The result of the implemented research is the development of a technology for sprouted lentil (lentil malt) production using cold plasma-treated aqueous solutions. The object of the study was lentil grain. The main technological task is to obtain high-quality lentil malt suitable for producing gluten-free beer and highly nutritious foods. The rationality of using cold plasma-treated aqueous solutions as an intensifier of lentil grain germination process and high-quality lentil malt disinfectant is experimentally proven. It is confirmed that using cold plasma-treated aqueous solutions can accelerate the process of lentil bean moistening by 2 times. The germination indicators of lentils also experienced positive changes, with germination energy increased by 8–16 %, germination capacity by 3–10 %, and sprout length by 12–29 %. An analysis of the amino acid composition of lentil grain and lentil malt was carried out. Thus, the experimental samples had an increased content of amino acids: non-essential by 2.7 %, essential by 3.6 %. There was also an increase in the content of B vitamins (B_1, B_2, B_5, B_9), as well as PP and C, which indicates an increased biological value of lentil malt obtained by the presented technologies. In addition, the work noted the steady antiseptic properties of activated aqueous solutions in relation to lentil malt.

The intensive technology of obtaining lentil malt can be implemented in the industrial production of malt for the brewing industry. In addition, sprouted lentil beans have health-improving properties and can be used in the production of functional products. The presented technology of lentil bean malting will be in demand in the production of highly nutritious and healthy grain products and fermented beverages

Keywords: lentil malt, plasma-chemical activation, aqueous solutions, hydrogen peroxide

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DEVELOPMENT OF LENTIL MALT PRODUCTION TECHNOLOGY USING PLASMA-CHEMICALLY ACTIVATED AQUEOUS SOLUTIONS

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1. Introduction

Lentils (Lens culinaris L.) are a versatile and nutrient-rich food legume with pronounced health benefits. In the modern world, the demand for lentils began to rise. As people try to minimize health problems through a healthy diet, lentils are becoming increasingly popular [1]. They contain many proteins and amino acids and are well ab-

sorbed by the human body. So, they become an integral part of a healthy and high-protein diet. Lentils are an important highly nutritious crop grown and consumed worldwide due to their high content of elements, including minerals. Thus, they have a high content of Ca, K, P, Fe, Mn, Cu, Mo, B, I, C, Zn. In addition, they contain Omega-3 and Omega-6 fatty acids. Also, lentil beans contain B vitamins, vitamins A, PP, and sprouted grains contain vitamin C. Lentils play an important role in food security, especially in low-income countries.

Lentil germination is one of the ways to increase biological value by using the enzymatic system of lentil grain. A promising area of technological research is the development of modern production technology for high-quality lentil malt. Sprouted lentil grain is advisable to use both in fermentation technologies (production of gluten-free beer) and as a filler in functional food products. In order to intensify and improve the course of the special malting process, it is rational to use environmentally safe process intensifiers and disinfectants.

Applied scientific research in this area is important, and the relevance of the topic is reflected in the development of production technology for high-quality lentil malt. The future scientific value lies in the development of innovative lentil malting technology and the implementation of technological solutions in specialized production.

2. Literature review and problem statement

As a rule, lentils are processed before use. Several processing methods are most common, including heating, germination, fermentation, and extrusion. These methods are often used to prepare this popular legume, turning it into tasty and nutritious dishes, as well as optimizing its medicinal properties. However, both in vitro and in vivo studies using processed lentils have effectively demonstrated their functional benefits, including cardioprotective, antidiabetic, anti-inflammatory, and anticarcinogenic effects [1]. This evidence suggests that consuming processed lentils canreduce the likelihood of developing non-communicable chronic diseases such as diabetes, heart disease, etc. Preservation of biologically active substances, including phenolic compounds and flavonoids, is a key factor in the beneficial health effects of processed lentils [1]. These biologically active compounds affect human physiology by neutralizing excess free radicals or oxidants that damage cells.

The technology of malt production from legume seeds is not yet widely used among scientists and industrial maltsters. However, this method of seed modification has been successfully used by mankind for thousands of years to improve the technological parameters, as well as to change the taste and aroma of various food products [2].

Whole legumes are rich in nutrients, but people with gastrointestinal disorders often avoid eating them due to high levels of fermentable oligo-, di-, monosaccharides and polyols [3]. Lentils contain oligosaccharides. Oligosaccharides of the raffinose family are sugars that are considered antinutrients, they are not digested by human gastric enzymes and can lead to flatulence [4]. Legume seeds are often rich in these compounds, and this can be burdensome for many people whose diet consists of large amounts of these foods. The process of lentil germination reduces the content of raffinose and phytic acid and phytate and decreases the content of anti-nutrients [5, 6]. An unsolved issue is the directed intensification of lentil germination. This is due to the specifics of selecting an effective germination activator that does not contain toxic chemical compounds.

In sprouted lentils, the fiber, fat and ash content decreases and the protein content increases, while the amylose content in starch granules remains constant. Lentil starch granules remain almost intact during germination, and no enzymatic activity of α- and β-amylases is observed. Starch decomposition is essential for producing malt for beverage fermentation. This makes sprouted lentils unsuitable for the short-term fermentation required in beverage production [7]. Selection of lentil germination parameters that would allow universalizing their use remains an unsolved issue.

Scientists are currently analyzing [8] whether it is possible to brew beer without using classic cereals, so that the beverage produced is easily accessible to the population suffering from celiac disease and other gluten-related disorders. So, it is noted that lentil seeds should be malted and then ground using the congress mashing procedure. It is noted that beer can be produced from lentil malt, but it is characterized by a lower alcohol content, some differences between the concentrations of various volatile substances (such as acetaldehyde, ethyl acetate and 1-propanol) compared to classic beer produced from barley malt [9]. But despite the low mashing quality, legume seed malt has increased friability, higher protein content, lower starch content and lower phytic acid concentration [9]. Overall, the use of green lentil malt shows promising results for its potential use in brewing [10]. Research shows that it is possible to create malt from legume seeds, but the malting and mashing characteristics must be adjusted for these special malts, and enzyme preparations must be used [11]. The potential of using fermentation and germination to change the nutritional and sensory properties of lentil-based beverages is being explored [12]. Therefore, the development of lentil malt technology, which would allow obtaining high-quality malt that meets the needs of brewers and has a high amino acid content, remains an unsolved problem.

Moreover, adding sprouted lentil grains to cereal prods ucts has been identified as one of the future trends in the food industry [13]. Sprouting is recognized as the most effective technique for reducing anti-nutritional factors and improving the physicochemical profile of lentils, which meets the current nutritional needs of modern society [14]. That is, an unsolved issue is the development and implementation of lentil bean germination technologies in order to widely use them in the production of high-value and nutritious foods.

Improving the malting process is an important task in obtaining lentil malt. Rationalization of technology is a basic task. Innovative technological solutions are aimed at intensifying the process, improving the quality of malt and reducing resource consumption [15].

Thus, in the process of soaking raw materials for malt production, various germination accelerators are used. Lentils, like most cereals and legumes, are also treated with intensifying solutions to accelerate germination.

An important technological aspect is obtaining well-sprouted lentil grain, rich in biologically active components that can enrich the human body with useful components and improve vital indicators. It is also important to obtain microbiologically clean and safe grain for consumer health.

An interesting option to overcome technological difficulties can be the use of cold plasma-treated aqueous solutions in the process of lentil germination. This new approach was applied in [16], so modern plasma-chemical technologies in the food industry have recently found wide application. It was analyzed that they are used for wastewater treatment of food enterprises [17], in the production of microgreens and highly nutritious sprouts from the grain of various crops [18]. The main attention of scientists is drawn to studying the influence of plasma-chemical activation on the course of processes in grain material during its moistening and germination [19]. However, studies of their impact on the technological process of lentil malt production have not been fully implemented.

Cold plasma treatment of water and aqueous solutions allows using specific properties of water without contaminating it with toxic chemical compounds [20]. During the cold plasma treatment of water, processes are implemented that contribute to changing the reactogenic properties of aqueous solutions [19, 20]. Therefore, the properties of activated water arising after plasma-chemical treatment are widely used in various areas of the food industry. Plasma-chemically treated water has established antiseptic and antibacterial properties, is a cluster structure and can exhibit functional properties that were little studied before, but can be useful from a practical point of view [16]. Activated water contains hydrogen peroxides and superoxide compounds, excited particles and radicals [16], which play an important role in the course of biochemical processes in grain. Therefore, it is appropriate to study the effect of such solutions on lentil grain.

All this suggests that research on using plasma-chemical activation of aqueous solutions in the technological process of lentil germination for various purposes is promising. In addition, the production of new health food products is promising, in which sprouted lentils will become an enriching component.

3. The aim and objectives of the study

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

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

– to study the sorption properties of lentil beans during soaking;

– to investigate the technological parameters of lentil grain germination;

– to examine the amino acid and vitamin composition of lentils and lentil malt;

– to study the microbiological indicators of lentil malt;

– to develop a flow diagram of lentil 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 lentil grain. To investigate the process of lentil grain germination, cold plasma-treated solutions were chosen as a malting stimulator. They are also called plasma-chemically activated aqueous solutions. Such technological solutions are already used in food technology, including the technology of malting various grain crops [16, 18], but it is interesting from a scientific point of view to further research and more thoroughly implement the presented technology in legume germination.

The working hypothesis of the study is the intensification of lentil grain malting and enrichment with biologically active components of lentil malt by using activated aqueous solutions. Cold plasma-treated aqueous solutions were used as a moistening agent for grain material at all process stages.

Non-equilibrium plasma-activated solutions were prepared 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 LLC Scientific and Production Enterprise KNP-TECHNOLOGY (Dnipro, Ukraine). The research was conducted on the basis of the research and production laboratory for determining the quality of grain and grain products, the 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 lentil malting process was carried out using a special technology of mains water treatment with cold non-equilibrium plasma [15–17]. To implement research, a special laboratory-type plasma-chemical installation was used [17]. Such equipment is an absolute analog of an industrial installation for processing aqueous solutions. Its advantages include the fact that it makes it easier to carry out laboratory studies of grain material with a certain number of repetitions of experiments. Such an installation is represented by a three-arc plasma-chemical plant and consists of a reactor, anodes, a cathode, a reflux condenser, a power source, and a vacuum pump [17]. For lentil grain germination, plasma-chemically activated aqueous solutions were prepared, the characteristics of which are given in Table 1. The active substance, namely hydrogen peroxide in the treated water was determined by iodometry and the values were simultaneously recorded by the express method.

Table 1

Parameters of cold plasma treatment of technological solutions

Experiment No.	Water	Activation time, min	Concentration of hydrogen peroxide in aqueous solution, mg/l
1 (control)	Mains	–	–
2	plasma-chemically activated	5	100
3	plasma-chemically activated	7	200
4	plasma-chemically activated	10	300
5	plasma-chemically activated	20	400
6	plasma-chemically activated	25	500
7	plasma-chemically activated	30	600
8	plasma-chemically activated	60	700

Mains water treatment was carried out at an experimental laboratory installation. The processing time was regulated, it varied from 5 minutes to 1 hour. In activated aqueous solutions, the concentration of hydrogen peroxide ranged from 100–700 mg/l, depending on the treatment time (Table 1).

4. 2. 2. Selection of raw materials for lentil malt production and features of soaking and germination of lentil grains

Lentil grain was chosen as the raw material for malt production. The technological process was implemented by the classic malting technology using a box-type laboratory malt house. At the initial stage, lentils were cleaned of impurities, beans were washed and disinfected with activated aqueous solutions. Prolonged soaking of beans was implemented using a 2.5:1 hydromodule. The soaking time was 48 hours, until the lentil beans reached a moisture content of 46–48 %. Lentils were germinated for 120 hours at a constant temperature of 18 °C. Lentil malt was dried at a temperature of 40–60 °C to a moisture content of 5–7 %. Next, the lentil malt was cooled and ground.

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

4. 3. 1. Methods of studying the sorption properties of lentils

In the analysis of sorption properties, standard methods for determining moisture content were used. So, the moisture content of lentil beans was recorded every 6 hours at the stage of soaking lentils in activated aqueous solutions during the first 48 hours of the experiment. When soaking grain material, the air-water method was used. Recording of moisture parameters was carried out by drying grain samples by a standard method using a drying cabinet. At the same time, an express method of moisture recording using a SuperPro automatic moisture meter (Manufacturer: SUPERTECH AGROLINE AGROELECTRONICS, Denmark) was used.

4. 3. 2. Method of studying the germination indicators of lentil grain

Germination energy and capacity are important technological indicators for grain intended for malt production. The presented indicators are determined by conventional methods. The length of lentil bean sprouts was measured on the 4th day of germination using a Dnipro-M HP-15 digital caliper.

4. 3. 3. Methods of studying the amino acid and vitamin composition of lentils and lentil malt

Monitoring of the amino acid content in lentil grain and lentil malt was carried out by ion-exchange liquid column chromatography on a T339 automatic amino acid analyzer, manufactured in the Czech Republic, Prague. Determination of vitamins B_1 and B_2 was carried out by the fluorimetric method, which is based on the release of bound forms of thiamine and riboflavin by acid and enzymatic hydrolysis. To determine vitamins B_5 and B_9 and C, the method of reversed-phase HPLC with UV detection is used. Vitamin PP was determined by a colorimetric method, which is based on the release of bound forms of niacin by hydrolysis, purification of the hydrolyzate, quantitative production of the glutaconaldehyde derivative and colorimetric determination of its mass fraction at 400–425 nm compared to the standard solution.

4. 3. 4. Methods of determining the microbiological indicators of lentil malt

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

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

For the quantitative analysis of experimental results and further substantiation of conclusions and recommendations based on the results of the conducted research, statistical data processing methods were used [21].

Mathematical formalization of lentil moisture ($Y1$, %), depending on soaking time (t, hours), was carried out using linear paired regressions with numerical coefficients A0 and A1 according to the formula:

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

The adequacy of the entire equation to the actual data of a sample of N observations was confirmed by the coefficient of determination R^2. The significance of the coefficient $A1$, as an indicator of lentil moisture dynamics, at a certain level of hydrogen peroxide concentration in plasma-chemically activated solutions was checked using the Student's test ($Tregr$). Moreover, the inequality with the critical value $Tcrit(\alpha; N-2)$:

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

meant the reliability of the coefficient $A1$ with a given significance α and degree of freedom N–2.

The study of lentil grain germination indicators ($Y2$, % or mm) depending on the concentration of hydrogen peroxide (X, mg/l) in plasma-chemically activated solutions was based on the construction of quadratic univariate regressions with numerical coefficients $B0$, $B1$, $B2$ according to the formula:

$$Y2=B0+B1\times X+B2\times X^2. \quad (3)$$

The adequacy of the entire equation to the actual 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:

$$Fregr>Fcrit(\alpha; 2; N-3), \quad (4)$$

with the critical value $Fcrit(\alpha; 2; N-3)$ with the significance α and degrees of freedom 2 and N–3. Further, to specify the optimal concentration of hydrogen peroxide ($Xopt$), the $Y2$ indicator was maximized, which resulted in:

$$Y2\max=B0+B1\times Xopt+B2\times Xopt^2. \quad (5)$$

To analyze changes (ΔP, %) in the amino acid composition of lentil malt, a comparison was made of the content of J amino acids from K groups in the experiment

($P2$, mg/100 g of product) and the control ($P1$, mg/100 g of product), where:

$$\Delta P=(P2-P1)/P1\times 100. \quad (6)$$

The conclusion about the similar nature of the advantages of using plasma-chemically activated technological solutions over classical technology was confirmed. So, based on one-way analysis of variance, comparing the calculated Fisher's test (*Fanova*) with the critical value $Fcrit(\alpha; K-1; J-K)$ with the significance α and degrees of freedom $K-1$ and $J-K$, i. e.:

$$Fanova \leq Fcrit(\alpha; K-1; J-K). \quad (7)$$

Visualization of relative changes (ΔS, percentage points) in the vitamin composition of the experimental ($S2$, %) and control ($S1$, %) lentil malt was carried out according to the indicators calculated for each vitamin by the formula:

$$\Delta S=S2-S1, \quad (8)$$

where $\Sigma S2=\Sigma S1=100$ %.

Contamination of lentil malt with fungal microflora ($Y3$, % of infected grains), depending on peroxide concentration (X, mg/l) in cold plasma-treated solutions, is mathematically formalized by linear paired regressions with numerical coefficients $C0$ and $C1$ according to the formula:

$$Y3=C0+C1\times X. \quad (9)$$

The adequacy of these equations to the actual data of samples of N observations was confirmed by the coefficient of determination R^2. The significance of the $C1$ coefficient, as an indicator of the rate of reduction of fungal microflora contamination, was checked using the Student's test (Tregr). In particular, the inequality with the critical value $Tcrit(\alpha; N-2)$:

$$|Tregr| > Tcrit(\alpha; N-2), \quad (10)$$

meant the reliability of the $C1$ coefficient with a given significance α and degree of freedom $N-2$.

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

5. Results of studies of the process indicators of lentil malt production

5. 1. Study of sorption properties of lentil beans during soaking

To intensify the malting process of lentil grain, it was soaked in cold plasma-activated technological solutions with a peroxide concentration of 100–700 mg/l. This will contribute to the accumulation of moisture in the grain and the activation of a complex of hydrolytic enzymes, which will enable the accumulation of biopolymers in lentil raw materials.

Moisture saturation of lentil samples was analyzed in order to determine optimal activation parameters for aqueous solutions. Thus, the rate of moistening of lentil grains with plasma-chemically activated solutions affects the subsequent course of lentil malt production. The lentil grain had an initial moisture content of 15 %, and was moistened to a moisture content of 46–48 %. The research results are shown in Table 2.

Table 2

Change in lentil moisture content during soaking, %

Experiment	Concentration of hydrogen peroxide, mg/l	Soaking time, h								
		0	6	12	18	24	30	36	42	48
1 (control)	–	15.0	20.3	28.4	36.6	44.1	45.5	46.6	47.1	48.0
2	100	15.0	21.6	31.7	37.2	45.8	46.4	47.0	48.1	49.3
3	200	15.0	22.9	33.5	39.7	46.4	47.1	48.2	49.4	50.0
4	300	15.0	24.5	35.3	40.8	47.6	48.0	49.1	50.2	51.1
5	400	15.0	25.6	38.4	42.5	48.1	50.4	51.6	52.3	52.8
6	500	15.0	25.1	37.2	41.9	47.8	48.6	48.9	49.5	50.8
7	600	15.0	24.8	35.9	41.1	47.5	48.5	48.7	48.9	50.2
8	700	15.0	24.2	35.1	40.5	47.1	47.9	48.3	48.6	50.1

The results of moisture analysis of the studied material are given in Table 2. Therefore, the study of the effect of plasma-chemical activation of technological solutions on lentil grain was aimed at obtaining a fixed moisture content for germination, which is 48 % for lentils. The temperature regime of technological solutions during lentil grain moistening was 18 °C, the moistening time varied from 24 to 48 hours. The control lentil reached the required moisture level after 48 hours. When using cold plasma-treated aqueous solutions, the desired result was achieved after 24 hours of soaking. The fastest achievement of the desired moisture content of 48 % was observed at a hydrogen peroxide concentration of 400 mg/l. That is why this concentration is recommended for activating technological solutions.

To compare and justify the recommended concentration of hydrogen peroxide in plasma-chemically activated solutions according to Table 2, linear paired regressions (1) were constructed for 8 samples of $N=8$ observations, describing an increase in lentil moisture (Table 3).

As shown in Table 3, all regressions are adequate to the sample data, because their coefficients of determination R^2 belong to the range from 0.825 to 0.904. To assess the significance of the regression coefficients, the level of $\alpha=0.05$ was chosen. According to inequalities (2) at $Tcrit(0.05; 6)=2.447$, for all constructed regressions $A1$ are reliable indicators of an increase in the lentil moisture level in % for each additional hour of soaking at the corresponding level of hydrogen peroxide concentration.

Table 3

Dynamics of lentil moisture when using different cold plasma-treated solutions

Concentration, mg/l	Regression	R^2	$Tregr$	$A1$, %/h
0	$Y1=18.158+0.823\times t$	0.904	7.496	0.823
100	$Y1=19.458+0.816\times t$	0.886	6.830	0.816
200	$Y1=20.492+0.823\times t$	0.878	6.556	0.823
300	$Y1=21.550+0.822\times t$	0.862	6.121	0.822
400	$Y1=22.458+0.859\times t$	0.858	6.021	0.859
500	$Y1=22.558+0.795\times t$	0.825	5.313	0.795
600	$Y1=22.092+0.796\times t$	0.835	5.515	0.796
700	$Y1=21.642+0.795\times t$	0.844	5.696	0.795

Fig. 1 shows the effect of hydrogen peroxide concentration on the growth rate of lentil moisture.

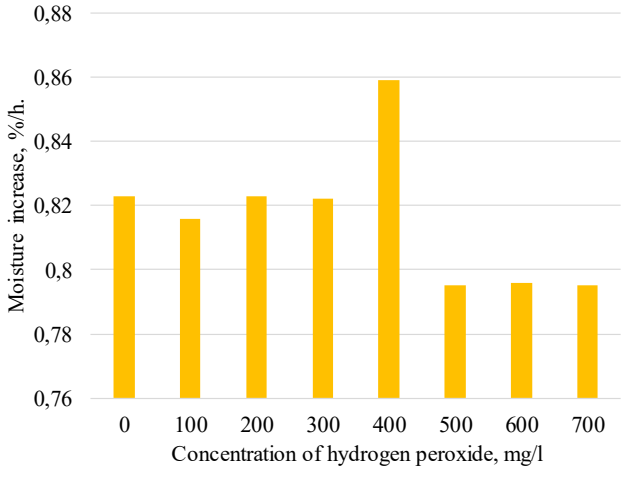

Fig. 1. Effect of hydrogen peroxide concentration on the growth rate of lentil moisture

Therefore, it can be seen (Fig. 1) that the maximum value of $A1$=0.859 %/h is observed when the concentration of hydrogen peroxide reaches 400 mg/l. This confirms the preference of this particular solution in ensuring the fastest achievement of the technologically necessary lentil moisture content of 48 % from its initial level of 15 %.

5. 2. Study of germination indicators of lentil grain

An important technological parameter of any malt raw material is the germination energy and capacity of lentil grains (Table 4). The parametric indicators of the technological solutions are identical to the material moisture study. The basic technological characteristic is a combination of increasing indicators of achieving the required moisture content and germination activity of lentil grains. The overall positive dynamics of these indicators will make it possible to develop optimal parameters for processing technological solutions. It should be noted that the specified peroxide content in technological solutions does not harm lentil grain during the implementation of the technological process. It also does not alter the organoleptic properties of lentil malt. The initial viability of the studied lentil grain was 100 %, that is, the maximum germination indicator could be a limit of 100 %.

The germination indicators of lentil grain showed a dynamic increase when using cold plasma-treated technological solutions. The increase in germination energy is from 8 to 16 %, and the increase in the germination capacity index, respectively, is 3–10 %.

The length of lentil bean sprouts on the 4th day of germination was also measured. The obtained results are shown in Table 5.

Sprout length also had steady dynamics of increase by 12–29 %. Thus, the dynamics of sprout growth is maximum at a peroxide concentration in the solution of 400 mg/l, which indicates the maximum intensifying effect in this mode of treatment of technological solutions.

So, according to Tables 4, 5, quadratic univariate regressions (3) were constructed for 3 samples of N=8 observations, describing the germination energy and capacity and the average length of lentil sprouts depending on the concentration of hydrogen peroxide in plasma-chemically activated solutions. As shown in Table 6, all regressions are adequate to the sample data, because their coefficients of determination R^2 belong to the range from 0.984 to 0.998, as well as at the level of significance α=0.05 and the critical value $Fcrit$(0.05; 2; 5)=5.786 for all constructed regressions, the Fisher's test (4) is met.

Table 4

Germination indicators of lentil grain when using cold plasma-treated solutions

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Germination indicators, %	
			Energy	Capacity
1 (control)	mains	–	81	90
2	activated	100	89	93
3	activated	200	93	96
4	activated	300	96	98
5	**activated**	**400**	**97**	**100**
6	activated	500	95	99
7	activated	600	94	98
8	activated	700	92	96

Table 5

Monitoring the length of lentil sprouts when using cold plasma-treated solutions

Experiment	Water	Concentration of hydrogen peroxide, mg/l	Average length, mm
1 (control)	mains	–	33.92
2	activated	100	38.12
3	activated	200	41.01
4	activated	300	43.22
5	**activated**	**400**	**43.91**
6	activated	500	43.87
7	activated	600	42.74
8	activated	700	41.05

Table 6

Mathematical description of lentil grain germination indicators depending on hydrogen peroxide concentration

Indicator $Y2$	Regression	R^2	$Fregr$	$Y2$max	$Xopt$, mg/l
Germination energy	$Y2=81.958+0.069\times X-0.00008\times X^2$	0.969	78.977	96.9 %	430.7
Germination capacity	$Y2=89.583+0.043\times X-0.00005\times X^2$	0.984	150.038	99.3 %	445.1
Average sprout length	$Y2=34.025+0.045\times X-0.00005\times X^2$	0.998	1468.981	44.1 mm	447.2

Based on the maximization of reliable constructed regressions (Table 6) according to formula (5), it was specified that the maximum germination indicators of lentil grain will be observed when it is treated with plasma-chemically activated solutions with a hydrogen peroxide concentration from 430.7 to 447.2 mg/l.

5. 3. Study of the amino acid and vitamin composition of lentils and lentil malt

An important indicator of lentil malt is the amino acid composition of the finished product. So, the next step was

to analyze the amino acid composition of grain and lentil malt. The results are given in Tables 7, 8. An experimental group with maximum germination energy and capacity was selected for the study.

Table 7

Content of non-essential and semi-essential amino acids in lentil malt, mg/100 g of product

Amino acid	Lentil beans	Lentil malt	
		Control (classical technology)	Experiment (using plasma-chemical activation)
Cystine	921	1,077	1,108
Alanine	4.09	5.15	5.29
Arginine	1,951	2,218	2,258
Histidine	651	938	974
Aspartic acid	2,229	3,471	3,505
Glycine	1,097	1,741	1,837
Glutamic acid	3,591	3,799	3,908
Proline	807	931	984
Serine	961	972	979
Total	12,212	15,152	15,558

Analyzing the results given in Table 7, note that the amount of non-essential and semi-essential amino acids in the experimental samples has increased. So, the total amount of amino acids is 406 mg/100 g of product greater than in the control. Compared to the amino acid content in unsprouted lentil beans, the increase in amino acids was 27 %.

Table 8

Content of essential amino acids in lentil malt, mg/100 g of product

Amino acid	Lentil beans	Lentil malt	
		Control (classical technology)	Experiment (using plasma-chemical activation)
Valin	798	1,548	1,574
Isoleucine	1,031	1,695	1,772
Leucine	2,398	3,031	3,078
Tyrosine	902	981	997
Lysine	2,341	2,699	2,791
Methionine	458	725	773
Threonine	1,250	1,803	1,881
Tryptophan	172	275	304
Phenylalanine	1,057	1,393	1,452
Total	10,407	14,150	14,662

In Table 8, special attention should be paid to the fact that the amount of essential amino acids in the experimental samples has increased. Thus, the total amount of amino acids is 512 mg/100 g of product higher than in the control. Compared to the amino acid content in unsprouted lentil beans, the increase in amino acids was 41 %.

According to formula (6) of the presented method for analyzing amino acid composition values, according to Tables 7, 8, differences in the content of K=2 groups of non-essential, semi-essential and essential amino acids were calculated. The calculated results for J=18 amino acids are shown in Table 9.

Table 9

Differences in the amino acid composition of the experimental and control lentil malt

Non-essential and semi-essential amino acids		Essential amino acids	
Name	ΔP, %	Name	ΔP, %
Cystine	2.88	Valine	1.68
Alanine	2.72	Isoleucine	4.54
Arginine	1.80	Leucine	1.55
Histidine	3.84	Tyrosine	1.63
Aspartic acid	0.98	Lysine	3.41
Glycine	5.51	Methionine	6.62
Glutamic acid	2.87	Threonine	4.33
Proline	5.69	Tryptophan	10.55
Serine	0.72	Phenylalanine	4.24
Average	3.00	Average	4.28

Checking the criterion of one-way analysis of variance (7) with a significance level α=0.05 made it possible to state that the advantages of using plasma-chemically activated technological solutions over classical technology are similar in groups:

$$Fanova=1.285\leq 4.494=Fcrit(\alpha;\ 1;\ 16),$$

giving an average increase of 3 % for non-essential and semi-essential amino acids and an average increase of 4.28 % for essential amino acids.

An important stage of research on lentil malt quality is the analysis of changes in the vitamin composition during the germination of lentil beans. The results of the grain material study are shown in Table 10.

Table 10

Vitamin composition of lentils and lentil malt, mg/100 g of product

Indicator	Lentil beans	Lentil malt	
		Control (classical technology)	Experiment (using plasma-chemical activation)
Vitamin B_1	0.48	0.71	0.82
Vitamin B_2	0.22	0.46	0.51
Vitamin B_5	1.38	2.18	2.25
Vitamin B_9	0.45	0.84	0.92
Vitamin PP	1.77	2.18	2.26
Vitamin C	–	0.03	0.05

Based on the data given in Table 10, it should be noted that the amount of vitamins in lentil malt was greater than in the control. Therefore, the absolute advantages of using plasma-chemically activated technological solutions over classical technology in this case are indisputable, and they do not significantly distort the vitamin composition. This is confirmed by the results of determining the relative changes in the content of 6 vitamins in lentil malt in the experiment and control, made according to Table 10 using formula (8). Visualization of the calculated results is presented in Fig. 2.

Fig. 2 shows that the most sensitive to the use of plasma-chemical activation of technological solutions was vitamin B_1, which had the largest absolute increase. Vitamins B_9, B_2 and C practically retained their weight in the total vitamin

composition of lentil malt. While vitamins PP and B_5 were the least sensitive in the experiment compared to the control.

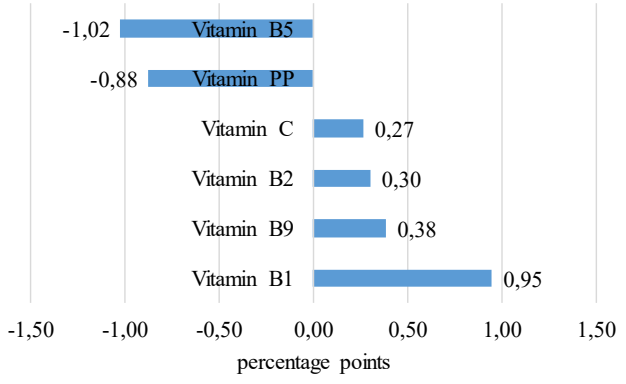

Fig. 2. Differences in the vitamin composition of lentil malt using plasma-chemical activation of technological solutions

However, all changes (Fig. 2) were in the range of ±1 %. This means that using plasma-chemically activated process solutions will not spoil the relative proportions of vitamins in lentil malt compared to classical technology.

5. 4. Study of microbiological indicators of lentil malt

The microbial state of lentil malt has a significant impact on the quality of products obtained using it. The presence of pathogenic microbiota on the surface of the finished lentil malt was studied. The results are presented in Tables 11, 12:

Table 11

General microbiological indicators of lentil malt (n=5, p≥0.95)

Groups of microorganisms	Sample	
QMAFAnM, thousand CFU/g	Control	3.9
	Experiment	Not found
Fungi, thousand CFU/g	Control	2.1
	Experiment	Not found
Escherichia coli bacteria (E. coli) in 0.1 g of product	Control	0.06
	Experiment	Not found

Table 12

Contamination of lentil malt with fungal microflora ((n=5, p≥0.95), % of infected grains

Type of fungal microflora	Concentration of peroxides in cold plasma-treated solutions, mg/l							
	0	100	200	300	400	500	600	700
Aspergillus	99	75	41	11	0	0	0	0
Alternaria	43	28	17	9	0	0	0	0
Penicillium	32	16	10	5	0	0	0	0
Fusarium	15	10	5	3	0	0	0	0
Mucor	33	17	11	3	0	0	0	0

Considering Tables 11, 12, it should be noted that cold plasma-treated solutions inhibit microflora on the surface of lentil malt, including the most resistant microbiota, namely, fungal. And with a sufficient concentration of peroxides (400 mg/l of hydrogen peroxide) qualitatively disinfect lentil malt.

According to Table 12, linear paired regressions (9) were constructed for 5 samples of N=5 observations, describing a decrease in lentil malt contamination with fungal microflora depending on peroxide concentration in cold plasma-treated solutions.

As shown in Table 13, all regressions are adequate to the sample data, because their coefficients of determination R^2 belong to the range from 0.920 to 0.983. To assess the significance of the regression coefficients, the level of α=0.05 was chosen. According to inequalities (10) at $Tcrit$(0.05; 3)=3.182, for all constructed regressions C1 are reliable indicators of a decrease in lentil malt contamination with fungal microflora.

Table 13

Mathematical description of lentil malt contamination dynamics

Type of fungal microflora	Regression	R^2	$Tregr$	$C1$×100, units/sq.cm per 100 mg/l
Aspergillus	$Y3$=97.6–0.262×X	0.979	–11.78	–26.2
Alternaria	$Y3$=40.4–0.105×X	0.983	–13.3	–10.5
Penicillium	$Y3$=27.6–0.075×X	0.920	–5.887	–7.5
Fusarium	$Y3$=14.0–0.037×X	0.970	–9.773	–3.7
Mucor	$Y3$=28.8–0.080×X	0.929	–6.273	–8.0

Moreover, these indicators make it possible to organize its species by sensitivity to an increase in peroxide concentration in cold plasma-treated solutions (Fig. 3):

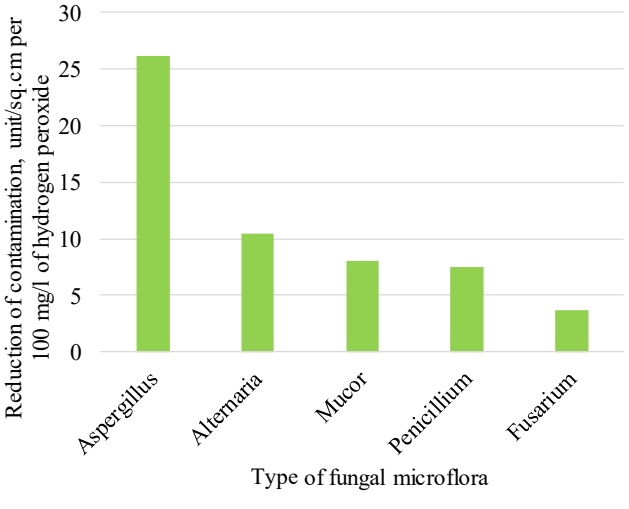

Fig. 3. Comparison of the rate of reduction of lentil malt contamination when using cold plasma-treated peroxide solutions

Namely, as illustrated in Fig. 3, the least resistant was Aspergillus (–26.2 units/sq.cm with an increase in peroxide concentration by 100 mg/l), while Fusarium demonstrated the greatest resistance (–3.7 units/sq.cm with an increase in peroxide concentration by 100 mg/l).

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

In order to implement the proposed technology in malt production, a flow diagram of lentil malt production using plasma-chemically activated aqueous solutions was developed (Fig. 4).

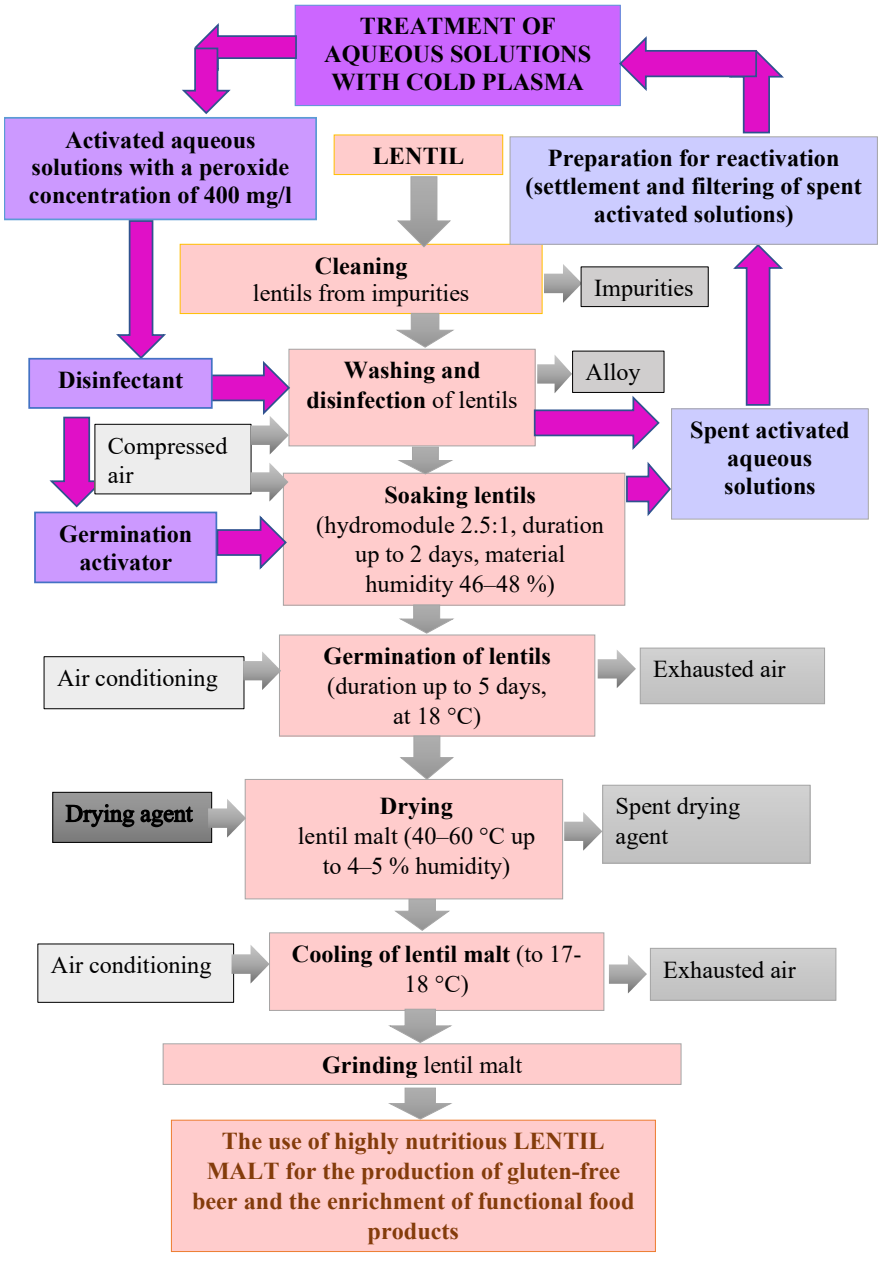

Fig. 4. Flow diagram of lentil malt production using cold plasma-treated aqueous solutions

The flow diagram of lentil malt production using cold plasn ma-treated aqueous solutions shown in Fig. 4 gives a compree hensive idea of the course of the lentil malting process, taking into account the use of the proposed germination activator.

6. Discussion of the results of research on lentil malt production technology

Analysis of the results obtained in Table 2 allows us to note that cold plasma-treated aqueous solutions significantly shorten the process of lentil soaking from 48 hours to 24 hours, with a peroxide concentration in the solution of 400 mg/l. This can be seen by analyzing Fig. 1, namely, that the maximum value of $A1$=0.859 %/h is observed when the concentration of hydrogen peroxide reaches 400 mg/l. The use of solutions with the indicated concentration allows to shorten the lentil soaking stage by 2 times. As shown in Table 3, all regressions are adequate to the sample data, because their coefficients of determination R^2 belong to the range from 0.825 to 0.904. This is due to the fact that activated aqueous solutions are able to defuse much more actively into lentil grain than ordinary water [16].

Studies of germination indicators also confirm the working hypothesis, namely, the germination indicators of lentil grain showed a dynamic increase when using cold plasma-treated technological solutions. The increase in germination energy is from 8 to 16 %, and the increase in the germination capacity index, respectively, is 3–10 % (Table 4). The sprout length also had steady dynamics of increase by 12–29 % (Table 5). Based on the maximization of reliable constructed regressions (Table 6), it can be concluded that the maximum germination indicators of lentil grain will be observed when it is treated with plasma-chemically activated solutions with a hydrogen peroxide concentration from 430.7 to 447.2 mg/l. The conducted studies show that

the process of germination activation has been launched successfully and malting proceeds evenly and efficiently. A positive change in germination indicators, as a rule, indicates the dynamism of the malting process and obtaining a high-quality finished product [19, 20].

Considering the results given in Table 7, it should be noted that the amount of non-essential and semi-essential amino acids in the experimental samples increased. Thus, the total amount of amino acids is 406 mg/100 g of product higher than in the control. Compared to the amino acid content in unsprouted lentil beans, the increase in amino acids was 27 %. So this indicates the active work of proteolytic enzymes and the maximum dissolution of lentil proteins. This conclusion is confirmed by the data given in Table 8. The amount of essential amino acids in the experimental samples increased. Thus, the total amount of amino acids is 512 mg/100 g of product greater than in the control. Compared to the amino acid content in und sprouted lentil beans, the increase in amino acids was 41 %. So we can talk about a natural and permanent increase in the level of amino acids in sprouted lentils. This will make it possible to recommend the obtained grain product for wide consumption.

Analyzing Table 10, it is also possible to observe an increase in the content of B vitamins (B_1, B_2, B_5, B_9), as well as PP and C. The most sensitive to the use of plasma-chemical activation of technological solutions was vitamin B_1, which had the largest absolute increase (Fig. 2). Vitamins B_9, B_2 and C practically retained their weight in the total vitamin composition of lentil malt. While vitamins PP and B_5 were the least sensitive in the experiment compared to the control. An increase in the amount of these vitamins indicates an increased biological value of lentil malt obtained by the presented technologies.

Sprouted lentil grains contain microorganisms on their surface, in particular, pathogenic ones. Plasma-chemically activated aqueous solutions are known to have a disinfecting effect [16–19]. Considering Fig. 3, it should be noted that Aspergillus was the least resistant (–26.2 units/sq.cm with an increase in peroxide concentration by 100 mg/l), while Fusarium demonstrated the greatest resistance (–3.7 units/sq.cm with an increase in peroxide concentration by 100 mg/l). Analyzing Tables 11, 12 it should be noted that lentil malt treated with plasma-chemically activated aqueous solutions with a peroxide concentration of 400 mg/l does not contain pathogenic microorganisms, including molds.

The introduction of malt production technology using an innovative component in the industry requires the development of a flow diagram of lentil malt production using cold plasma-treated solutions. Such a flow diagram was created and tested in a scientific laboratory (Fig. 4). Accordingly, it contains classical technological operations, as well as washing and soaking lentils with cold plasma-treated aqueous solutions. The presented solutions are used at the stage of washing and soaking lentils before germination, so the presented implementation does not require significant changes in the lentil malting process line. Used activated aqueous solutions are settled, filtered and sent for repeated plasma-chemical activation [15]. Such a technological solution to water use when implementing the technology of plasma-chemical activation of aqueous solutions makes it possible to significantly save water resources [17]. The results of studies on the process parameters and changes in the composition of lentil malt make it possible to improve existing classical malting technologies.

The disadvantages of the studies include the lack of data on the enzymatic activity of lentil malt. These data are planned to be obtained in the future when continuing to study the technology of lentil malt production using plasma-chemical treatment of technological solutions.

The accompanying limitations of the presented research may concern the provision of malt production with a sufficient amount of cold plasma-activated aqueous solutions. Therefore, an urgent problem is currently being solved, namely, LLC Scientific and Production Enterprise KNP-TECHNOLOGY (Ukraine) is increasing its production capacity for producing plasma-chemically activated aqueous solutions. In the future, this aspect will provide specialized processing enterprises with activated aqueous solutions. This will make it possible to more widely implement innovative technological solutions regarding the use of plasma-chemical treatment of solutions in the food industry.

The prospect of the research consists in developing a production technology for lentil sprouts, lentil microgreens.

7. Conclusions

1. Sorption processes in grain material during soaking using cold plasma-treated aqueous solutions were investigated. It was found that the recommended soaking time for lentils is 24 hours at a peroxide concentration in the solution of 400 mg/l.

2. The germination indicators of lentil grain were studied, so when using activated solutions (peroxide concentration 400 mg/l), the germination energy increased by 16 %, and the germination capacity, respectively, by 10 %, the sprout length increased by 29 %.

3. The study of the amino acid and vitamin composition showed positive results. The experimental samples had an increased content of amino acids: non-essential by 2.7 %, essential by 3.6 %. There was also an increase in the content of B vitamins (B_1, B_2, B_5, B_9), as well as PP and C.

4. Studies of the microbiological indicators of lentil malt showed no pathogenic microflora, including mold, on the surface of the grain material at a peroxide concentration in the solution of 400 mg/l.

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.

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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.

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