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Article

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RESEARCH AND COMPARATIVE ANALYSIS OF THE QUALITATIVE PARAMETERS OF FOOD POWDERS PRODUCED FROM GRAIN RAW MATERIALS USING AN IMPROVED JET MILL

The object of the study is samples of food powders obtained by grinding the products of the collection and processing of a number of grain crops, using air-grinding technology in an improved jet mill. One of the most important problems of the modern food industry is that for the production of flour from cereals endosperm is used while the most important nutrients are found in shells and the germ of the grain.

As a result of its grinding in conventional mills, common at existing mills, large pieces of bran and a large variation in the particle size of the grinding products are obtained, and this method is energy-intensive.

According to the authors, the best solution to ensure truly whole grain grinding – that is, grinding grains with shells – is air grinding in jet mills. An improved jet mill makes it possible to grind both endosperm and grain shells into flour of the same consistency. From the same amount of raw material, therefore, it is possible to produce approximately 30 % more final grinding products. It is also important that the improved jet mill, under proven conditions, spends no more energy for grinding than a conventional mill.

For research, the most popular products ground in such a mill were taken – wheat flour (black grain), buckwheat flour (from roasted buckwheat) and wheat bran. The first two products are whole grain milled, and the bran is produced from the collapse of wheat grown in accordance with the requirements of organic farming. Samples of powders obtained by grinding these products in an improved jet mill were compared with control samples – produced from similar raw materials in a roller mill – the most common design in service with mills. Physical indicators of the powders, thermophysical properties and biotechnological parameters were carried out.

The obtained results allow to state that whole grain grinding produced on an improved jet mill has the characteristics better or close to standard types of flour produced on conventional mills. It allows them to be used without significant changes in the formulation of products with their addition (bakery, pasta, etc.), and also to create new dietary, healthy products rich in biologically active substances.

Keywords: *whole grain flour, air milling, jet mill, flour quality analysis, wheat, buckwheat, bran, dietary products.*

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1. Introduction

The continued growth of the world's population combined with the problems caused by unhealthy, carbohydrate-refined foods, make the issues of maximizing the extraction of substances beneficial to the body from produced agricultural raw materials extremely relevant. In November 2022 population reached the level of 8 billion people, by 2035 it is expected to reach 9 billion, and by 2058 – 10 billion. At the same time production of grain crops in 2006, 2007, 2010, 2012, 2018, 2021 declined and, apparently, will be observed in the future due to the depletion of land and water resources suitable for agriculture, as well as the limited opportunities for intensifying agriculture without a significant increase in investment in this area.

The main product of «high processing» in the food industry of the world is still various food powders and final food products produced with their use. According to 2019 data, the world production of flour amounted to 233 million tons. China is the leader in the production of food powders. In 2019, the volume of cereal flour production in China amounted to 71.9 million tons (31 % of the global production). However, almost all of this flour is made from endosperm – peeled from the shells and germ of the grain.

From the point of view of modern millers, everything that is in the grain, except for the mealy core, is bran. At the same time, bran is from 15 to 40 % of the grain mass (depending on the type of cereal, variety and growing conditions). All the substances necessary for the development of the body, in addition to carbohydrates – amino acids, oils, vitamins, trace elements are found just in bran. However, the installations available at the mills, due to the rigidity of the bran fiber fibers, cannot grind bran into flour of the same dispersion as from endosperm. The addition of coarsely ground bran to ordinary flour, in most cases, does not give any positive effect, since large pieces of bran do not have time to be digested during the time they pass through the human digestive tract. Moreover, people who consume a lot of bread with large bran additives often have damage to the walls of the digestive tract.

The correct solution to this contradiction is the creation of technologies that allow grinding into fine flour of approximately the same consistency both the endosperm and the shell of the grain. In search of technologies that allow the production of biologically active flour for healthy (including dietary) nutrition, the authors of this article turned to the technology of air grinding, produced on the basis of jet (or, as they are also called, «vortex») mills. Unlike roller, hammer and a number of other widespread types, jet mills solve the problem of grinding grain together with shells, as well as other types of food raw materials, into flour of the same dispersion, regardless of what the raw material is. Grinding in jet-type mills is carried out due to the collision of solid dry particles with each other or with a target at high speeds, often exceeding the speed of sound. However, jet mills produced by the world's major manufacturers allow their use only for the production of small volumes of products or for the manufacture of the most valuable types of powders. For further advancement in this direction, it was necessary to find and implement improved engineering solutions that would reduce energy consumption during air grinding to a level corresponding to energy consumption (and, consequently, production costs) to the level of the most common types of flour milling equipment. Then there are opportunities for commercially justified processing of the most massive types of raw materials, including those that were previously practically not used (or were used to a very small extent) as food.

In order to be able to recommend any new grinding technology to consumers, it is necessary to obtain scientific data on the characteristics of food powders obtained with its help, in accordance with the indicators approved in national and international standards.

Since, among the existing methods for the production of food powders, air grinding technology has been increasingly used in recent decades, this is of interest to scientists and manufacturers in the properties of various fine powders produced on the basis of this technology.

Especially great attention to new methods of ultrafine grinding of products is caused by Chinese scientists [1]. At the same time, among the technologies of food micronization, high-speed pulverization with an air flow – jet grinding – is of increasing interest. A number of Chinese researchers have already noted the positive impact of this grinding technology on improving the quality of food [2] and increasing the level of medicinal properties of food powders [3].

Recently, many studies have focused on the use of jet grinding in the grinding of cereals, including wheat [4]. In particular, a group of Korean scientists conducted a comparative study of the effect of two grinding methods (jet and hammer) on samples of wheat with different hardness (hard, medium and soft) in the production of whole grain flour. They found that, regardless of the variety, with jet milling flour had a significantly smaller particle size (D50) than with hammer milling, but the percentage of damaged starch grains, the content of wet gluten and its extensibility differed slightly [5].

Greek scientists also studied the effect of various types of grinding on the characteristics and properties of flour. The results of their measurements showed that, compared with the standard method, air milling significantly affected the characteristics of wheat flour. Therefore, particles of flour obtained in a jet mill, according to their data have a smaller size and less dispersion in the range of starch granules. The water absorption capacity of flour was found to be higher with air milling, but the number of damaged starch grains increased as their size decreased. In addition, starch gelatinization was faster in such flour, and the storage modulus values were higher when heated, which, according to the researchers, indicated a developed, elastic structure, which is important for ensuring proper dough structure during baking [6].

Of particular interest in recent years is the possibility of ultra-fine grinding of bran and its use as an essential additive to bread. Experts from South Korea made microfine wheat bran using a jet mill and obtained bread enriched with finely ground bran powder. According to them, such bread has very good physical characteristics and consumer properties [7].

Another group of Korean scientists measured the physical and chemical properties of dough and bread made from wheat flour, replaced by two types of bran obtained by jet grinding and hammer milling in the amount of 0, 5, 10, 15, 20 and 25 % to flour and endosperm. The particle size and dietary fiber content of the hammer mill bran was greater than that of the jet mill bran. The researchers noted that bread made with 5 % or 10 % of endosperm flour substitution for bran, regardless of the type of grinding, had a higher specific volume and lower crumb hardness than wheat bread. However, bread made with a bran content of 15 % or more had a reduced specific volume and higher crumb hardness [8].

Studies on the impact of jet milling on the quality of flour were carried out not only with wheat, but also with other types of agricultural raw materials. Therefore, a group of Chinese researchers carried out air grinding of corn grits for the production of corn flour. Then the composition, functional and physical-chemical properties of the obtained flour samples were determined. According to scientists, the properties of corn flour produced in a jet mill are directly proportional to the grinding time. Such milling has a direct effect on starch damage, which leads to an increase in functional properties, including the degree of gelatinization, hydration, solubility index and water absorption index. In addition, air milling led to a decrease in the gelatinization transition temperature and gelatinization enthalpy of the recovered starch. There was a decrease in the minimum and final viscosity, and an increase in the peak viscosity of the cornmeal. However, this method did not affect the primary protein structure of corn and the protein content of corn flour. The researchers concluded that air milling breaks particles into smaller fractions from an ordered to a disordered (amorphous) structure due to the breaking of intermolecular bonds, which can have a significant impact on the compositional, functional, and physicochemical properties of flour [9].

At the same time, these studies do not allow making an unambiguous conclusion about the advantages and possibilities of jet milling for the production of whole grain flour from raw materials of various crops. They do not take into account the whole range of quality characteristics of food powders, fixed in international standards. In addition, the grinding products were produced by researchers, mostly in small laboratory rather than industrial jet mills, which reduce the value of research in terms of application of their results in practice. The situation is understandable, since until recently jet mills, with rare exceptions, were not considered as a technology for the industrial production of flour from cereals, and if such production was carried out, then it was focused on flour from refined grains, and not on whole grain grinding. Thus, the limited amount of information on the effect of air milling on the physical and chemical characteristics of ingredients and products from them, especially in terms of the possibilities of whole grain grinding, makes in-depth studies of food powders produced on an improved jet mill relevant.

The aim of the study was to determine how air grinding in an improved jet mill will affect the main physical, thermophysical and biotechnological parameters of food powders in comparison with control – analogues obtained from the same raw materials, but in roller mills of Ukrainian flour mills.

Such a study makes it possible to evaluate the possibility of using air grinding on an improved jet mill. First of all, the authors were interested in the results of whole grain grinding and caryopses for the production of food powders. The dispersity and saturation of such powders with biologically active substances should make it possible to produce useful, dietary foodstuffs that promote health and active longevity.

To achieve this aim, the following objectives were performed:

1) a search was made for technologies that meet the requirements of the project and a suitable advanced jet mill was found;

2) selected plant materials grown on the principles of organic farming;

3) grinding of raw materials was carried out on an improved jet mill;

4) laboratory equipment was selected, on which the main, fixed in the standards, studies of the qualitative characteristics of food powders were carried out.

2. Materials and Methods

The object of the study is samples of food powders obtained by grinding the products of the collection and processing of a number of grain crops, using air-grinding technology in an improved jet mill.

Since the authors of the article were interested in the possibility of obtaining inexpensive, but high-quality food powders there was a search for equipment that could produce such powders on an industrial scale. Such powders (including from little-used food raw materials) have the widest possible range of biologically active substances that can be used in the production of health benefits (including dietary products).

To obtain objects of study, an improved jet mill was chosen [10]. In this jet mill, grinding is carried out in a cylindrical chamber of an improved design, and the separation of products into fractions is carried out by a classifier located on the same axis as the grinding chamber.

Grinding in an advanced jet mill occurs due to the friction of the particles of raw materials among themselves in a spiral, like a tornado, an air vortex at supersonic speed. This air flow is created by a compressor that supplies compressed air to the Venturi nozzles that exit at an angle into the grinding chamber.

There was demonstrated that by improving the design, it was possible to reduce the energy consumption for air grinding to a level corresponding to the costs in conventional mills, and by controlling the speed of the classifier rotor, it was possible to well regulate the fineness of grinding.

The authors of this article obtained food powders with various degrees of grinding from a wide range of food raw materials processed in an improved jet mill of Kovalenko V. V.

At the first stage, special attention was paid to the types of raw materials that are not widely used for food processing (soft wheat, buckwheat, bran). However, they can become a new inexpensive source for the production of healthy food, since these types of raw materials are the richest in scarce biologically active substances.

On the other hand, the raw materials chosen for the experiments represent the most common crops in Ukraine. Therefore, the object of research was flour from black grain wheat not hulled (taken into grinding along with the shells). Wheat bran was prepared for grinding in a 50/50 mixture of white and black grain wheat. The studied buckwheat was taken for grinding without special cleaning, but pre-roasted.

The following methods were used for development:

1. The results of the morphological properties of the powders were analyzed using a Tescan MIRA 3 LMU scanning electron microscope; two areas were selected for research on each sample, which were taken at different magnifications.

2. Water activity in powders was determined with a Rotronic HygroLab-2 water activity analyzer at room temperature.

3. The dry method was used to determine the particle size distribution. Particle size distribution and equivalent diameters at 10 % (D10), 50 % (D50), and 90 % (D90) cumulative volumes and specific surface area were determined using a Bettersizer 2600 laser particle size analyzer.

4. Water-absorbing, water-retaining, fat-absorbing, fat-retaining, emulsifying ability and emulsion stability were determined by centrifugation method.

3. Results and Discussion

3.1. Physical indicators of food powders. Granulometric measurements taken for the study of food powders showed that the improved jet mill provides a slightly different quality of grinding, depending on the processed raw materials. So roasted buckwheat powder after air milling has a bimodal particle size distribution.

On the contrary, samples of whole grain wheat flour are unimodal – they have one sharp peak in comparison with traditional grinding, i. e. there are practically no bulk-size fractions. Wheat bran after air milling has undergone significant grinding and has a wide particle size distribution (Table 1).

Fig. 1–3 show illustrative graphs of the distribution of density and particle size in food powders obtained by air grinding and in control samples obtained from the same raw materials using conventional flour milling technology.

Table 1

Particle size of food powders

Product	Size, microns					
	D10		D50		D90	
	Air grinding	Control	Air grinding	Control	Air grinding	Control
Black wheat	23.21	26.07	21.17	69.47	12.29	266.7
Wheat bran	267.9	1059	615.9	798.1	377.4	1593
Roasted buckwheat	104.2	112.1	216.8	279.7	100.7	985.8

Different types of distribution of particles of different flours are determined by the hardness, viscosity, moisture, oiliness, amount and structure of cellulose fibers in the feedstock. However, the results were certainly influenced by the type of grinding equipment, as well as the time spent on grinding, as well as the energy applied to the particles to ensure their crushing. Studies have shown that the values of D10, D50, D90 significantly decreased after air grinding and depend on the type of raw material, which indicates that the effect that air grinding provides on the milled raw materials is much more effective in a properly designed jet mill than in roller mills type.

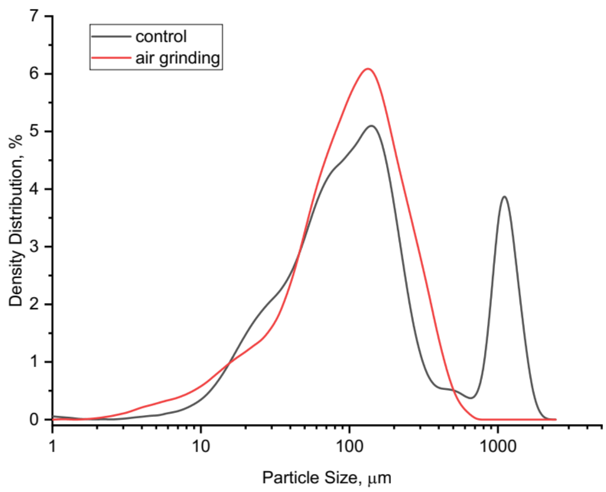

Fig. 1. Particle size distribution profile of black wheat flour with different methods of whole grain grinding

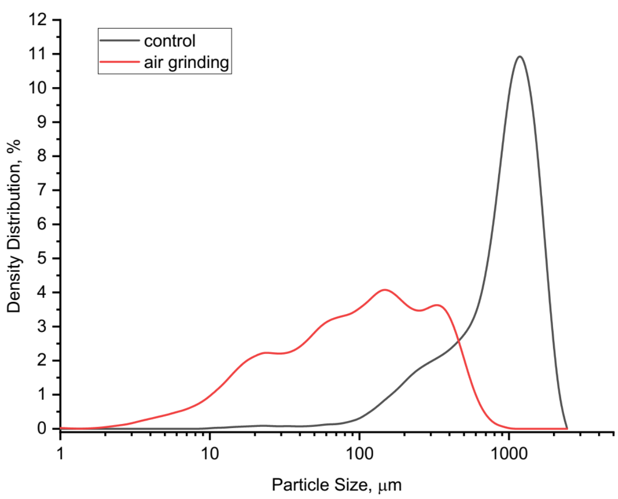

Fig. 2. Particle size distribution profile of wheat bran with different methods of whole grain grinding

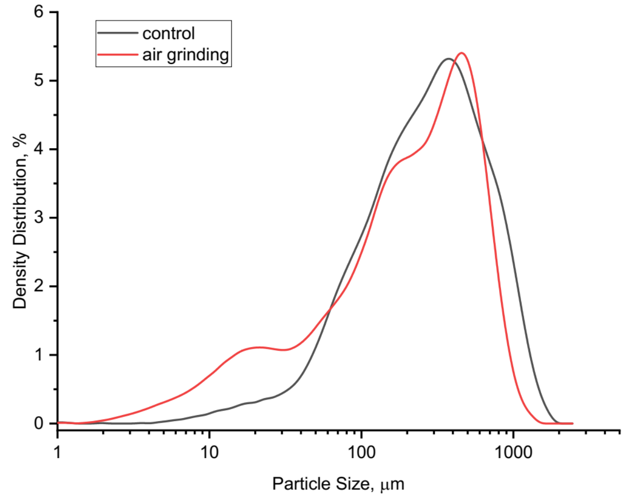

Fig. 3. Particle size distribution profile of roasted buckwheat powder with different methods of whole grain grinding

The granulometric data were confirmed and specified by using scanning microscopy for each sample of air-ground food powder and the control (analog, which was ground on conventional flour-grinding equipment), Fig. 4.

The photo analysis indicates selective differences in the shapes, sizes and surfaces of the powder granules using air grinding and conventional grinding. As can be seen in Fig. 4, the particle sizes of food powders obtained by air milling technology have a more regular shape, as well as more crushed ones.

In addition, the roughness of wheat bran powders crushed by traditional technology is greater, which indicates damage due to mechanical impact. Morphological observations of the surface of buckwheat powder after air milling indicate that the air flow affects the powders in all cases, increasing their surface area.

In foods, smaller particle size results in faster digestion of starch. Small particles have a high surface to volume ratio, which increases the access of enzymes to the interior of the particle, taking advantage of the absence of intact cell walls [11].

Increased surface area of food materials can accelerate the absorption of water by materials, improving the solubility of dry foods and increasing accessibility to chemical reactions (oxidation, digestion, release of flavor, catalyst, and enzyme activity) [12]. pH measurements showed that the acidity of food powders differed little with different grinding methods. Fluctuations are within the measurement error.

The exception is roasted buckwheat, where apparently finer grinding during air milling releases 1.8 times more fatty acids, found mainly in the outer shells of the grain (Table 2).

The measurement of the specific surface area of air milled food powders shows significant advantages of being able to use a jet mill compared to conventional milling with a roller mill.

Moreover, if for black grain wheat the growth seems not very significant by 22–23 %, for fried buckwheat the increase in specific surface increased by 272 %, and for bran – by a phenomenal 1575 % (Table 3).

Nearly 16 times the specific surface area of food powders in the case of bran grinding suggests that for grain hulls, jet milling provides a new level of grinding.

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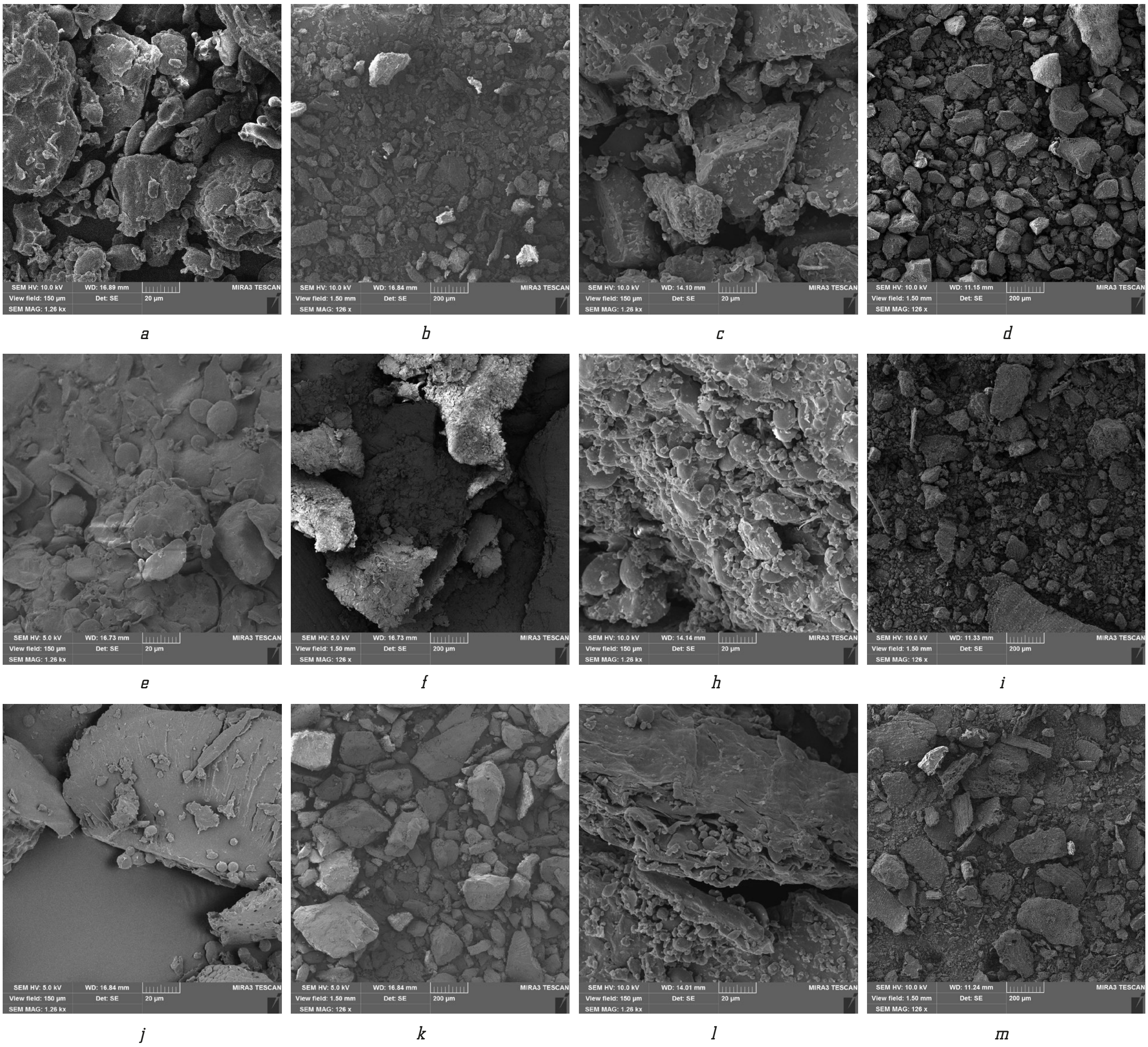

Fig. 4. The morphology of the surface of food powders is presented on microphotographs of various resolutions:
a, b – Photos 1, 2. Whole grain black wheat flour obtained by conventional technology; *c, d* – Photos 3, 4. Whole meal black wheat flour obtained by air milling technology; *e, f* – Photos 5, 6. Wheat bran flour obtained by conventional technology; *h, i* – Photos 7, 8. Wheat bran flour obtained by air milling technology; *j, k* – Photos 9, 10. Fried buckwheat whole grain flour obtained by conventional technology; *l, m* – Photo 11, 12. Whole grain roasted buckwheat flour obtained by air milling technology

Table 2

Comparative data on the acidity of food powders, pH units

Product	Air grinding	Control	Difference
Black wheat	2.6	2.6	0
Wheat bran	2.0	2.2	0.2
Roasted buckwheat	3.2	1.8	1.4

Table 3

Specific surface area, m^2/kg

Product	Air grinding	Control	Difference
Black wheat	56.52	46.20	10.32
Wheat bran	71.53	4.54	66.99
Roasted buckwheat	48.14	17.69	30.45

3.2. Thermophysical properties of food powders. The study of the thermophysical properties of samples of air grinding and control samples of grinding of a similar composition obtained in a roller mill was conducted using a water activity analyzer. Results showed that, due to the specifics of grinding, a number of parameters of food powders obtained in a jet mill are close to the standard, but still, they are generally higher than those of controls.

For example, in wheat flour, the specific moisture content during air grinding is 17–18 % higher. The specific enthalpy also increases and the dew point temperature is more than 2.3 °C (Table 4).

The thermophysical properties of bran almost do not change depending on the grinding, except for the fact that in the powder obtained in the jet mill, the saturation vapor pressure increases by 0.28 GPa and the vapor concentration at saturation increases by 0.21 g/m^3 (Table 5).

Table 4

Comparative thermophysical properties of black wheat flour

Index	Unit of measurement	Air grinding	Control	Difference
Water activity	a_w	0.594	0.503	0.091
Specific humidity	g/kg	7.03	5.99	1.04
Saturated steam pressure	GPa	18.95	19.08	–0.13
Specific enthalpy	J/g	34.64	32.07	2.57
Dew point	°C	8.7	6.37	2.33
Vapor concentration at saturation	g/m^3	14.16	14.25	–0.09

Table 5

Comparative thermophysical properties of wheat bran powder

Index	Unit of measurement	Air grinding	Control	Difference
Water activity	a_w	0.542	0.548	–0.006
Specific humidity	g/kg	6.46	6.44	0.02
Saturated steam pressure	GPa	19.08	18.80	0.28
Specific enthalpy	J/g	33.30	33.00	0.3
Dew point	°C	7.48	7.42	0.06
Vapor concentration at saturation	g/m^3	14.27	14.06	0.21

For roasted buckwheat flour, an increase in all thermophysical parameters during air grinding is observed in comparison with control samples obtained in conventional factory mills. An increase in specific enthalpy and specific humidity by 4–5 % can be considered a rather significant effect (Table 6).

Table 6

Comparative thermophysical properties of roasted buckwheat flour

Index	Unit of measurement	Air grinding	Control	Difference
Water activity	a_w	0.562	0.549	0.007
Specific humidity	g/kg	6.71	6.44	0.27
Saturated steam pressure	GPa	19.10	18.76	0.34
Specific enthalpy	J/g	33.94	32.57	1.37
Dew point	°C	8.02	7.42	0.6
Vapor concentration at saturation	g/m^3	14.27	14.03	0.24

In general, the definition of indicators related to the activity of water in food powders says that for products that have been dried beforehand (like wheat bran) or dehydrated during roasting (like whole grain buckwheat), thermophysical parameters do not change significantly. The growth of some indicators by 4–5 %, characteristic of the samples obtained by air grinding, can be explained by the additional dispersion and accessibility to moisture that occurs in food powders during air grinding.

Air grinding gives a much greater effect when grinding grains that have not undergone pre-treatment. A significant increase in a number of indicators associated with the activity of water in whole grain wheat flour during air milling indicates that this grinding method provides high quality and increases the shelf life of both flour and food products obtained from it. Water activity, expressed as the ratio of water vapor pressure over a given product and over pure water at the same temperature, characterizes the state and ability to participate in physical, chemical and biochemical reactions. The release of water from the bound state during air grinding ensures its activity, because. Tightly bound water is not a solvent and does not react in food preparation.

3.3. Biotechnological parameters of food powders. Centrifugation of samples of air milling and control samples of grinding of a similar composition, obtained in a roller mill, showed significant differences in jet mill products over control ones in almost all biotechnological parameters: water-absorbing ability (WAA), moisture-retaining ability (MRA), fat-absorbing ability (FAA), fat-retaining ability (FRA) and emulsifying ability (EA), as well as emulsion stability (ES). WAA, MRA, FAA and FRA were determined in ml/g, while ES and EA were determined as a percentage.

The results of the determination are shown in diagrams (Fig. 5–7).

An analysis of the obtained results makes it possible to make a correlation between the particle sizes and the functional properties of the powders. Thus, during air grinding of black grain wheat, the particle size decreases and, accordingly, the water absorption capacity, water-holding capacity, fat-absorbing capacity, fat-retaining capacity and emulsifying capacity increase significantly. With air milling, the surface of the starch granules, which are abundant in whole grain wheat flour, becomes wider, the granule area and the surface area of the flour particles increase, and, consequently, water diffusion occurs. In addition, the sensitivity of starch to hydrolysis and the availability of enzymes, in particular α-amylase to starch cells, increase due to the disaggregation of wheat flour components. Torn off starch granules from the protein matrix can also lead to rapid starch hydrolysis.

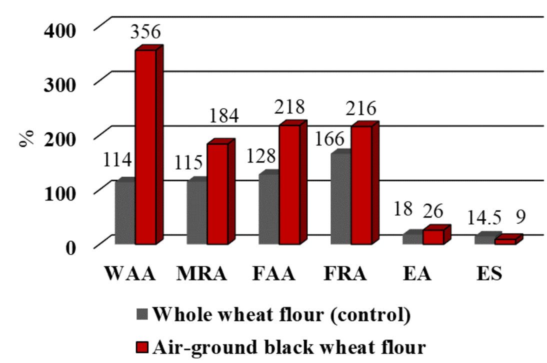

Fig. 5. Comparison of functional parameters of whole grain flour from black wheat during air grinding (experimental sample) and conventional grinding (control)

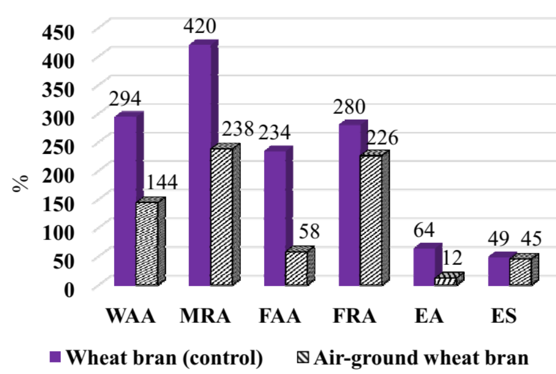

Fig. 6. Comparison of functional parameters of crushed wheat bran during air (experimental sample) and conventional grinding (control)

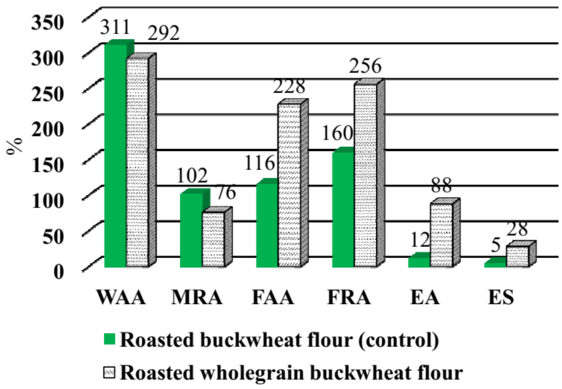

Fig. 7. Comparison of functional parameters of fried whole-grain buckwheat flour with air (experimental sample) and conventional grinding (control)

Analysis of the results of studies of fried buckwheat and wheat bran indicates a decrease in the water-absorbing capacity and water-holding capacity of the prototypes compared to the control. This is because the surface components of the granules, such as proteins, can create a surface membrane that acts as a physical barrier to degradation. The protein layers must be substantially degraded before starch degradation occurs. In the samples of fried buckwheat flour, the indicators of fat-absorbing capacity and fat-retaining capacity increased, which is explained by the peculiarities of the lipid composition of the powders. The analysis of functional properties in terms of their practical significance should be considered in the context of applications in the food industry. These samples are mostly used in the baking industry.

When kneading dough, the flour particles are hydrated after the addition of water, which leads to an increase in the mobility of their molecular chains and swelling of the starch granules. In addition to the action of water, the supply of mechanical energy during dough kneading leads to a redistribution of flour particles and to the formation of a viscoelastic protein network. One of the important factors affecting the viscoelastic properties of the dough is the amount of added water. However, let's give an example: there are two recipes for making bread; they are the same except for one ingredient (for example, flour from the distribution network and flour obtained by air grinding). The same amount of water was added to both recipes. After kneading the dough, fermenting it and subsequent operations with the same parameters of the technological process, bread was baked that differed significantly in volume, porosity structure, and crumb condition: one was of good quality, large volume with loosened crumb, and the other with inelastic, poorly developed porosity and small volume. This happened because the water-absorbing and water-holding abilities of the powders differed significantly from each other. Water molecules act as plasticizers and soften the texture of the dough. Dough with a water content below the optimum results in an uneven distribution of the protein network, which forms the frame of the bread. Dough with more than optimal water content has more aggregated proteins, less interconnected. In addition, there is competition between starch and protein for available water, which plays an important role. The amount of water in the dough affects the mobility of the gluten proteins gliadins and glutenins during dough preparation and thus the development of the gluten framework. When additional ingredients are added to the traditional bread recipe (or when the components of the recipe are replaced by these ingredients), depending on the indicators of water-absorbing and water-retaining abilities, the dynamics of water absorption changes significantly, since gluten molecules must compete not only with starch, but also with substances that also absorb and hold water.

If to analyze the powders under study and compare them with controls, let's draw the following conclusions: the water-absorbing and water-holding capacity of black grain wheat is higher than its analogue – whole grain wheat flour (control) and significantly higher than premium wheat flour, from which most types of bakery are traditionally made. This means that when making bread using this powder, it will be possible to develop an optimal network of gluten in the dough, it will require more water than dough made from control, but bread quality indicators will be higher, in particular bread specific volume and porosity. After all, moisture will be well retained, which means that the gluten subunits will properly connect to each other. The consequence of this is a strong viscoelastic protein network, which can contain gas generated during dough fermentation. As for fried buckwheat and wheat bran, their water absorption and water holding capacity are lower than the control. This is a positive factor in the technology of bakery products, since these powders contain a large amount of dietary fiber in their chemical composition. When using well-known analogues, when they are added to the dough, they compete for water with gluten proteins, swell and thereby compact the structure of the dough. It loses its elastic properties, viscosity increases and the dough is not able to properly retain carbon dioxide to loosen the dough piece. Lack of hydration maintains protein-protein hydrogen bonds and thus leads to compaction of the dough mass, which prevents gliadins from incorporating into the gluten network and achieving high bread volume.

3.4. Discussion. The strengths of this study lie in the fact that a comprehensive analysis of the qualitative characteristics (for all main types of standard indicators) was carried out for various types of food powders, including whole grains, obtained as a result of air grinding technology in an improved jet mill. This may provide a basis for the introduction of technology that will significantly increase the quantity and quality of food even in the case of reduced harvests.

The weaknesses of this study are related to the fact that in order to fully determine the beneficial qualities of food powders produced using improved air milling technology, it is necessary to conduct a quantitative analysis of the substances contained in them, as well as studies with food industry products that are obtained from whole grain powders grinding.

Additional opportunities when using these results in industrial conditions are associated with the possibility of correlating the recipes for the preparation of products using food powders produced using existing technologies with whole grain flour made by air milling in an improved jet mill.

To make a final decision on the benefits of air-milled whole grain flour, it is necessary to conduct in-depth studies, including with an expanded range of food powder varieties, ascertaining their composition and properties of products obtained from them.

4. Conclusions

1. Whole grain food powders obtained by the advanced jet mill have properties close to standard flours produced

by conventional mills in terms of physical, thermophysical and biotechnological parameters. This allows them to be used without a significant change in the formulation of traditional products based on cereal flour (bakery products, pasta, boiled dough products, etc.).

2. Measurements have shown that the improved jet mill ensures the production of flour of the same consistency both from the endosperm and from other parts of the grain (germ, shells). Particles of such flour should be equally efficiently processed and absorbed by the body. From the same amount of raw material, therefore, it is possible to produce approximately 30 % more final grinding products. At the same time, the flour is really whole grain – saturated with not only a variety of carbohydrates necessary for the development of the body, but also proteins, unsaturated fats, vitamins, microelements.

3. The advanced jet mill, unlike traditional mills, has no rubbing parts. Therefore, it does not contaminate the grinding products with technogenic components, and the constant temperature of the ground substance in the air stream allows many biologically active substances that are sensitive to temperature increase to be preserved in the flour.

4. Participation in the process of obtaining raw materials for the experiments described in this article showed that the improved jet mill allows to produce flour with the specified parameters, with almost the same energy consumption as conventional grinding methods. Thus, it becomes possible to produce flour by air grinding at the same cost as in a conventional mill, but it can be really whole grain flour, providing, through products made on its basis, consumers not only with energy, but also with everything necessary for a healthy and active life. If necessary, on the basis of various raw materials, the production of dietary in composition or, on the contrary, saturated with substances products that promote recovery from specific diseases, disease prevention, and active longevity can be ensured.

Conflict of interest

The authors declare that there is no conflict of interest regarding this study, including financial, personal nature, authorship or other nature that could affect the research and its results presented in this article.

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Data availability

The manuscript has no associated data.

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