted in comparing the calculated value of F2

$$F2 = \frac{M(M-1)\sum\nolimits_{n=1,\dots,N}\left(\overline{U2_n} - \overline{U}\right)^2}{\sum\nolimits_{m=1,\dots,M}\sum\nolimits_{n-1,\dots,N}\left(U_{mn} - \overline{U1_m} - \overline{U2_n} + \overline{U}\right)^2}, \tag{5}$$

with critical value $F(\alpha; N-1; (N-1)(M-1))$ with significance level a and degrees of freedom $N-1$ and $(N-1)(M-1)$.

If the inequality was true

$$F1 > F(\alpha; M-1; (N-1)(M-1)),$$

or

$$F2 > F(\alpha; N-1; (N-1)(M-1)), \tag{6}$$

then the resulting feature significantly depended on the dynamics of the corresponding factor. If the inequality was true

$$F1 \leq F(\alpha; M-1; (N-1)(M-1))$$

or

$$F2 \leq F(\alpha; N-1; (N-1)(M-1)), \tag{7}$$

then the corresponding factor did not have a significant impact on the resulting trait.

To analyze the amino acid composition of germinated corn grain, a comparison of the deviation of the test samples from the control for essential and non-essential amino acids was carried out. First, the sample data were cleaned of outliers using the IQR method of the interquartile range. Namely, values that were outside the standard range were eliminated from further consideration

$$[Q1 - 1{,}5\times(Q3 - Q1); Q3 + 1{,}5\times(Q3 - Q1)], \tag{8}$$

where $Q1$ and $Q3$ denoted the first and third quartiles of the sample data.

Then, a one-way analysis of variance was applied to the two sample groups V_{1j}, $j = 1, \dots, J1$ and V_{2j}, $j = 1, \dots, J2$. The overall mean and individual means in each sample group were calculated using the following formulas:

$$\overline{V} = \left(\sum\nolimits_{j=1,\dots,J1} V_{1j} + \sum\nolimits_{j=1,\dots,J2} V_{2j}\right) / (J1 + J2),$$

$$\overline{V1} = \sum\nolimits_{j=1,\dots,J1} V_{1j} / J1,$$

$$\overline{V2} = \sum\nolimits_{j=1,\dots,J2} V_{2j} / J2.$$

Testing the similarity of changes in the composition of essential and non-essential amino acids of germinated corn grain involved comparing the calculated F value

$$F = \frac{\left(J1\cdot\left(\overline{V1} - \overline{V}\right)^2 + J2\cdot\left(\overline{V2} - \overline{V}\right)^2\right)\cdot(J1 + J2 - 2)}{\sum\nolimits_{j=1,\dots,J1}\left(V_{1j} - \overline{V1}\right)^2 + \sum\nolimits_{j=1,\dots,J2}\left(V_{2j} - \overline{V2}\right)^2}, \tag{9}$$

with critical value $F(\alpha; 1; J1 + J2 - 2)$ with significance level a and degrees of freedom 1 and $J1 + J2 - 2$. Then the inequality

$$F > F(\alpha; 1; J1 + J2 - 2), \tag{10}$$

disproved the hypothesis of insignificant differences between the averages of the compared sample groups. Implementation of inequality

$$F \leq F(\alpha; 1; J1 + J2 - 2), \tag{11}$$

refuted the hypothesis of significant differences between the means of the compared sample groups.

Mathematical analysis of the dynamics of the vitamin composition of corn malt in the control (with sample data $X1_s$, $s = 1, \dots, S$) and the experiment (with sample data $X2_s$, $s = 1, \dots, S$) was carried out using the paired T-test. The calculated value T_{calc} was determined by the formula

$$T = \overline{X12}\cdot\sqrt{S(S-1)} / \sqrt{\sum\nolimits_{s=1,\dots,S}\left(\overline{X12} - (X1_s - X2_s)\right)^2}, \tag{12}$$

where $\overline{X12} = \sum\nolimits_{s=1,\dots,S}(X1_s - X2_s) / S$.

The critical value for a two-sided test with significance level α and degrees of freedom $S-1$ is denoted as $T(\alpha; S-1)$. Then the inequality

$$|T| > T(\alpha; S-1), \tag{13}$$

rejected the hypothesis of insignificant differences in pairwise compared samples. Fulfillment of the inequality

$$|T| \leq T(\alpha; S-1), \tag{14}$$

refuted the hypothesis of significant differences in pairwise compared samples.

To compare the effects of plasma-chemically activated aqueous solutions on the contamination of corn malt with fungal microflora, linear regressions of the form were constructed

$$Y = B_0 + B_1 \cdot X. \tag{15}$$

Their numerical coefficients B_0 and B_1 were found by the least squares method on the sample data of the regressand Y_j and the regressor X_j, $j = 1, \dots, J$. The adequacy of the created regressions was assessed by the coefficient of determination R^2.

The average values of the regressand and the regressor are denoted as $\overline{X} = \sum\nolimits_{j=1,\dots,J} X_j$ and $\overline{Y} = \sum\nolimits_{j=1,\dots,J} Y_j$. The dependencies formalized by equation (15) allowed to calculate the elasticity coefficients E by the formula

$$E = B_1 \cdot \overline{X} / \overline{Y}. \tag{16}$$

The values of the elasticity coefficients reflected the percentage change in the contamination rate in the case of a 1% increase in the H_2O_2 concentration.

5. Results of the study on indicators of the corn malt production process

5. 1. Study of indicators of germination and moisture content of corn grain during germination

Important technological indicators of the suitability of grain raw materials for the production of high-quality corn malt are germination energy and germination ability (Table 1). Corn grain is selected with a mandatory viability within 98–100%, the purpose of this study is to achieve the maximum level of germination of raw materials. That is, corn grain should germinate by 100%, which will allow synchronizing biochemical processes in the grain material and obtaining uniformly germinated corn malt.

Table 1

Technological indicators of the suitability of corn grain for malting

Experiment	Water	Water activation time, min.	Concentration of H_2O_2, mg/l	Technological indicators, %	
				germination energy	germination capacity
1	tap water	–	–	86	91
2	activated	10	300	88	93
3	activated	15	350	90	94
4	activated	20	400	91	96
5	activated	25	450	92	98
6	activated	30	600	94	99
7	activated	40	650	95	100
8	**activated**	**60**	**700**	**96**	**100**
9	activated	80	750	95	98

Technological indicators of corn grain when using plasma-chemically activated aqueous solutions have significantly improved. A steady dynamics of increasing energy and germination ability when using plasma-chemically activated aqueous solutions has been noted. Germination energy increased by 12%, and germination ability by 9%.

Mathematical processing of the data in Table 1 based on regression-correlation analysis by formulas (1), (2) revealed reliable (at the level of 98.8% and 95.6%) dependences of germination energy on activation time and germination ability on the concentration of H_2O_2, as illustrated in Fig. 1, 2 and in Table 2.

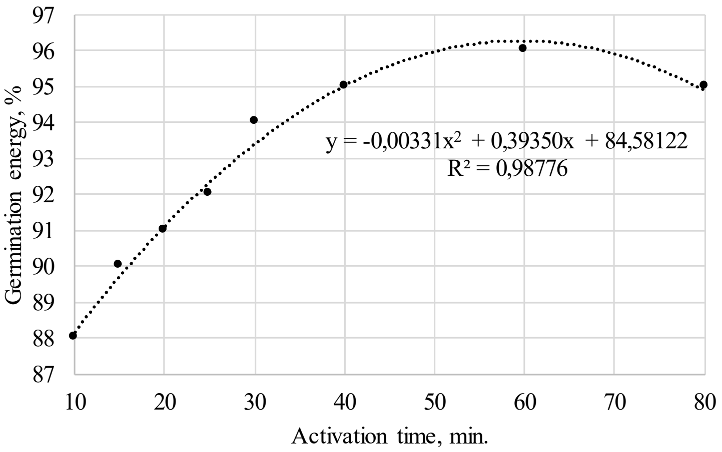

Fig. 1. Graph of the dependence of corn grain germination energy on activation time

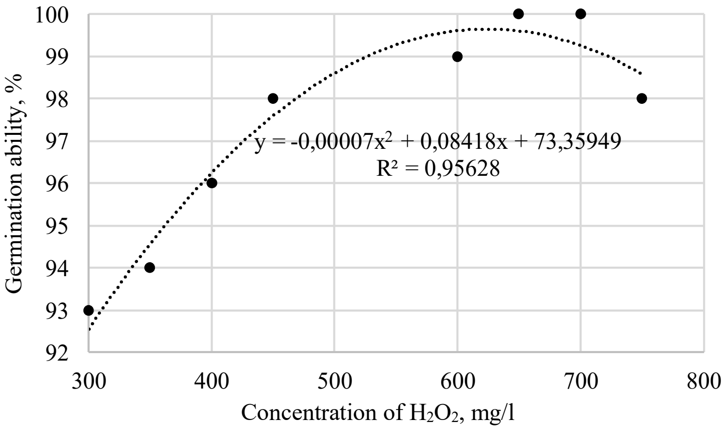

Fig. 2. Graph of the dependence of the ability of corn grain to germinate on the concentration of H_2O_2

The smoothed maxima, respectively, were 96.28% for 59.44 min. activation and 98.67% at 601.29 mg/l solution concentration. This is generally consistent with experimental measurements with uneven steps, taking into account the established plateau-like nature of the maximum germination energy and the peak nature of the maximum germination ability of corn grain.

Table 2

Mathematical approximation of technological indicators of corn grain suitability for malting

Dependency	Regression	R^2	X_{max}	Y_{max}
germination energy from activation time	$Y = 84.58 + 0.39X - 0.00331X^2$	0.988	59.44	96.28
germination ability from H_2O_2 concentration	$Y = 73.36 + 0.08X - 0.00007X^2$	0.956	601.29	98.67

The rate of moisture absorption by corn grain depends on the time of contact with the aqueous solution and its chemical nature. So, below is a study of the process of moisture saturation of corn grain when using activated aqueous solutions (Table 3). For clarity of interpretation of the results of the measurements, they are displayed in Table 3 in the form of a heat map with color gradation from minimum values (red) to maximum values (green).

Table 3

Dependence of the degree of moisture absorption of corn grain on the time of soaking in activated solutions with different concentrations of H_2O_2, %

Concentration of H_2O_2, mg/l	Soaking duration, hours								
	0	10	20	30	40	50	60	70	**80**
0	14	18	21	25	28	32	35	36	37
300	14	19	25	32	34	36	37	38	39
350	14	20	26	33	37	40	39	41	42
400	14	23	29	35	38	41	42	43	44
450	14	22	30	36	39	42	43	44	45
600	14	24	31	38	40	43	44	45	46
650	14	26	34	39	41	44	45	46	47
700	14	28	36	42	43	44	46	47	**48**
750	14	25	34	39	41	44	45	46	46

The results of monitoring the moisture content of corn grain are given in Table 3. It showed that the technological optimum of corn grain moisture content was achieved after 30 hours of soaking. So this is 2.5 times faster than when using the classical technology of corn malting. So the expected result is that on the third day of germination the germination energy reaches 96%, and on the fifth day the corn grain germinates by 100%.

5. 2. Study of the dynamics of enzymatic activity of corn malt, analysis of amino acid composition and vitamin content

The enzymatic activity of corn malt has a significant impact on the formation of the quality of the finished product, namely, it contributes to the acceleration of the accumulation of enzyme systems from the germinating grain. The result of this process is a deeper hydrolysis of starch and nitrogenous compounds. So for corn malt the level of activity of hydrolytic enzymes is important. Amylolytic enzymes implement the process of splitting starch into sugars, proteolytic enzymes are responsible for the process of splitting proteins into amino acids. Monitoring of the amylolytic activity of corn malt is given in Table 4.

Table 4

Amylolytic activity of corn malt, units/g

T, °C	Experimental samples	Time, day				
		1	2	3	4	5
15	control	65	145	192	215	243
	research	92	158	223	236	255
20	control	87	164	249	270	288
	research	102	181	289	299	326
25	control	91	178	242	314	334
	research	108	201	**261**	**328**	**364**
30	control	98	159	163	195	228
	research	112	170	188	209	258

Analysis of the amylolytic activity of enzymes in corn malt showed an increase in the indicator throughout the malting process, so the increase in this indicator ranged from 108 units/g on the first day of germination and reached a maximum of 364 units/g on the fifth day, i.e. the indicator increased by 2.8–3.4 times.

The method of two-factor analysis of variance without repetitions allowed to identify the following features of the amylolytic activity of corn malt. According to formulas (4)–(7), calculations were carried out for the experimental sample of Table 3 at $M = 4$ temperature gradations and $N = 5$ germination time gradations. Based on inequalities with a standard level of statistical significance $\alpha = 0.05$

$$F1 = 7.45 > 3.49 = F(0.05; 3; 12),$$

and

$$F2 = 34.22 > 3.26 = F(0.05; 4; 12).$$

It was found that the factors of temperature and germination time cause statistically significant differences in the manifestation of amylolytic activity of corn malt. In particular, according to formulas (3), it was found that the maximum average values of $\overline{U1_3} = 252.4$ units/g and $\overline{U2_5} = 300.8$ units/g correspond to a temperature of 25°C and the fifth day of germination.

It should be noted that a similar nature of the dependences was also inherent in the control sample. Namely, according to formulas (4)–(7), calculations were carried out for the control sample in Table 3. Inequalities

$$F1 = 7.2 > 3.49 = F(0.05; 3; 12),$$

and

$$F2 = 35.48 > 3{,}26 = F(0.05; 4; 12).$$

found that different gradations of temperature and germination time are statistically different. The maximum average indicators of amylolytic activity of corn malt in the control sample units/g and units/g were also at a temperature of 25°C and on the fifth day of germination. Thus, the qualitative signs of the manifestation of amylolytic activity of corn malt when using plasma-chemically activated aqueous solutions did not change, while the quantitative indicators showed a positive increase.

Also, an analysis of the proteolytic activity of corn grain during its germination was carried out, the monitoring results obtained are given in Table 5.

Table 5

Proteolytic activity of corn malt, mg/100 g

T, °C	Experimental samples	Time, day				
		1	2	3	4	5
15	control	8	22	81	120	137
	research	10	44	87	131	149
20	control	11	31	89	127	146
	research	14	58	116	197	165
25	control	16	44	91	145	132
	research	**19**	**62**	**192**	**268**	**256**
30	control	20	51	96	132	130
	research	23	74	125	146	145

Analysis of the activity of proteolytic enzymes showed a steady increase in the indicator throughout the entire process of germination of corn grain, the increase ranged from 19 units/g on the first day of germination and reached a maximum of 256 units/g on the fifth day (i.e., an increase of almost 14 times). A significant increase in proteolytic activity will contribute to a further increase in the amount of amino acids in corn malt.

The method of two-factor analysis of variance without repetitions allowed to identify the following features of the activity of proteolytic enzymes in corn malt. According to formulas (4)–(7), calculations were performed for the experimental sample in Table 4 at $M = 4$ temperature gradations and $N = 5$ germination time gradations. Based on inequalities with a standard level of statistical significance $\alpha = 0.05$

$$F1 = 5.82 > 3.49 = F(0.05; 3; 12),$$

and

$$F2 = 24.84 > 3.26 = F(0.05; 4; 12).$$

It was found that the factors of temperature and germination time cause statistically significant differences in the manifestation of the activity of proteolytic enzymes of corn malt. In particular, according to formulas (3), it was found that the maximum average values $U1_3 = 159.4$ of mg/100 g and $U2_4 = 185.5$ mg/100 g correspond to a temperature of 25°C and the fourth day of germination.

However, significant differences were observed in the control sample. Namely, according to formulas (4)–(7), calculations were made for the control sample in Table 4. Inequalities

$$F1 = 2.79 < 3.49 = F(0.05;\, 3;\, 12)$$

and

$$F2 = 206.08 > 3{,}26 = F(0.05;\, 4;\, 12)$$

found that different temperature gradations are not statistically significant at the $\alpha = 0.05$ level for the proteolytic activity of corn malt, although the germination time has a significant effect on it. In addition, the maximum average activity indicators of proteolytic enzymes of corn malt in the control sample $U1_4 = 85.8$ mg/100 g i $U2_5 = 136.3$ mg/100 g were at a temperature of 30°C and on the fifth day of germination. Therefore, the use of plasma-chemically activated aqueous solutions allows to change the dynamics of the proteolytic activity of corn malt, accelerating the achievement of the desired indicators at lower temperatures.

An important technological characteristic of corn malt is its amino acid composition. An important stage of the study is the analysis of the amino acid composition of corn malt. The results are given in Table 6. For the study, malt obtained by classical technology and the experimental group with the maximum activity of proteolytic enzymes were used.

Table 6

Amino acid composition of germinated corn grain, mg/100 g

Amino Acid	Corn Malt	
	Control	Experiment
Essential amino acids		
Lysine	232	251
Threonine	295	327
Valine	148	197
Methionine	36	49
Isoleucine	198	233
Leucine	716	772
Phenylalanine	312	358
Sum of essential amino acids	1937	2187
% of total amino acids	25.19	25.99
Replaceable amino acids		
Histidine	1628	1784
Arginine	208	264
Aspartic acid	585	623
Serine	358	389
Glutamic acid	1501	1580
Proline	388	408
Glycine	306	341
Alanine	655	702
Cystine	0.56	0.65
Tyrosine	122	137
Total nonessential amino acids	5751.56	6228.65
Total number of amino acids	7688.56	8415.65

Analyzing the obtained results, given in Table 6, it should be noted that the number of amino acids in the experimental samples had a pronounced growth dynamics, both for replaceable and non-replaceable amino acids. The total number of amino acids increased by 9.5%. Mathematical analysis of the sample groups regarding the percentage changes in the content of amino acids in the experiment relative to the control began with checking the data for outliers. According to formula (8), arginine was eliminated from further consideration, which increase by 26.9% went beyond the standard permissible range

$$[6.5 - 1.5\times(12.3 - 6.5);\, 12.3 + 1.5\times(12.3 - 6.5)] = \\ =[-2.2;\, 21.0].$$

One-way analysis of variance for the remaining $J1 = 7$ essential amino acids and $J2 = 9$ alternative amino acids was performed according to formulas (9)–(11). Testing with a standard level of statistical significance $\alpha = 0.05$

$$F = 5.09 > 4.60 = F(0.05;\, 1;\, 14),$$

refuted the hypothesis of similarity of average changes in the group of essential and non-essential amino acids, i.e. confirmed a higher average increase in essential amino acids and a slower average increase in non-essential amino acids in the composition of experimental samples of corn malt.

An important component of studies of the nutritional value of corn malt is the analysis of the vitamin composition of the product. Germination of corn grains helps to increase their nutritional value, especially in terms of vitamins [34]. In order to assess the nutritional value of corn malt, the vitamin composition of malt obtained using plasma-chemically activated aqueous solutions was analyzed, the results are presented in Table 7.

Table 7

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

Indicator	Corn grain	Corn malt	
		Control	Experiment
Vitamin A	2.95	5.9	7.1
Vitamin D	0.89	1.88	2.15
Vitamin E	1.77	2.62	2.98
Vitamin B_1	0.02	0.04	0.05
Vitamin C	6.52	9.24	10.72

Analyzing the results given in Table 6, it should be noted that the content of vitamins in the experimental samples increased by 14–25%. Mathematical analysis of the dynamics of the vitamin composition of corn malt was performed using the paired T-test. Calculations according to formulas (12)–(14) were performed using sample data on the percentage change in the composition of vitamins in the control and experimental samples relative to the corresponding baseline indicators in corn grain (Table 8).

Paired T-test with a standard level of statistical significance $\alpha = 0.05$

$$|T| = |-5.886| > 2.776 = T(0.05; 4),$$

revealed a significantly greater increase in the content of vitamins in the experiment after the use of plasma-chemically activated aqueous solutions.

Table 8

Dynamics of the vitamin composition of corn malt, %

Vitamin	Control	Experimental
Vitamin A	100.0	140.7
Vitamin D	111.2	141.6
Vitamin E	48.0	68.4
Vitamin B_1	100.0	150.0
Vitamin C	41.7	64.4

5. 3. Study of quality indicators of corn malt

The basic technological characteristics of corn malt are the mass fraction of the extract, saccharification time, acidity and amino nitrogen content. Monitoring of these indicators allows to assess the prospects of using the obtained corn malt in brewing technology. The results of the study of corn malt are presented in the Table 9.

When analyzing the results, it should be noted that the extractivity increased by 5.7%, the saccharification time decreased by 25 minutes, the acidity decreased by 0.3 units, and the amine nitrogen content increased by 52.7 mg/100 g. All this indicates the production of higher-quality corn malt compared to the classical technology.

Table 9

Technological characteristics of corn malt

No.	Indicator	Malt	
		Control	Experiment
1	Mass fraction of extract (extractivity), %	76.9	82.6
2	Saccharification time, min.	40	15
3	Acidity (pH)	5.8	5.5
4	Amine nitrogen content, mg/100 g	35.7	88.4

5. 4. Monitoring of microbiological indicators of corn malt

Corn grain is a raw material obtained under non-aseptic conditions, that is, significantly infected with pathogenic microflora, based on this, it is appropriate to study the disinfecting properties of plasma-chemically activated aqueous solutions in relation to grain raw materials. The microbiological state of corn malt affects the subsequent quality of beer and products produced from the presented raw materials. Monitoring of the microbiological state of corn malt showed the results shown in Table 10.

Analyzing the results of the study are given in the Table 10 it was noted that plasma chemically activated aqueous solutions significantly reduce microbial contamination of corn malt. Therefore, H_2O_2 present in solutions allows to destroy even persistent pathogenic microflora present on the surface of corn grain. This means that corn malt will not have mold microflora on its surface (aspergillus, Alternaria, Penicillium, Fusarium, Mucor), which are extremely dangerous when consuming drinks and food. And at the determined concentration of peroxides (650 mg/l H_2O_2), corn malt does not have pathogenic microflora on its surface.

The comparison of the effect of plasma chemically activated aqueous solutions on pathogens depending on the H_2O_2 concentration was carried out using the method of correlation-regression analysis based on formulas (15), (16). The obtained results are shown in Table 11.

The created linear regressions were reliable at the level of 98.4–99.9%. The results of the comparison of fungal microflora are arranged in Table 11 by decreasing resistance to plasma-chemically activated aqueous solutions. Thus, it was established that the disinfecting effect on pathogens increased in order from Mucor, Fusarium, Alternaria, Penicillium to the most sensitive Aspergillus.

Table 10

Infection of corn malt with fungal microflora ($n = 5$, $p \geq 0{,}95$), units/sq.cm

Pathogens	Control	Concentration of H_2O_2 in plasma-chemically activated aqueous solutions, mg/l			
		350	450	650	750
Aspergillus	88	14	2	0	0
Alternaria	27	6	1	0	0
Penicillium	19	5	0	0	0
Fusarium	7	2	0	0	0
Mucor	29	10	8	0	0

Table 11

Mathematical formalization of the dynamics of contamination of corn malt with fungal microflora

Pathogen	Regression	R^2	E
Mucor	$Y = 28.642 - 0.049X$	0.984	–0.83
Fusarium	$Y = 7.060 - 0.015X$	0.995	–1.35
Alternaria	$Y = 26.896 - 0.058X$	0.999	–1.37
Penicillium	$Y = 19.104 - 0.042X$	0.998	–1.39
Aspergillus	$Y = 87.045 - 0.196X$	0.993	–1.51

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

In connection with the technological necessity of implementing the proposed technology into production, a technological scheme for the industrial production of corn malt using plasma-chemically activated aqueous solutions was developed (Fig. 3).

Fig. 3 shows a technological scheme of corn malt production using plasma-chemically activated aqueous solutions, it allows to have a full-scale idea of the implementation of the corn grain germination process, taking into account the use of the malting process activator presented in the work.

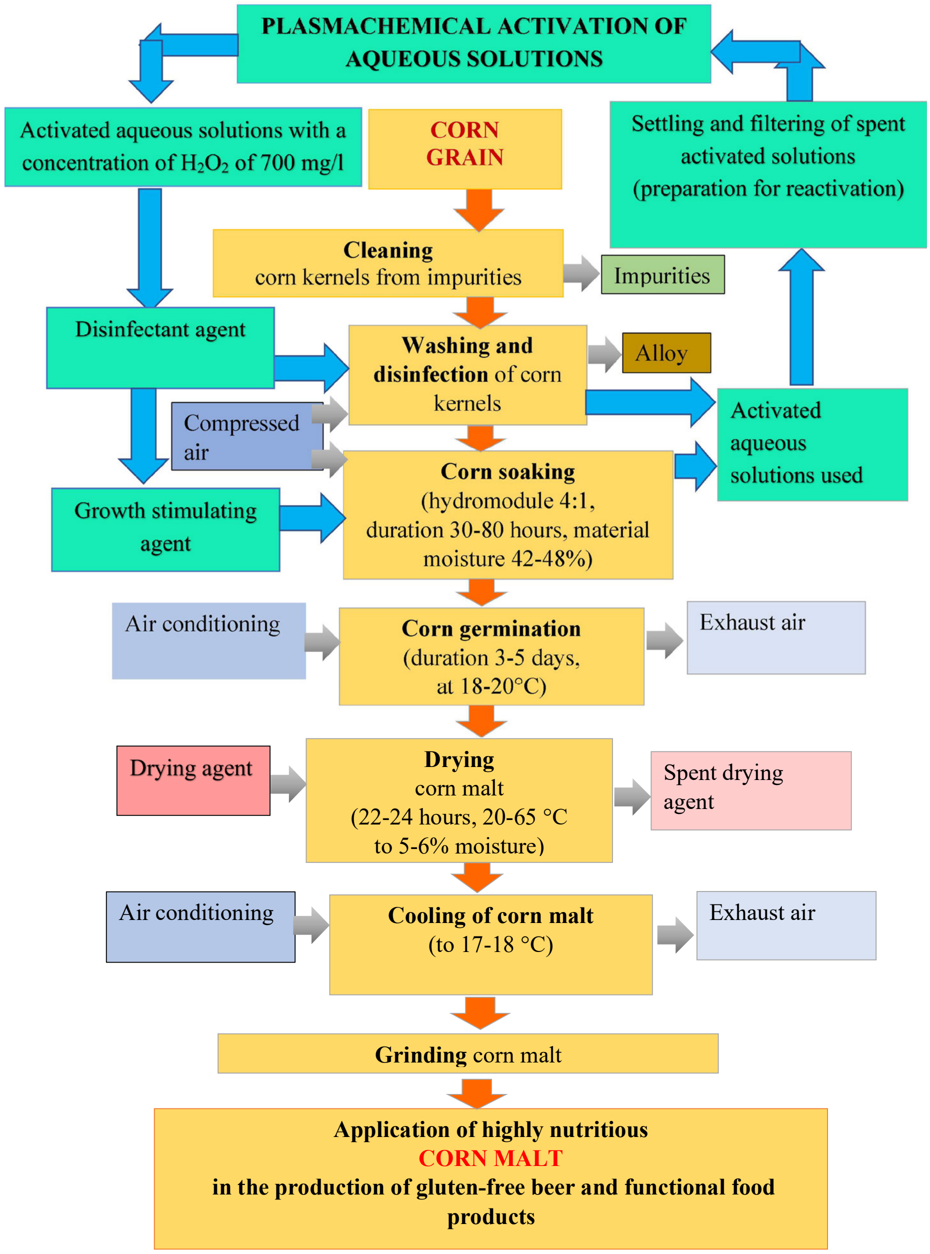

Fig. 3. Technological scheme of corn malt production using aqueous solutions treated with cold plasma

6. Discussion of the results of the study of corn malt production technology

Analysis of the results obtained in Table 1 allows to note that the technological indicators of corn grain when using plasma-chemically activated aqueous solutions have significantly improved. A steady dynamics of increasing energy and germination ability when using plasma-chemically activated aqueous solutions has been noted. Thus, the germination energy increased by 12%, and the germination ability by 9%. Table 2 shows a mathematical approximation of the technological indicators of the suitability of corn grain for malting. It confirmed the dependence of germination energy on the activation time of solutions and the dependence of germination ability on the concentration of H_2O_2 in plasma-chemically activated solutions. Fig. 1 shows the dependence of the germination energy of corn grain on the activation time, which clearly confirms the data given in Table 1. Fig. 2 shows the dependence of the germination ability of corn grain on the concentration of H_2O_2. Thus, mathematical processing of the data in Table 1 based on regression-correlation analysis using formulas (1), (2) revealed reliable (at the level of 98.8% and 95.6%) dependences of germination energy on activation time and germination ability on H_2O_2 concentration, as illustrated in Fig. 1, 2 and Table 2.

The results of monitoring corn grain moisture are given in Table 3 and showed that the technological optimum of corn grain moisture was achieved after 30 hours of soaking. So this is 2.5 times faster than when using the classical corn malting technology. So the expected and scientifically confirmed result is that on the third day of germination, the germination energy reaches 96%, and on the fifth day, the corn grain germinates by 100%. The intensification of the processes of moistening and germination is due to the fact that activated aqueous solutions, due to the peculiarities of their chemical composition, contribute to the acceleration of the natural diffusion of moisture into corn grain [24, 25].

The results of studies of biochemical changes in corn grain also confirm the proposed working hypothesis, according to which all biochemical processes are intensified in the grain. Thus, the analysis of amylolytic enzyme activity (Table 4) in corn malt showed an increase in the indicator throughout the malting process, namely, the increase in this indicator ranged from 108 units/g on the first day of germination and reached a maximum of 364 units/g on the fifth day, i.e. the indicator increased by 2.8–3.4 times. In turn, monitoring of the activity of proteolytic enzymes (Table 5) showed a steady increase in the indicator throughout the germination process of corn grain, the increase ranged from 19 units/g on the first day of germination and reached a maximum of 256 units/g on the fifth day (i.e. it increased by almost 14 times). A significant increase in proteolytic activity will contribute to the further accumulation of amino acids in corn malt. Thus, the increase in enzymatic activity ensured a more intensive breakdown of complex compounds with their transition to an accessible and soluble form [35, 36].

Considering the results given in Table 6, it should be noted that the number of amino acids in the experimental samples had a pronounced growth trend, both for replaceable and essential amino acids. The total number of amino acids increased by 9.5%. In addition, analyzing the results given in Tables 7, 8, it should be noted an increase in the content of vitamins in the experimental samples by 14–25%. Thus, the number of vitamins A, D, E, B_1, C increased, which allows to state the presence of an increased number of biologically active components in germinated corn grain. Therefore, this allows to recommend the resulting grain product for widespread use in nutrition for the prevention of vitamin deficiency.

The study of the qualitative indicators of corn malt also showed positive dynamics. Analyzing the results given in Table 9, it should be noted that the extractivity increased by 5.7%, the saccharification time decreased by 25 minutes, the acidity decreased by 0.3 units, and the content of amine nitrogen increased by 52.7 mg/100 g. All this indicates that corn malt of higher quality was obtained compared to malt produced using classical technology. The improvement in quality indicators is due to the intensification of biochemical and enzymatic processes during the germination of corn grain, which contributes to the deep breakdown of complex organic compounds, the accumulation of available nutrients and an increase in the enzymatic activity of corn malt [6]. As a result, the resulting malt is characterized by better technological properties, which are given above.

Corn has a lot of pathogenic microorganisms on the surface of the grain, and accordingly, when moistened, they begin to multiply. It is a well-known fact that plasma-chemically activated solutions have antiseptic properties [24–27]. Analysis of the results of the study given in Table 10 clearly demonstrated that the use of activated aqueous solutions significantly reduces the level of microbial contamination of corn malt. This is due to the presence of hydrogen peroxide (H_2O_2) in the solutions, which provides effective inactivation of even resistant forms of pathogenic microflora on the surface of the studied material. Thus, as a result of the treatment, the development of mold microorganisms, in particular the genera Aspergillus, Alternaria, Penicillium, Fusarium and Mucor, which pose a potential danger when using corn malt in the production of fermented food products and beverages, is significantly reduced or completely stopped.

Fig. 3 shows a technological scheme for the production of corn malt using plasma-chemically activated aqueous solutions. It provides a comprehensive understanding of the organization of the process of germination of corn grain in production conditions, taking into account the use of the malting process activator proposed in the work, which allows for a more visual representation of all stages of the technological cycle.

Among the limitations of the presented study, it is worth noting the lack of results on the cytolytic activity of grain material during germination. Obtaining the relevant data is expected at the next stages of work in the course of further development of this area of the study.

Concomitant limitations of the presented study may relate to the industrial production of plasma-chemically activated aqueous solutions. However, this problem is practically solved at the moment, since Scientific and Production Enterprise "KNP-TECHNOLOGY" LLC is an active manufacturer of solutions activated by cold plasma. An industrial reactor makes it possible to obtain the necessary amount of technological solutions [24, 25]. This, in turn, will contribute to the supply of food enterprises with activated aqueous solutions and will expand the possibilities of implementing innovative technological solutions related to the use of plasma chemical treatment of solutions in the food industry. A promising direction of the study is the development of technology for the production of fermented corn malt and the production of microgreens from corn grains.

The disadvantages of this study are the lack of data on monitoring the activity of cytolytic enzymes, which is planned to be implemented in further studies of the technological features of the course of the corn malting process.

7. Conclusions

1. The germination indicators and changes in the moisture content of corn grain during germination were studied. It was established that when using activated solutions with a peroxide concentration of 700 mg/l, the germination energy increased by 12%, and the germination capacity by 9%. The optimal moisture level for the start of germination was achieved after 30 hours of soaking.

2. The enzymatic activity of corn grain during germination was studied, the amino acid composition and vitamin content were analyzed. Thus, the amylolytic activity increased by 2.8–3.4 times. The proteolytic activity of corn malt increased by 93%, and the total amount of amino acids increased by 9.5%. The content of vitamins A, D, E, B_1, C increased, the amount of which increased by 14–25%.

3. The qualitative indicators of corn malt were studied. The studies showed an increase in extractability by 5.7%, the saccharification time decreased by 25 minutes, the acidity decreased by 0.3 units, and the content of amine nitrogen increased by 52.7 mg/100 g.

4. The study of microbiological indicators of corn malt showed that at a certain concentration of peroxides (650 mg/l H_2O_2) corn malt did not have pathogenic microflora on its surface.

5. A technological scheme for the production of corn malt using plasma-chemically activated aqueous solutions (700 mg/l H_2O_2) as a germination intensifier and disinfectant of the germination technological process was developed. Accordingly, the optimal parameters of the corn grain malting process were indicated, namely the hydromodule 4:1 and the soaking duration – 30 hours. The scheme also shows the possibility of reusing technological solutions by settling them and repeated plasma-chemical activation.

Conflict of interest

The authors declare that they have no conflict of interest regarding this study, including financial, personal, authorship or other, that could influence the study and its results presented in this article.

Financing

The study was conducted without financial support.

Data availability

The manuscript has no linked data.

Use of artificial intelligence tools

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

Authors' contributions

Olena Kovalova: Conceptualization, Methodology, Project administration, Writing – original draft, Investigation; **Natalia Vasylieva**: Data curation, Formal analysis, Investigation, Validation; **Tatiana Gontar:** Investigation, Resources, Visualization, Writing – review & editing; **Yana Svishchova:** Formal analysis, Investigation, Methodology, Software; **Oleg Kolontaievskyi:** Investigation, Validation, Visualization, Writing – review & editing; **Anna Sokolenko:** Data curation, Formal analysis, Resources, Validation; **Inna Zabrodina:** Investigation, Methodology, Resources, Supervision; **Serhii Stankevych:** Formal analysis, Resources, Validation, Visualization; **Tetiana Novozhylova:** Data curation, Methodology, Resources, Writing – review & editing; **Maryna Ponomarova:** Formal analysis, Software, Validation, Visualization.

References

1. Ai, Y., Jane, J.-l. (2016). Macronutrients in Corn and Human Nutrition. Comprehensive Reviews in Food Science and Food Safety, 15 (3), 581–598. https://doi.org/10.1111/1541-4337.12192
2. Piazza, S., Bani, C., Colombo, F., Mercogliano, F., Pozzoli, C., Martinelli, G. et al. (2024). Pigmented corn as a gluten-free source of polyphenols with anti-inflammatory and antioxidant properties in CaCo-2 cells. Food Research International, 191, 114640. https://doi.org/10.1016/j.foodres.2024.114640
3. Bandeira, C. M., Evangelista, W. P., Gloria, M. B. A. (2012). Bioactive amines in fresh, canned and dried sweet corn, embryo and endosperm and germinated corn. Food Chemistry, 131 (4), 1355–1359. https://doi.org/10.1016/j.foodchem.2011.09.135
4. Flores-Calderón, A. M. D., Luna, H., Escalona-Buendía, H. B., Verde-Calvo, J. R. (2017). Chemical characterization and antioxidant capacity in blue corn (Zea maysL.) malt beers. Journal of the Institute of Brewing, 123 (4), 506–518. https://doi.org/10.1002/jib.444
5. Romano, G., Tufariello, M., Calabriso, N., Del Coco, L., Fanizzi, F. P., Blanco, A. et al. (2023). Pigmented cereals and legume grains as healthier alternatives for brewing beers. Food Bioscience, 52, 102463. https://doi.org/10.1016/j.fbio.2023.102463
6. Ledley, A. J., Elias, R. J., Hopfer, H., Cockburn, D. W. (2021). A Modified Brewing Procedure Informed by the Enzymatic Profiles of Gluten-Free Malts Significantly Improves Fermentable Sugar Generation in Gluten-Free Brewing. Beverages, 7 (3), 53. https://doi.org/10.3390/beverages7030053
7. Dabija, A., Ciocan, M. E., Chetrariu, A., Codină, G. G. (2021). Maize and Sorghum as Raw Materials for Brewing, a Review. Applied Sciences, 11 (7), 3139. https://doi.org/10.3390/app11073139
8. Cadenas, R., Caballero, I., Nimubona, D., Blanco, C. A. (2021). Brewing with Starchy Adjuncts: Its Influence on the Sensory and Nutritional Properties of Beer. Foods, 10 (8), 1726. https://doi.org/10.3390/foods10081726
9. Sokrab, A. M., Mohamed Ahmed, I. A., Babiker, E. E. (2012). Effect of germination on antinutritional factors, total, and extractable minerals of high and low phytate corn (Zea mays L.) genotypes. Journal of the Saudi Society of Agricultural Sciences, 11 (2), 123–128. https://doi.org/10.1016/j.jssas.2012.02.002
10. Gong, K., Chen, L., Li, X., Sun, L., Liu, K. (2018). Effects of germination combined with extrusion on the nutritional composition, functional properties and polyphenol profile and related in vitro hypoglycemic effect of whole grain corn. Journal of Cereal Science, 83, 1–8. https://doi.org/10.1016/j.jcs.2018.07.002
11. Partichelli, C. P., Silveira, V. C. C., Manfroi, V., Rodrigues, R. C. (2024). Exogenous enzymes for gluten-free beer production: A review of the industrial practice and its implications for scientific research. Innovative Food Science & Emerging Technologies, 95, 103709. https://doi.org/10.1016/j.ifset.2024.103709
12. Ledley, A. J., Elias, R. J., Cockburn, D. W. (2024). The role of starch digestion in the brewing of gluten-free beers. Food Bioscience, 61, 104949. https://doi.org/10.1016/j.fbio.2024.104949
13. Hager, A.-S., Taylor, J. P., Waters, D. M., Arendt, E. K. (2014). Gluten free beer – A review. Trends in Food Science & Technology, 36 (1), 44–54. https://doi.org/10.1016/j.tifs.2014.01.001
14. Cela, N., Galgano, F., Perretti, G., Di Cairano, M., Tolve, R., Condelli, N. (2022). Assessment of brewing attitude of unmalted cereals and pseudocereals for gluten free beer production. Food Chemistry, 384, 132621. https://doi.org/10.1016/j.foodchem.2022.132621
15. Kerpes, R., Fischer, S., Becker, T. (2017). The production of gluten-free beer: Degradation of hordeins during malting and brewing and the application of modern process technology focusing on endogenous malt peptidases. Trends in Food Science & Technology, 67, 129–138. https://doi.org/10.1016/j.tifs.2017.07.004
16. Canelo-Álvarez, F., Figueroa-Cárdenas, J. d. D., Martínez-Cruz, E., Pérez-Robles, J. F., Arámbula Villa, G., Mariscal-Moreno, R. M., Véles Medina, J. J. (2023). Effect of nixtamalization on gluten-free whole corn, dough viscoelasticity, and the bread-making quality of leavened corn bread. International Journal of Gastronomy and Food Science, 31, 100648. https://doi.org/10.1016/j.ijgfs.2022.100648
17. Olaimat, A. N., Al-Rousan, W. M., Al-Marazeeq, K. M., Osaili, T. M., Ajo, R. Y., Angor, M., Holley, R. A. (2023). Physicochemical and sensory characteristics of gluten-free corn-based biscuit supplemented with walnut and peanut for celiac patients. Journal of the Saudi Society of Agricultural Sciences, 22 (7), 413–419. https://doi.org/10.1016/j.jssas.2023.03.007
18. Bresciani, A., Giordano, D., Vanara, F., Blandino, M., Marti, A. (2021). High-amylose corn in gluten-free pasta: Strategies to deliver nutritional benefits ensuring the overall quality. Food Chemistry, 353, 129489. https://doi.org/10.1016/j.foodchem.2021.129489
19. Francisco, Á. R., José, d. l. R. M., Igor, H. (2021). Development of a no added sugar kombucha beverage based on germinated corn. International Journal of Gastronomy and Food Science, 24, 100355. https://doi.org/10.1016/j.ijgfs.2021.100355

20. Kumar, S., Paramasivan, K., Mutturi, S. (2025). Microbiology and health benefits of beer. Microbiology and Health Benefits of Traditional Alcoholic Beverages, 65–90. https://doi.org/10.1016/b978-0-443-13322-0.00010-1
21. Tovar, G. I., Briceño, S., Suarez, J., Flores, S., González, G. (2020). Biogenic synthesis of iron oxide nanoparticles using Moringa oleifera and chitosan and its evaluation on corn germination. Environmental Nanotechnology, Monitoring & Management, 14, 100350. https://doi.org/10.1016/j.enmm.2020.100350
22. He, W., Wang, Y., Dai, Z., Liu, C., Xiao, Y., Wei, Q. et al. (2019). Effect of UV-B radiation and a supplement of $CaCl_2$ on carotenoid biosynthesis in germinated corn kernels. Food Chemistry, 278, 509–514. https://doi.org/10.1016/j.foodchem.2018.11.089
23. Paucar-Menacho, L. M., Martínez-Villaluenga, C., Dueñas, M., Frias, J., Peñas, E. (2017). Optimization of germination time and temperature to maximize the content of bioactive compounds and the antioxidant activity of purple corn (Zea mays L.) by response surface methodology. LWT - Food Science and Technology, 76, 236–244. https://doi.org/10.1016/j.lwt.2016.07.064
24. 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
25. 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
26. 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
27. 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
28. 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
29. Kovalova, O., Vasylieva, N., Dikhtyar, A., Andrieieva, S., Omelchenko, S., Kotliar, O. et al. (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
30. 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
31. 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. Eastern-European Journal of Enterprise Technologies, 4 (11 (130)), 76–86. https://doi.org/10.15587/1729-4061.2024.308298
32. Cetinkaya-Rundel, R., Hardin, J. (2021). Introduction to Modern Statistics. OpenIntro, 549.
33. Greene, W. (2017). Econometric Analysis. London: Pearson Learning Solutions, 1176.
34. Vasylieva, N., Pugach, A. (2017). Economic assessment of technical maintenance in grain production of Ukrainian agriculture. Bulgarian Journal of Agricultural Science, 23 (2), 198–203. Available at: https://www.agrojournal.org/23/02-04.pdf
35. Chaves-López, C., Rossi, C., Maggio, F., Paparella, A., Serio, A. (2020). Changes Occurring in Spontaneous Maize Fermentation: An Overview. Fermentation, 6 (1), 36. https://doi.org/10.3390/fermentation6010036
36. Geißinger, C., Gastl, M., Becker, T. (2021). Enzymes from Cereal and Fusarium Metabolism Involved in the Malting Process – A Review. Journal of the American Society of Brewing Chemists, 80 (1), 1–16. https://doi.org/10.1080/03610470.2021.1911272