The object of research reported in this paper is grain and leguminous crops of Republic of Kazakhstan.

Grains and leguminous crops, as well as products that are made from them, are of great importance in human nutrition because they are sources of protein, fat, carbohydrates, some vitamins, and macro and microelements. They contain plant fibers, as well as a number of biologically active substances necessary for the normal functioning of the entire human body. At the same time, modern technologies for processing and manufacturing products from cereals are associated with significant losses of nutrients embedded in them by nature when producing refined products. The problem that needs to be solved is to study the impact exerted on grain crops by various processing techniques and to propose the most optimal ones that make it possible to maximally preserve the nutrients of grain raw materials laid down by nature.

A comparative study of the following grain processing techniques was carried out: micronization, extrusion, germination, and fine grinding. Processing modes have been proposed, which could significantly reduce the loss of useful substances of the grain.

The chemical and vitamin composition of processed products has been studied. It was established that fine grinding and extrusion processing are the most acceptable because they allowed the use of grain without separating the shells containing the main nutrients of the grain.

The suggested processing modes contribute to the production of grain bases and additives with the most optimal vitamin-mineral formulation.

This study's results contributed to a better understanding of the impact of the examined techniques for processing grains and legumes on the vitamin-mineral complex of the resulting products. Grain processing modes can be recommended for practical application

Keywords: grain crops, fine grinding, extrusion, micronization, germination, vitamin composition, mineral complex

UDC 664.788
DOI: 10.15587/1729-4061.2022.261747

DEVELOPMENT OF TECHNOLOGIES FOR OBTAINING GRAIN BASES AND SPECIAL ADDITIVES FROM LOCAL GRAIN RAW MATERIALS TO MAKE PRODUCTS OF INCREASED NUTRITIONAL VALUE

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Received date 30.05.2022
Accepted date 29.07.2022
Published date 30.08.2022

***How to Cite**: Chakanova, Z., Shaimerdenova, D., Bekbolatova, M., Sarbasova, G., Iskakova, D., Yesmambetov, A. (2022). Development of technologies for obtaining grain bases and special additives from local grain raw materials for the production of products of increased nutritional value. Eastern-European Journal of Enterprise Technologies, 4 (11 (118)), 23–34. doi: https://doi.org/10.15587/1729-4061.2022.261747*

1. Introduction

Improving human health through nutrition has been and remains a difficult area of research, because the food of modern man, for the most part, does not meet the biological requirements of his body. The disadvantages of nutrition include the consumption, in large quantities exceeding the necessary norms, of meat, fats, sugar, salt, irritating seasonings, alcoholic beverages, etc. [1]. This is added to by the influence of most of the treatments used in the production of food, which deprives them of vitamins and other biologically valuable substances laid down by nature in the raw materials.

The analysis shows that the promising and most common group of products for full human nutrition are cereal products. Cereal bases and additives from cereals can be considered as sources of carbohydrates, proteins, minerals, vitamins, and other physiologically active compounds [2].

Preservation of the original properties with further improvement of the quality of food products during processing is an important area of research in the food industry.

All grain raw materials go through different types and levels of processing to become edible and tasty. Pre-treatment of grain is necessary to prepare it for further processing. The grain undergoes operations such as cleaning, grinding, steaming, germination, etc., which change the nutritional qualities of the grain depending on the type and depth of processing. Since the components in the grain are unevenly distributed, processing can greatly affect the composition of the resulting products.

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Therefore, the study of the effect of various types of processing on the chemical and mineral composition of the resulting grain products is of interest and is relevant. This information will help to understand the relative nutritional value of processed food grains.

2. Literature review and problem statement

Paper [3] notes that cereals are grown in large quantities and provide more food energy around the world than any other types of crops, as a result of which they are called food crops. As the main sources of energy, they also supply the body with various nutrients and components such as phytochemicals.

At the same time, phytochemicals, according to scientists [4], are represented by phenols, phytoestrogens, and fermentable carbohydrates. Carbohydrates (dietary fiber and resistant starch or oligosaccharides) help lower cholesterol, protect against cardiovascular disease, and reduce the risk of cancer.

According to [5], cereals representing bread crops are mainly characterized by a high carbohydrate content, classified as bioavailable and non-bioavailable (or fiber) for human nutrition, and leguminous crops are high in protein. Minerals in cereals are secondary (1–3 %). However, a high vitamin B content is essential for nutrition [6]. The cited paper does not propose a way to best preserve the nutrients of the grain. The solution to the problem is proposed to begin with a detailed study of existing grain processing technologies.

Depending on the structure of each grain and the amount of its chemical constituents, there are significant differences between cereals and even between species and varieties in each grain, which must be taken into consideration when choosing a processing technique.

It is also believed [7] that all over the world, cereals are a staple food and good sources of vitamins A, B, and E. However, according to the authors, the vitamin content can be reduced after grinding and cooking. Although several papers have documented that wheat sprouts are rich in vitamins B_2 and B_9, to find out, the authors believe, more detailed studies are needed that would suggest a processing technique that allows maximum preservation of the vitamin complex of grains.

According to [8], the proportion of nutrients varies between different crops and depends on the methods of processing and cooking. Compared to endosperm, the seed shell contains more nutrients, and, therefore, using grain grinding to produce refined flour reduces the nutrient content. According to the authors, cereals and legumes undergo various types of primary processing so that they can be further used for food production or cooking. The authors believe that processing changes the quality of the grain. As long as whole grains are used, all nutrients and phytochemicals are retained but removing any part of the grain leads to a decrease in nutrients, which requires additional studying [8]. Determining the optimal modes of grain processing remains a task, the solution of which in each case requires a special approach. First of all, it is necessary to determine the purpose of the processing.

According to [9], 70–80 % of the original vitamins are lost during grain grinding. The larger the portion of grain removed, the greater the loss of nutrients. When wheat is ground into wheat flour, there is a loss of approximately 70 % of vitamins and minerals (range 25–90 %) and fiber, a loss of protein of 25 %, a loss of manganese of 90 %, a loss of zinc and linoleic acid of 85 % and an 80 % loss of magnesium, potassium, copper, and vitamin B_6. Therefore, the suggestions of grinding techniques that preserve the nutrients of the grain as much as possible are in demand. In the data presented, the loss of the vitamin complex is associated with the grinding technology, the principle of which is to separate the grinding products into fractions. The use of large fractions containing shell parts with the highest content of vitamins for food purposes is not proposed. The solution to the problem can be offered by special mills, the principle of operation of which makes it possible to get fine flour from whole grains.

The authors of [10] consider the principles of new technologies for processing legumes to improve quality, functionality, and safety. Among the various new technologies, radio frequency, microwave, irradiation, and high-pressure treatment have found potential applications for processing and adding value. Although new technologies are promising, the authors believe that the cost of equipment remains a bottleneck for their application in the food industry. Therefore, the solution to the problem may be in the plane of reducing the cost of processing.

Thus, the study of the influence of various techniques for processing grain raw materials and the establishment of the most optimal ones, making it possible to preserve the vitamin-mineral complex in the products obtained, is in demand [11]. The results reported in previous studies show a wide variation in the final data on the content of nutrients remaining in processed products. The problem is the lack of one grain-processing technology, as a result of which the final product would be characterized by both high organoleptic properties and a chemical composition corresponding to the raw materials used.

The analysis showed that various processing technologies are designed to release and increase the availability of nutrient and phytochemical components in cereals. Among these, the most common method is mechanical treatment, resulting in a reduction in particle size, the destruction of cereal matrices, or the degradation of fibrous polymers.

At the same time, finely ground grain products can be used as special additives due to the high concentration of biologically active substances in the mass less than the mass of the raw materials by 6–8 times [12].

In other words, our review of food crop processing technologies showed that there are various processing techniques that allow for fuller use of grain resources. At the same time, there is not enough information on the optimal processing method that makes it possible to preserve the greatest amount of useful substances laid down by nature in the grain.

3. The aim and objectives of the study

The purpose of this study is to determine the most promising ways of processing grain raw materials for maximum preservation of nutrients.

To accomplish the aim, the following tasks have been set:
– to select crops for research;

– to establish the modes of processing of the selected grain raw materials: grinding, micronization, extrusion, germination;

– to conduct a comparative analysis of the chemical and vitamin composition of processed grain products and determine the optimal techniques for processing the selected grain raw materials.

4. The study materials and methods

4. 1. Selection of cereals for research

The choice of grain and leguminous crops was carried out on the basis of data on the chemical composition of grain, which was determined by the methods described in the following regulatory and methodological documents:

– GOST 12038-84 «Seeds of agricultural crops. Methods for determining germination» – analogous to FAO. SEEDS TOOLKIT. Module 3: Seed quality assurance. ISBN 978-92-5-130951-3 (FAO). Available at: https://www.fao.org/3/ca1492en/ca1492en.pdf.

– GOST 29033-91 «Grain and products of its processing. Fat Determination Method» – analogous to AOAC Official Method 939.05 Fat Acidity-Grains Titrimetric Method.

– GOST 10846-91 «Grain and products of its processing. Protein determination method» – analogous to ISO 1871. Agricultural food products. Determining nitrogen content by the Kjeldahl method. General guidelines.

– GOST 31675-2012 «Feed. Methods for determining the content of crude fiber using intermediate filtration» – analogous to ISO 6865:2000. Animal feeding stuffs — Determining crude fiber content — Method with intermediate filtration.

– ST RK 1564-2006 «Determination of the main indicators of grain quality using infrared analyzers» – analogous to: Method of near-infrared spectroscopy for protein determining. Method 39-10, approved by the American Association of Cereal Chemists (AACC). Scope — wheat of all classes; Methodology for the analysis of grain and grain products by the method of reflection spectroscopy in the near-infrared region (NIR). ICC Recommendation No. 202 (International Association for Cereal Science and Technology – International Society for Cereal Chemistry); Official method FOSFA (Federation of Oils, Seed and Fast Association – Federation of Producers of Oils, Seeds and Fats). The field of application is simultaneous determining the content of fat, moisture, and volatile substances, protein in soybeans.

4. 2. Selection of grinding modes

The choice of grinding modes was carried out according to the analysis of the yield of grinding grain and leguminous crops at the mills MLU-202 Buhler, Quadrumat-Junior Brabender, and CM (centrifugal mill). The yield of grinding was determined by the method described in [13].

Determining the particle size of the obtained ground products was carried out on the scanning electron microscope Quanta 3D 200i from images of surface morphology, and the elemental composition – on this microscope by energy dispersion spectroscopy [14].

4. 3. Selection of modes of micronization of grain crops

The choice of micronization modes was carried out according to the indicator of water absorption capacity of grain crops in accordance with [14].

Micronization was carried out in a microwave oven. The processing involved increasing the power from 500 watts to 800 watts depending on the humidity and exposure of the treatment in time from 3 to 7 minutes, according to the plan of the full-factor experiment, and the processing conditions (Table 1).

Table 1

Plan of full-factor experiment and processing conditions for the micronization of grain and leguminous crops

Experimental batch No.	Moisture content, %	Processing parameters for grain crops		Processing parameters for legumes	
		Processing power, W	Exposure time, min	Processing power, W	Exposure time, min
1	25	700	7	800	15
2	15	700	7	800	15
3	25	500	7	700	15
4	15	500	7	700	15
5	25	700	3	800	10
6	15	700	3	800	10
7	25	500	3	700	10
8	15	500	3	700	10

Based on the results of the full-factor experiment, the micronization modes of selected grain and leguminous crops were determined [15].

4. 4. The choice of modes of extrusion of grain crops

Extrusion of selected crops was carried out on a laboratory experimental twin-screw extruder of the brand "LS32-II - Double-screw testing extruder" (China). Samples with an average grinding size (sieves Ø1, Ø2 mm) were prepared for the studies. The samples were then moistened in the range of 14.0–16.0 % and fed into a stirring device to achieve uniformity and uniform humidification.

Determining the value of thermodynamic parameters for the study of the starch gelling process and determining the initial extrusion temperature during the preparation of extrusion samples were carried out on the differential scanning calorimeter DSC 1/200W from METTLER TOLEDO (Switzerland) according to the following procedure. The product batch was placed in a stainless-steel ditch and deionized water was added in a volume of up to a humidity of 70 %. The cuvette was sealed, balanced at room temperature, and then scanned from 0 to 200 °C at a speed of 100 °C/min. An empty ditch was used as a reference sample, the DSC was calibrated with indium. As a result, the initial gelling temperature (T_i), the maximum gelling temperature ($T_{\max}$), and the final gelling temperature (T_f), as well as the enthalpy of gelling (ΔHg), were determined.

4. 5. Choice of methods for germination of grain crops

The germination method complied with the requirements of GOST 12038-84 "Seeds of agricultural crops. Methods for determining germination" [16]. Further, the obtained sprouts of grain and leguminous crops were dried by the convection method using a thermal electric emitter at 400 °C for 20 hours.

4. 6. Determining the most optimal technique for processing cereals

We determined the optimal technique for processing grain crops according to the comparative characteristics of the chemical composition of finely dispersed, micronized, extruded, and sprouted grain products in line with GOST 29033-91 "Grain and products of its processing. Method for determining fat", GOST 10846-91 "Grain and products of its processing. Method for determining protein", GOST 31675-2012 "Feed. Methods for determining the content of crude fiber using intermediate filtration", ST RK 1564-2006 "Determining the main indicators of grain quality using infrared analyzers".

Mathematical processing of research results was carried out under the SPSS software program (IBM, USA) and the "Data Analysis" package in MS Excel.

5. Results of studying the optimal techniques for processing grain and leguminous crops

5. 1. Selection of cereals for research

From the main areas of growth of grain and leguminous crops of Republic of Kazakhstan, the following species and varieties were selected:

– barley, varieties "Sabir" (Akmola region), "Arpa elita" (Almaty region), "Ilek 9" and "Ilek 36" (Aktobe region);

– millet, varieties "Kormovoye 89" (LLP NPCHK named after A. I. Baraev), "Yantarnoye" (Almaty region), "Pamyat Bersiev" and "Yarkoe 6" (Aktobe region);

– buckwheat, varieties "Saulyk" (Almaty region), "Batyr" (Akmola region);

– peas, varieties "Oris" (Akmola region) and "Aksary" (Almaty region);

– lentils, varieties "Stepnaya" (Almaty region), "Krapinka" (Akmola region), "L-4 400" (Kostanay region);

– beans, variety "Georgian" (Almaty region);

– chickpeas, variety "Yersultan" (Almaty region);

– corn, variety "Dobrynya" (Almaty region).

For the selected varieties, an analysis of the chemical composition was carried out.

The results of our analyses made it possible to select from the analyzed cereals and leguminous crops using the SPSS software program the most preferred for use in the production of special additives and grain bases (Fig. 1, 2).

The highest protein content was observed in the buckwheat of the variety "Saulyk" Almaty region – 12.5 %. In terms of fat content among all grain crops, it was observed in the millet of the "Memory of Bersiev" variety (Aktobe region) – 3.8 %. The highest starch content of all grain crops was found in the corn of the "Dobrynya" variety (Almaty region) – 64.4 %.

The analysis showed that kazakhstani varieties of leguminous crops have a high content of mass fraction of protein. The maximum protein content was observed in the lentils of the varieties "Krapinka" (Akmola region) – 27.9 %, "Almaty" and "L-4 400" (Kostanay region) – 27.8 %. The minimum protein content was observed in the peas of the "Oric" variety with a value of 23.2 %. In terms of fat content, among all leguminous crops, the chickpeas of the "Yersultan" variety stood out significantly – 5.8 %, which is almost 2 times higher than that of other crops.

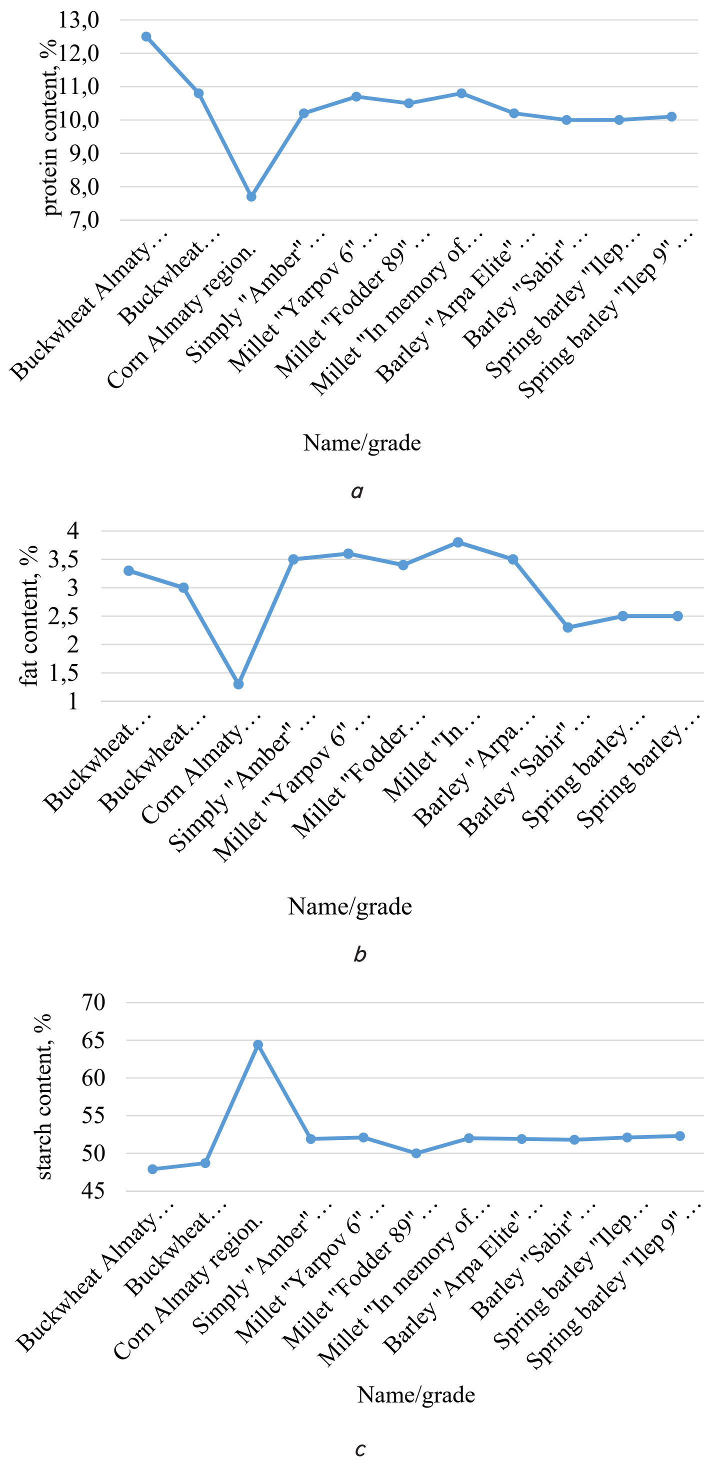
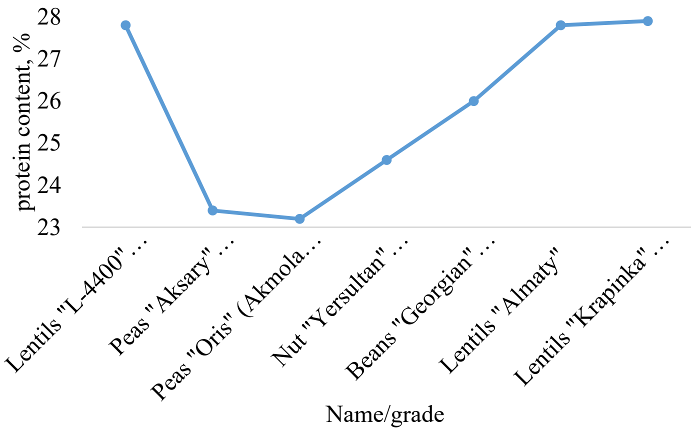
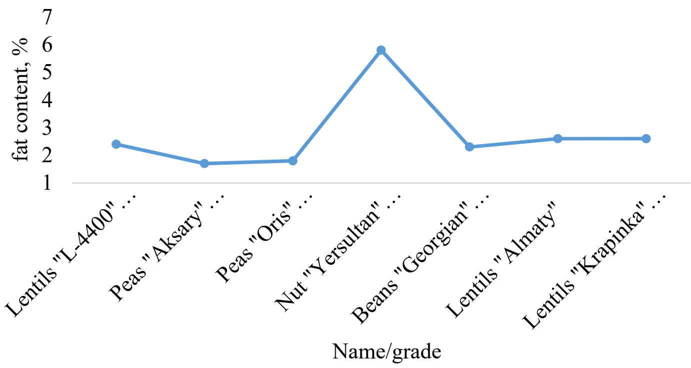


Fig. 1. The results of statistical processing under the SPSS software program for the selection of cereals: *a* — protein content in cereals; *b* — fat content in cereals; *c* — starch content in cereals



a



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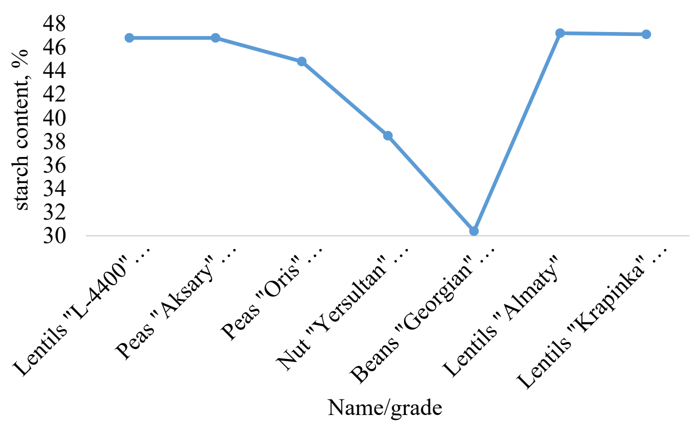


c

Fig. 2. The results of statistical processing under the SPSS software program for the selection of leguminous crops: *a* – protein content in leguminous crops; *b* – fat content in leguminous crops; *c* – starch content in leguminous crops

5. 2. Defining processing modes for the selected grain raw materials: grinding, micronization, extrusion, germination

5. 2. 1. Defining grain grinding regimes

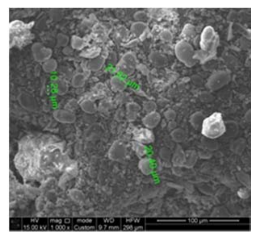
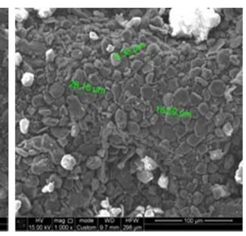
The selected samples of grain and leguminous crops were crushed at the milling plants MLU-202 Buhler, Quadrumat-Junior Brabender, and CM (centrifugal mill). The calculation of the yield of grinds showed that the greatest yield was obtained at the mill CM (Table 2).

Table 2

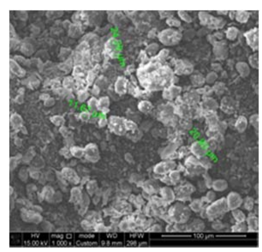
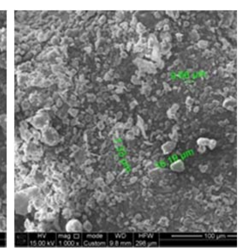
Comparative analysis of the yield of grinding of cereals and legumes on three types of mills

Crop	Yield, %		
	MLU-202 Buhler	Quadrumat-Junior Brabender	CM
Buckwheat	67	70	99
Millet	65	71	98
Lentils	68	69	99
Chickpeas	63	70	98

The greatest yield of flour was obtained at the centrifugal mill. To establish the grinding size, the grinding products of the centrifugal mill were sent to the Quanta 3D 200i scanning electron microscope and it was determined from the images of the surface morphology that the size was from 200 nanometers to 40 micrometers (Fig. 3).

a *b*

c *d*

Fig. 3. Images of fine powder from: *a* – chickpeas; *b* – lentils; *c* – buckwheat; *d* – millet

Using energy dispersion spectroscopy, the elemental composition of the obtained finely dispersed powders was determined by X-ray microanalysis in a scanning electron microscope (Fig. 4, Table 3).

The results of our studies of the elemental composition show that among all crops, buckwheat stands out favorably, in which the presence of chemical elements Mg, P, S, K, Ca, Na, Si was noted.

Table 3

Elemental composition of finely dispersed powders of chickpeas, millet, lentils, buckwheat

Crop	Chemical element, at %								
	C	O	Mg	P	S	K	Ca	Na	Si
1. Chickpeas	66.30	33.03	0.06	0.10	0.01	0.44	0.06	–	–
2. Millet	63.76	35.79	0.10	0.12	–	0.18	0.05	–	–
3. Buckwheat	66.31	33.16	0.10	0.07	0.03	0.15	0.03	0.06	0.09
4. Lentils	65.85	33.63	0.12	0.09	0.04	0.22	0.03	–	0.02

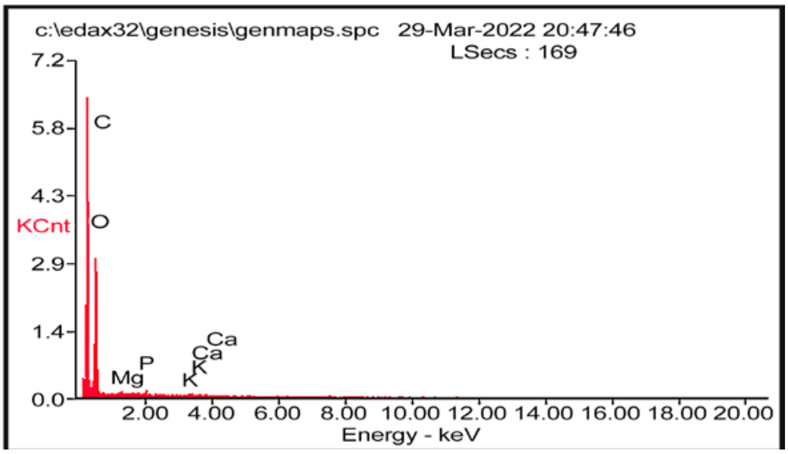


Fig. 4. Elemental composition of finely dispersed chickpea powder

5. 2. 2. Defining micronization regimes for grain crops

As a result of our experiments, according to the plan of the full-factor experiment, micronized samples of buckwheat, millet, lentils, and chickpeas were obtained, the total number of which was 32. For further studies, these samples were crushed to medium grinding (sieves No. Ø1, Ø2 mm). A comparative analysis of the water absorption capacity of experimental batches (Fig. 5) made it possible to identify the most optimal micronization modes.

Table 4

Optimal micronization modes

Operation	Buckwheat	Millet	Chickpeas	Lentils
Humidification, %	15	25	25	25
Softening, min	60	30	30	30
Material heating temperature, °C	120–140	100–105	120–130	120–130
Processing time, min	7	3	15	15
Radiation power, watt	700	700	800	700
Cooling $w_{product}$ %	13	10	13	13

The greatest water absorption capacity, in comparison with the control sample, for which the finely dispersed raw materials of each culture is taken, was demonstrated by the buckwheat of experimental batch No. 2 (swelling number – 3.4). This is followed by the millet of experimental batch No. 5 (swelling number – 2.0), the lentils of experimental batch No. 3 (swelling number – 2.3), and the chickpeas of experimental batch No. 1 (swelling number – 2.2). Based on the results of our research, the most optimal micronization modes were determined (Table 4).

The resulting optimal micronization modes make it possible to obtain grain bases with the highest quality indicators for use in food.

5. 2. 3. Selection of grain extrusion modes

In order to determine the optimal modes of extrusion, thermodynamic melting parameters of selected samples of grain crops were determined (Table 5), reflecting the behavior of starch that makes up the grain during heating, obtained by differential scanning calorimetry.

Table 5

Thermodynamic parameters of grain melting

Crop	T_i, °C	T_{max}, °C	T_f, °C	T_f–T_i (°C)	ΔH (J/g)
Millet	107.99	114.14	116.15	8.16	–58.32
Buckwheat	131.24	147.71	158.00	26.79	–50.16
Lentils	110.32	115.23	118.12	7.8	–56.41
Chickpeas	109.55	123.97	136.53	26.98	–50.01

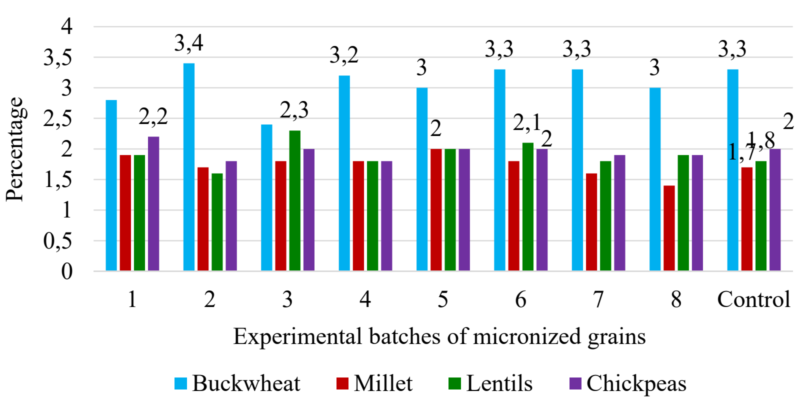


Fig. 5. Indicators of water absorption capacity of experimental batches of micronized grains of grains and leguminous crops

At the same time, the authors of [17] warn that high temperature and pressure can lead to the degradation of polysaccharides with the release of oligosaccharides and an increase in soluble dietary fiber, which is undesirable for food.

According to the results of our studies, the melting point of starch varied within different limits: T_i – from 107.99 °C to 131.24 °C; T_{max} – from 114.14 °C to 147.71 °C; T_f – from 116.15 °C to 158.0 °C, depending on the type of grain raw materials (Table 6). This is due to the fact that starch of different origins has a different structure and, accordingly, behaves differently in the processes of heating and cooling [18–21].

Based on the data, the optimal modes for processing grain crops have been determined, including the parameters of softening, grinding, extrusion of grain crops, and drying of extrudate (Table 6).

Table 6

Optimal extrusion modes

Operation	Lentils	Chickpeas	Buckwheat	Millet
Starting moisture content, %	8 %	10 %	16 %	12 %
Softening, min	exposure – 20	exposure – 20	exposure – 20	exposure – 15
Grinding	Sieve pass – Ø3	Sieve pass – No. 1, No. 2	Sieve pass – No. 1, No. 2	Sieve pass – No. 1, No. 2
Humidity of crushed grain	11 %	12 %	15–16 %	14 %
Softening of crushed grain, min	exposure – 15–20 min	exposure – 15–20 min	exposure – 15–20 min	exposure – 15 min
Extrusion of crushed grain	material heating temperature – 110–130 °C	material heating temperature – 70–80 °C	material heating temperature – 150–160 °C	material heating temperature – 110–130 °C
	auger rotation speed – 300–350 rpm	auger rotation speed – 250–300 rpm	auger rotation speed – 250–300 rpm	auger rotation speed – 250–300 rpm
Short-term drying of the extrudate	drying agent temperature – 50–60 °C	drying agent temperature – 50–60 °C	drying agent temperature – 50–60 °C	drying agent temperature – 50–60 °C
	10 %	10 %	10–12 %	10 %

Thus, based on our studies of thermodynamic melting parameters, the optimal temperature boundaries of grain extrusion of the examined samples have been determined [15].

5. 2. 4. Choosing methods for grain crop germination

Germination modes were established according to the time of obtaining germinal roots no more than 5 mm long in 85–90 % of the grains, which made it possible to determine optimal germination modes (Table 7).

Table 7

Optimal modes of grain crop germination

Crop	Soaking time in water, hour	Germination temperature	Germination period, day	Maximum germination length, mm
Buckwheat	8	20	3	3–4
Millet	10	20	4	4–5
Chickpeas	10	20	3	4–5
Lentils	8	20	4	3–4

Germination modes were established according to the time of obtaining germinal roots no more than 5 mm long in 85–90 % of the grains, which made it possible to determine optimal germination modes (Table 8).

Table 8

Optimal modes of grain crop germination

Crop	Soaking time in water, hour	Germination temperature	Germination period, day	Maximum germination length, mm
Buckwheat	8	20	3	3–4
Millet	10	20	4	4–5
Chickpea	10	20	3	4–5
Lentils	8	20	4	3–4

On average, the soaking time was determined at 8–10 hours, germination was 3–4 days. These optimal modes allowed 90 % of the grains to germinate.

5. 3. Comparative analysis of grain products and determining optimal processing techniques

The resulting experimental samples of finely dispersed, micronized, extruded and sprouted grain products were analyzed for chemical composition to determine the processing technique that makes it possible to maintain the chemical composition of the grain at an optimal level.

Determining the chemical composition of all obtained experimental samples:

1) crushed to fine grinding – control;

2) extruded;

3) micronized;

4) sprouted.

That has made it possible to establish the following (Fig. 6–10).

The greatest losses of chemical composition were noted in buckwheat in terms of protein content during germination – from 12.5 % in finely dispersed by 98.0 %, to 0.3 %. The fat content decreased during extrusion from 2.37 % in fine grain to 74.0 % and amounted to 0.61 %. The largest reduction in fiber content was from 4.51 % in a control (finely dispersed) sample to 0.16 % during germination, which is a loss of 96.0 %.

Losses of millet protein were practically not detected during extrusion, insignificant during germination (2.4 %), and more significant during micronization (16.0 %). More significant was the loss of the amount of fat 51.25 % during germination and 80.0 % during extruding. At the same time, the loss of fiber was insignificant.

In all operations with chickpeas, an increase in protein content was detected, which requires, in our opinion, more thorough research. When sprouting chickpeas, there was also a 5 % increase in the amount of fiber compared to the control and a decrease in micronization and extrusion by 5.5 and 53.4 %, respectively. The amount of fat in all operations decreased from 35.5 % with micronization to 55.2 % with extrusion.

All types of lentil processing also showed an increase in protein content compared to fine grinding, which demonstrates that the behavior of the protein complex of leguminous crops during treatments requires careful study. There was also an increase in the fiber content during germination and micronization by 31.2 and 4.6 %, respectively. And only during extrusion, losses were found at the level of 15.6 % compared to the control. The fat content has also not undergone significant changes, which also requires study.

The results of determining the vitamin composition of processed buckwheat products are shown in Fig. 10.

In processed buckwheat products, 8 types of vitamins were found only in extruded samples, whereas in micronized 6 species, 5 types of vitamins were found in sprouted ones. The results of determining the vitamin composition of processed millet products are shown in Fig. 11.

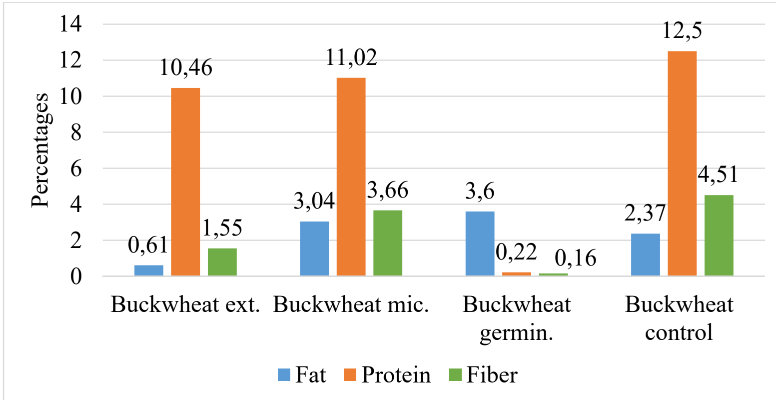


Fig. 6. Chemical composition of processed buckwheat products

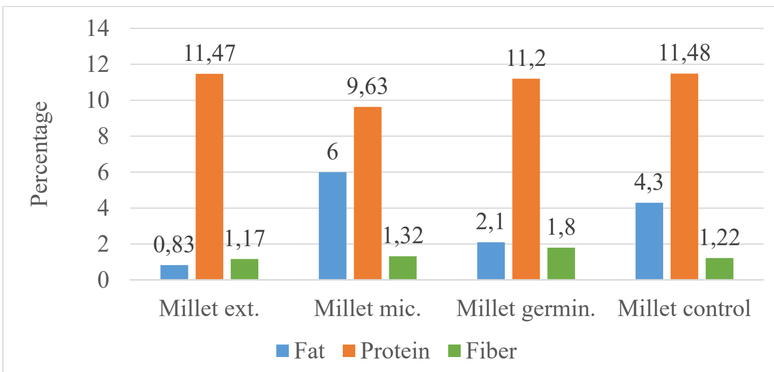


Fig. 7. Chemical composition of processed millet products

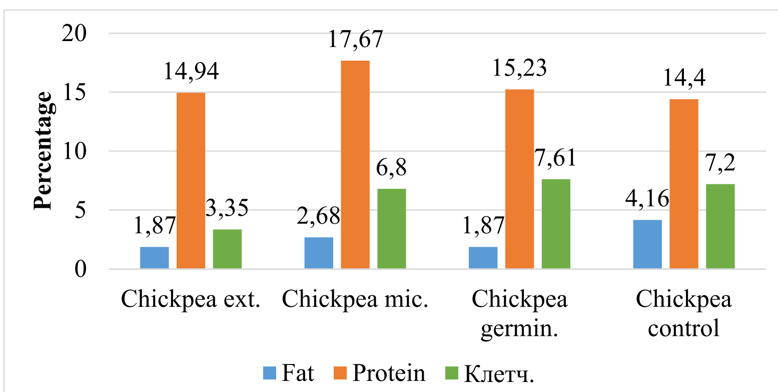


Fig. 8. Chemical composition of processed chickpea products

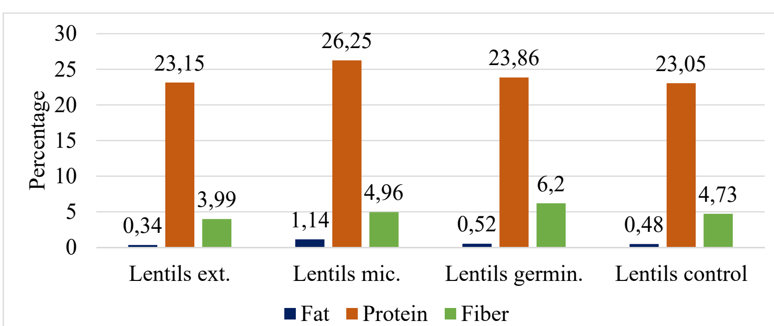


Fig. 9. Chemical composition of processed lentil products

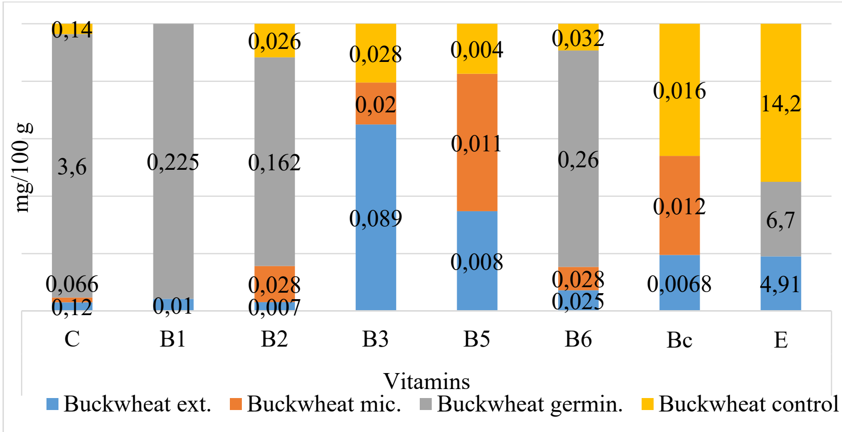


Fig. 10. Vitamin composition of processed buckwheat products

The vitamin composition of processed millet products is characterized by the fact that 6 types of vitamins out of 8 analyzed were not found in the sprouted grain, 2 types in the micronized grain, and 1 type of vitamin in the extruded grain. The results of determining the vitamin composition of processed chickpea products are shown in Fig. 12.

Of the eight types of vitamins analyzed in processed chickpea products, all the vitamins remained in the sprouted and extruded grain, and 1 type of vitamin was missing in the micronized one.

The results of determining the vitamin composition of processed lentil products are shown in Fig. 13.

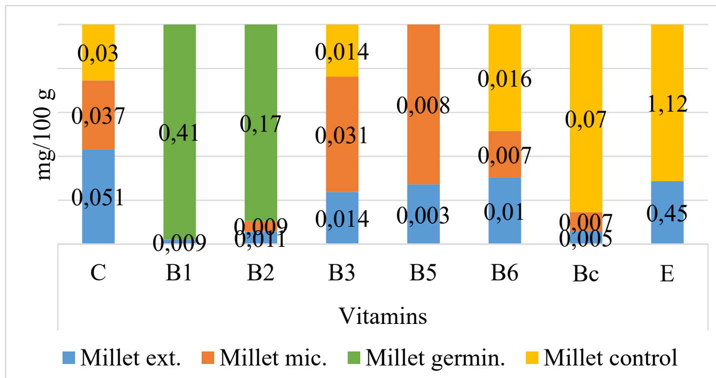


Fig. 11. Vitamin composition of processed millet products

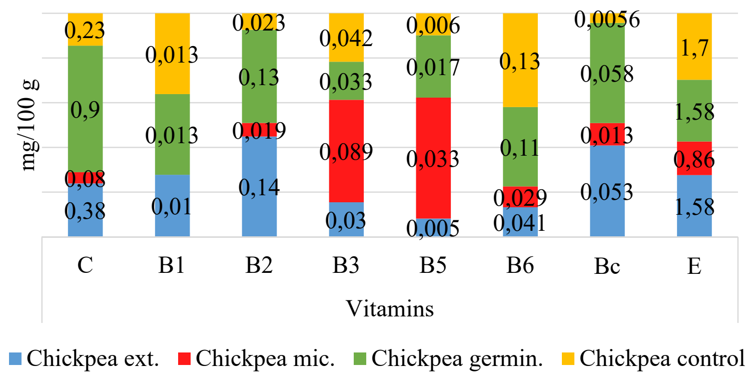


Fig. 12. Vitamin composition of processed chickpea products

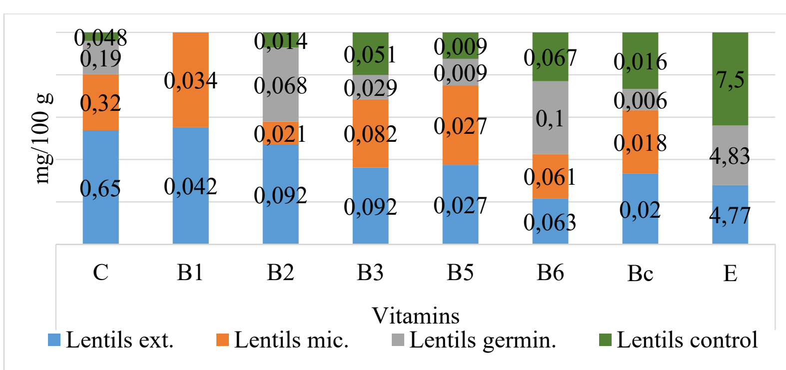


Fig. 13. Vitamin composition of processed lentil products

In processed lentil products, 8 vitamins were found only in extruded samples, whereas in micronized and sprouted ones, 7 types of vitamins are found.

6. Discussion of results of research to determine the optimal technique for processing crops

The sufficiency of mineral micronutrients – a prerequisite for human well-being – can be ensured through a variety of diets or the consumption of mineral-rich foods [16]. According to the authors, in the human diet, mineral trace elements mainly come from plant sources, in particular, from the main grain. Analysis of all samples of fine powders revealed that all the products obtained had in their composition such valuable and necessary elements for human nutrition as K, Ca, Mg, R. Buckwheat and lentils also had a popular element Si.

The data show that the resulting fine powders can be recommended as special additives and grain bases for use in high-nutritional products.

In all extruded products (Fig. 6–9), there is a significant decrease in fat. According to the authors of [22], this is due to the influence of extrusion, which significantly reduces the content of fatty acids (palmitic, oleic, linoleic, and linolenic acids) and α-, β- and γ-tocopherols compared to control. The authors associate a significant decrease in the content of fatty acids and tocopherols during extrusion with the formation of amylose-lipid complexes [16, 23, 24].

As for proteins, according to the authors of [25], extrusion can improve digestibility by denaturing proteins, and sometimes affecting the allergenic properties of food proteins.

The process of micronization, according to the authors of [26], usually leads to a change in the structure of the solubility of proteins due to denaturation. It was noted that an increase in grain moisture and micronization temperature gradually reduced the solubility of nitrogen in cereals and legumes [27–29]. The authors hypothesized that adopting suitable micronization conditions (humidity levels of 10–14 %, 115 °C for cereals, and 140 °C for legumes) could minimize protein denaturation.

In the studies, the micronization of buckwheat and millet showed a decrease in protein content, which is explained by its denaturation (Fig. 6, 7), but in chickpeas and lentils, micronization led to an increase in the protein content (Fig. 7, 8). According to [30], micronization shows an increase in seed volume (~13–30 %) of legumes due to rapid internal heating and increased water vapor pressure inside the material, which led to an increase in the protein content.

As for fiber, it has not undergone significant changes, which is consistent with the data in [31] reported by the researchers.

Thus, the greatest loss of protein and fat content is observed in the sprouted grain, which is explained by the breakdown of complex chemical compounds during germination to simple ones (Fig. 6–9) [32], then during extrusion, and then during micronization.

However, the analysis of the vitamin composition of the processed products obtained has revealed (Fig. 10–13) that extrusion is the most promising from the point of view of increasing and preserving all vitamins, along with the control one.

Thus, while in buckwheat during germination and micronization three types of vitamins from the analyzed 8 species were not detected, then only 2 types were not found during extrusion (Fig. 10).

According to researchers [3, 33, 34], in general, vitamins vary greatly in chemical structure and composition. Their stability during the thermal process, which include micronization and extrusion, is also variable. The degree of degradation depends on various parameters during food processing, for example, on humidity, temperature, exposure time. In addition, the content of vitamins, as a rule, is not related to their initial level in foods and depends on the type of grain.

For example, extrusion affects the stability of fat-soluble vitamins such as vitamin E. This vitamin is a natural antioxidant in cereal grains, and therefore the level of vitamin E has decreased (by 63 %) in extrusion-treated buckwheat products [33].

The proposed regimes of fine grinding, in comparison with traditional grinding, made it possible to ensure the preservation of almost the entire vitamin composition in the resulting grain bases. Conventional grain grinding results in large losses (in descending order) of thiamine (vitamin B_1), biotin (vitamin B_7), vitamin B_6, folic acid (vitamin B_9), riboflavin (vitamin B_2), niacin (vitamin B_3), and pantothenic acid (vitamin B_5); significant losses of calcium, iron, and magnesium also occur [8].

Similar results were reported in [34, 35].

Our results make it possible to apply the developed modes of fine grinding for practical application. However, the limitation is the need to use a special centrifugal mill, which is not yet widely represented in the industry. The devised modes of extrusion can be widely used without restrictions.

Research should continue toward developing technologies, methods, and equipment for grinding grain and leguminous crops, as a result of which it would be possible to obtain finely dispersed flour from whole grains with the most preserved vitamin-mineral complex of grain raw materials.

The list of cereals and legumes that should be extruded to establish treatment regimes should also be expanded.

7. Conclusions

1. Based on statistical processing, according to the analysis of the chemical composition, 2 types of cereals and 2 types of leguminous crops were selected for further work:

– buckwheat, variety "Saulyk" (region of growth – Almaty region). With qualitative characteristics: protein – 12.5 %; fat – 3.3 %; fiber – 9.1 %; starch – 47.9 %; ash content – 1.8 %;

– millet, variety "Memory of Bertev" (region of growth – Aktobe region). With qualitative characteristics: protein – 10.2 %; fat – 3.8 %; fiber – 9.3 %; starch – 52 %; ash content – 2.0 %;

– lentils, variety "Krapinka" (region of growth – Akmola region); With qualitative characteristics: protein – 27.9 %; fat – 2.6 %; fiber – 3.7 %; starch – 47.1 %; ash content – 2.7 %;

– chickpeas, variety "Yersultan" (region of growth – Almaty region). With qualitative characteristics: protein – 24.6 %; fat – 5.8 %; fiber – 5.0 %; starch – 38.5 %; ash content – 0.9 %.

2. The resulting optimal modes of grinding, micronization, and extrusion make it possible to obtain grain bases with the highest quality indicators for use in food. For example, the centrifugal mill has made it possible to obtain finely dispersed powders of grain and leguminous crops with a yield of 99 % and particle sizes from 200 nanometers to 40 micrometers.

According to the results of optimization of the process of micronization of grain and leguminous crops, the following moisture levels and time of softening were determined: for buckwheat – 15 % and 60 min, for millet, chickpeas, and lentils – 25 % humidity and 30 min. The heating temperature and processing time were determined for buckwheat – 120–140 °C and 7 min, for millet – 100–105 °C and 3 min, for chickpeas and lentils – 120–130 °C and 15 min. Radiation power, for buckwheat, millet, and lentils was 700 watts, for chickpeas – 800 watts.

During the extrusion of grain raw materials, the melting point of starch varied within: T_i – from 107.99 °C to 131.24 °C; T_{max} – from 114.14 °C to 147.71 °C; T_f – from 116.15 °C to 158.0 °C, depending on the type of grain raw materials. That has made it possible to establish optimal extrusion modes: the time of grain separation is 20 minutes, crushed grain – 15–20 minutes, the heating temperature – from 80 to 1600 °C.

3. The comparative analysis of the chemical and vitamin composition of processed grain products makes it possible to choose the optimal techniques for processing the selected grain raw materials.

When processing buckwheat, the optimal technique is fine grinding, which makes it possible to preserve the vitamin-mineral complex, and extrusion, accompanied by the least loss of protein and fat.

Millet is recommended to be treated by extrusion, which minimizes protein loss, and fine grinding, in which the vitamin-mineral complex is almost completely preserved.

It should be noted that in all operations with chickpeas, an increase in the protein content was noted, which probably requires more thorough research. The comparative analysis of the vitamin-mineral and chemical composition of chickpeas under different processing techniques makes it possible to establish the optimal method-extrusion.

All types of lentil processing also showed an increase in protein content compared to fine grinding, which demonstrates that the behavior of the protein complex of leguminous crops during treatments requires careful study. Of all the processing techniques studied, fine grinding should be taken as the most acceptable one for lentils.

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.

Acknowledgments

This study was carried out within the framework of the project “Development of technology for the production of food products of high nutritional value and long shelf life using nutrients and nano carboxylates (trace elements)” under the budget program 267 “Increasing the availability of knowledge and scientific research” by the Ministry of Agriculture of the Republic of Kazakhstan”.

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