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Research of quality indicators of different types of wholegrain flour

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Abstract. The concept of modern nutrition involves the presence of the maximum amount of nutrients, including vitamins, essential amino acids, carotenoids, natural antioxidants, minerals, phenolic and tannin compounds, organic acids, and dietary fibre, which is why the food industry is interested in developing wholegrain products based on crops such as wheat, rye, barley, triticale, buckwheat, corn, and rice. The purpose of the study is to evaluate wholegrain flour using modern production technologies and control its quality, which will lead to a new level of development in the Ukrainian food industry and ensure increased profitability of the flour milling and baking industries.

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Methods used in the study: theoretical – analysis, synthesis, comparison and generalisation; experimental – identification and measurement to determine the physicochemical, organic, grinding, flour-milling and baking quality indicators of wholegrain wheat flour. Characterising the experimental data of different types of wholegrain flour, it was established that the content of dry matter, crude protein, crude fat, crude fibre or fibres, mineral content, and easily hydrolysed carbohydrates (starch, hemicellulose) were in the range of 84.7-88.8%, 10.2-16.3%, 0.9-1.7%, 2.3-4.8%, 1.2-3.2%, and 77.5-84.2%, respectively. Indicators such as ash content and flour size directly depended on the grinding scheme and the integrity of all anatomical grain particles. The technology of wholegrain wheat flour production combines the advantages of existing milling methods with minimising the adverse effect on the qualitative and quantitative gluten content, which varied from 21% to 36% in wholegrain flour samples, and the gluten deformation index ranged from 53.8 to 81.7 units. The materials of the study are of practical significance and indicate the need for further research, since when assessing the quality indicators and examining the characteristics of wholegrain wheat flour, attention should be devoted to the further development of optimal technology for the production of bread from this raw material

Keywords: wheat grain; baking properties; nutritional value; gluten; chemical and technological parameters

INTRODUCTION

Changes in the structure of food consumption in Ukraine and the expansion of the range of bakery, confectionery and culinary products made from flour require a broader understanding of its quality indicators and monitoring of the safety of food raw materials. More and more caterers are opting for wholegrain bread as it contains all the nutrients the body needs. The relevance of the issue of providing high-quality wholegrain flour is conditioned upon the current situation: a decline in grain quality and the need to find new approaches; development of technological methods and solutions that allow producing raw materials with high consumer properties. Wholegrain flour retains all the natural nutritional value of grains and provides consumers with important biologically active substances. According to D.O. Zhygunov (2017), one of the biggest challenges facing the flour and grains industry is the launch of new, high-quality and safe products. The nutritional value of wholegrain flour is about 12% protein; 2% fat, including 0.4% saturated fatty acids; 70% carbohydrates, including 2% sugar; and 1-2% fibre. M.F. Kravchenko *et al*. (2022) report that the priority in the development of functional grain products is using different crops with chemical composition correction: buckwheat, oatmeal, barley, rice, soybeans, which have high nutritional value but still have low consumer demand. Currently, the "8 Grains" multicomponent bread mix is gaining popularity in Ukraine, containing 56.4% soft wheat flour, 17.6% barley flour, 14.1% oat flour, 3.5% rye flour, 1.4% buckwheat flour, 1.4% corn flour, 1.4% durum wheat flour, 1.4% rice flour, 1.4% millet flour, and 1.5% flaxseed.

D. Marchenkov *et al*. (2021) provide information on modern flour production technologies, including chemical bleaching, stabilisation and the addition of preservatives and leavening agents, which reduce the biological and nutritional value of bakery products by extracting most vitamins, protein components, macro- and microelements from grain raw materials. These ingredients are mostly contained in the grain hull, therefore, in high-grade flour, they are 2-3 times less. O. Zakharchuk *et al*. (2023) state that in the production of high-grade flour, more than 70% of electricity is consumed by the grinding and decanting system since conventional graded grain milling is based on the stepwise mechanical separation of endosperm, germ and hull. Refined flour has some adverse effects on healthy eating, including weight gain, gastrointestinal diseases, diabetes, reduced metabolism and gluten content.

According to O. Dragan *et al*. (2021), wholegrain flour is produced only by grinding grain, thus all the properties of grain are preserved, it can be rye, wheat, multigrain, spelt, corn, barley, buckwheat, oat, rice, deodorised soya, flaxseed or any other specific purpose flour, provided that the wholegrain part is crushed and not sieved. Flour must correspond to the requirements of international standards: ISO 5530-1:2013 (2013) and ISO 5530-2:2012 (2012), which regulates the moisture content, quantitative and qualitative gluten content, falling number, ash content, whiteness, vitreous content, and percentage of the main nutrients. DSTU 2209-93 (1993) applies to various types of flour, including by-products and waste from flour milling. In addition, the quality characteristics of wheat flour meet the requirements of TC U (Technical Conditions of Ukraine) 10.6:30816688:001-202; wholegrain rye flour meets the requirements of DSTU 8791:2018 (2018); multigrain flour meets the requirements of TC U 15.6-13929625-001:2011, usually a composition of wheat, oat, millet, buckwheat, and rice. Wholegrain rice flour is gluten-free and contains half the amount of crude fat, and helps to normalise metabolic processes and improve memory and brain function. Buckwheat flour contains a large amount of crude protein, Zinc, and Copper. Wholegrain flaxseed flour in bread production has enveloping properties that lead to the normalisation of stomach acidity.

O. Ivanishcheva & O. Pahomska (2021) report on promising developments in wholegrain flour technology: Institute of Food Chemistry of the National Academy

of Sciences of Ukraine – flour "Zdorovye", according to TC U 156-02128514-006-2005; OJSC "Dobrodiya" – wholegrain flour according to TC U 15.6-0092737-006-2002; CJSC "Zhmenka" – wholegrain fine flour "Extra" according to TC U 15.636594696-001-2009. For the domestic market, LLC "Grain Base of Ukraine" produces coarse flour with a production capacity of 15 tonnes per day, providing the population with high-quality food.

The purpose of the study is to evaluate the current technologies for the production and quality monitoring of wholegrain flour, which will lead to a new level of the Ukrainian food industry and ensure increased profitability in the bakery sector.

THEORETICAL OVERVIEW

Wholegrain flour is made from unhulled seeds that are milled together with the hull and grain germ. Despite the coarseness of the resulting product, it is called wholemeal flour, or single-grind flour. In her work, N.V. Vasylenko *et al*. (2018) state that to assess the quality of flour in practice, a classification is given that is divided into 5 groups: general technological; physical and technological; chemical and technological, indicators of protein-protease and carbohydrate-amylase complexes, physical properties of dough; baking indicators and safety of raw materials.

A. Wójtowicz *et al*. (2020) report that wheat flour is classified according to the main biochemical and physical characteristics that determine nutritional value and consumer value. The characteristics are determined by the composition and structure of the flour particles and the consumer (technological) benefit. Flour classification is divided into types, species and grades. J. Lin *et al*. (2019) describe the types of grain crops by biochemical and anatomical characteristics used for flour production. According to S. Ma *et al*. (2022), the main difference between wholegrain and varietal flour is that the former contains bran and germ, while the latter consists only of the kernel endosperm. The endosperm consists mainly of starch and crude protein. Bran and germ consist of vitamins, minerals, crude protein, crude fat and crude fibre. M. Gómez *et al*. (2020) estimated that wholegrain flour contains carbohydrates, vegetable crude fibre, crude protein, crude fat, pectin, vitamins E, A, B, PP, H, Phosphorus, Selenium, Magnesium, Zinc, Ferrous, Iodine, Sodium, Calcium, Potassium, Chromium and Copper. Wholegrain flour varies significantly from ordinary flour in terms of its physical and mechanical properties and chemical composition, as the germ, husk and endosperm are milled together, thereby increasing the content of crude fibre by 10 times, calcium by 2 times, phosphorus by 3 times, magnesium by 5 times, iron by 3 times, vitamin PP by 3 times, and vitamins B_1 and B_2 by 2 times.

Wholegrain flour consists of large particles of grain endosperm, fruit hulls and germs that are not uniform in size; the size is limited by residues on wire mesh sieves No. 067 to no more than 2%, silk fabric No. 38 and polyamide fabric No. 41/43 PA to no less than 35%. W. Gao *et al*. (2020) inform that an important indicator of wholegrain flour quality is organoleptic characteristics and crunch: colour – white with yellow or grey colour and visible particles of seed hulls; crunch – the presence of a sandy feeling on the teeth; smell – pleasant aroma, in the presence of a sour or musty smell, it is concluded that the flour may be old, spoiled or stored improperly; taste – fresh, slightly sweet, without bitter or sour taste. S. Pradana-López *et al*. (2022), report that organoleptic indicators are used to determine the degree of infestation, the presence of cobwebs, larval peel, if these signs are not detected during the initial inspection, detailed sieving is conducted. The qualitative standardisation of flour in terms of ash content is established by the ratio of bran to endosperm, as the germ contains much more ash than the endosperm. The work of P. Skřivan *et al*. (2021) found that for each type of flour, there are ash content standards, not more than for: high-grade wheat – 0.55%, semolina – 0.6%, 1st grade – 0.75%, 2nd grade – 1.25%, sown rye – 0.75%, wholegrain – 1.45-2%.

Gluten is represented by a group of proteins found in the stocks of wheat, barley, rye and oats. The beneficial properties of wheat gluten include the presence of 18 types of essential amino acids, including methionine, lysine and threonine. According to A. Cappelli *et al*. (2020), the percentage of gluten in wholegrain flour is 18-22%, in the highest grade – 32%, in the first grade – 30%, in the second grade – 25%. The quality of gluten is determined by its firmness, elasticity and extensibility. Gluten is divided into three groups according to its extensibility: strong (8-10 cm), medium (11-16 cm) and weak (>16 cm). The flour falling number determines the taste, volume and appearance of bakery products and is measured by the mechanical impact of a laboratory mixer that destroys starch at high temperatures. The Grain X Hagberg-Perthen Falling Number Meter can be used to quickly and accurately measure α-amylase activity in flour, thus avoiding sprouting and enzyme activity. The work of S. Navrotskyi *et al*. (2019) reports that the optimal falling time, depending on the variety, is 260-280 s for whole wheat, 400 s for high-grade wheat, 350 s for first-grade wheat, 340 s for second-grade wheat, 105 s for whole rye.

MATERIALS AND METHODS

The following methods were used to examine the quality of wholegrain flour: theoretical methods – analysis, synthesis, analogy, comparison and generalisation; research methods – identification and measurement to determine physicochemical, organoleptic, milling and baking parameters. The information base of this study was established by regulations, food quality standards, scientific and analytical materials of official publications. An essential task of the State Food and Consumer Service of Ukraine is to track the flow of bakery food products, protect consumer rights, control the safety

and quality of wholegrain flour, provide new methods for establishing a single production cycle and improve them. According to the FAO, national policies designed to increase productivity, food security and supply are therefore focused on the efficient use and processing of grain raw materials.

The study included flour from different producers made from soft wheat grain grown in 2020 in different regions of Ukraine with an average crude protein content of 10-14%. The object of the study was the experimental samples of flour with a shelf life of 10 months, packed in paper bags of 1000±1.5-2% g: No. 1 – wholegrain wheat flour of wholemeal mill grinding; No. 2 – wholegrain wheat flour of wholemeal mill grade; No. 3 – wholegrain wheat flour of spelt mill grinding; No. 4 – wholegrain wheat flour of spelt mill grinding; No. 5 – organic wholemeal wheat flour; No. 6 – wholemeal wheat flour; No. 7 – special wholemeal wheat flour; No. 8 – wholemeal mill flour; No. 9 – wholemeal wheat flour. The requirements were set for the quality of wholegrain flour supplied to the production process in terms of the following indicators: technological – moisture, colour, smell, taste, crunch, pest infestation, the content of fine grain fraction; milling – moisture content, specific gravity, ash content, grinding, actual nutrient composition; baking properties – gluten content and quality, falling number, dispersed composition.

The quality of wholegrain flour was standardised according to the state standard DSTU 3768:2019 (2019). To determine the commercial quality of wholegrain flour, the following methods were used: sampling; colour and smell determination; percentage of dry matter. The quality of wholegrain flour was measured by determining the amount and quality of gluten, the gluten deformation index (GDI) according to DSTU ISO 13690:2003 (2009) and according to DSTU ISO 21415-2:2009 (2009). Several special laboratory tests in biology edited by V.V. Vlizlo *et al*. (2012) were used: total nitrogen content converted to crude protein by the Keldahl method; crude fat by the method of extraction with organic solvents, crude fibre or dietary fibre; crude ash, BEA (nitrogen-free extractive substances), which are represented by a group of easily hydrolysed carbohydrates). Mycotoxins are generated in many grains by microscopic mould fungi that develop during long-term storage. According to DSTU EN 12955-2001 (2001), the presence of mycotoxins Aflatoxin, T-2 toxin, and deoxynivalenone (DON) was determined in wholegrain flour using a Sunrise enzyme-linked immunosorbent assay. Bread quality tests were performed to examine the functional activity of wholegrain flour: bread volume, porosity, and specific volume of bread.

The results were analysed statistically, reliable conclusions were drawn and comparisons were made between the wholegrain samples. The data obtained on the chemical composition of wholegrain flour was summarised, and as a result, it was possible to draw fairly reliable conclusions about milling, storage conditions, the safety of use, basic physical and chemical parameters, commercial qualities, and characteristics of baked bread.

RESULTS

The quality of wholegrain flour is significantly influenced by the processing technologies for different types of grains, which are separated for mechanical processing using millstones and rollers. Two technologies are distinguished: the stone mill and the vertical mill. Their essence is to grind grain between millstones of solid stone. The advantage of these methods is the preservation of nutrients, natural taste and aroma, and a homogeneous end product. Grain threshing using two rollers differs from the previous grain processing techniques as it separates the grain into three parts – gluten, flour, and bran – which are mixed in the required quantities. The process of shredding with crushing rollers, while retaining nutrients, is less efficient than other methods.

To increase the moisture content and saturation of wholegrain flour, the grain is soaked and heat-treated. The advantage of the maceration process is the reduction of anti-nutrients in the grain, such as phytic acid, tannins or tannins, trypsin inhibitors and alkyl resorcinols. The presence of anti-nutrients in whole grains can interfere with the normal absorption of nutrients. Maceration – is the process of restoring grain by soaking it in water, acid or alkaline solutions for a specific period and then drying and milling it. Maceration is usually performed at low or high temperatures and in the presence of enzymes. Notably, maceration can increase flavour intensity and improve aroma. Grain heat treatment – an increase in the temperature of the raw material just before milling using drying shafts, special ovens or industrial dryers. Due to the different technical and biochemical characteristics of different wheat varieties, the parameters of hydrothermal treatment of wheat grain vary from those of other crops, with the optimum moisture content being 12-14%. The experiment determined the food parameters of wholegrain flour, such as moisture content, gluten quality and quantity, fibre deformation index (FDI), falling number (FN), and flour size, the data are presented in Table 1.

Table 1. *Quality indicators of the tested wholegrain flour samples*

No.	Product name	Moisture content, %	Gluten		FN, sec	Size, %	
			%	FDI, units		sieve No. 067	sieve No. 38
1.	Wholegrain wheat flour, mill-ground, wholemeal flour	12.64	27.4	81.8	375	6	60

Table 1, Continued

No.	Product name	Moisture content, %	Gluten		FN, sec	Size, %	
			%	FDI, units		sieve No. 067	sieve No. 38
2.	Wholegrain wheat flour of the wholemeal milling	13.16	21.2	71.3	333	0.4	49
3.	Spelt wholegrain wheat flour, mill-ground, wholemeal flour	12.45	36.5	85.6	388	3	56
4.	Spelt wholegrain wheat flour for wholemeal milling	12.56	32.4	81.1	354	1	50
5.	Organic coarse wholegrain wheat flour	14.24	24.8	68.1	311	-	30
6.	Coarse wholegrain wheat flour	10.44	25.7	79.2	336	0.4	51
7.	Extra coarse wholegrain wheat flour	13.2	23.4	75.9	330	-	50
8.	Milestone wholegrain wheat flour	12.79	15.8	53.7	274	16	30
9.	Wholegrain wheat flour	11.88	21.7	72.6	323	0.6	62

Source: *compiled by the authors*

The gluten content and FDI of wholegrain flour are important in determining the structural and mechanical properties of the dough and baking properties, which are standardised at no less than 18%. The highest gluten content was observed in flour samples 3 and 4 – 36.5% and 32.4%, respectively. Therewith, in samples 1, 5, 6 and 7, the gluten content was in the range of 24.8-27.4%, and the lowest crude gluten content was observed in samples 2 and 9 – 21.2% and 21.7%. However, only one of the flour samples, No. 8, contains a low gluten level of 15.8%, which is not regulated by the standard. The qualitative composition of gluten, expressed in conventional units of FDI, varied according to the quantitative composition. As a result of the evaluation of the tested samples of wholegrain flour for moisture content, ash content, gluten, size at the passage through sieve No. 067, and size at the passage through sieve No. 38, it was determined that they were in the range of 10.4-14.2%, 1.1-1.6%, 21-36%, 0.4-16%, 30-62%, respectively.

It is recommended to evaluate the size of wholegrain flour; the finer it is ground, the higher the content of damaged starch grains, which are more likely to be affected by enzymes, thus, the dough made from wholegrain flour is more actively thinned, and the bread produced has a sticky crumb and a smaller volume. The size of the coarse grinding of the upper part of the flour is controlled by the residue on sieve No. 067 and the passage speed on sieve No. 38. These indicators differed significantly in the flour samples tested. Thus, in samples 1 and 3, the percentage residue on sieve No. 067 is within 3-6%, in sample 8-16%, and in samples 2, 4, 5, 6, 7 and 9, within 0.4-1%. The percentage of fine flour that passed through sieve No. 38 was highest in samples 1, 2, 3, 6, 7 and 9, ranging from 50-60%. Therewith, for samples 5 and 8, the content of the respective fractions did not exceed 30%.

The chemical composition of flour depends on the grain grade, climatic and agronomic conditions of cultivation, flour grade and milling scheme, in particular, wholegrain flour is close to the chemical composition of the wheat grain from which it is made, as presented in Table 2.

Table 2. *Chemical composition in absolute dry matter, %*

No.	Product name	Protein	Fat	Fibre	Ash	NES
1.	Wholegrain wheat flour, mill-ground, wholemeal flour	11.16	1.37	2.37	1.73	83.37
2.	Wholegrain wheat flour of the wholemeal milling	15.83	1.07	2.43	2.59	78.08
3.	Spelt wholegrain wheat flour for wholemeal milling	10.49	0.9	2.78	1.62	84.21
4.	Spelt wholegrain wheat flour for wholemeal milling	13.72	1.14	3.65	2.13	79.36
5.	Organic coarse wholegrain wheat flour	11.66	1.62	4.84	3.15	78.73
6.	Coarse wholegrain wheat flour	16.33	1.22	2.76	1.17	77.53
7.	Extra coarse wholegrain wheat flour	14.26	1.64	2.35	2.79	78.96
8.	Milestone wholegrain wheat flour	10.21	1.18	2.33	2.2	84.08
9.	Wholegrain wheat flour	13.04	1.3	2.5	2.65	80.51

Note*: NES – nitrogen-free extractive substances*
Source*: compiled by the authors*

Characterising the experimental data of wholegrain flour, which is characterised mainly by energy raw materials, containing 84.7-88.8% dry matter, 10.2-16.3% crude protein, 0.9-1.7% crude fat, 2.3-4.8% crude fibre, 1.2-3.2% ash, 77.5-84.2% NES, represented mainly by 65-75% starch. Therewith, the average nutritional value of 1 kg of wholegrain flour in terms of absolute dry matter is 1.35 feed oat units, 90-140 g of digestible protein, depending on the type of flour. In addition, the chemical composition of flour depends on the composition of the grain from which it is made and its grade. The higher the grade of flour, the higher the starch content. The content of other carbohydrates, and fat, ash and protein increases with the grade of flour. In particular, wheat flour contains a wide range of macro- and microelements: Phosphorus (P), Calcium (Ca), Magnesium (Mg), Zinc (Zn), Ferric (Fe), Copper (Cu) and other minerals that are important for maintaining the vital functions of the human body, as detailed in Table 3.

Table 3. *Content of nutrients on an absolutely dry matter basis*

No.	Product name	P, g/kg	Ca, g/kg	Mg, g/kg	Fe, mg/kg	Zn, mg/kg	Cu, mg/kg
1.	Wholegrain wheat flour, mill-ground, wholemeal flour	3.66	0.5	37.91	36.5	18.67	5.41
2.	Wholegrain wheat flour of the wholemeal milling	3.92	0.4	37.01	37.03	19.91	5.96
3.	Spelt wholegrain wheat flour, mill-ground, wholemeal flour	4	0.48	32.48	36.03	21.09	14.23
4.	Spelt wholegrain wheat flour for wholemeal milling	4.23	0.54	39.78	36.79	22.54	19.65
5.	Organic coarse wholegrain wheat flour	4.66	0.69	41.44	48.76	24.7	6.34
6.	Coarse wholegrain wheat flour	3.57	0.57	39.76	38.25	18.29	6.55
7.	Extra coarse wholegrain wheat flour	3.57	0.67	37.37	42.83	19.29	6.32
8.	Milestone wholegrain wheat flour	3.1	0.54	32.27	45.28	21.74	17.38
9.	Wholegrain wheat flour	3.97	0.43	37.36	55.57	24.32	20.73

Source: *compiled by the authors*

Flour consists mainly of organic and a small amount of inorganic (mineral or ash) substances, which are concentrated mainly in the aleurone layer, hulls and germ. Characterising the experimental data on the macro- and microelemental composition of different types of wholegrain flour, it was established that it contains Phosphorus – 3.1-4.7 g/kg, Calcium – 0.43-0.67 g/kg, Magnesium – 32.4-41.4 g/kg, Ferrous – 36.5-55.6 mg/kg, Zinc – 18.3-24.7 mg/kg, and Copper – 5.4-20.7 mg/kg. There is a difference in mineral composition between wholegrain flour varieties due to different milling and conditioning techniques. Mycotoxins are poisonous metabolic products of about 160 moulds that develop on the surface of grain and feed. The most toxic is aflatoxin B_1, which has carcinogenic, teratogenic and mutagenic effects. As part of the study, the safety of this food raw material was assessed, as it is easily contaminated, as presented in Table 4.

Table 4. *Mycotoxin content (aflatoxin, DON, T-2)*

No.	Product name	Aflatoxin (total), mg/kg	DON, mg/kg	T-2, mg/kg
1.	Wholegrain wheat flour, mill-ground, wholemeal flour	-	0.0005	0.001
2.	Wholegrain wheat flour of the wholemeal milling	-	-	-
3.	Spelt wholegrain wheat flour, mill-ground, wholemeal flour	-	-	-
4.	Spelt wholegrain wheat flour for wholemeal milling	-	-	-
5.	Organic coarse wholegrain wheat flour	-	-	-
6.	Coarse wholegrain wheat flour	-	-	-
7.	Extra coarse wholegrain wheat flour	-	-	-
8.	Milestone wholegrain wheat flour	-	-	-
9.	Wholegrain wheat flour	-	-	-
Standardisation according to DSTU 3768:2009		⩾0.005	⩾0.1	⩾0.1

Source: *compiled by the authors*

The maximum permissible levels of mycotoxins are: not more than 0.005 mg/kg for aflatoxin, not more than 0.1 mg/kg for DON, not more than 0.1 mg/kg for T-2. As a result of the experiment, it was established that the sample of wholegrain wheat flour (wholemeal) contains 0.0005 mg/kg DON, 0.001 kg/kg T-2, which limits its use for baby food and pasta. No mycotoxins were detected in the other wholegrain samples. The results of bread production from the tested wholegrain flour samples are presented in Table 5.

Table 5. *Physico-chemical characteristics of bread made from wholegrain flour*

No.	Product name	Bread volume, cm^3	Porosity, %	Specific bread volume, cm^3/g
1.	Wholegrain wheat flour, mill-ground, wholemeal flour	372	63.7	1.8
2.	Wholegrain wheat flour of the wholemeal milling	432	66.3	2.1
3.	Spelt wholegrain wheat flour, mill-ground, wholemeal flour	498	68.6	2.3
4.	Spelt wholegrain wheat flour for wholemeal milling	515	72.1	2.5
5.	Organic coarse wholegrain wheat flour	451	70.3	2.2
6.	Coarse wholegrain wheat flour	585	72.7	2.7
7.	Extra coarse wholegrain wheat flour	470	70.4	2.2
8.	Milestone wholegrain wheat flour	260	47.4	1.3
9.	Wholegrain wheat flour	447	68.9	2.1

Source*: compiled by the authors*

The baked bread was characterised by a developed and uniform porosity, a deep and smooth crust surface without side accents, and a pleasant taste and aroma. Flour sample No. 6 was defined by the largest bread volume of 585 cm^3, high porosity of 72.7% and low ash content, as the bran was separated and not mixed with the flour during production. Flour samples No. 3, 4 and 7 had a high bread volume and porosity of about 70%, which was due to a high gluten content of more than 24% and flour size in the range of 50-56% when passing through sieve No. 38. Flour sample No. 8 did not form a gluten crust, had the smallest volume of bread among the tested samples, low porosity (47%) and the lowest gluten level.

DISCUSSION

The flour examined was produced using stone and roller milling methods. The grinding size is related to the baking properties of the flour, its swelling rate and water absorption capacity. The selected milling methods have a significant impact on the quality of flour, especially wholegrain flour, the rheological properties of the dough and the characteristics of the bread. The size of the coarse grinding of the upper part of the wholegrain experimental flour was controlled by the residue on sieve No. 067 and the passage speed on sieve No. 38. Uneven grain size can reduce the baking performance of flour. According to J. Bressiani *et al.* (2019), the need to standardise wholegrain wheat flour by size and estimate the size of wholegrain flour particles from 194.9 to 830 μm is emphasised. Higher-grade flours usually have a more uniform particle size distribution (consisting of particles of more uniform size and shape) than lower-grade flours. The particle size of high-grade flour is between 30 and 40 microns, while wholegrain flour is more commonly between 30 and 670 microns.

When preparing flour-based dishes, bakery and confectionery products, the amount of flour used depends on its moisture content, which is based on 14.5%. The moisture content of the wholegrain flour samples was within the permissible limits, with the highest value recorded in sample No. 7 at 14.2%. The research of J. van Rooyen *et al.* (2022) demonstrated that soft wheat grain is quickly saturated with water, but moisture content characterises the nutritional value of the grain and its suitability for storage and processing. Wheat is considered a suitable raw material for long-term storage if it is stored in dry form and has a mass fraction of dry matter of at least 86%. For long-term storage of wholegrain flour, it is necessary to maintain a temperature of 5-15°C and relative humidity of 60-70%, as grain and flour storage is adversely affected by sudden fluctuations in temperature and relative humidity.

Wholegrain flour produced using different milling technologies differed significantly in organic quality, thus, it is important to assess the FDI indicator. The lower the FDI content, the stronger the gluten and the shorter the stretch; the higher the FDI, the weaker and more malleable it is. The gluten content of the wholegrain flour samples ranged from 21% to 36%, with the FDI ranging from 53.8 to 81.7 units. Therewith, sample No. 8 of wholegrain mill wheat flour demonstrated an unusually low gluten level of 16%. J.C. Cancilla *et al.* (2022) report that according to world standards, soft wheat is regulated by classes: for class 1, the gluten content is 30-32%, class 2 – 26-28%, class 3 – 22-23%,

and class 4 – 16-18%; and the FDI index for class 1, 2 of soft wheat ranges from 43-77 units, for classes 3 and 4 – 18-102 units. The gluten index of durum wheat by class is 28% for class 1, 25% for class 2, 22% for class 3, and 18% for class 4. The gluten index for durum wheat should be in the range of 18-102 units. Bread producers have different approaches to the choice of raw materials, some select high-quality wheat and spelt to produce wholegrain flour, which is much more expensive due to its significantly higher baking properties, while others use cheaper flour. As described by J. Kuang *et al*. (2022), the elasticity and resilience of dough depends on the gluten content. The amount of gluten in flour affects the protein value, organoleptic properties of raw materials, keeping the form of semi-finished products, and the preservation of the form of products during drying and cooking. Flours with tearable gluten are unsuitable for baking products with forms, such as tubes or pasta, as these products boil quickly and do not retain their original appearance. Food processors distinguish three groups of flour by gluten: Group I is defined by good quality – 45-75 units; Group II by satisfactory strength – 20-40 units; Group III by unsatisfactory strength – 0-15 units.

The chemical composition of wholegrain flour was examined for dry matter, crude protein or protein, crude fat or lipids, crude fibre or fibres, minerals, and NES, but particular attention should be paid to the carbohydrate content. The total carbohydrate content corresponds to the sum of crude fibre and NES, which is in the range of 79.8-89%, where non-starch polysaccharides are represented by crude fibre, and starch and sugar are represented by NES. According to C.J. Seal *et al*. (2021), grains are a complex mixture of different forms of carbohydrates distributed in different amounts in grain fractions, and the carbohydrate content in wholegrain flour was in the range of 81.7-75.9%, starch – 55-60%, total sugar – 3.5-4%, crude fibre – 2.1-3.3%.

Mineral elements have no energy value but are important nutrients for the development and normal functioning of the body. Minerals are concentrated in the grain hull and are largely removed during conventional milling, thus, monitoring macro- and microelements in wholegrain flour is an important stage of research. The macro- and microelement composition of the experimental wholegrain flour was as follows: Phosphorus – 3.1-4.7 g/kg, Calcium – 0.43-0.67 g/kg, Magnesium – 32.4-41.4 g/kg, Ferrous – 36.5-55.6 mg/kg, Zinc – 18.3-24.7 mg/kg and Copper – 5.4-20.7 mg/kg. According to the research of W. Biel *et al*. (2021), wholegrain wheat flour is rich in minerals: Potassium – 15.8 g/kg, Magnesium – 29.3 g/kg, Phosphorus – 40.4 g/kg, Ferrous – 20.6 mg/kg, Manganese – 170 mg/kg, Copper – 47.5 mg/kg, Selenium – 23.1 mg/kg, Zinc – 24.7 mg/kg. Consumption of bread made from wholegrain flour covers the needs for B_3, B_5, PP by one quarter, as the content of these vitamins is B_1 – 19.8 IU, B_5 – 20.2 IU, PP – 26.7 IU.

Compared to conventional wheat, spelt contains more protein, fat, fibre, vitamins and minerals, and the nutrients in spelt are highly soluble in water, thus, being easily and quickly absorbed by the body. According to the physical and chemical parameters of the bread, sample No. 4 (wholegrain wheat flour milled from spelt) was defined by a total volume of 515 cm^3, porosity of 72.1% and specific volume of 2.5 cm^3/g. Following O. Pysarets *et al*. (2020), wholegrain spelt flour is a valuable functional raw material in the technology of bakery products production, but it has significant differences in rheological properties from conventional wheat flour, which is why it requires certain technological measures to improve the quality of finished products. Products made from spelt flour have a smooth surface, dark golden colour and regular shape, specific volume of 2.4 cm^3/g, and porosity of 68%. Spelt flour dough takes longer to knead and has better stability, but when heated, the dough weakens and thins out more, which helps to keep it fresh longer.

To enrich bread and bakery products, it is recommended to use a combined mixture of millet, buckwheat, oat flour, oat flakes and wheat germ. The inclusion of protein products in the dough increases both the protein content and the content of minerals, vitamins B and PP, which improves the quality of the product, improves its organoleptic and physicochemical characteristics, and extends the shelf life. As argued by L. Ghelardini *et al*. (2022), wheat germ flakes in the amount of 8-12% by weight of wholegrain flour increase the protein content by 22.8%, carbohydrate content by 4 times, fat content by 3.5 times, and fibre content by 15 times. Consumption of one such loaf of bread per day will satisfy the daily requirement for vitamins and minerals.

CONCLUSIONS

Ukraine's bakery industry is one of the main sectors of the food industry to ensure stable production of bread, bakery and other flour products in volumes that meet national food security standards. The benefits of consuming wholegrain flour have a positive impact on health, as they help maintain normal gastrointestinal function, and optimal blood sugar levels, and balance the diet with essential ingredients. The popularity of whole grains is growing every year, and more and more people are actively including whole grain products enriched with dietary fibre, protein, vitamins and minerals in their daily diet.

The monitoring of the Ukrainian market demonstrated no significant differences in the quality of wholegrain wheat flour, thus, a national standard should be developed to enable its wider use in the food industry and healthy food technologies. The analysis of experimental data obtained from different types of experimental flour demonstrated that the content of dry matter, crude protein, crude fat, crude fibre, minerals and

NES was within the range of 84.7-88.8%, 10.2-16.3%, 0.9-1.7%, 2.3-4.8%, 1.2-3.2% and 77.5-84.2%, respectively. The qualitative and quantitative gluten content of wholemeal flour varies from 21% to 36%, and the FDI ranges from 53.8 to 81.7 units. The results of the safety assessment of this raw material demonstrated that the sample of wholegrain flour (wholemeal flour) contained DON – 0.0005 mg/kg, T-2 – 0.001 kg/kg, therefore, it is restricted for use in baby food and pasta, in particular, no mycotoxins were detected in other flour samples.

The study of the quality of different types of wholegrain flour is an important area in the food industry, as the variety of production methods and uses can affect the quality of the final food product. Indicators such as ash content and flour size specifically depend on the milling method and the completeness of all anatomical particles. For a more accurate assessment of the quality of wholegrain flour, further research is needed using various methods and relevant factors: product composition, cooking methods, and taste preferences. The quality of flour produced by different milling equipment differs in terms of nutritional, organic and technical characteristics.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Biel, W., Jaroszewska, A., Stankowski, S., Sobolewska, M., & Kępińska-Pacelik, J. (2021). Comparison of yield, chemical composition and farinograph properties of common and ancient wheat grains. *European Food Research and Technology*, 247, 1525-1538. doi: 10.1007/s00217-021-03729-7.
[2] Bressiani, J., Oro, T., Da Silva, P.M.L., Montenegro, F.M., Bertolin, T.E., Gutkoski, L.C., & Gularte, M.A. (2019). Influence of milling whole wheat grains and particle size on thermo-mechanical properties of flour using Mixolab. *Czech Journal of Food Sciences*, 37(4), 276-284. doi: 10.17221/239/2018-CJFS.
[3] Cancilla, J.C., Pradana-López, S., Pérez-Calabuig, A.M., López-Ortega, S., Rodrigo, C., & Torrecilla, J.S. (2022). Distinct thermal patterns to detect and quantify trace levels of wheat flour mixed into ground chickpeas. *Food Chemistry*, 384, article number 132468. doi: 10.1016/j.foodchem.2022.132468.
[4] Cappelli, A., Oliva, N., & Cini, E. (2020). Stone milling versus roller milling: A systematic review of the effects on wheat flour quality, dough rheology, and bread characteristics. *Trends in Food Science & Technology*, 97, 147-155. doi: 10.1016/j.tifs.2020.01.008.
[5] Dragan, O., Berher, A., Plets, I., Biloshkurska, N., Lysenko, N., & Bovkun, O. (2021). Modelling and factor analysis of pricing determinants in the state-regulated competitive market: The case of Ukrainian flour market. *International Journal of Computer Science and Network Security*, 21(7), 211-220. doi: 10.22937/IJCSNS.2021.21.7.25.
[6] DSTU 2209-93. (1993). Retrieved from http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=85607.
[7] DSTU 3768:2019. (2019). Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=82765.
[8] DSTU 8791:2018. (2018). Retrieved from http://online.budstandart.com/ru/catalog/doc-page?id_doc=78652.
[9] DSTU 12955-2001. (2001). Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=85573.
[10] DSTU 13690:2003. (2009). Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=86198.
[11] DSTU 21415-2:2009. (2009). Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=86207.
[12] Gao, W., Chen, F., Wang, X., & Meng, Q. (2020). Recent advances in processing food powders by using superfine grinding techniques: A review. *Comprehensive Reviews in Food Science and Food Safety*, 19(4), 2222-2255. doi: 10.1111/1541-4337.12580.
[13] Ghelardini, L., Aglietti, C., Benigno, A., Capretti, P., Gonthier, P., Luchi, N., & Moricca, S. (2022). Development of a new LAMP assay for the fast diagnosis of *Gnomoniopsis castaneae*. *Journal of Plant Pathology*, 104, article number 1237. doi: 10.1007/s42161-022-01234-8.
[14] Gómez, M., Gutkoski, L.C., & Bravo-Núñez, Á. (2020). Understanding whole-wheat flour and its effect in breads: A review. *Comprehensive Reviews in Food Science and Food Safety*, 19(6), 3241-3265. doi: 10.1111/1541-4337.12625.
[15] ISO 5530-1:2013. (2013). Retrieved from https://www.iso.org/standard/43417.html.
[16] ISO 5530-2:2012. (2012). Retrieved from https://www.iso.org/ru/standard/50934.html.
[17] Ivanishcheva, O., & Pahomska, O. (2021). Trends in the formation of the quality of functional bakery products. *Young Scientist*, 5(93), 159-163. doi: 10.32839/2304-5809/2021-5-93-30.
[18] Kravchenko, M.F., Romanovska, O.L., & Danyliuk, I.P. (2022). *Technological features of flour composite mixtures*. Riga: Baltija Publishing. doi: 10.30525/978-9934-26-205-0-9.
[19] Kuang, J., Huang, J., Ma, W., Min, C., Pu, H., & Xiong, Y. L. (2022). Influence of reconstituted gluten fractions on the short-term and long-term retrogradation of wheat starch. *Food Hydrocolloids*, 130, article number 107716. doi: 10.1016/j.foodhyd.2022.107716.

[20] Lin, J., Gu, Y., & Bian, K. (2019). Bulk and surface chemical composition of wheat flour particles of different sizes. *Journal of Chemistry*, 2019, article number 5101684. doi: 10.1155/2019/5101684.
[21] Ma, S., Wang, Z., Liu, H., Li, L., Zheng, X., Tian, X., Sun, B., & Wang, X. (2022). Supplementation of wheat flour products with wheat bran dietary fiber: Purpose, mechanisms, and challenges. *Trends in Food Science & Technology*, 123, 281-289. doi: 10.1016/j.tifs.2022.03.012.
[22] Marchenkov, D., Khorenzhy, N., Voloshenko, O., Zhygunov, D., Marenchenko, O., & Zhurenko, O. (2021). Investigation of quality indicators of wholemeal industrial-made flour. *Food Science and Technology*, 15(4), 87-94. doi: 10.15673/fst.v15i4.2258.
[23] Navrotskyi, S., Guo, G., Baenziger, P.S., Xu, L., & Rose, D.J. (2019). Impact of wheat bran physical properties and chemical composition on whole grain flour mixing and baking properties. *Journal of Cereal Science*, 89, article number 102790. doi: 10.1016/j.jcs.2019.102790.
[24] Pradana-López, S., Pérez-Calabuig, A.M., Otero, L., Cancilla, J.C., & Torrecilla, J.S. (2022). Is my food safe? AI-based classification of lentil flour samples with trace levels of gluten or nuts. *Food Chemistry*, 386, article number 132832. doi: 10.1016/j.foodchem.2022.132832.
[25] Pysarets, O., Biela, N., & Polonska, T. (2020). Research of rheological properties of dough from spelled flour of different grinding. *Food Resources*, 8(14), 157-164.
[26] Seal, C.J., Courtin, C.M., Venema, K., & de Vries, J. (2021). Health benefits of whole grain: Effects on dietary carbohydrate quality, the gut microbiome, and consequences of processing. *Comprehensive Reviews in Food Science and Food Safety*, 20(3), 2742-2768. doi: 10.1111/1541-4337.12728.
[27] Skřivan, P., Sluková, M., Jurkaninová, L., & Švec, I. (2021). Preliminary investigations on the use of a new milling technology for obtaining wholemeal flours. *Applied Sciences*, 11(13), article number 6138. doi: 10.3390/app11136138.
[28] van Rooyen, J., Simsek, S., Oyeyinka, S.A., & Manley, M. (2022). Holistic view of starch chemistry, structure and functionality in dry heat-treated whole wheat kernels and flour. *Foods*, 11(2), article number 207. doi: 10.3390/foods11020207.
[29] Vasylenko, N.V., Pravdziva, I.V., Zamlila, N.P., Volohdina, H.B., Humeniuk, O.V., & Koliuchyi, V.T. (2018). Factors affecting the quality of grain and flour of new varieties of soft winter wheat. *Myronivskyi Visnyk*, 6, 99-107. doi: 10.31073/mvis201806-08.
[30] Vlizlo, V.V., Fedoruk, R.S., & Ratych, I.B. (2012). *Laboratory research methods in biology, animal husbandry and veterinary medicine.* Lviv: Spolom.
[31] Wójtowicz, A., Oniszczuk, A., Kasprzak, K., Olech, M., Mitrus, M., & Oniszczuk, T. (2020). Chemical composition and selected quality characteristics of new types of precooked wheat and spelt pasta products. *Food Chemistry*, 309, article number 125673. doi: 10.1016/j.foodchem.2019.125673.
[32] Zakharchuk, O., Hutorov, A., Vyshnevetska, O., Nitsenko, V., Balezentis, T., & Streimikiene, D. (2023). Ukraine's market of certified seed: Current state and prospects for the future. *Agriculture*, 13(1), article number 61. doi: 10.3390/agriculture13010061.
[33] Zhygunov, D.O. (2017). Determining the quality indicators of flour from different systems of the technological process during graded milling of wheat. *Grain Products and Mixed Fodder's*, 17(4), 30-36.

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Анотація. Концепція сучасного харчування передбачає наявність максимальної кількості поживних речовин, зокрема вітамінів, незамінних амінокислот, каротиноїдів, природних антиоксидантів, мінеральних речовин, фенольних та дубильних сполук, органічних кислот, харчових волокон, тому харчова промисловість проявляє великий інтерес до розробки цільнозмеленого зерна на основі злакових культур – пшениці, жита, ячменю, тритікале, гречки, кукурудзи, рису. Метою дослідження є оцінка цільнозмеленого борошна за сучасних виробничих технологій та контроль їх якості, що призведуть до нового рівня розвитку української харчової промисловості та забезпечать підвищення рентабельності борошномельної та хлібопекарської галузей. Методи, що використовувались у процесі дослідження: теоретичні – аналізу, синтезу, порівняння та узагальнення; дослідні – ідентифікаційний та вимірювальний з визначення фізико-хімічних, органічних, подрібнювальних, борошномельних й хлібопекарських показників якості цільнозмеленого пшеничного борошна. Характеризуючи експериментальні дані різних видів цільнозмеленого борошна, встановлено, що вміст сухої речовини, сирого протеїну, сирого жиру, сирої клітковини або волокон, мінеральної частини, легкогідролізованих вуглеводів (крохмаль, геміцелюлоза) знаходилися в межах 84.7-88.8 %, 10.2-16.3 %, 0.9-1.7 %, 2.3-4.8 %, 1.2-3.2 %, 77.5-84.2 % відповідно. Такі показники, як зольність і крупність борошна, безпосередньо залежали від схеми помелу, цілісності всіх анатомічних частинок зерна. Технологія виробництва цільнозмеленого пшеничного борошна поєднує переваги існуючих способів помелу з мінімізацією негативного впливу на якісний й кількісний вміст клейковини, зокрема у зразках цільнозмеленого борошна він варіювався від 21 % до 36 %, індекс деформації клейковини – від 53.8 до 81.7 одиниць. Матеріали статті складають практичну значимість й вказують на необхідність подальших досліджень, тому що проводячи оцінку показників якості та вивчивши характеристики цільнозмеленого пшеничного борошна треба звернути увагу на подальшу розробку оптимальної технології виробництва хліба з даної сировини

Ключові слова: зерно пшениці; хлібопекарські властивості; харчова цінність; клейковина; хіміко-технологічні показники