Development of new resource-saving, environmentally friendly technological processes in flour grinding production

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Abstract. The gist of this article boils down to methods for processing secondary raw materials in flour milling. Methods for separating the wheat germ in both the grain cleaning and grinding departments have been studied. A method has been proposed for obtaining wheat germ using a beaker with subsequent pneumatic separation of passing products. To grind wheat germ to a finely dispersed composition with a solid particle size of less than 100 microns, a dry mechanical activation method using a disintegrator is provided. The chemical and amino acid composition of the resulting wheat germ flour was studied. The homogeneous fine composition of wheat germ flour made it possible to use it in the production of bakery products without deteriorating their quality. The developed technology for processing wheat germ is resource saving, environmentally friendly and allows you to preserve completely all biologically valuable substances present in the by-products of wheat processing.

1 Introduction

One of the important sectors of the agro-industrial complex is the flour and cereal industry. Food products produced from flour are of paramount importance for human life. Therefore, the daily provision of the population with grain processing products is considered important [1].

Raw materials for flour milling production in Russia are available in sufficient quantities. In the Russian Federation, the flour milling industry is represented by about 300 large and medium-sized enterprises, of which 85% of the volume of all products produced is distributed to the share of large enterprises. Approximately 1.5 thousand small mills with a daily productivity of 10-20 tons are used to produce flour. The flour mills of Moscow and St. Petersburg, which are the largest in the world, together can process about 10 thousand tons of grain per day. The largest grain processing enterprise in the Urals, OJSC Yekaterinburg Flour Mill, today processes 250 tons of grain daily. The plant uses modern technology with a fully automated production process control system, which allows it to produce high-quality flour of all grades.

In recent years, in the flour milling industry of different countries, there has been a prevailing tendency to produce different types of flour from a mixture of certain varieties

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with the addition of various ingredients according to consumer requests [2]. This direction has a dual significance: firstly, it allows for the economical use of grain, and secondly, it allows obtaining products enriched with essential components and balanced in chemical composition [3].

The primary products of flour milling production are wheat and rye flour. Intermediate products of grain grinding include grains of various sizes. Secondary products are flour, husks, germ, bran, feed grain products and bran [4]. Depending on the technological equipment used, as well as on the quality characteristics of the raw materials, the yield of different types of flour is determined. When grinding grain using modern equipment, it is possible to achieve a yield of premium wheat flour of 76%, bran - 21%, feed products - 2.4%, waste - 0.6%. With varietal grinding from 100 tons of grain, the yield of premium, first and second grade flour will be 79 tons and 20 tons of bran. When 96 tons of wallpaper flour are produced, the bran yield is 1 ton. Every year, about 5 million tons of waste and secondary raw materials are generated in the grain processing industry [5].

For the processing of secondary raw materials in flour milling, resource-saving and environmentally friendly processes are the production of wheat bran and germ flakes for preventive and therapeutic nutrition [6].

The composition of wheat bran includes dietary fiber - 42-44%, proteins - 15-16%, vitamins: PP, E, macro elements: potassium, calcium, magnesium, phosphorus, microelements: iron, manganese, selenium, zinc. Consumption of refined foods containing a minimum of dietary fiber leads to diseases of the digestive system of the human body. Therefore, the introduction of wheat bran and germ flakes into the diet as a source of dietary fiber is relevant [7].

2 Materials and Methods

The objects of research are wheat germ for the development of innovative technologies for new food products and complex food additives. To separate the embryo, a production scheme was used in the grain cleaning department. To grind the wheat germ, the dry mechanical activation method was used using a DESI-11 disintegrator.

The mass fraction of protein in wheat germ flour was determined taking into account the amount of total nitrogen determined by the Kjeldahl method, and subsequent recalculation using a coefficient of 6.25 according to GOST 10846-91 “Grain and products of its processing. Method for protein determination."

The mass fraction of fat in flour was determined using a Soxhlet apparatus. The essence of the method is to extract crude fat from the product with a solvent, then remove the solvent, dry and weigh the extracted fat.

Determination of the content of water-soluble pentosans in flour was carried out according to the method [8].

The mass fraction of fiber was determined according to GOST 31675-2012 “Feed. Methods for determining crude fiber content using intermediate filtration.”

The amino acid composition of wheat germ flour was determined by hydrolyzing the sample to amino acids and subsequent quantification of the resulting amino acids on an amino acid analyzer.

Organoleptic characteristics of bakery products were determined in accordance with GOST 5667-65 “Bread and bakery products. Acceptance rules, sampling methods, methods for determining organoleptic characteristics and weight of products.”

The moisture content of the crumb of the buns was determined according to GOST 21094-75 “Bread and bakery products. Method for determining humidity".

The acidity of the bread crumb was determined in accordance with GOST 5670-96 “Bread products. Methods for determining acidity".

The porosity of the crumb was determined according to GOST 5669-96 “Bakery products. Method for determining porosity."

The mass fraction of sugar in bakery products was determined by the hot titration method according to GOST 5672-68 “Bread and bakery products. Methods for determining the mass fraction of sugar."

The mass fraction of fat in bakery products was determined by the refractometric method according to GOST 5668-68 “Bread products. Methods for determining the mass fraction of fat."

3 Results and Discussions

An analysis of foreign and domestic technological solutions for obtaining wheat germ showed that flour mills currently use modern equipment using grain cleaning and grinding departments.

Obtaining germs in the grain cleaning department is based on separating part of the germ during dry peeling of grain on rinsing or brushing machines [9].

Scientists in Britain propose using specially designed peeling devices to better separate the germ when grinding wheat grains [1].

The germ obtained in the grain cleaning department remains almost intact, has long-term shelf life, maintaining its volumetric mass, but at the same time contains a high amount of minerals, which makes it difficult to use in food production. However, wheat germ is a necessary part of the grain when moistening wheat, because the constituent elements of the embryo participate in biochemical reactions and help accelerate the transfer of moisture and heat. Therefore, in many countries they try to preserve the germ in the grain and separate it after cooling in the preparatory department or when grinding the grain in the grinding department. In addition, to preserve the embryo in the grain during the moistening period, a drum in a beaker made of cast iron or thick wire with punched holes and brush machines are used [10].

In Hungary, the germ is separated using a specially designed machine with a capacity of about 3.5-4.0 t/h, in which the wheat grain is cut into 3 parts. The part of the grain containing the germ is directed into a vertical spiral chamber, in which the germ is cleaned with brushes and the mixture of germ particles, hulls and endosperm is separated in the pneumatic separation channel of the germ separation machine. The shells and endosperm particles, cleared of germ particles, as well as the middle part of the grain, devoid of the germ, and the part of the grain from the beard side, are sent to various systems of the grinding department [9].

The principle of isolating the germ in the grinding department is based on the fact that the germ, compared to other anatomical parts of the grain, has increased plasticity due, firstly, to the high fat content, and secondly, to the higher humidity obtained as a result of moistening the grain before the first tearing system and its short-term release. Thus, the embryo as an elastic-plastic body, when exposed to compressive forces arising between the rollers at $k = 1.0\text{-}1.5$, is flattened, and flakes are formed.

Currently, there are quite a large number of options for technological schemes for selecting wheat germ in the grinding department of flour mills, which, depending on the type of grain grinding adopted, available equipment and other factors, provide for the isolation of the germ on various systems of the technological process of grain processing: from sieve, grinding or grinding systems.

Thus, in Poland, in small-capacity factories with complex grinding with reduced enrichment of intermediate products, the germ is obtained in two sequentially operating germ systems, to which large grains enriched on a sieve machine from the first two torn systems are sent, as well as enriched middle and first fractions of fine grains from III torn system. The drainage of sieve No. 1, 1 is a germ in the form of flakes, which is then controlled on a flat sieve No. 095. This technological scheme makes it possible to obtain up to 0.3% of germ flakes with a purity of about 70% [9].

The technological scheme of wheat grinding at factories with a capacity of 100-120 tons/day in Italy is characterized by the use of a crushing (flashing) system in front of the first torn system, the presence of 5 torn systems, 2 sorting systems, 8 screeners, and 8 grinding systems. In the torn process, grooved rollers are used, in embryonic systems and in the grinding process, micro-rough rollers are used. In the absence of grinding systems, as in Polish factories, for the selection of the embryo, the passage of a sieve, enriching coarse grit with I grit and II grit of small systems, a sieve, enriching large and medium grit with III grit of large and small systems, as well as enriched medium grit IV the torn small system directly enters the 1st embryonic system, the upper discharge from which with particles of the flattened embryo is transferred to the 2nd embryonic system. Germ flakes are selected from the second embryonic system [11].

In US mills, to select the germ, large grains I and II of the torn and special system, after enrichment in a sieve shaker, are sent for grinding. Depending on the productivity, the mills are equipped with from 1 to 4 grinding systems. In the process of grinding grains, the goal is not so much to separate the shell particles from the aggregates of grains, but to obtain the upper run-off products with the maximum germ content. The upper runoff from sieve No. 10 of the first two grinding systems goes to the embryonic system, and the second and third runoff goes to the sieve bars, the runoff from which is also sent to the embryonic system. On the micro-rough rollers of the embryonic system, embryonic flakes are formed, which are collected by sieves No. 1 and 2. The amount of germ flakes is 20-30% of the mass of the product entering the germinal system. The fat content in germ flakes reaches 12-18% [12]. The option of installation as an upper sieve with a size of 600 microns is possible. In this case, the germ-containing product is additionally sifted on a sieve separator with a sieve with a hole size of 910 microns. By passing the sieve, bran and small particles of the germ are selected. The sieve waste represents germ flakes in the amount of 0.60% of the grain weight sent to the first tattered system.

The embryo selection scheme in English mills is more complex [1]. The second passes of the sieve, enriching large grains of the I and II torn systems, are sent to the grinding system No. 1. The second discharge from sieve No. 080 of the III torn system is sent to a pneumatic aspirator, from which the fraction with a large number of germ particles is sent to the first embryonic system. The fraction with a predominance of shells with endosperm particles is sent to the small torn IV system. The upper discharges of the grinding systems No. 1 and 2, as well as the discharge from the sieve that enriches the fine grains of the grinding system No. 1, are also directed to the first embryonic system. The exit and third pass of sieve No. 11 of the sieve shaker, which receives the first exit of the first grinding system, is directed to the second embryonic system. By gathering the upper silk sieves No. 10 of the germinal systems, germinal flakes are selected; the second gathering of the second embryonic system is feed flour. The recovery of flour with an ash content of 0.60-0.62% on germinal systems is 10-12% relative to the load on each system with the ash content of the incoming product being 1.70-1.85 and 1.84-1.95%. On torn and grinding systems, the grooves are arranged “point against point”, the speeds of the rapidly rotating rollers are 4 and 3.5 m/s, respectively, and the ratio of the roller speeds is K = 2.5; on embryonic systems, the peripheral speed of the rollers is 3 m/s, and their ratio K = 1.0.

The germ selection scheme developed by Bulgarian researchers is different in that the first germ system receives large grains from the first and second grinding systems, as well as the waste product from the first grinding system. The rollers of the above-mentioned, as well as germinal systems, have a micro-rough surface (all torn and other grinding systems have grooved rollers), which, obviously, makes it possible not to over-grind the germ particles, and on germinal systems to obtain germ flakes. The upper discharges from the first and second germinal systems are further processed in the entolator, and then returned to the second germinal system, where the collection of sieves No. 1.0 and No. 063 produces large and small fractions of the germ. This treatment makes it possible to separate more completely the embryo from the intergrowths with the endosperm due to its high plasticity.

In the Czech Republic and Slovakia, large and small seeds are selected at the stage of grinding intermediate products by the first and second runs of the last grinding system. On the first grinding systems, finely grooved rollers are used to remove fused shells from the surface of grains; on the latest grinding system, rollers with a micro-rough surface are installed, which promotes the formation of germ flakes. Large and small germ flakes are selected by gathering metal woven sieves No. 1.4 and No. 1.0, respectively. The fourth grinding system receives waste from previous grinding systems, as well as from sieves that enrich medium and fine grains [13].

Research by V.A. Morgun [6] found that the maximum amount of the whole embryo in free form is in the second exit product of the second torn system - up to 0.60% of the embryo (relative to the load on the first torn system). In subsequent systems, the germ is crushed and ends up mainly in the dunes of the grinding systems, where the fat content is 5.4-7.2%, and in the bran, where the fat content is only 3.2-4.1%.

The data obtained made it possible to develop a technology for selecting a large germ product, in which the germ content is 25-30%, which involves sorting the 2nd output product of the II torn system in a sieving screen, flattening the fraction containing the maximum amount of whole germ on a roller machine with micro-rough surface of the rollers, followed by sorting in a sifter, at the top of which the germ-containing product is selected, which has a valuable chemical composition: ash - 2.47-2.75%, fat - 5.0-6.0%, protein - 16.0-17 ,5%. This product can be used for the preparation of bakery products for dietary and therapeutic purposes.

In our country, the selection of wheat germ in the production of flour began at the beginning of the 20th century. However, the intensification of flour-grinding production in order to increase the productivity of enterprises and the yield of high-grade flour, the installation of rollers with a grooved surface in the grinding process (in factories with traditional equipment) did not allow organizing its industrial production as a separate product of wheat processing; Only at certain factories did specialists independently select the embryo. Thus, a scheme for obtaining the embryo from grinding systems was recommended. The second fraction of coarse and medium grains from the first two grinding systems, characterized by a high germ content, are enriched in the aspirator, and then sent to two (to improve the quality of the resulting germ flakes) sequentially operating germ systems ($k = 1.25$-1.5; $Vb = 4.5$ m/s, micro-rough rollers). Using these systems, large and small fractions of the embryo are obtained from nylon sieves No. 10 and No. 25, respectively [14].

Under the guidance of Candidate of Technical Sciences G.A. Usov developed a rotational-cascade technology for producing flour from wheat germ by the method of dry mechanical activation, which implements a complex of known grinding methods. This technology has a higher disaggregating and mechanically activating effect on organic polymers (by 15-18%), which is confirmed by determining the activity of an aqueous suspension with flour using the conductometric method.

Our research has developed a method for obtaining wheat germ in the preparatory department, which makes it possible to obtain wheat germ flour in an amount of 0.01-0.15%. The diagram is shown in Figure 1.

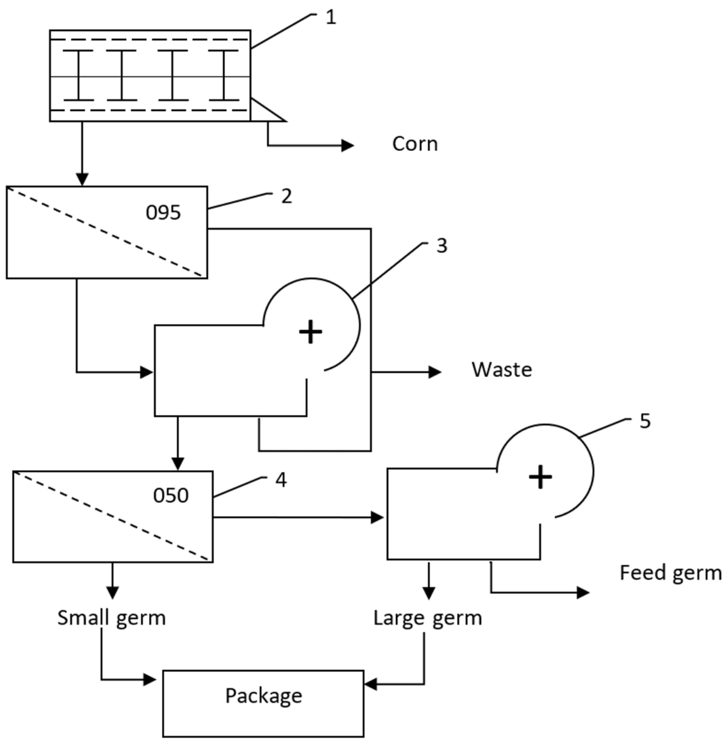

Fig. 1. Embryo separation scheme

The peculiarity of the proposed technology is the isolation of the germ during the preparation of grain for grinding from the products of the first and (or) repeated peeling on beakers 1; sifting followed by pneumatic separation of pass-through products on vibrating sieve 2 (sieve No. 095, sieve vibration frequency - 550-600 rpm), further separation on pneumatic classifier 3 (air flow speed 3.6-3.8 m/s, height of pneumatic separating channel 800 -900 mm); separating the isolated product on vibrating sieve 4 (sieve 050) into small and large fractions of wheat germ. The large fraction is additionally subjected to pneumatic classification 5 (air flow speed 3.5-4.0 m/s), which makes it possible to obtain 93-95% of a large undestroyed embryo (total yield up to 0.05% relative to the weight of the grain; volumetric mass - 630 -660 g/l; weight of 1000 pieces - 0.43-0.47 g), which can be used for food purposes, and 5-7% of small destroyed and undestroyed fodder wheat germ. The resulting embryo is packaged in ordinary containers and can be stored for 6-8 months at a humidity of 14.0 ± 0.1%.

The next task was to grind the wheat germ in order to use it for the preparation of baked goods of improved quality and increased nutritional value.

However, when grinding wheat germ using known industrial methods, flour is obtained with a polydisperse composition of solid particles, the size of which ranges from 100 microns to several millimeters [15].

Coarse particles, as well as the very heterogeneity of the classification composition of grinding, significantly worsen the organoleptic quality indicators (taste, appearance, crumb condition) and the physical properties of enriched products (porosity, volume).

To increase the efficiency of using wheat germ in the production of bakery products, grinding by dry mechanical activation was used. Mechanical activation of a substance makes it possible to increase the technological activity of the surface of a dispersed product due to a large amount of mechanical energy. The process is carried out in a high-speed mode of repeatedly repeated compressive loads in cramped conditions with a period between loadings of less than 0.025-0.030 and a number of 40 or more repeated loads on the crushed product. Therefore, excess free energy of the system appears; intermolecular bonds that stabilize the supramolecular structure of natural polymers are broken; a decrease in density and an increase in surface area are observed [16].

Khodakov G.S. [15] applied an energy law that maximally takes into account energy costs during mechanical activation. In accordance with this law, the work of friction or the work of surface deformation and destruction, the energy of plastic deformations depend on the degree of grinding of solid particles and are proportional to the surface area. The dependence taking into account the energy consumption during the deformation of solids is expressed by the equation:

$$\mathrm{de} = \frac{9\alpha_2}{\alpha_1} l \frac{dS}{S} + \left(\frac{3\alpha_2 \beta l - \gamma}{\alpha_1} + \delta\right) dS - \frac{\alpha_2 \beta l^2}{4\alpha_2} S dS, (1)$$

where e is the energy for doing work;
$\alpha 1$ – particle area coefficient;
$\alpha 2$ – particle volume coefficient;
S – specific surface area of the crushed material;
β – plastic deformation energy density;
γ – surface density of friction and energy of formation and destruction of aggregates;
l – the thickness of the layer in which plastic deformation occurs;
δ – free energy per unit surface.

It follows from the equation that the energy density of plastic deformations depends on the design, geometric dimensions of the grinding elements and technological parameters of the grinding machine. To achieve a certain level of energy density, which is transferred to the crushed particle during the destruction process, it is necessary to increase the energy intensity of the grinding apparatus by increasing the kinetic energy of the working bodies when they come into contact with the crushed material [17]. An increase in energy density is facilitated by a decrease in the contact area, and therefore the number of crushed particles that receive energy.

Analysis of the increase in free energy shows that the growth rate can be many times higher under certain conditions, such as increases in the specific surface area of the dispersed system compared to an increase in free energy due to internal deformations. One of the main conditions for intensively increasing the internal energy of the dispersed material by grinding is the high energy potential of the grinding machine, which ensures deformation of the internal structure of the crushed particles [18]. Grinding of wheat germ was carried out to a fine composition with a solid particle size of less than 100 microns using a DESI-11 disintegrator.

The chemical composition of the resulting wheat germ flour without mechanical activation and with mechanical activation is shown in Table 1.

Table 1. Chemical composition of wheat germ flour

Indicators	Content, wt. %	
	wheat germ flour without mechanical activation	wheat germ flour after mechanical activation
Proteins	32,5±0,8	32,8±0,8
Fats	7,8±0,5	7,8±0,5
Mono- and disaccharides	25,2±0,2	29,6±0,2
Pentosans	10,1±0,2	10,0±0,2
Cellulose	3,8±0,1	3,5±0,1
Ash	4,07±0,2	4,55±0,2

According to the results of Table 1, it follows that the use of mechanical activation of wheat germ flour leads to some changes in its chemical composition, for example, the mass fraction of sugar increases by 17%, ash content by 11%, and fiber content decreases by 8% compared to the chemical composition of the original flour wheat germ. This is due to significant destruction of the structure of natural polymers during mechanical activation.

The amino acid composition of wheat germ flour protein is shown in Figure 2.

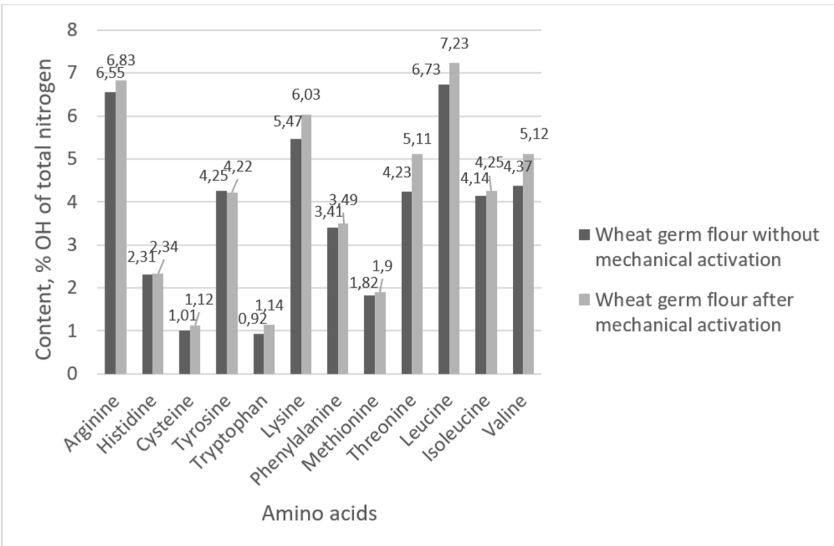

Fig. 2. Amino acid composition of wheat germ flour

From Figure 2 it can be seen that the amino acid composition of wheat germ flour protein is represented by all essential amino acids, and due to mechanical activation, the quantitative composition of amino acids increases by an average of 8-10%.

The purpose of further work was to study the effect of wheat germ flour before and after mechanical activation on the quality of urban bread.

For the control sample, the dough was prepared according to the recipe for city rolls from first-grade wheat flour using non-dairy technology. Wheat germ flour was added to the experimental samples both before mechanical activation and after mechanical activation in an amount of 3, 5, 7, 9% by weight of wheat flour.

As a result of a study of the organoleptic characteristics of baked buns using non-mechanically activated wheat germ flour, it was found that the introduction of this additive in a dosage of more than 5% worsens the quality of the finished products: the buns have a slightly vague shape, a rough surface, and a crumb with uneven porosity. The organoleptic characteristics of samples with the addition of non-mechanically activated wheat germ flour in amounts of 3 and 5%, as well as samples with the introduction of wheat germ flour after mechanical activation in dosages of 3, 5 and 7%, are not inferior to the control. However, a loaf made with mechanically activated wheat germ flour at a dosage of 9% has a vague ridge on the surface and a crumb with insufficiently developed porosity.

Thus, samples of buns with the introduction of wheat germ flour before mechanical activation in an amount of 5% and with the introduction of wheat germ flour after mechanical activation in an amount of 7% were selected as optimal. The organoleptic characteristics of these samples are presented in Table 2.

Table 2. Organoleptic quality indicators of finished products

Quality indicators	Samples of buns		
	control	with wheat germ flour without mechanical activation in an amount of 5%	with wheat germ flour after mechanical activation in an amount of 7%
Form	oblong-oval, regular	oblong-oval, regular	oblong-oval, regular
Colour	light yellow	golden yellow	golden brown
Surface	with a comb along the bun, without cracks or tears	with a comb along the bun, without cracks or tears	with a comb along the bun, without cracks or tears
Crumb condition:			
Bakedness	baked, not wet, not sticky to the touch	baked, not wet, not sticky to the touch	baked, not wet, not sticky to the touch
Kneadness	without lumps and traces of unmixing	without lumps and traces of unmixing	without lumps and traces of unmixing
Porosity	medium, developed, without voids and compactions	medium, developed, without voids and compactions	small, thin-walled, developed, without voids and compactions
Taste	characteristic of this type of product, without foreign tastes	characteristic of this type of product with a pleasant grain flavor	characteristic of this type of product with a pleasant grain flavor
Smell	characteristic of this type of product, without foreign odors	characteristic of this type of product, without foreign odors	characteristic of this type of product, without foreign odors

From Table 2 it follows that the sample using wheat germ flour after mechanical activation differs from the rest in having a more intensely colored crust color. This is due to the presence in mechanically activated wheat germ flour of a larger amount of sugars and amino acids, which enter into the reaction of melanoid formation during baking. The crumb of this sample has developed, fine, thin-walled porosity, which is explained by the fine particle size of the wheat germ flour used [19, 20].

Table 3 shows the physical and chemical characteristics of the finished products.

Table 3. Physico-chemical qualities of finished products

Quality indicators	Samples of buns		
	control	with wheat germ flour without mechanical activation in an amount of 5%	with wheat germ flour after mechanical activation in an amount of 7%
Crumb moisture, %	41,2±0,5	42,5±0,5	41,8±0,6
Crumb acidity, degrees	2,5±0,2	2,8±0,2	3,0±0,2
Crumb porosity, %	71,4±0,3	72,7±0,3	73,2±0,3
Mass fraction of sugar in terms of dry matter, %	4,15±0,05	4,18±0,05	4,32±0,05
Mass fraction of fat in terms of dry matter, %	2,10±0,01	2,12±0,01	2,11±0,01

When analyzing the physicochemical parameters of the buns, it was revealed that the porosity of the sample using mechanically activated wheat germ flour in an amount of 7% is higher by 1.8% compared to the control and by 0.5% compared to the sample with the addition of non-mechanically activated wheat germ flour (5%), and this sample is also distinguished by a slightly increased mass fraction of sugar compared to other samples.

All experimental products meet the requirements of GOST 31805-2018 “Bakery products made from wheat flour” in terms of organoleptic and physico-chemical indicators. General technical conditions".

4 Conclusion

Thus, the developed technology for processing wheat germ is resource saving, environmentally friendly and allows you to preserve completely all biologically valuable substances present in the by-products of wheat processing. Grinding of wheat germ by the method of dry mechanical activation made it possible to use it in the production of bakery products from first-grade wheat flour in an amount of up to 7% by weight of flour in order to improve their quality, expand the range, increase nutritional value, as well as the rational use of grain production waste.

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