Ecological, biotechnological and economic aspects of wheat grain processing

I Jarkova\(^*\), J Slepokurova\(^1\), N Alekhina\(^1\) and A Samokhvalov\(^1\)

\(^1\)FSBEI VO "Voronezh State University of Engineering Technologies", Revolution Avenue, 194039, Voronezh, Russia

\(^*\) Corresponding author: zharir@mail.ru

Abstract. The article is devoted to the consideration of issues related with finding ways how to reduce the environmental burden in the wheat grain processing. Based on the analysis of the current state and prospects for the development of the grain processing, flour and bakery industries, the prospect of finding technological solutions for the processing of wheat grain, precluding the formation of bran as a by-product, is substantiated. It has been shown that, due to its chemical composition, wheat bran is a valuable ingredient from a biomedical point of view for inclusion in the diet of a modern person. It is noted that currently used in the baking industry for the enrichment of high-grade wheat flour with dietary fiber and bran can not be called the best from an economic point of view, since they lead to a significant increase in the cost of the final product for the consumer. The authors proposed the most rational from an environmental and nutritional points of view, the method of processing wheat grain, the technology of grain bread of high nutritional value from bioactivated wheat. Due to the process of bioactivation, the content of phytin in the grain is reduced by 75% compared with the original, that allows increasing the bioavailability of the mineral substances of bread for the human body to assimilate. Economic calculations have shown the advantage of the proposed technology of “Bioamarant” bread compared to a wheat flour product containing wheat diet bran (“Dairy-bran bread”): the cost is lower by 19.54%. When producing bread from bioactivated wheat in the amount of 22.5 tons / day, 13.4 tons of wheat should be spent. That is, the absence of the process of grinding this amount of wheat grain prevents the formation of 2.5 tons of bran per day, as well as the formation of emissions into the atmosphere in the amount of 3.2-6.5 tons (in terms of a year) of harmful substances, which will certainly allow reduce environmental stress.

1. Introduction
The main grain crop in the world is wheat. According to FAO, its global production in 2014 was 729.0 million tons. According to forecasts of the Organization of Economic Cooperation and Development and the USDA, the world wheat harvest in 2024/2025 will be 776.2 million tons. At the same time, among the world leaders in terms of wheat cultivation the third place belongs to Russia [1-3].

Russia exports a third part of the grown grain, about 11% is reserved to the seed fund, 10% is feed grain, and the main part (almost half of the crop) is sent for processing (Figure 1), which results are in a variety of main products. At the same time, the main production is accompanied by the accumulation of by-products (Figure 2).
According to the data provided by the Expert-Analytical Center of Agribusiness [6], wheat flour is produced mainly from the highest grade wheat flour (Fig. 3, a): its annual production for the period 2010-2018. Exceeded the production of first-grade flour by 2.3-3.2 times, and second-grade flour and wheat-rye - by 6.9-11.4 times. The average annual production of wheat flour of the highest grade for the entire period under consideration exceeded the same indicator of the production of first grade flour and the total volume of second grade wheat flour and wheat rye flour, respectively, in 2.7 and 9.6 times (Fig. 3, b).
Figure 3. Characteristics of the production volumes of wheat grain processing products in Russia for the period 2010-2018 (in 2018 it is included the production from January to August)

In this way, the statistical data show that at the present stage the process of processing grain into final (commercial) products is accompanied by the receipt of by-products, in particular bran, in the most technologically possible amounts. It is known that during the production of wheat flour of the highest grade, 18.5-21.5% (according to [7] - 12.1-19.1%) bran are formed in parallel, that means the production of 8.402 million tons of wheat flour in 2017 was accompanied by the accumulation of 2.334 million tons of bran. According to [8], in 2007 in Lithuania, the production of 0.402 million tons of flour and cereals was accompanied by the formation of 65.594 million tons of bran. According to the news agency APK-Inform [9], in 2014 the production of wheat flour in Russia amounted to 8.900 million tons, and wheat bran - 2.500 million tons.

According to the Russian Research Institute of grain and its processed products (RRIG), the volume of bran produced at Russian grain processing enterprises can reach 4,500–5,000 tons [10].

Existing volumes and methods of processing wheat grain contribute to the exacerbation of the problem of by-products and waste using and utilization. It should be noted that at the present time bran that is formed in large volumes is not rationally used [11]. Due to the large volumes of this by-product,
a negative impact on the environment can occur, such as soil contamination (dumps), water (wastewater from washing machines) [10].

The main method of wheat bran utilization is currently the production of animal feed and poultry feed [12, 13]. This method is economically least expensive and therefore is beneficial for milling enterprises. This is confirmed by the data from the analysis of the products sold range by large milling enterprises, including: OJSC Buturlinovsky Milling Plant (Buturlinovka, Voronezh Region), OJSC Melkombinat (Tver), OJSC Voronezhsky MK, Voronezh, LLC Tambovkrakhmal Agrokombinat (the village of Umet of the Tambov Region), Kursk Bread Products Plant CJSC (Kursk), Rybinsk Milling Plant JSC (Rybinsk, Yaroslavl Region).

Flour mills sell bran in mound or in compacted (granulated) form. Bran using in unconsolidated form (mound) has significant drawbacks: high costs for their storage and transportation; it takes a lot of space and requires special conditions for storage and transportation; strongly dusty, that increases the risk of fire [14].

Production of dietary bran, which can be used as a raw material for the food industry, is possible. However, the production of dietary wheat bran is insignificant. This is primarily due to necessity of significant financial costs on the part of the enterprise not only for the installation of additional equipment, which makes it possible to obtain a product that meets safety standards requirements of regulatory documents, but also for measures to ensure environmental safety of production associated with necessity of cleaning large volumes of wastewater [8]. The discharge of wastewater from grain processing operations usually requires a permission. Compliance with new legal requirements for environmental protection, health, safety and hygiene may require capital investments in new equipment [15].

Experts note the low technological level of the Russian grain processing industry and the almost complete absence of enterprises that integrate deep grain processing (the production of flour from grain is not deep processing) [16].

RRIG scientists believe that deep processing of grain, including wheat, is one of the promising areas of the grain industry development, the main task of which is the effective all components of grain raw materials using. In the classical sense, this is the process of the grain separating into its components, as a result of which it can be isolated: separate protein fractions, for example, gluten, concentrates and protein isolates are obtained; fractions of starch (A, B, C); soluble and insoluble dietary fiber; some other components [1]. The authors [17] proposes a method of wheat bran utilization by carrying out the enzymatic hydrolysis of starch, followed by the production of bioethanol. A biotechnological method has been developed to process wheat bran to produce a product that can be used to prevent mold growth when storing wet fodder grain and vegetables; as an effective fertilizer while growing organic vegetables and berries; to combat mold while growing food mushrooms [18].

However, these developments of large-scale industrial implementation are currently not received.

Analysis of the scientific and technical information on the problem under consideration has shown that the search for ways how to reduce the environmental burden from the by-product (wheat bran) generated at the flour mills, which are justified from an economic and biomedical point of view, is relevant.

In this regard, we can formulate the objectives of the study:
1. To assess the significance of the wheat bran composition from biomedical point of view.
2. To analyze the existing technologies of using wheat bran in the baking industry.
3. To develop the technology of grain bread with high nutritional value made from bioactivated wheat.
4. To substantiate the possibility of reducing the environmental burden of wheat bran storage and utilization and the economic efficiency of the developed technology for grain bread.

2. Methods
The assessment of significance of the wheat bran composition from biomedical point of view and ways how to use them for reducing the environmental burden was carried out by means of available scientific
meta-analysis, technical, statistical and patent information. The assessment of the reduction of environmental stress in the implementation of the proposed method for the production of grain bread was carried out empirically. In addition, analytical and graphical methods, including logical and process approaches, were applied.

The bioactivation of wheat grain was carried out as follows: the wheat grain was preliminarily cleaned of weed and grain impurities, washed. Next, wheat was kept for 20-24 hours in water at a temperature of 18-20 °C, and then germinated for 10-12 hours. In the process of bioactivation of the grain, the content of phytin was determined by its extraction with hydrochloric acid, followed by precipitation with ferric chloride and the formation of iron phytate insoluble in dilute acid. After the ashing, phosphorus phytin was determined by a colorimetric method (according to Fiske-Subbarou).

The calculation of the cost of the proposed grain bread was performed by the calculation method.

3. Results and Discussion

The problem of grain bran utilization for food purposes was considered by researchers for a long time, and if in the 40s of the last century (immediately after the end of the Second World War) bran acted as an accessible source of protein [19], then at the beginning of the XXI century the focus shifted to the possibility of isolated extraction of these, the protein component [20], as well as the increasing importance of bran, is becoming a source of dietary fiber [21].

The recommended consumption rate of wheat bran is up to 40 g per person with an average weight of 70 kg [22]. This is due to the high content in the bran of biologically valuable substances (table 1), including dietary fiber, protein, minerals, vitamins (B6, PP, E, etc.), phenolic substances with antioxidant properties [22]. It is generally recognized the benefits and feasibility of the inclusion of bran in the formulation of products intended to improve the performance of carbohydrate and lipid metabolism in patients with diabetes mellitus [23-29] for the prevention of cardiovascular diseases [22, 25, 26, 28, 29], normalization of body weight [26, 27], which have antioxidant properties [22].

| Table 1. Nutritional Information on Wheat Bran |
|-----------------------------------------------|
| Indicators                                   | Wheat bran diet GOST R 53496 | Wheat bran |
| Mass fraction of protein, %                  | 16.0                          | 13.2-18.4<sup>1</sup> |
| Fat content, %                               | 3.8                           | 3.5-3.9<sup>1</sup> |
| Mass fraction of starch, %                   | 16.6                          | 13.8-24.9<sup>1</sup> |
| Mass fraction of dietary fiber, %            | 47.0                          | 43.2 |
| Mass fraction of soluble dietary fiber, %    | 9.82<sup>1</sup>              |         |
| Mass fraction of insoluble dietary fiber, %  | no standard                   | 33.38<sup>1</sup> |
| Ash content, %                               | 5.5                           | 3.4-8.1<sup>1</sup> |
| Biologically active components               |                               |         |
| Phytic acid, mg%                             | no standard                   | 2180-5220<sup>1</sup> |
| Ferulic acid, mg%                            |                               | 500-1500<sup>1</sup> |
| Vitamins, mg / 100 g:                        |                               |         |
| betaine                                      | no standard                   | 1000-1300<sup>1</sup> |
| choline                                      |                               | 47-100<sup>1</sup> |
| niacin                                       |                               | 14-18<sup>1</sup> |
| nicotinic acid                               | 15.5                          | no information |
| tocopherols                                  | 7.0                           | 1.4<sup>1</sup> |
| pantothenic acid                             | 2.2-3.9<sup>1</sup>           |         |
| riboflavin                                   | 0.39-0.75<sup>1</sup>         |         |
| biotin                                       | no standard                   | 0.048<sup>1</sup> |
| thiamine                                     |                               | 0.54<sup>1</sup> |
| pyridoxine                                   |                               | 1-1.3<sup>1</sup> |
Mineral substances, mg / 100 g

| Substance | Value |
|-----------|-------|
| Na        | 25.2±8.74<sup>2</sup> |
| K         | 405.5±50.8<sup>2</sup> |
| Ca        | 41.5±10.8<sup>2</sup>  |
| Mg        | 190.6±43.4<sup>2</sup> |
| Fe        | 11<sup>1</sup>; 5.68±0.95<sup>2</sup> |
| Zn        | 7.3<sup>1</sup>; 3.58±0.55<sup>3</sup> |
| Se        | 78<sup>1</sup> |

<sup>1</sup> – according to the source [25]; <sup>2</sup> – according to the source [22]

The dietary fibers that make up the bran base have a high water-absorbing capacity, which can contribute to faster saturation and speed up intestinal motility [25]. In addition, dietary fibers can serve as a substrate for the development in the large intestine of microorganisms that synthesize metabolites that improve human health [30, 31].

In the food industry can be used bran made according to GOST R 53496-2009 and corresponding in terms of safety requirements of the TP TC 021/2011 TR.

One of the trends in the production of “healthy” foods is the production of wheat flour with a high content of dietary fiber, which is achieved by adding bran and / or dietary fiber to the highest-grade wheat flour [25, 26, 32]. There are various methods of pretreatment of bran before mixing them with flour (grinding, extrusion, heat treatment, biological treatment), aimed at minimizing their negative impact on the technological properties of flour and, as a consequence, preserving the high quality of bread produced from it [25, 33]. When dosing bran to 15% by weight of flour, the use of improvers, in particular distilled monoglyceride Myverol™, is recommended to correct the rheological characteristics of the dough and the quality of the bread [26].

Technologies for the use of bran have been developed, subjected to thermoplastic extrusion in the production of cakes and products from shortcrust [34], the production of extruded products [27].

It is noted that the biological value of proteins in a mixture of the highest grade of wheat flour and wheat bran is higher than in the highest grade of wheat flour [19]. This is due to the introduction of bran lysine and tryptophan.

Technologies for the production of bakery products from whole-ground flour (without the selection of bran) have been developed [35, 36].

Nutritionists advise to minimize the use of refined products, to enrich the diet with ballast substances, including dietary fiber, "use unmilled grain", i.e. with shells [21, 28, 37].

The technology for the production of whole-grain bread in which the process of fine grinding of grain and the production of whole-grain mixture occurs using a rotary pulsation hydromechanical homogenizer [38] has been developed.

The main issue requiring attention when consuming whole grains is the presence of phytin in its membranes, which reduces the bioavailability of the mineral substances present in the product and, above all, calcium. We have proposed a method for the production of bread from bioactivated wheat (Fig. 4). It was established that during the swelling of wheat grain within 24 hours in drinking water and its subsequent germination within 12 hours, the content of phytin is reduced by 75% compared with the original grain [39].

The advantage of bread making technology is also a reduction in the cost of its production compared to traditional bakery making technologies: a significant reduction in cost due to the difference in the price of flour and grain, an increase in bread yield [40, 41].

It should be noted that the tendency of reducing the demand for the bran production of mixed feeds (as the main way of their processing) is forming, since in 2016 there is a decrease in the price of feed grain, which is more preferable for this industry in terms of the usefulness of the composition [9].

The use of bran as a fuel is also known [42]. However, it should be noted that the burning of bran is accompanied by the slagging of heating surfaces, sintering of the ash residue, complicates the operation
of blower fans and reduces the efficiency of combustion, which together leads to low plant efficiency and high operating costs [43].

To confirm the effectiveness of reducing the environmental burden in the implementation of our proposed method for the production of grain bread, we will carry out a calculation using the example of Voronezh - city of 1 million and 200 thousand people. Suppose that grain bread from bioactivated wheat grain will be consumed by every fourth inhabitant of a vegetable garden in the amount of 50 g per day, that means daily production of such bread should be 22.5 tons. To ensure such a volume of production, 13.4 tons of wheat must be spent (from which 10.9 tons of flour can be obtained). Since we use whole grains, this technological method allows us to avoid the formation and the need to utilize 2.5 tons of bran per day, as well as the formation of emissions into the atmosphere, accompanying the process of grinding the grain. As a reference, it should be noted that according to the methodology “Determination of gross and specific emissions to the atmosphere for grain processing enterprises and elevators” (Annex No. 37 to the order of the Minister of Environmental Protection No. 298 of November 29, 2010), the amount of harmful substances emitted into the atmosphere is 1-2 kg per ton of flour produced, which will reduce the environmental burden in the amount of 3.2-6.5 tons of harmful substances per year.

The advantage of the technology of making grain bread from bioactivated wheat is a reduction in the cost of its production compared to traditional technologies for preparing bakery products: a significant reduction in cost due to the difference in the price of flour and grain, reduction in energy costs, increase in bread yield. Confirmation of the economic feasibility of using the proposed technology is the calculation of production costs for traditional and developed technologies, respectively (Table 2).

**Table 2. Calculation of the planned cost estimate and the project of the wholesale price of products**

| Costing items                        | The cost of 1 ton of bread, rubles: |
|--------------------------------------|-------------------------------------|
|                                      | "Milk-bran" (control)               |
|                                      | «Bio-amaranth»                       |
| Raw materials, basic&supporting materials | 23,030                             |
| Transportation and procurement costs                      | 2,300                               |
| Fuel                                                  | 2,300                               |
| Electricity                                           | 2,300                               |
| Basic and additional salary                          | 4,610                               |
| Social insurance contributions                       | 1,390                               |
| Equipment maintenance costs                          | 1,150                               |
| General running costs                                | 1,150                               |
| Water from the network                                | 1,150                               |

**Figure 4.** Functional diagram of the production of bioactivated wheat grain

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Production cost 38,240 30,760
Selling expenses 0,290 0,240
Total cost 38,530 31,000
Profitability, % 20 20
Price per unit of product (weight 0.5 kg), rubles 25.4 20.4

The calculated indicators show that the feasibility of using new technology, as the cost of 1 ton of «Bio-amaranth» bread is on 19.54% lower than the control product («Milk-bran» bread), and the price of 0.5 kg of the control and experienced products is 25.4 rub. and 20.4 rub. respectively.

4. Conclusions

In this way, based on the completed research, we can make the following conclusions:

1. Due to its chemical composition, wheat bran is a valuable medico-biological ingredient for inclusion in the modern person diet.

2. The technologies used in the baking industry for the enrichment of high-grade wheat flour with dietary fiber and bran are not the best from the economic point of view, since they lead to a significant increase in the cost of the final product for the consumer. This is largely due to the need to solve environmental problems arising from the organization of the grinding of grain into flour.

3. We have proposed a method for processing wheat grain, precluding the formation of bran (Fig. 5) - the technology of grain bread of enhanced nutritional value from bioactivated wheat grain was developed. Due to the process of bioactivation, the content of phytin in the grain is reduced by 75% compared to the original, which allows increasing the bioavailability of the mineral substances of bread for the human body to digest.

4. Economic calculations showed the advantage of the proposed technology of «Bio-amaranth» bread compared to a wheat flour product containing wheat diet bran (dairy bran bread): the cost price is lower by 19.54%.

5. When producing bread from bioactivated wheat in the amount of 22.5 tons / day, 13.4 tons of wheat should be spent. That is, the absence of the process of grinding this amount of wheat grain prevents the formation of 2.5 tons of bran per day, as well as the formation of emissions into the atmosphere in the amount of 3.2-6.5 tons (in terms of a year) of harmful substances, which will certainly allow reduce environmental stress.
Wheat bran - a by-product of the milling industry

Ways to reduce environmental stress

- Feed production
- Alternative energy source
- Substrate for growing food mushrooms
- Production of dietary fiber
- Raw materials for the biotechnology industry, including the fermentation industry
- Special treatment (including hydrothemic)
- Dietary food bran by-products

Food production:
- ready-to-eat cereal products;
- enrichment of wheat flour with dietary fibers and/or bran;
- inclusion of flour products in the recipe;
- filler for fermented milk drinks

Food technologies that exclude the formation of bran

- Flour production without selection of bran (whole ground)
- Production of grain bread (from whole, crushed, dispersed, bioactivated grain)

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