

This paper describes the materials and results of studying the properties of such a leguminous crop as the chickpea variety Miras 07 of Kazakhstan selection in order to obtain gluten-free flour and further process it to produce confectionery products.

The research involved the ultra-high-frequency (UHF) treatment of chickpea grain to improve quality indicators and reduce anti-alimentary factors.

A change in the protein fraction of chickpeas was determined under exposure to ultra-high-frequency processing. The study has proven the effectiveness of ultra-high-frequency treatment of chickpea for 180 seconds.

Based on chemical analysis, it was found that the exposure to ultra-high-frequency treatment fully preserved the vitamin and mineral complex, compared with untreated chickpeas. When chickpea grain is heated for 180 seconds, up to 20 % of the starch contained in the grain passes into dextrin, which is easily absorbed by humans while the toxic substances are destroyed.

The change in the protein fraction of chickpeas during ultra-high-frequency processing was determined. With ultra-high-frequency treatment of chickpea flour at 180 seconds of exposure, the protein fraction content remains unchanged at 79.8 %. The result based on the IR spectrum data indicates that ultra-high-frequency processing did not affect the protein-amino acid composition of the examined Miras 07 chickpea variety.

The current study has confirmed the effectiveness of ultra-high-frequency chickpea treatment, which leads to the intensification of biochemical processes in the processed product due to the resonant absorption of energy by protein molecules and polysaccharides.

Under the influence of ultra-high-frequency treatment, there is a decrease in the microbiological contamination of raw materials while the organoleptic indicators improve. According to the microbiological indicators of chickpea flour, the content of microorganisms was 1×10^3 CFU/g, which meets the requirements for sanitary and hygienic safety

Keywords: leguminous crop, Miras 07 chickpea variety, ultra-high-frequency processing, gluten-free flour

DETERMINING THE OPTIMAL PARAMETERS OF ULTRA-HIGH-FREQUENCY TREATMENT OF CHICKPEAS FOR THE PRODUCTION OF GLUTEN-FREE FLOUR

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1. Introduction

One of the pressing social problems in many countries is celiac disease, a genetic disease characterized by digestive disorders. According to doctors and nutritionists, 1 person out of 100 is susceptible to this disease [1].

People with celiac disease need to replace the traditional diet containing gluten with gluten-free. To feed this category of persons, it is necessary to use those crops and products from them that do not contain gluten in their composition but could give a product that does not differ from the grain analog. Raw materials for the production of gluten-free products can be crops and products from them: buckwheat, rice, quinoa, millet, amaranth, sorghum, corn, flax, soybeans, sunflower, amaranth [2].

The gluten-free diet is in high demand among children with severe autism. Some believe that gluten (a protein found in wheat and some other cereals) and casein (a protein found in dairy products) can worsen the symptoms of autism, causing inflammatory processes in the intestines that affect brain function [3].

Despite the prevalence of the celiac disease among the child population 1:262 [4, 5], this issue is not given due attention in Kazakhstan. Medical institutions in which patients are observed are forced to find ways to provide special healing gluten-free products. Moreover, there are no enterprises that manufacture such products for this segment of consumers. Imported gluten-free products of unknown quality offered in the Kazakhstan market are sold at inflated prices.

Undoubtedly, there are many recipes for gluten-free products in the world but a special role belongs to the quality of the raw materials used to make them. Kazakhstan grain crops have excellent quality and favorably differ from analogs. The content of such trace elements as boron, iron, zinc, and others in them is 30–40 % higher than that in the grain of foreign varieties [6].

Analysis of the studied indicators of leguminous crops revealed that legumes are characterized by a high content of protein, fat, and minerals [7–9]. These advantages of leguminous crops predetermine the prospects for the development and improvement of technology for processing legumes to create flour, and further use in the production of gluten-free confectionery.

Legumes have unsatisfactory technological properties, the main of which are the need for preliminary mechanical preparation – collapse, grinding, hydrothermal processing, prolonged heat treatment. In addition, almost all pulses are sources of anti-alimentary substances. All this is the reason for the limited use of leguminous crops in the diets of the population [10]. Given this, the use of heat treatment is crucial for improving the technological properties of legumes. Thus, it is a relevant task to study the effect of ultra-high-frequency chickpea processing on the nutritional and biological value of the finished product.

2. Literature review and problem statement

In the world, there are various technologies for making gluten-free products but the fundamental difference between each technology is a different recipe for products and the quality of the raw materials used.

The list of raw materials to produce gluten-free products, proposed by Codex Alimentarius, includes corn, rice – raw materials with a high content of starch. Recommended for use are buckwheat, millet, amaranth, flax (raw materials with a high content of polysaccharides), as well as high-protein peas and chickpeas [11].

Legumes differ significantly in their technological characteristics from the grain of traditional grain crops, the technology of industrial processing of which into flour has been worked out in detail for many years, so it is necessary to find ways to improve its processing.

To use legumes for the development of technology, it is very important to take into consideration their properties, which differ from other crops. Legumes differ significantly in their characteristics from the grain of traditional grain crops, the technology of industrial processing of which into flour has been worked out in detail for many years. In addition, pulses are a source of anti-alimentary compounds that prevent the absorption of essential nutrients.

The process of flour production consists of two stages – preparatory and direct grinding of grain. To reduce energy costs for its implementation and increase the yield of flour, it is proposed to carry out preliminary heat treatment of cereals, which helps reduce the strength of raw materials [12].

In [13], cereals were subjected to heat treatment with ultra-high-frequency fields, which leads to changes in the structure of starch, contributing to an increase in its sorption activity. The study has shown that when treated with a field power in the range of 400–600 W, the organoleptic parameters of the grain improved. It is also proven that irradiation in ultra-high-frequency fields reduces contamination with microorganisms and, consequently, increases the shelf life of finished products [14].

Ultra-high-frequency treatment is one of the promising methods for processing grain crops. In the process of treatment in a microwave oven, infrared radiation penetrates the grain and causes rapid internal heating of the grain from the inside. At the same time, the structural frame of the grain is destroyed and the strength of the grain decreases, which helps reduce energy costs during its further processing [15].

Work [12] reports the results of studying the heat treatment of leguminous crops by micronization. It is shown that the selected optimal modes of micronization of leguminous raw materials, that is processing time, for all crops was 60 seconds, humidity for peas – 18 %, lentils – 15 %, chickpeas – 20 %. Before micronization, the process of de-wetting was used [16]. When the raw material is de-wetted, it swells, thereby reducing strength, which helps reduce energy costs during its further processing. The disadvantage of this technique is the need to cool the heated micronized grain with additional energy spent and the time for its processing lengthened.

Work [17] reports a study on the extrusion of soybean flour. The technology involved preliminary crushing, the removal of the seed membrane, inactivation of lipoxygenase by dry heating, followed by moistening to 20 %, and extrusion of the product. The disadvantages of the extrusion process are the complexity of the design, the uncontrolled technological process, and significant losses of time to manufacture products.

There is a known technique of heating grain material using infrared irradiation (IR), in which the grain material is processed at a grain temperature of 15–25 °C and a moisture content of 10–15 %, and heated to a temperature of 170–190 °C [18]. This technique of heat treatment of grain significantly increases the content of dextrin in the grain, contributes to its disinfection and hardening. Starch granules undergo deeper changes in IR treatment than in other processing techniques. The disadvantage of this technique is the duration of the technological process, the need for bulky and difficult-to-operate equipment.

An option for overcoming the relevant shortcomings may be the use of ultra-high-frequency processing of raw materials. This is the approach used in paper [19]. With ultra-high-frequency processing of chickpeas, the organoleptic indicators of the finished products improve; it also affects the content of proteins, fats, carbohydrates in them.

Numerous studies are being conducted on the heat treatment of grain crops to increase their nutritional value. However, studies on the ultra-high-frequency processing of leguminous crops of Kazakhstan selection are not numerous yet. In this regard, it is advisable to investigate the issue of ultra-high-frequency processing of raw materials that could make it possible to obtain high-quality products, stabilize the output of the finished product, and increase its shelf life. At the same time, it is important to define the optimal modes of ultra-high-frequency processing of raw materials in order to study the influence of treatment time on the quality indicators of the protein fraction, as well as the nutritional and biological value of the chickpea variety Miras 07.

3. The aim and objectives of the study

The purpose of this study is to determine the rational parameters for the process of ultra-high-frequency treatment of the Miras 07 chickpea variety, intended for the production of gluten-free flour.

To accomplish the aim, the following tasks have been set:

- to investigate the effect of ultra-high-frequency processing on the quality indicators of the Miras 07 chickpea variety;
- to examine the effect of ultra-high-frequency processing on the protein fraction of the Miras 07 chickpea variety;
- to determine the effect of ultra-high-frequency processing on the nutritional and biological value of chickpea flour.

4. The study materials and methods

4. 1. Examined materials

The object of research is the Miras 07 chickpea variety, selected by scientists at the Kazakh Research Institute of Agriculture and Crop Production. This variety is intended for food purposes.

Acceptance rules and sampling methods, methods of testing cereals were carried out according to GOST 26312.1-84 and 26312.6-84. Ultra-high-frequency processing was carried out in a microwave oven at 800 W. During the experiments, the optimal time of stay, as well as the time of heating of raw materials in the working zone of ultra-high-frequency equipment, were studied and determined.

To establish the optimal grinding size, the grain was ground at the laboratory mill Hawos Pegasus 380 V (Germany) with built-in sieves Ø1 mm (medium grinding) and Ø2 mm (coarse grinding).

We determined the IR spectrum at the spectrophotometer “Nicolet 5700” (made by Thermo Electron Corporation, USA) in tablets with Kbr. This device helped obtain the results for the processed and untreated samples of chickpea flour. The spectral analysis is based on the measurement of different effects arising from the interaction of radiation with the investigated composition [20, 21]. This procedure is used in the food industry to obtain an accurate, unambiguous characteristic of the substance. The analysis is carried out for any substances and regardless of their aggregate state, which allows for research at any stage of food production, semi-finished products.

The water absorption capacity of chickpea flour was determined by the generally accepted procedure for changing the mass of samples in the process of their hydration [22].

We determined the quality characteristics of gluten-free chickpea flour in accordance with the standards; chickpea flour – GOST 8758-76. The physical-chemical parameters of chickpea flour were determined by standard methods: the mass fraction of protein – according to GOST 10846-91; the mass fraction of fat – according to GOST 5899-85 [23].

Microbiological contamination was determined according to GOST 10444.15-94. For seeding, samples of chickpea flour were selected, flushes were taken with a cotton swab into a test tube with 10 ml of sterile solution. The cultivation of microorganisms was carried out according to GOST 26670-91.

We determined the colony-forming units (CFU) according to GOST 10444.15-94. We determined the yeast and molds in line with GOST 10444.12-2013. The number of mesophilic anaerobic and facultative-anaerobic microorganisms was determined by GOST 33536-2015 [24]. The method is based on seeding a certain amount of product into an agarized nutrient medium or its dilution. Next, the process of aerobic cultivation of crops at a temperature of $(30 \pm 1)^\circ\text{C}$ – (72 ± 3) h, counting the grown visible colonies and mesophilic aerobic, facultative-anaerobic microorganisms per 1 g of product was carried out.

We determined gluten in flour mixtures using the immuno-enzymatic analyzer Multiscan FC of the Rieder brand (Finland) using the Immunolab Gliadin test kits (Germany).

The protein was determined by the nitrogen content at the Kjeldahl analyzer UDK159. Determining the amino acid composition of the protein was carried out by HELC at the Knauer Smartline 5000 chromatograph, using inverse phase chromatography at the Diasphere column – 110. Photometric detection at λ 248 nm. The injection volume was 20 μl . Quantitative calculation of the amino acid content was carried out according to the ratio of the areas of peaks of the standard and the sample.

The content of vitamins (B₁ thiamine chloride, B₂ riboflavin, B₃ pantothenic acid, B₅ nicotinic acid, B₆ pyridoxine, B₉ folic acid, C ascorbic acid) was determined using the electrophoresis “Kapel 105” (Russia). The presence of other substances, amino acids (arginine, lysine, tyrosine, phenylalanine, histidine, leucine and isoleucine, methionine, valine, proline, threonine, serine, alanine, glycine, cysteine, aspartic acid and asparagine, glutamic acid and glutamine, tryptophan) was established by the same method.

The high-performance liquid chromatographer “Agilent-1200” (USA), diode-matrix, fluorescent and refractometric detectors were used to determine the content of aflatoxins – B₁, amino acids, carbohydrates, fat-soluble vitamins.

With the help of the atomic absorption spectrometer “KVANT-Z.ETA” (Russia), we conducted an elemental analysis of liquid samples of various origins and compositions at the level of concentrations measured in $\mu\text{g/l}$ – ng/l . The device is used to quantitatively determine: 1 – Cu Copper, 2 – Al Aluminum, 3 – Zn Zinc, 4 – Pb Lead, 5 – Cr Chromium, 6 – Ni Nickel, 7 – Cd Cadmium, 8 – As Arsenic, 9 – Sn Tin.

The results of experimental studies were treated using the standard software Microsoft Excel.

5. Results of studying the technological properties of the Miras 07 chickpea variety for the production of gluten-free confectionery

5. 1. Results of studying the effect of ultra-high-frequency processing on the quality indicators of chickpeas

The results of our study carried out to determine the qualitative characteristics of the Miras 07 chickpea variety are given in Table 1.

Table 1 shows that chickpeas are characterized by a high content of protein, starch, fat, and minerals. All quality characteristics complied with regulatory data, so the proposed chickpeas can be used for processing in the food industry.

A study on the treatment of chickpea seeds in an ultra-high-frequency oven was carried out. The initial stage for obtaining chickpea flour was a thorough cleaning of chickpeas from all impurities, washing, and drying for 8 hours, then chickpeas were treated for 60–300 seconds in a microwave oven at 800 W. As a control option, a raw sample of the Miras 07 chickpea variety was taken.

Based on the experimental data, we established the dependence on the moisture content ($W, \%$) and the duration of ultra-high-frequency treatment (t, s), which was analyzed. The optimal indicators of ultra-high-frequency processing of a sample of the Miras 07 chickpea variety were studied (Table 2).

Based on the result of our experimental studies, at the ultra-high-frequency treatment of chickpeas for 60 seconds, the moisture content is reduced by 3.25 times; when processing for 180 seconds, respectively, it is reduced by 4 times compared to the control. With an increase in ultra-high-frequency treatment time to 300 seconds, in comparison with the control, the indicator is reduced by 4.8 times, which leads to excessive drying of chickpeas. Chickpeas overheat and the first burnt grains appear. At the same time, the volume of grain changes, along with the technological properties of cereals.

Table 1

Qualitative characteristics of chickpeas

Indicator	Qualitative characteristic indicator	
	chickpeas, according to normative document	Miras 07 chickpea variety
Humidity, %, not exceeding	14.0	11.5
Weed impurity, % not exceeding	1.0	0.7
Grain admixture, %, not exceeding	2.0	2.0
Pest infestation	not allowed	not detected
Protein content, %	20.47	24.6
Starch content, %	41.8	46.0
Fat content, %	4.3	5.8
Ash content, % not exceeding	3.15	3.3

Table 2

Indicators of the moisture content and processing time of the Miras 07 chickpea variety

Crop	Moisture content after de-wetting, W, %	Moisture content after MWO	
		time, t, s	moisture content
Chickpeas (control)	30.2	–	14
Miras 07 chickpea variety		60	4.3
		180	3.5
		300	2.9

Next, the organoleptic parameters of chickpea flour before and after ultra-high-frequency processing, given in Table 3, were studied.

Based on the organoleptic indicators (Table 3), it can be concluded that with ultra-high-frequency processing of 180 seconds, the leguminous taste of chickpeas and the smell are suppressed, they acquire a pleasant aroma characteristic of roasted seeds.

Table 3

Organoleptic indicators chickpeas before and after ultra-high-frequency processing

Indicator	Chickpeas before treatment	Treated chickpeas		
		60 seconds	180 seconds	300 seconds
Color	White-yellow	White-yellow	Yellowish	Yellowish with a brown tint
Smell	Pronounced smell of legumes	The smell of fresh chickpeas	The smell of roasted nuts	The smell of heavily roasted walnut
Taste	Characteristic taste without foreign tastes (not sour), not bitter	Characteristic weakly fried without foreign tastes	The taste of roasted chickpeas with a nutty flavor	Highly fried taste

5. 2. Results of studying the protein fraction of the Miras 07 chickpea variety

Next, we performed a study into the fractional composition of flour proteins from the processed Miras 07 chickpea variety, the Republic of Kazakhstan, Almaty Oblast: the results are shown in Fig. 1.

Fig. 1 shows a comparison of the protein composition of flour from the non-treated and treated Miras 07 chickpea variety.

Our study into the fractional composition of chickpea flour revealed that proteins are represented mainly by globulins and albumins. When processing for 60–180 seconds, the globulin and albumin fractions of the proteins change slightly, and, in 300 seconds, there is a decrease to 75 % (Fig. 2). According to the results of our experiment, it can be explained that the processing of the Miras 07 chickpea variety with an exposure time of 180 seconds confirms the rational mode of ultra-high-frequency treatment.

Next, the processed samples of flour from the Miras 07 chickpea variety (the Republic of Kazakhstan, Almaty Oblast) were taken to study the interpretation of infrared spectra in order to identify the total protein amine groups. The result of the samples' IR spectrum acquisition is the observed bands that differ from the simplest diatomic molecules. The oscillations of visible peaks in polyatomic molecules do not belong to only one bond or group of atoms; on the contrary, all the atoms of the molecules are in small motion (Fig. 2).

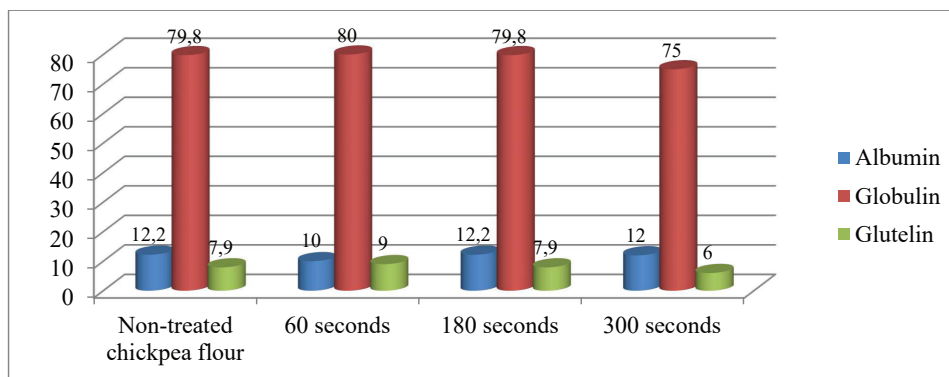


Fig. 1. Fractional composition of chickpea flour proteins

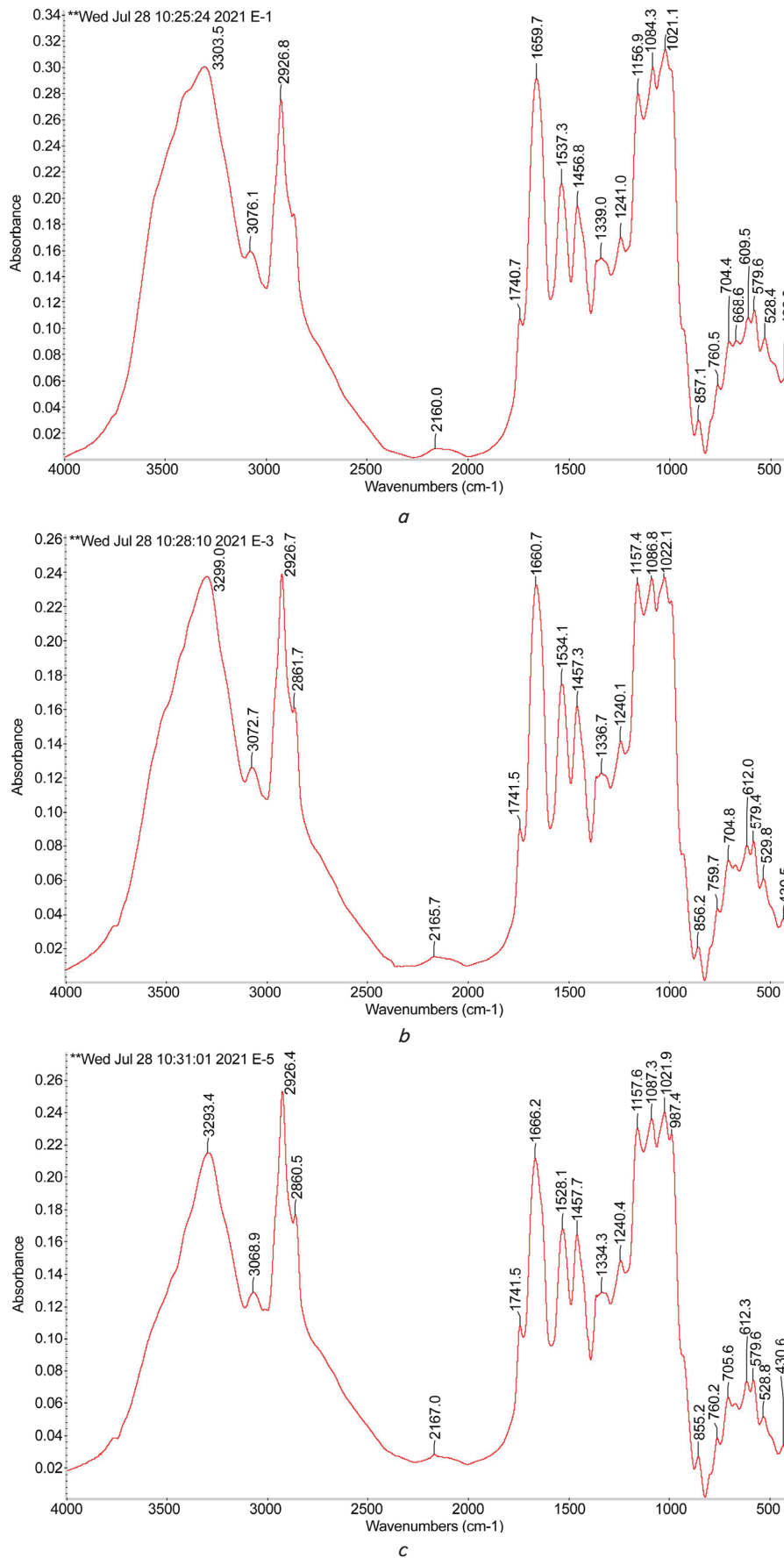


Fig. 2. The results of IR analysis at the spectrophotometer “Nicolet 5700” in tablets with Kbr: *a* – treated chickpeas, 60 seconds; *b* – treated chickpeas, 180 seconds; *c* – treated chickpeas, 300 seconds

Fig. 2 shows in the acquired IR spectra of samples No. 1–3 the found single bands that demonstrate the presence of secondary amines. We observed the absorption bands, protein amines of valent NH_2 -groups, and variable bands in the samples, respectively: $a - 3,303.5$; $b - 3,299.0$; $c - 3,293.4 \text{ cm}^{-1}$.

When a hydrogen bond is formed, the frequency of oscillations decreases while the bands expand. At the same time, there are free and bound hydrogen bonds. The highly structured wide bands of valence oscillations are the total amine groups such as NH_3^+ , NH_2^+ , NH^+ at: $a - 3,076.1$; $b - 3,072.7$; $c - 3,068.9 \text{ cm}^{-1}$.

In the intervals at $1,022.1$; $1,086.8 \text{ cm}^{-1}$, the interpretation of the spectra of the absorption bands of the valent symmetric and valent asymmetric oscillations is noticed. These fluctuations are identical for the groups of carboxylic acids $\text{C}-\text{O}-\text{C}$ of ethers and acetals in the range from $1,157.4$; $1,240.1$; $1,336.7 \text{ cm}^{-1}$.

Free groups of carboxylic acids are absorbed in the zone at $1,800-1,740 \text{ cm}^{-1}$. Our observation showed that sample (c) contains α , β -unsaturated, as well as aromatic carboxylic acids in the presence of hydrogen bonds. The frequency of the bands decreases to $1,741.5-1,660.7 \text{ cm}^{-1}$; the presence of $\text{C}=\text{O}$ group of valence oscillations is noticed.

At the interval of two bands of $1,457.3$ and $1,534.1 \text{ cm}^{-1}$, the average frequencies of oscillations of chemical bonds of groups of aromatic $\text{C}-\text{C}$ hydrocarbons are manifested, as well as $1,660.7$ (strong), $1,741.5$ (average). For alkyne groups, triple bond oscillations are manifested at the low-frequency end of $2,165.7 \text{ cm}^{-1}$ and very weak $\text{C}\equiv\text{C}$ bonds of valence oscillations are noticeable.

The spectra acquired after ultra-high-frequency processing demonstrate new peaks in samples (a) and (c), compared with the control sample, at the frequencies of 668.6 and 987.4 cm^{-1} (also, $3,299.0 \text{ cm}^{-1}$ wide bands of valence oscillations of the $\text{B}-\text{OH}$ bond). This is explained by the fact that these absorption bands correspond to deformation fluctuations of the groups of organophosphorus ($\text{P}-\text{H}$ grouping) and boron-organic compounds ($\text{B}-\text{C}$ and $\text{B}-\text{Cl}$ valence bonds).

The results of the experimental data on the analysis of the IR spectrum confirmed that ultra-high-frequency processing of the Miras 07 chickpea variety for 180 seconds is expedient. Compared with samples (a) and (c), there are no oscillation peaks that affect the organoleptic and technological properties of the raw material.

5. 3. Results of studying the effect of ultra-high-frequency processing on the nutritional and biological value of chickpea flour

A study was conducted to determine the water absorption capacity of the ultra-high-frequency-processed chickpea flour in comparison with the untreated flour: the results are shown in Fig. 3. The figure illustrates that the lowest water absorption capacity is demonstrated by the flour from unprocessed raw materials.

The water absorption capacity of the flour from the Miras 07 chickpea variety, depending on the duration of processing (Fig. 3), is described by the following regression equations:

– for non-treated flour

$$y = 16.87x + 40.35, R^2 = 0.96;$$

– for treated flour

$$y = 15.3x + 51.867, R^2 = 0.8461,$$

where x is the processing time, s;

y – the water absorption capacity of flour, %;

R – the value of the approximation confidence.

A study was conducted to determine the amino acid and vitamin composition of the gluten-free flour from the processed and unprocessed Miras 07 chickpea variety.

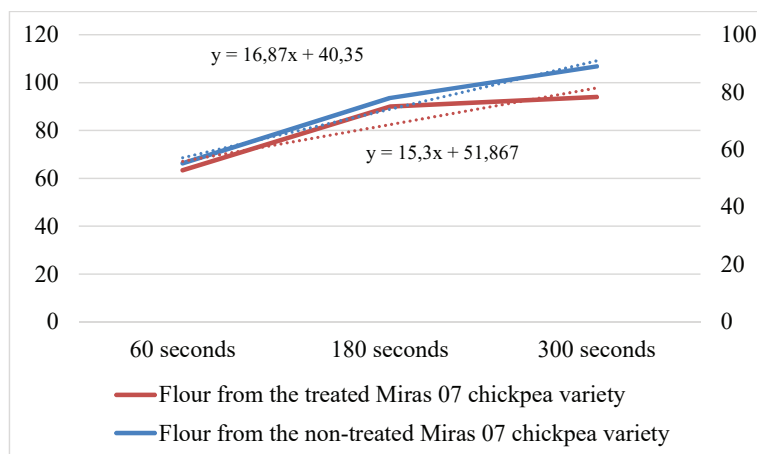


Fig. 3. The water absorption capacity of chickpea flour

Fig. 4 shows data on the amino acid composition of chickpea flour processed over 60–300 seconds, as well as non-treated flour.

Changing or denaturing protein in foods is important for the food industry as the denatured proteins are well digested and absorbed by the human body. During denaturation, the quaternary, tertiary, and partially secondary structure of the protein molecule is disturbed while their primary structure does not change; the indicators are kept within the normal range or fluctuate at 0.5 units. Protein denaturation leads to an increase in the number of peptides and free amino acids so that the amino acid composition of processed foods does not decrease [25].

A study was conducted to examine the vitamin and mineral composition of the treated samples of chickpea flour. The study results showed that the content of B vitamins is in the range from 0.05 mg to 0.236 mg. The content of such elements as Fe, Ca, Zn, and I in the UHF-treated samples is not significantly reduced compared to the mineral content in the treated samples (Table 4).

Thus, it can be concluded that in the process of ultra-high-frequency treatment, the content of microelement and vitamin composition almost does not change.

To study the shelf life of chickpea flour, we investigated its microbiological indicators. The results of contamination chickpea flour with microorganisms, in CFU/ml, are shown in Fig. 5.

A study was conducted to determine the gluten content in processed chickpea flour using the Immunolab Gliadin kit at an immune-enzymatic analyzer (Fig. 6). As a result of the study, the detection limit was no more than 10 mg/kg of gluten in the commercial sample.

For comparison, wheat flour of the highest grade was used. The studies have shown that a positive result was registered in the wheat flour; in the chickpea flour – a negative result was registered; this indicates that chickpea flour is gluten-free.

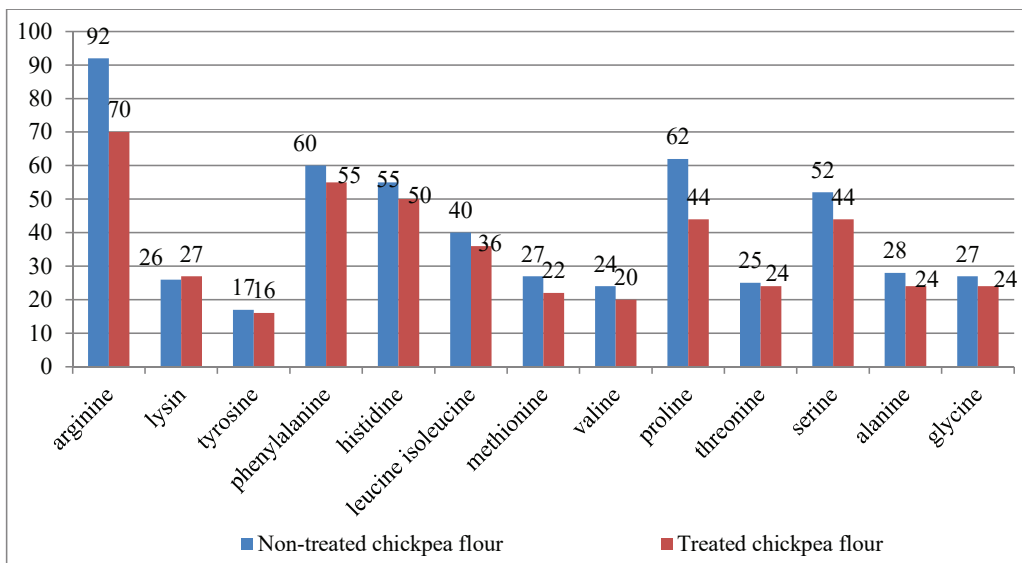


Fig. 4. The amino acid composition of chickpea flour

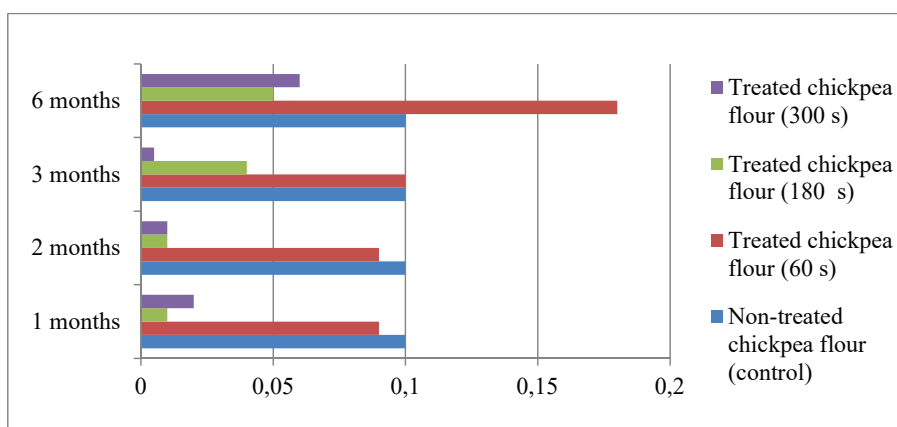


Fig. 5. Microbiological parameters of chickpea flour during storage, in CFU/g

No.	OD1	OD2	Mean O	Gliadin	Gluten	Result
1	3,8	0,99	2,4	>60	>120	Positive
2	1,9	1,198	1,549	0,13	0,27	Negative
3	1,5	1,369	1,437	0,57	1,13	Negative
4	0,9	1,7	1,3	1,09	2,19	Negative
5	1,4	1,07	1,274	1,19	2,39	Negative
6	1,253	1,4	1,151	1,67	3,34	Negative
7	1,3	1,7	1,35	0,9	1,8	Negative
8	0,7	0,8	1,2	1,48	2,96	Negative
9	1,7	1,527	1,25	1,29	2,57	Negative
10	0,7	1,9	1,314	1,04	2,08	Negative

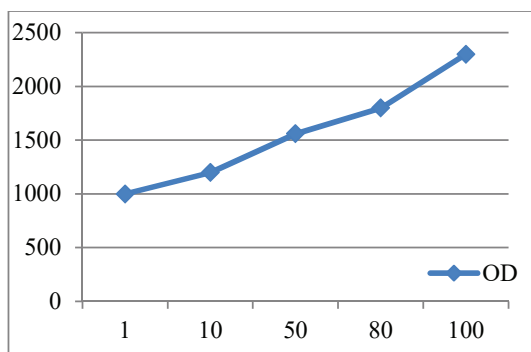


Fig. 6. Results of studying the gluten content of chickpea flour: *a* – the quantitative content of gluten in the sample; *b* – standard curve for gluten content

Table 4

The content of minerals and vitamins in chickpea flour

Indicator	Flour from non-treated chickpeas	Flour from the treated Miras 07 chickpea variety		
		60 s	180 s	300 s
1	2	3	4	5
Iron, mg/100 g	6.61±0.3	5.24 ±0.1	5.110±0.1	4.86±0.1
Ca, mg/100 g	5.8±0.2	71.1±0.2	65±0.1	45±0.1
Zn, mg/100 g	2.72±0.5	2.78±0.1	2.76±0.1	2.71±0.1

Continuation of Table 4

1	2	3	4	5
I, mg/100 g	0.0670±0.002	0.067±0.005	0.055±0.1	0
Vitamin B ₁ (thiamine), mg	0.49	0.47	0.49	0.49
Vitamin B ₂	0.11	0.09	0.11	0.11
Vitamin B ₆	0.49	0.46	0.49	0.49
Vitamin B ₉	437	389	392	258
Vitamin PP	0	0	0	0

6. Discussion of results of studying the technological properties of flour made from the Miras 07 chickpea variety

The above study of the chemical composition of the Miras 07 chickpea variety (Table 1) shows that it is characterized by a high protein content – 24.6 %, fat – 5.4, which indicates that the raw material is high in protein. Most of the carbohydrates of the examined sample are represented by starch – 46 %.

As evidenced by the data given in Tables 2, 3, the ultra-high-frequency chickpea processing over 180 seconds leads to that the moisture content is reduced by 4 times compared to control. With an increase in the time of ultra-high-frequency treatment to 300 seconds, the moisture content index decreased by 4.8 times, while there is a sharp drying of chickpeas, which could make it difficult to process them further.

As a result of ultra-high-frequency processing, the volume of chickpea grain increases in volume in direct proportion to the power of the ultra-high-frequency field. As a result of our research, the most rational time of ultra-high-frequency treatment (180 seconds) was established. In addition, when irradiated in an ultra-high-frequency field, contamination with microorganisms decreases and, consequently, increases the shelf life of chickpeas, by reducing the moisture content index.

Based on our organoleptic analysis (Table 3), it was determined that ultra-high-frequency processing has a positive effect on the main indicators of taste and aromatic properties of the product.

The results of our studies into the content of the fractional composition of chickpea proteins in the Miras 07 variety (Fig. 1) were compared with those treated samples, compared with the control unprocessed chickpeas. The amino acid content includes globulin – 79.8 %, albumin – 12.2 %, glutelin – 7.9 %. Under the influence of ultra-high-frequency processing, denaturation of proteins occurs, as a result of which the spatial arrangement and shape of polypeptide chains are lost. The native conformation of the protein molecule is disturbed but the primary level of the spatial structure of the protein and its chemical composition remains unchanged.

The results of the samples' acquired IR spectra (Fig. 2) showed that during the ultra-high-frequency treatment of chickpeas, a slight change in protein amine groups occurs. Based on the IR spectrum, changes in absorption bands are observed in the range of 500–1,000 cm⁻¹ for the C-H valent bonds in the strong region.

With ultra-high-frequency processing, only the initial properties of protein substances change, the reactivity of some chemical groups that make up the molecule increases, solubility and hydrophilicity decrease [19, 22].

Our data (Fig. 3) indicate that with different durations of ultra-high-frequency treatment, an increase in the water absorption capacity of chickpea flour is observed. For comparison, processing over 60 seconds helps increase the water absorption capacity of flour by 1.2 times, over 180-second processing of chickpea flour – by 1.4 times, and, over 300 seconds, by 1.5 times, respectively. The high water-absorbing capacity of chickpea flour is determined by the presence of high-molecular compounds (proteins, polysaccharides) in the chickpea grain, which, in the process of swelling, are able to bind and retain moisture.

The analysis of the amino acid composition of chickpea proteins in the samples processed (Fig. 5) for 60 to 180 seconds showed that chickpea flour from the Miras variety contains a full set of amino acids: arginine (2.23 %), serine (1.26 %), histidine (1.33 %), phenylalanine (1.45 %). Other types of amino acids range from 0.41 % to 0.58 %. With an increase in the ultra-high-frequency processing time to 300 seconds, the amino acid content gradually decreases. Thus, the amount of arginine was 1.52 %, methionine, tyrosine, threonine – from 0.04 to 0.93 %, and the content of serine, proline was from 0.44 to 0.93 % above average.

The obtained data indicate that the amino acid composition of chickpea flour is reduced. With prolonged processing of raw materials (300 seconds), the nutritional value of chickpea flour decreases due to the loss of part of amino acids, which leads to the destruction of proteins.

The results of our studies of vitamin and mineral composition indicate that the content of B vitamins is in the range from 0.05 mg to 0.236 mg. The content of elements such as Fe, Ca, Zn, and I in the treated samples is not significantly reduced compared to the mineral content in the treated samples.

In terms of QMAFAnM in the processed chickpea flour, the content of microorganisms is minimal, 10×1² CFU/g; when processing over 60 seconds, the largest growth is 10×5³ CFU/g. The largest increase is seen on a raw sample of chickpea flour where the growth of microbes occupies an average position – 10×1³ CFU/g.

The maximum level of yeast at 1.0*10² CFU/g and molds at 3.0*10³ CFU/g, characterizing the shelf life of chickpea flour, was found in an untreated sample. However, these samples also meet the requirements from regulatory documentation, which makes it possible to guarantee a high level of quality and safety of the raw materials for the further production of gluten-free confectionery.

Thus, as our study showed, the ultra-high-frequency processing of Miras 07 chickpea variety has made it possible to significantly reduce the processing time of cereals, to 180 seconds. That occurs as a result of volumetric heating in a microwave field, which does not affect the protein-amino acid composition, water absorption capacity, and organoleptic indicators of flour quality.

The prospect of further research is the development of technology of gluten-free flour confectionery products from processed chickpea grain of the Miras 07 variety, studying the nutritional biological value of the developed products, establishing the shelf life of gluten-free products.

7. Conclusions

1. Our studies have confirmed effectiveness of the ultra-high-frequency chickpea processing for 180 seconds, at which biochemical processes in the treated product are intensified due to the resonant absorption of energy by protein molecules and polysaccharides. At the ultra-high-frequency processing of chickpeas for 180 seconds, up to 20 % of the starch contained in the grain passes into dextrin, which is easily absorbed by humans while the toxic substances are destroyed. There is a slight denaturation of the protein.

2. The change in the protein fraction of chickpeas at the ultra-high-frequency treatment has been determined. With the ultra-high-frequency processing of chickpea flour for 180 seconds, the protein fraction content remains unchanged at 79.8 %. The results based on the acquired IR spectrum data indicate that ultra-high-frequency treatment did not affect the protein-amino acid composition of the examined Miras 07 chickpea variety.

3. Our data on the water absorption capacity of chickpea flour at a 180-second treatment indicate its increase by 1.4 times compared to control. Based on the results of the analysis of the amino acid composition of chickpea proteins in the processed samples during treatment for 180 seconds, a complex of essential amino acids in the range from 1.3 to 2.5 % was revealed. Based on our chemical analysis, it was found that during ultra-high-frequency processing for 180 seconds, the vitamin and mineral complex is completely preserved compared to non-treated chickpeas. Under the influence of ultra-high-frequency processing, there is a decrease in the microbiological contamination of raw materials while the organoleptic indicators improve. According to the microbiological indicators of chickpea flour, the content of microorganisms was 1×10^3 CFU/g, which meets the requirements for sanitary and hygienic safety.

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