

The object of this study is the quality of bread using wheat flour mixed with sorghum flour.

The implementation of the task of stable provision of the population with good quality bread and high nutritional value is based on improving the technology of bread using sorghum flour in accordance with the global trend of safe and healthy nutrition.

The results on the chemical composition and nutritional value (amino acid content, mineral composition, and vitamins) of sorghum flour were obtained, a comparative analysis with wheat flour was carried out.

An analysis of the amylographic characteristics of flour and dough with the addition of various amounts of sorghum flour, improvers, and enzyme preparations was carried out. As a source of nutrients, the effect of sorghum flour on the rheological and baking properties of wheat dough was studied. The effect of the studied flour on the quality of finished bread was established.

The complex effect of the Emceft improver and the KAZenzym enzyme preparation on the quality of dough and bread, including from sorghum flour, was studied. The use of sorghum flour of the Kazakhstan 20 variety for the production of bread in combination with an improver and an enzyme preparation has improved the chemical composition, rheological and baking properties of the dough.

Research shows that bread with the use of sorghum flour diversifies the diet and promotes human health due to its nutritional composition and potential as a gluten-free food.

The scope and conditions of practical use of the results are the possibility of using sorghum for bread making. Achieving these capabilities is based on the developed technology of bread in combination with an improver and an enzyme preparation

Keywords: sorghum, whole grain flour, rheological properties of dough, alveograph, baking improvers, nutritional value, gluten-free bread

REVEALING THE INFLUENCE OF SORGHUM FLOUR ON THE RHEOLOGICAL AND BAKING PROPERTIES OF DOUGH, THE QUALITY AND NUTRITIONAL VALUE OF BREAD

Zhibek Ussembayeva

Doctor of Technical Sciences*

Nurlan Dautkanov

Candidate of Technical Sciences*

Moldir Yerbulekova

PhD

Department of State Scientific and Technical Expertise

National Center of Science and Technology Evaluation JSC

Bogenbay batyr, 221, Almaty, Republic of Kazakhstan, 050026

Dina Dautkanova

Corresponding author

Doctor of Technical Sciences*

E-mail: Dida09@yandex.ru

*Department of Crop Production Processing

Kazakh Research Institute of Processing and Food Industry

Gagarin ave., 238 G, Almaty, Republic of Kazakhstan, 050060

Received date 27.05.2024

Accepted date 09.08.2024

Published date 30.08.2024

How to Cite: Ussembayeva, Z., Dautkanov, N., Yerbulekova, M., Dautkanova, D. (2024). Revealing the influence of sorghum flour on the rheological and baking properties of dough, the quality and nutritional value of bread. *Eastern-European Journal of Enterprise Technologies*, 4 (11 (130)), 43–55. <https://doi.org/10.15587/1729-4061.2024.310516>

1. Introduction

Providing a system of high-quality and safe nutrition for the population, including the formation of the foundations of a healthy lifestyle, is an integral part of national security and state policy.

It has been reliably established that a person needs essential nutrients – macronutrients (proteins, fats, and carbohydrates, including dietary fiber) for a full life. The body also needs to consume micronutrients – vitamins, minerals, as well as minor and biologically active substances with an established physiological effect [1, 2].

Sorghum (*Sorghum bicolor* L. Moench) is a cereal plant grown in 85 countries and in terms of grain production in the world is second only to wheat, rice, corn, and barley. However, in most countries of the world it was mainly used as animal feed [3].

Scientists and practitioners worldwide unanimously recognize the feasibility of expanding sorghum cultivation areas in the context of global warming due to the ability of sorghum to form high yields of grain and green mass in such conditions.

In addition, sorghum grain is rich in carbohydrates, proteins, amino acids, carotene, minerals, and tannins, which play an important role in human nutrition [4].

Due to its interesting nutrient content, sorghum can be used to improve the nutritional value of starch-based products, which are usually made from incomplete grain flour, such as wheat, rice, and corn [5, 6].

Sorghum is a strategic gluten-free crop. Resistance to drought and heat, an interesting composition associated with its similarity to corn, combined with resistant starch and phenolic compounds provide the possibility of its use as a useful food product for humans.

Studies show that sorghum contributes to dietary diversity and promotes human health due to its nutritional composition and potential as a functional food. Among the physiological effects already investigated, sorghum shows good antioxidant activity. Lower glycemic response and greater benefit for gut microbiota compared to other cereals [7, 8]. In the last decade, there has been increasing interest in the health benefits of sorghum consumption [9–11]. Sorghum, rich in phenolic compounds, inhibits cancer cell activity, including proliferation, growth, and tumor activity. Sorghum increases the expression of cardiovascular, platelet aggregation with reduced health and modulated platelet microparticles. Sorghum also suppresses inflammatory markers and reduces lipid accumulation. Sorghum contributes to dietary diversity and promotes human health due to its nutritional composition and potential as a functional food such as bakery products [9, 10]. Sorghum grain is known for its rich phytochemical composition, phytosterols, policosanols, which help reduce cholesterol levels [12].

Diabetes is one of the most complex chronic diseases worldwide. Phenolic extracts of sorghum have been found to effectively suppress the development of diabetes by reducing serum glucose, total cholesterol, and triglycerides [13].

In this regard, the use of sorghum for the development of healthier food products [9, 10, 13–15], including bakery products, is relevant. Thus, sorghum does not contain gluten, which is useful for those suffering from celiac disease and is suitable for those who adhere to a gluten-free diet. Gluten-free bakery products have been developed [9, 14]. In addition, sorghum is rich in fiber and can contain varying levels of resistant starch (up to 67 %), which supports diets for obesity and diabetes. Sorghum grains are used as an alternative to cereal grains or can replace wheat or other cereals in innovative bakery products for human consumption [13], cakes, cookies, pizza [15], sorghum pasta and pasta [10]. In Western countries, the use of sorghum in human food has increased due to its antioxidant potential, which plays a role in reducing the risk of chronic diseases (obesity, cardiovascular disease, hypertension, diabetes, cancer) [7, 9].

Increased consumption of whole grains correlates with a decrease in the incidence of non-communicable chronic diseases, which increasingly arouses the interest of researchers in studying cereals such as sorghum in food products and most often in bread [16, 17].

Sorghum grain is the fifth most produced in the world, it grows on all continents in countries with hot climates, which is important in the context of global warming. Sorghum is considered an unconventional type of raw material for bakery production, possessing high nutritional value, special properties, such as the absence of gluten and a fine structure of starch grains. Analysis of literary data indicates the effectiveness and safety of sorghum [3, 6, 18–20].

The uniqueness of the chemical composition of sorghum seeds is determined by the following aspects:

- significant content of protein substances (more than 12 %), sorghum contains more protein or at the same level as wheat grain, more than corn, rye, etc.;
- rich amino acid composition containing all essential amino acids;
- higher amino acid rate of essential amino acids compared to wheat, corn, rice, millet, etc.;
- high lipid content in sorghum (2.8–4.2 %), more than in wheat, barley, rye, etc.,

- the presence of starch in sorghum (67.5–74.5 %) in the form of a polygonal microcrystalline structure with a smaller granule diameter – compared to wheat flour;

- high level of dietary fiber;

- vitamin and mineral value of sorghum grain [3, 6, 18].

Research on the use of sorghum of Kazakh selection in bread baking is important because it addresses the issues of using a climate-resistant crop of domestic selection that has nutritional value and a low glycemic index. Therefore, research on the effect of sorghum flour of Kazakh selection on the chemical composition, rheological, baking properties of dough and the nutritional value of bread is relevant.

Being a versatile and drought-resistant grain plant grown throughout the world and rich in phytonutrients, sorghum has attracted attention due to its potential health benefits. Despite the growing interest in sorghum products, including bakery products, there are a number of issues that require careful research to assess the combined effect of sorghum mixed with wheat flour on the quality of finished products. Possibilities of expanding the range of bakery products using sorghum flour, including gluten-free, dietary, and medicinal products. Effective technologies are needed to commercialize the results of scientific research.

2. Literature review and problem statement

Works [18, 21] report the results of research in the field of development of bakery products with sorghum flour. It is shown that the chemical composition and nutritional value of flour from sorghum seeds, baking properties of a mixture of wheat flour and sorghum have been studied. The possibility of using sorghum flour for the preparation of bakery products due to the presence of enzymes that affect the protein and carbohydrate-amylase complexes of wheat flour is shown. For the preparation of bread, sorghum was used in sprouted form or in the form of a gelatinized water-flour mixture. In this case, not only the organoleptic (sensory) and physicochemical indicators are improved, but also the nutritional value of bakery products. However, issues related to the fact that the use of sorghum in the process of preparing bakery products requires a preliminary preparation stage, which complicates the technological process, remain unresolved. Before adding sorghum, it is sprouted, or a gelatinized water-flour mixture is prepared from it. The additional stage lengthens the bread production process and increases the cost of commercialization. A way to overcome these difficulties may be to find simpler and more effective ways to use sorghum in bakery technology. Study [22] reports research into the preparation of bread with sorghum flour and whole grain wheat flour type 550. It is shown that two options were considered: with enrichment with lactic acid bacteria *Lactobacillus plantarum* and without enrichment. The results of the studies showed that the fat and crude fiber in bread with sorghum flour were higher compared to bread made from whole grain wheat flour. In addition, the content of magnesium, potassium, and iron was much higher than in whole grain flour. A significant improvement in sensory characteristics was observed in bread in which lactic acid bacteria were used. But there are still unresolved issues related to the stage of sorghum flour application and the introduction of additional complication of the technological process by enriching it with lactic acid bacteria, which requires increased microbiological control. The cost part

increases, the technological process is lengthened, and commercialization is complicated.

Paper [23] reports the results of studies on the use of sorghum in bread production. It is shown that the studies were focused on technological approaches to improving the quality of bread, which included sprouting sorghum grain, high pressure, the use of sourdough and the use of starch. But the problems of sensory indicators of bread remained unresolved, further optimization of technological methods for the perception of bread was required. In addition, the introduction of additional technological methods also complicates the technology of bread preparation and increases the cost of its commercialization. Therefore, simpler, more efficient, and reliable technologies for the preparation of bread with sorghum flour are needed. Papers [24, 25] report the results of studies on the use of white and bronze sorghum flour in bread preparation. It is shown that white and bronze sorghum provide opportunities to improve the nutritional value and quality of bread in terms of sensory and physical properties. The use of up to 75 % white sorghum flour (without theanines) in combination with 25 % potato starch or using 100 % bronze sorghum flour (containing theanine) for gluten-free bread has been proposed. But there are still unresolved issues related to the acceptance of the bread. The reason for this is the presence of theanines in the bronze sorghum genotype. It has been found [26] that the acceptance of GF bread developed using different types of sorghum and flour, the presence of theanines and other phenols in sorghum-based bread may contribute to a negative effect on acceptance. This makes the relevant studies impractical.

Sorghum flour usually contains a large amount of dietary fiber, fat, and protein, in addition to some micronutrients necessary for human consumption. However, there is a need to improve the consumer quality of bakery products using sorghum flour [4, 27]. Thus, a number of studies [19, 21] have shown that the use of sorghum flour contributes to the deterioration of the rheological characteristics of the dough and a decrease in the quality indicators of bread. Works [20, 28, 29] report the results of studies that gluten-free products (GF) often have low technological and sensory quality, do not have a good appearance and taste.

Paper [20] reports the results of studies on the use of sorghum in the production of gluten-free bread. It is shown that over the past ten years, commercial food products containing gluten (GC) ($n=7122$) and GF ($n=3153$) have been examined and compared worldwide. An assessment of the GF bread label ($n=935$) shows that this product consists of several raw ingredients and additives, which leads to high variability in carbohydrate content. Thus, the content of basic carbohydrates varies from 14 to 84 %, fat from 1 to 19 %, protein from 0 to 11 %, sugar from 0 to 24 %, and dietary fiber from 0 to 17 %. However, unresolved issues remain related to the fact that raw ingredients do not guarantee stable results, and this significantly affects commercial results. The reason for this is that gluten-free products, including bakery products, are still considered high-fat, low-protein and, in some cases, low-fiber products, highlighting the need for further research to improve the nutritional value of bakery products. Study [13] reports the results of studies on the effects of thermal processing of sorghum, such as boiling, steaming, roasting and extrusion, on the phenolic compounds of sorghum in the preparation of bakery products. It is shown that sorghum grain is rich in bioactive phenolic compounds such as ferulic acid, gallic acid, vanillic acid,

luteolin and apigenin, 3-deoxyanthocyanidins (3-DXA), which are known to provide many health benefits including antioxidant, anti-inflammatory, antiproliferative, antidiabetic and antiatherogenic activities. Compelling evidence suggests biological functions of sorghum phenolic compounds, but there are still unresolved issues related to the quality of finished products that require further research.

Papers [3, 15] report the results of studies on the replacement of flour from conventional cereals, such as wheat, with sorghum flour in the production of bakery products. It is shown that such a replacement contributes to the development of products with a lower glycemic index due to the content of dietary fiber and resistant starch in sorghum. This is explained by the fact that sorghum grain contains a higher content of resistant starch (RS) than other cereals, and, apparently, it is digested more slowly. However, issues related to the physicochemical properties of bread, such as volume, porosity, and elasticity of the crumb, remain unresolved. The reason for this was the low rheological properties of the dough.

Works [28, 29] report the results of studies on the acceptance of gluten-free bread developed using different types of sorghum and flour. It is shown that the presence of theanines and other phenols in bread can contribute to a negative effect on perception. However, issues related to the quality and acceptance of bread remain unresolved. The authors of the studies point to the advisability of conducting further studies and the need to select the most suitable improves for each sorghum variety so that the bread is well accepted.

Papers [28–30] report the results of studies of bakery products using sorghum. Paper [30] gives data on the production of gluten-free products prepared by replacing part of the wheat flour mixture with a new ingredient rich in resistant starch obtained from annealed white sorghum starch. Studies [28, 30] give data on the production of bakery products from a mixture of wheat and sorghum flour or flour from extruded sorghum. It is shown [28–30] that one of the main problems in the production of bakery products using sorghum and its commercialization is low structural-mechanical and rheological properties, sensory characteristics. Paper [28] especially emphasizes that sensory analysis is necessary to advance the project on the development of sorghum-based products, and, therefore, to achieve success, work is necessary on the sensory profiles of these products and consumer approval. The reason for this is the absence of gluten in sorghum, which directly affects the hardness and baking strength of the dough, and, consequently, the appearance, porosity state, and taste of bread. Low consumer properties of gluten-free bread indicate the need to search for gluten-free ingredients and ways to improve the organoleptic and physicochemical properties of finished bakery products.

Our review revealed two major problems with the use of sorghum flour in the production of bakery products. A first problem is related to finding ways to introduce sorghum into the dough since an additional technological method is almost always necessary, such as grinding, malting, fermentation, heat treatment, microbiological process, preparation of brew or sourdough, etc. [19]. A second problem is related to the quality and nutritional value of the final product: the appearance, sensory and physicochemical indicators of bakery products, which directly depend on the chemical composition, rheological and baking properties of the dough.

An option to overcome the difficulties may be the use of additives in the production of bread from a mixture of wheat and sorghum flour. This is the approach used in work [22].

Modified starches, proteases, flour improvers, transglutaminases (Tgase), emulsifiers, and albumins were used in the study. Good results were noted when using emulsifiers. However, the sensory and consumer properties of bread required optimization of additive levels. In addition, lyophilized dough from sorghum flour or a mixture of sorghum flour with native cassava starch was used to prepare bread, which also requires additional technological methods. All this allows us to state that it is advisable to conduct a study aimed at studying the effect of sorghum flour on the rheological and baking properties of dough, the quality and nutritional value of bread prepared with an improver and an enzyme complex.

3. The aim and objectives of the study

The purpose of our study is to determine the effect of sorghum flour of the Republic of Kazakhstan 20 variety on the chemical composition, functional, rheological, and baking properties of the dough, the quality and nutritional value of bread. This will make it possible to create the prerequisites for developing a recipe and technology for bread with increased nutritional value from Kazakhstani raw materials that are resistant to a changing climate.

To achieve this goal, the following tasks were set:

- to study the chemical composition and nutritional value (amino acid content, mineral and vitamin composition) and baking properties of sorghum flour for the possibility of using sorghum flour as a recipe component in bread production;
- to study the rheological and baking properties of the dough to establish the ratio of wheat and sorghum flour with the introduction of recipe components – an improver and an enzyme preparation;
- to evaluate the quality indicators of bread.

4. The study materials and methods

The object of our study is the quality of bread using wheat flour mixed with sorghum flour.

The implementation of the task of stable provision of the population with good quality bread and high nutritional value is based on the improvement of bread technology using sorghum flour in accordance with the global trend of safe and healthy nutrition.

The rheological parameters of the dough were determined on the Alveograph CH device from the company “CHOPIN Technologies” (France) [31]:

- *P* – elasticity (resistance to deformation) of the dough, mm H₂O;
- *L* – dough extensibility (maximum air volume in the bubble), mm;
- *G* – extensibility index;
- *W* – baking ability of the dough, flour strength, 10⁻⁴ J;
- *P/L* – the ratio of elasticity to extensibility;
- *Le* – elasticity index, %. $Le = P200/P \max$ (*IE* is always below 100 %).

During the study, trial baking of bread was carried out using the straight-dough method [7] with the addition of whole grain sorghum flour according to the recipe given in Table 1.

Control samples of bread were prepared on grade 1 wheat flour without adding sorghum flour and introducing an improver and enzyme preparation (C) and with the addition of

sorghum flour in ratios of 95:5 (C 5), 90:10 (C 10), 85:15 (C 15). An improver and enzyme complex were introduced into the test samples.

Table 1

Recipe for sample breads with the addition of whole grain sorghum flour

Sample ID	Flour content, %		Content of EMCEsoft P 10 improver, g/100 kg flour	Content of enzyme preparation KAZenzym 26007, g/100 kg of flour
	Wheat	From sorghum		
Control (C)	100	0	0	0
Experimental (E)	100	0	4	15
Control (C 5)	95	5	0	0
Experimental (E 5)	95	5	4	15
Control (C 10)	90	10	0	0
Experimental (E 10)	90	10	4	15
Control (C 15)	85	15	0	0
Experimental (E 15)	85	15	4	15

Moisture content was determined according to GOST 9404, ash according to GOST 27494.

The content of vitamins B₁, B₂, PP, C, E was determined according to GOST 29138, GOST 29139, GOST 29140.

The nutritional value of bread was assessed based on the content of protein, fat, carbohydrates, ash, vitamins, minerals, and amino acid composition.

In studies to improve the rheological properties of the dough, powdered L-cysteine, hydrocolloid flour improver EMCEsoft P 10 and an enzyme complex that stabilizes the properties of flour, KAZenzym 26007, were used.

After 14–16 hours of storage of bread after baking, the content of protein, water-soluble vitamins – thiamine and riboflavin, and mineral substances in it were determined by plasma spectrometry.

Organoleptic indicators of bread quality were determined according to GOST 31805, physicochemical indicators according to GOST 21094, 5669, 5670, structural and mechanical properties on the AP-2 device.

5. Results of investigating the effect of sorghum flour on the chemical, rheological, baking properties of dough and bread

5.1. Results of investigating the chemical composition and nutritional value and baking properties of sorghum flour

The results of investigating the chemical composition of flour from sorghum grain and wheat flour are given in Table 2.

The amino acid, mineral and vitamin composition of flour from sorghum grain and wheat flour is given in Tables 3, 4.

Table 2

Chemical composition of flour from sorghum grain and wheat flour of the 1st grade “Pioneer”

Component ID	Component content in flour (g/100 g)	
	Wheat	Sorghum
Moisture	14	11.9
Proteins	10.3	9.53
Fats	1.1	2.86
Carbohydrates	73.6	73.8
Dietary Fiber	2.7	5.8
Ash	0.5	0.57

Table 3

Amino acid composition of Pioneer wheat flour and sorghum flour

Amino acid ID	Volume of amino acids in flour, g/100 g of protein	
	Sorghum	Wheat
Essential		
Lysine	0.411	0.274
Threonine	0.426	0.298
Valine	0.496	0.473
Methionine	0.189	0.165
Isoleucine	0.529	0.388
Leucine	1.431	0.738
Phenylalanine	0.497	0.508
Tryptophan	0.452	0.131
Sum	4.365	2.973
Replaceable		
Histidine	0.310	0.223
Arginine	0.378	0.475
Aspartic	0.645	0.434
Serine	0.503	0.520
Glutamic	2.100	3.678
Proline	0.912	1.246
Glycine	0.302	0.385
Alanis	1.110	0.335
Cystine	0.135	0.274
Tyrosine	0.345	0.158
Amino acid total	11.420	7.728

Table 4

Mineral and vitamin composition of wheat flour "Pioneer" and sorghum flour

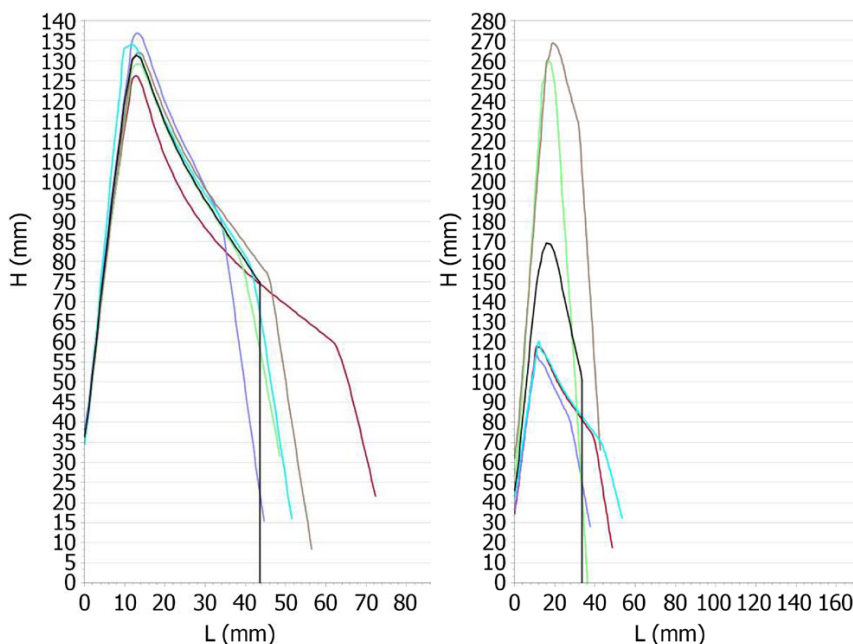
Component ID	Volume of components mg/100g flour	
	Wheat	Sorghum
Macro element		
Ca	28	205
K	169	825
Mg	47	128
Na	8	5
P	120	360
Trace element		
Fe	2.5	5.1
Mn	0.7	2.8
Cu	0.1	5.6
Zn	0.7	2.9
Vitamin		
B1	0.30	0.4
B2	0.10	0.20
B5	0.4	0.81
B6	0.2	0.35
E	0.1	0.7
PP	0.7	4.1
C	-	2.68

The study of the mineral and vitamin composition of Pioneer wheat flour and sorghum flour gives an idea of the nutritional value of flour as an ingredient of new bread.

5.2. Results of investigating the rheological and baking properties of dough made from wheat and sorghum flour

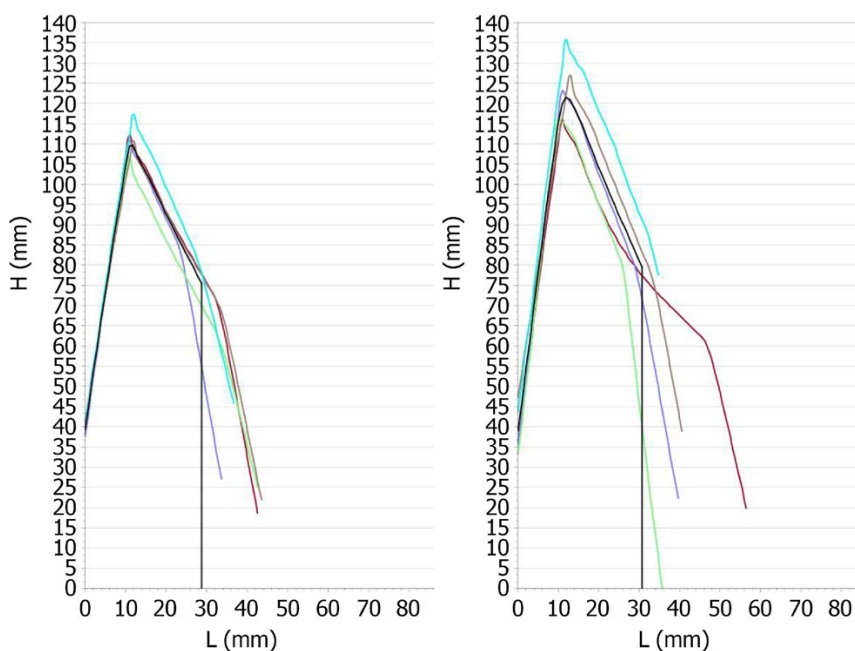
The results of investigating the rheological properties of dough on the Alveograph are shown in Fig. 1–3.

The results of investigating the rheological properties of the dough samples are given in Table 5.



a b

Fig. 1. Baking properties of dough on the Alveograph device: a – Pioneer flour (control); b – sample with the addition of 5 % whole grain sorghum flour



a b

Fig. 2. Baking properties of dough with the addition of 10 % whole grain sorghum flour on the Alveograph device: a – control; b – experimental sample

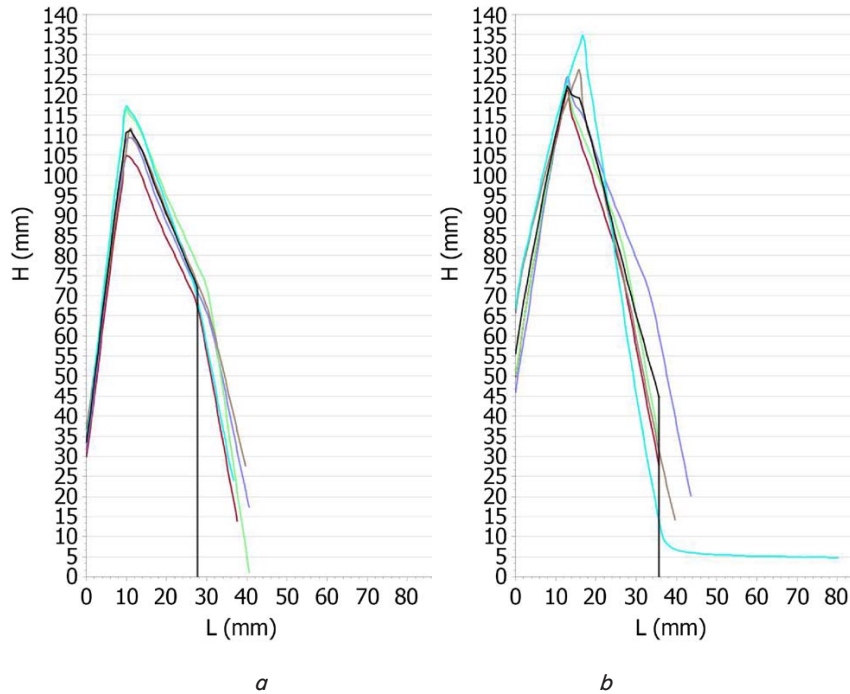


Fig. 3. Baking properties of dough with the addition of whole grain sorghum flour 15 % on the Alveograph device: *a* – control; *b* – experimental sample

Table 5

Baking properties of dough on the Alveograph device

Sample description	Test quality indicators					
	<i>P</i> , mm H ₂ O	<i>L</i> , mm	<i>G</i>	<i>W</i>	<i>P/L</i>	<i>Le</i> , %
Wheat flour (C)	145	43	14	279	3.37	61.3
Wheat flour plus 5 % sorghum (E)	186	33	11.8	287	5.64	–
Wheat flour plus 10 % sorghum (C 10)	121	28	287	164	4.32	–
Wheat flour plus 10 % sorghum (E 10)	134	30	12.2	192	4.47	–
Wheat flour plus 15 % sorghum (C 15)	122	27	11.5	157	4.52	–
Wheat flour plus 15 % sorghum (E 15)	134	35	13.1	208	4.83	–

Table 6

Effect of sorghum flour quantity on the quality of bread from Pioneer wheat flour, prepared by the straight-dough method using the EMCEsoft P 10 improver and the Kazenzym 26007 enzyme complex

Bread quality indicator ID	Bread quality indicators					
	From wheat flour Pioneer (C)	From a mixture of Pioneer wheat flour and sorghum flour at the ratio of				
		95:5 (C 5)	90:10 (C 10)	90:10 (E10)	85:15 (C 15)	85:15 (E 15)
Crumb moisture, %	44.2	44.2	44.2	44.3	44.0	44.0
Acidity, degree	2.4	2.4	2.6	2.6	2.6	2.6
Porosity, %	82	82	78	81	76	81
Specific volume, cm ³ /g	4.1	4.2	4.0	4.2	3.95	4.2
Structural and mechanical properties of the crumb, unit of the AP-4/2 device						
ΔH total	62	65	62	62	60	65
ΔH compression	45	50	45	45	45	50
ΔH elasticity	25	27	25	27	25	27
Crumb color	Light with a yellowish tint	Light with a yellowish tint	Light brown	Light brown	Brown	Brown
Crumb elasticity	Elastic	Elastic	Elastic	Elastic	Elastic	Elastic
Nature of porosity	Pores are small and medium, thin-walled					
Taste	Characteristic, pronounced bread				Characteristic, with a nutty taste	
Aroma	Characteristic pronounced bread				Characteristic, with a nutty smell	

5. 3. Evaluation of bread quality indicators

Samples of laboratory baked bread from a mixture of Pioneer wheat flour and sorghum flour (52 % yield) in ratios from 95:5 to 85:15 were prepared using the straight-dough method and analyzed for quality indicators. The effect of the amount of sorghum flour on the quality of bread from Pioneer wheat flour prepared using the straight-dough method with the use of the EMCEsoft P 10 improver and the Kazenzym 26007 enzyme complex is illustrated in Table 6.

The effect of the amount of sorghum flour on the chemical composition and vitamin content of bread is illustrated in Table 7.

In experimental samples, the use of the dough rheological properties improver EMCEsoft P 10 and the enzyme complex KAZenzym 26007 and their effect on the appearance of bread is shown in Fig. 4, 5. In experimental samples, the use of an improver and an enzyme preparation (Fig. 5) clearly demonstrates their effect on the appearance of bread.

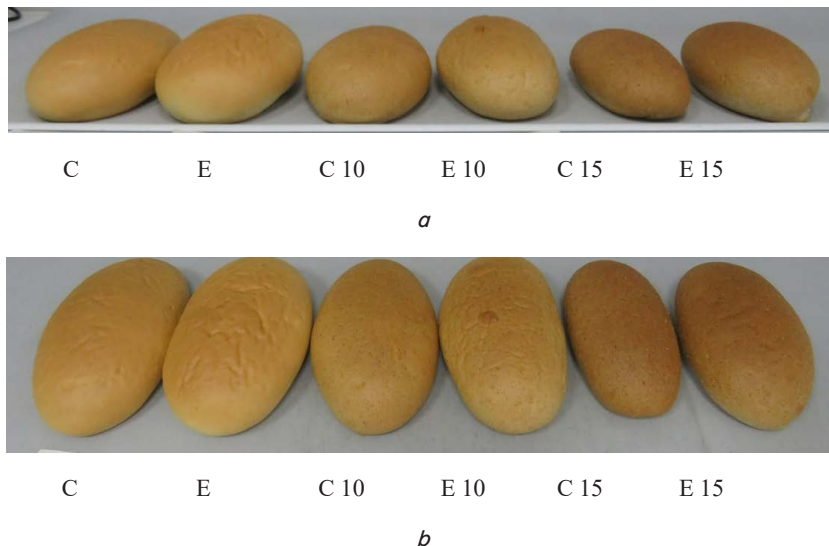


Fig. 4. Control and experimental samples of bread with the addition of whole grain sorghum flour: *a* – general view of the bread; *b* – view of the bread from above; C – control; E – test sample made of wheat flour with the addition of an improver and an enzyme preparation; C 10 – control sample with the addition of 10 % sorghum flour; E 10 – test sample with the addition of 10 % sorghum flour, an improver, and an enzyme preparation; C 15 – control sample with the addition of 15 % sorghum flour; E 15 – test sample with the addition of 15 % sorghum flour, an improver and an enzyme preparation

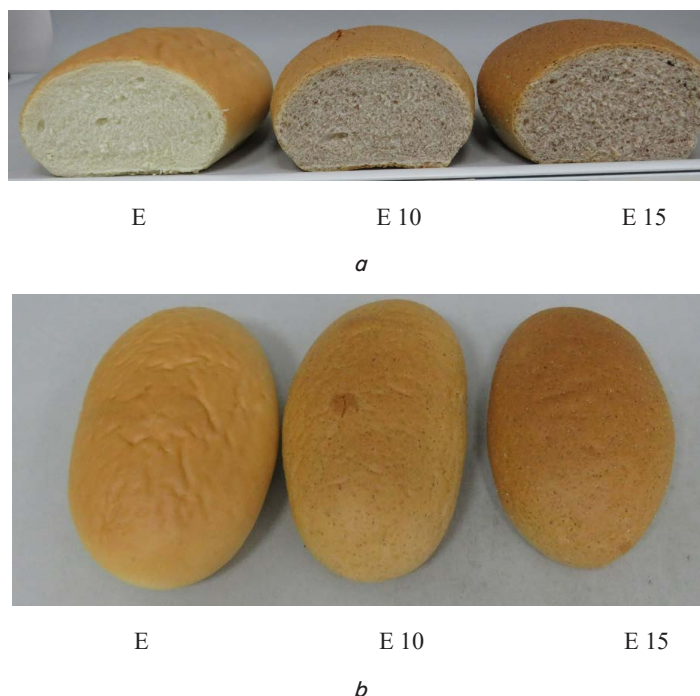


Fig. 5. Control and experimental samples of bread with the addition of whole grain sorghum flour, an enzyme preparation, and improver: *a* – view of the bread crumb; *b* – general view of the bread; E – experimental sample of wheat flour with the addition of an improver and an enzyme preparation; E 10 – experimental sample with the addition of 10 % sorghum flour, an improver, and an enzyme preparation; E 15 – experimental sample with the addition of 15 % sorghum flour, an improver, and an enzyme preparation

Table 7
Effect of sorghum flour quantity on the chemical composition and vitamin content of bread

Component ID	Number of components in bread made from			
	Wheat flour of the 1st grade	Mixtures of wheat flour and sorghum flour in the ratio of		
		95:5	90:10	85:15
Physical and chemical indicators, g/100 g, %				
Proteins	7.6	7.0	6.6	6.4
Fats	0.8	1.0	1.1	1.2
Carbohydrates	49	50	50.8	51
Moisture	37.8	37.8	37.4	37.4
Ash	1.7	1.8	1.85	1.87
Vitamin content, mg/%				
Thiamine B ₁	0.170	0.180	1.195	0.200
Riboflavin B ₂	0.060	0.068	0.070	0.073
PP	–	0.930	0.100	1.155
E	–	0.987	1.130	1.205

6. Discussion of results of investigating the effect of sorghum flour on the chemical, rheological, baking properties of dough and bread

The feasibility of using new types of raw materials in the baking industry is due to their chemical composition, food, biological, and physiological value, and the ability of the properties of this raw material to influence the ripening processes of semi-finished products, the quality of bread and its safety [2, 8].

In Kazakhstan, new improved varieties of grain sorghum have been created, for example, “Kazakhstanskoe 20”, and the sown areas of these crops have significantly increased [4].

Studies of the chemical composition and nutritional value of sorghum flour “Kazakhstanskoe 20” confirmed the data on the possibility of using sorghum flour as a fortifier of bakery products, which is confirmed and explained by the data of previously conducted studies [3, 7, 19, 20, 22, 29].

To develop the technology of bread using sorghum flour, the chemical composition, nutritional value of sorghum flour, baking properties, and a comparative analysis with Pioneer wheat flour were studied. The effect of adding sorghum flour in the amount of 5 %, 10 %, 15 % on the rheological, structural-mechanical, and baking properties of the dough and the processes occurring during dough maturation was also studied. In the studies, the Emceft P 10 flour improver was used to improve the rheological properties of the dough; and the KAZenzym 26007 enzyme complex was used to stabilize the baking properties of flour. A technology for making bread from a mixture of wheat and sorghum flour using the improver and enzyme complex was developed. The nutritional value of the bread was determined.

Sorghum flour and Pioneer wheat flour were used as the objects of the study. Baking properties of flour were determined on the Alveograph CH device.

The moisture content, protein, amino acid composition, carbohydrate content, lipids, ash, fiber, micro- and macro elements, and vitamins were determined in wheat flour and sorghum flour using the methods given in the Materials and Methods section.

A comparative analysis of the chemical composition of first-grade wheat flour with sorghum flour revealed significant differences in the main components (Table 2).

Sorghum flour contained 2.6 and 2.1 times more lipids and fiber, respectively, than wheat flour. The protein content is 7.5 % lower than that of wheat flour, which probably confirms the data that sorghum does not contain gluten [20, 21] and contributes to the development of gluten-free bakery products. The carbohydrates of the studied sorghum flour are represented by starch, the amount of which is at the level of wheat flour, mono- and disaccharides, the amount of which is 2 times greater compared to wheat flour. These data confirm the possibility of using cereal flour in starch-based products [5, 6]. The amino acid composition of sorghum flour (Table 4) was characterized by a greater amount of essential amino acids, by 47.8 %, compared to the wheat flour “Pioneer”. The amino acid score for lysine and threonine was 1.5 times higher compared to wheat flour. The studied sorghum flour has a unique mineral composition. It contains phosphorus and magnesium 3 and 2.7 times higher than wheat flour. Sorghum flour contains calcium 7.3 times; potassium – 5 times more than wheat flour “Pioneer”. Research data have shown that sorghum flour is the most important food source of microelements: iron: 2 times more than in wheat, manganese, and zinc 4 times, copper 56 times.

The study determined that the most important vitamins in the studied sorghum flour were thiamine (B₁), riboflavin (B₂), pantothenic acid (B₅), pyridoxine (B₆), niacin (PP), and ascorbic acid. The content of the above vitamins (Table 4) exceeds wheat flour by 1.3; 2; 2; 7; 6 times, respectively. Sorghum contains ascorbic acid vitamin C – 2.68 mg/100 g of flour. The content of mineral and vitamin composition of sorghum flour makes this crop necessary in the human diet. Thus, the advantage of this study is the establishment that sorghum flour “Kazakhstanskaya 20” has a high nutritional value, confirmed by the obtained results related to the chemical, mineral, amino acid, and vitamin composition. Our results are confirmed and explained by numerous studies on the nutritional value of sorghum [3, 6, 18, 19]. An improved sorghum variety has been developed and zoned in the Republic of Kazakhstan; it can grow in all regions with a climate similar to that of the Republic of Kazakhstan [4].

The obtained data correlate with the data of a number of researchers indicating the possibility of using sorghum to increase the nutritional value of bakery products [3, 6, 18, 21].

Further research into the effective use of sorghum flour Kazakhstanskaya 20 in bread-making technology involved using a mixture of Pioneer wheat flour and sorghum flour Kazakhstanskaya 20, which was confirmed by a series of laboratory baking cycles. During baking cycles, various technological factors varied (the ratio of these types of flour, methods of adding flour, and product recipes).

Based on the above, the study aimed to investigate the effect of the sorghum flour on the rheological and baking properties of the dough, and, accordingly, the quality of the bread. The study of the rheological properties of dough allows one to quickly and reliably assess the quality of flour and predict the quality of finished products.

The advantage of this study is the simple technique of adding sorghum to the mixture with wheat flour during dough preparation. The dough was prepared from mixtures of wheat flour with an increase in the amount of sorghum flour from 5 to 15 %.

In previous studies on the use of sorghum flour for bread preparation [9, 10], the recommended dosage of sorghum flour in relation to the content of wheat flour was 5–20 %.

Sorghum flour was added in sprouted form, in the form of a gelatinized water-flour mixture. However, with good quality of bakery products, the above methods complicate the technological process. Studies have been conducted on the preparation of bread with sorghum flour enriched with lactic acid bacteria *Lactobacillus plantarum* [24]. Other researchers included high pressure, used starters, used starch and additives when sprouting sorghum [19]. In all the studies cited, the need for additional technological methods is obvious: grinding, malting, fermentation, heat treatment, in some cases microbiological processes, which also complicates the technology of bread preparation and increases the cost of its commercialization. Therefore, more effective and reliable technologies for the preparation of bread with sorghum flour are needed.

It should be noted that bakery products using sorghum flour in a number of studies had underestimated physico-chemical and sensory indicators [22, 26].

Thus, a number of studies [21] have shown that the use of sorghum flour contributes to the deterioration of the rheological characteristics of the dough and a decrease in the quality indicators of bread.

Based on the above, our study set the task of investigating the effect of the sorghum flour on the rheological and baking properties of the dough, and accordingly the quality of bread. Studying the rheological properties of the dough makes it possible to quickly and reliably assess the quality of flour and predict the quality of finished products. Sorghum flour was added by simple mixing with wheat flour during the dough preparation process. The dough was prepared from mixtures of wheat flour with an increase in the amount of sorghum flour from 5 to 15 %. In addition, the Emceft P 10 improver and the KAZenzym enzyme complex were added to the dough per 100 kg of flour (Table 1). To establish the optimal ratio of wheat and sorghum flour with the addition of an improver and an enzyme preparation, the rheological and baking properties of the dough were studied (Fig. 1–3, Table 5).

The rheological properties of the dough were studied using such parameters as elasticity P (resistance to dough deformation), extensibility L , elasticity G , baking strength of flour W , the ratio of elasticity to extensibility P/L , and the elasticity index of the dough Le . Decoding the alveograms (Fig. 1) showed that the rheological and baking properties of the dough with the addition of 5 % sorghum flour changed compared to the dough made from Pioneer baking flour (control). Thus, the elasticity of the dough increased by 28.3 %, the ratio of elasticity to extensibility by 67.4 %, and the baking strength of flour by 3.0 %. Extensibility and elasticity decreased by 23.3 and 8.6 %, respectively. Thus, it can be concluded that the addition of 5 % sorghum flour improved the rheological and baking properties of the dough.

The advantage of our study is the establishment of a positive effect from a simple method of adding sorghum flour “Kazakhstanskoe 20” in an amount of 5 % in a mixture with wheat flour on the rheological and baking properties of the dough. This becomes possible due to the composition and properties of sorghum “Kazakhstanskoe 20”, which lead to an increase in the elastic properties of gluten. No additional technological methods were used.

The obtained data are explained by the effect of sorghum flour mixed with wheat flour on changing the gluten structure towards gliadin fractions, since sorghum flour contains little gluten.

A comparative analysis of the rheological and baking properties of the dough is shown in Fig. 1–3, and in Table 5. As the amount of sorghum flour in the mixture with wheat flour increased to 10 and 15 %, the rheological and baking properties of the dough improved only in the ratio of elasticity to extensibility by 28 and 34 %, respectively. The elasticity indices decreased by 16.6 and 16 %, respectively; extensibility – by 34 and 38.2 %; elasticity – by 16.5 and 10.2 %; baking strength of flour – by 53.8 and 41.3 %.

An increase in the amount of sorghum flour “Kazakhstanskoe 20” in a mixture with wheat flour from 10 to 15 % led to a deterioration in the rheological and baking properties of the dough, which predicts a deterioration in the quality of the finished product. Our data are explained by the peculiarity of sorghum protein substances, which have a relaxing effect on the dough gluten, leading to a decrease in elasticity and extensibility. Such results have been confirmed by a number of researchers [21, 22, 26].

In further studies, the flour improver EMCEsoft P 10 and the enzyme complex KAZenzym 26007 were used to improve the rheological and baking properties of the dough.

Comparative analysis of alveograms of dough with the addition of 10 and 15 % sorghum flour with the addition of an improver and an enzyme complex (Fig. 2, 3) revealed a positive effect from the introduction of the improver and the enzyme complex. Thus, the elasticity of the dough improved by 10.7 and 12 %, respectively; extensibility – by 7.1 and 29.6 %; elasticity – by 4.3 % and 14 %; baking strength of flour – by 17 and 32.5 %; elasticity to extensibility – by 3.4 and 6.8 %. The improvement of the dough properties changed towards strengthening and increasing the elasticity of the dough. Similar data were obtained when decoding the pharino-grams of dough kneading. With an increase in the amount of sorghum flour added from 5 to 15 %, the consistency and elasticity of the dough increased by 6–28 % and 7–39 %, respectively, and liquefaction decreased by 18–25 % compared to the control. The addition of sorghum flour to the dough led to an increase in the dough formation time and dough stability by 0.5–2.0 min, respectively, compared to the control.

Our results can be explained by the effect of sorghum flour in combination with the actions of the improver and enzyme complex on the rheological properties of the dough and the stabilizing properties of flour. Such results were predictable when selecting an improver and enzyme preparation.

When adding sorghum flour to a mixture with wheat flour and adding an improver and enzyme complex, a significant increase in the strength characteristics of a mixture of wheat flour with sorghum flour of 90:10 and 85:15 was observed. Gluten was characterized by the ability to resist the deforming load of compression by 6–24 % more than wheat flour gluten.

The total gas-holding capacity of the dough during its fermentation, determined by the rate of change in carbon dioxide pressure, depended on the amount of sorghum flour and was 0.748 % CO₂ to the mass of the dough in the dough made from wheat flour versus 0.770–0.867 % in the dough containing sorghum flour, which is 3–16 % more than in the control. No such studies were included in chapter 5

The results indicate a significant role of sorghum flour in combination with an improver and an enzyme complex in the adsorption binding of moisture, which increases the water absorption capacity of the dough by 5–24 %. Also, in strengthening the structural and mechanical properties of the dough and shifting them towards increasing elasticity

and flexibility, which is a consequence of the compaction of the structure of the dough proteins, due to the specific functional properties of sorghum flour proteins. An increase in the proportion of sorghum flour in a mixture with wheat flour from 5 to 15 % contributed to an increase in gas-holding capacity in the dough by 2–30 % compared to control (Fig. 1–3, Table 5).

Analysis of our findings revealed that the amount of sorghum flour introduced when replacing wheat flour had a significant effect on the quality of bread.

As can be seen from the data given in Table 7, with the addition of sorghum flour in the amount of 5–15 %, without the improver and the enzyme preparation, the specific volume of bread from the mixture of wheat and sorghum flour was 3–6 % lower than the control. The porosity of the bread was at the control level. The compressibility of the crumb in all variants was at the control level, except for the 85:15 variant – a slight decrease of 12 % was observed. When including the improver and the enzyme preparation in the bread recipe, the specific volume in the samples of bread from wheat and sorghum flour in the ratio of 90:10 and 85:15 with the improver and the enzyme preparation had the same indicators as control. When using wheat and sorghum flour in the ratio of 95:5, the specific volume was lower by 4.8 %. The porosity and total compressibility of the bread crumb corresponded to control.

During organoleptic evaluation, the experimental bread samples were characterized by developed thin-walled porosity, elastic crumb, characteristic taste, and aroma (Table 6, Fig. 4, 5). It should be noted that a characteristic nutty flavor appeared, but this does not reduce the taste properties of the bread, as well as a slightly brown color.

The advantage of this study is the production of high-quality bread from a mixture of wheat and sorghum flour in a ratio of 95:5 without additional technological methods. A simple, reliable, and effective technique.

The results of the effect obtained are explained by the influence of sorghum flour “Kazakhstanskoe 20” on the technological process of preparation and quality of bread. The sorghum variety “Kazakhstanskoe” can be a good raw material for bakery production. It was found that the optimal ratio of wheat flour and sorghum flour, providing the best indicators of bread quality without the introduction of an improver and enzyme complex, is 95:5, with their introduction they are 90:10 and 85:15, respectively.

The expediency and validity of using new types of raw materials in the technology of bakery production is largely determined by their effect on the nutritional value of bread.

It was found that an increase in the proportion of sorghum flour in a mixture with wheat flour and sorghum flour from 5 to 15 % led to a decrease in the protein content in bread from 8.0 to 15.8 % per 100 g of product. In bread prepared with sorghum flour, the amino acid composition of proteins significantly improved. The amino acid score of bread protein for lysine increased.

The use of sorghum flour in bread making increased the content of water-soluble B vitamins: thiamine by 5.8–17.6 % and riboflavin by 13.3–21.6 % compared to a sample of bread made from Pioneer wheat flour.

The potential for the effective use of sorghum flour in bread-making technology has been confirmed by a series of laboratory baking experiments using sorghum flour mixed with wheat flour and with the addition of the Emceft improver and the KAZenzym enzyme preparation. The use of these

additives significantly improves the appearance and quality of bread when using sorghum flour (Fig. 5). The results of the studies are explained by the chemical composition and nutritional value of sorghum flour “Kazakhstanskoe 20”, predicted by the rheological and baking properties of the dough, confirmed by the quality and nutritional value of bread and literary data [3, 8, 9, 13–15, 28, 30, 33].

Studies on the effect of sorghum flour “Kazakhstanskoe 20” on the chemical, rheological, and baking properties of the dough, the quality and nutritional value of bread made it possible to develop technologies for the preparation of high-quality and nutritional bread.

The advantage of these technologies is their simplicity and efficiency in commercialization.

The introduction of sorghum flour from 5 to 15 % during the preparation of bread significantly increases the nutritional value and provides prospects for further expansion of the range of bakery products, including gluten-free ones.

The limitations of this study include the need for zoning and adaptation of sorghum grain crops “Kazakhstanskoe 20”. However, this variety is easily replaced by other similar grain sorghum varieties.

Disadvantage is the need to conduct research on further increasing the amount of sorghum flour.

The development of this study may consist in increasing the amount of sorghum flour in the recipe for wheat bread and/or developing gluten-free bread with good consumer characteristics. When advancing the study, the following difficulties may arise:

- in terms of experiment, in obtaining whole grain sorghum flour for use in baking due to the high density of sorghum grains and the need to select modes for preparing sorghum grain for milling and choosing a technology for milling sorghum grain;
- in terms of methodology, the need to develop regulatory documentation for sorghum flour.

7. Conclusions

1. Significant differences in the chemical composition and nutritional value of sorghum flour “Kazakhstanskoe 20” and wheat flour “Pioneer” were established. Sorghum flour contained more lipids and fiber, respectively, by 2.6 and 2.1, compared to wheat flour. The protein content in sorghum flour is lower than in wheat flour by 7.5 %. The amino acid composition of sorghum flour was characterized by a higher amount of essential amino acids by 47.8 %. The amino acid score for lysine and threonine was 1.5 times higher compared to wheat flour. In sorghum flour, the content of phosphorus and magnesium is 3 and 2.7 times higher, calcium – 7.3 times; potassium – 5 times, than in wheat flour “Pioneer”. Sorghum flour is the most important food source of trace elements: iron: 2 times; manganese and zinc 4 times; copper 56 times exceeds wheat flour.

The content of vitamins B₁, B₂, B₅, B₆ and PP in sorghum flour exceeds wheat flour by 1.3; 2; 2; 7; 6 times, respectively. Sorghum contains ascorbic acid vitamin C – 2.68 mg/100 g of flour.

Our results of the chemical composition and nutritional value of flour from sorghum grain “Kazakhstanskoe 20” showed that the studied sorghum flour can be used as a recipe component in the production of bakery products, enriching the human diet.

2. The study of the rheological and baking properties of dough from a mixture of Pioneer wheat flour and "Kazakhstanskoe 20" sorghum allowed us to establish the optimal flour ratios that provide a stable improvement in dough quality. These are 95:5 without adding additives and 90:10 and 85:15, with the addition of 4 g Emceft P 10 and 15 g KAZenzym per 100 kg of flour.

The addition of 5% sorghum flour improved the rheological and baking properties of the dough compared to the dough made from Pioneer baking flour (control). Thus, the elasticity of the dough increased by 28.3%, the ratio of elasticity to extensibility by 67.4%, and the baking strength of the flour by 3.0%. Extensibility and elasticity decreased by 23.3 and 8.6%, respectively. Improvement of gluten properties with the addition of 5% sorghum flour to the mixture with wheat flour can be explained by a change in the gluten structure towards gliadin fractions since sorghum flour has little gluten.

Addition of the EMCEsoft P 10 flour improver and the KAZenzym 26007 enzyme complex improves the rheological and baking properties of the dough from a mixture of wheat and sorghum flour. Thus, the elasticity of the dough improved by 10.7 and 12%, respectively; extensibility – by 7.1 and 29.6%; elasticity – by 4.3% and 14%; baking strength of flour – by 17 and 32.5%; elasticity to extensibility – by 3.4 and 6.8%. Improvement of the dough properties changed towards strengthening and increasing the elasticity of the dough.

Our results indicate a significant role of sorghum flour in improving the rheological and baking properties of dough from a mixture of wheat and sorghum flour, which is a consequence of the compaction of the structure of dough proteins due to the specific functional properties of sorghum flour proteins.

The study of the amylographic characteristics of flour and dough with the addition of various amounts of sorghum flour showed a decrease in gluten, which directly affects the hardness, and therefore the appearance, porosity state, and sensory indicators of bakery products.

3. Sorghum flour "Kazakhstanskoe 20" improves the quality and nutritional value of bread from wheat and sorghum flour in a ratio of 95:5 without additives and 90:10 and 85:15, with the addition of Emceft P10 and KAZenzym.

Bread made from a mixture of wheat and sorghum flour in a ratio of 95:5 had high quality indicators. Thus, the specific volume is 2% higher; structural-mechanical properties assessed by the total compression deformation, plastic and elastic compression deformation of the bread crumb are 4.8; 11; 8% higher than control. Porosity and acidity of the bread are at the control level. The bread crumb is elastic, had small and medium thin-walled pores, with a characteristic pronounced bread taste like control, without a noticeable aftertaste. The potential for effective use of sorghum flour in bread-baking technology with the addition of the Emceft P10 improver and the KAZenzym enzyme complex has been shown. Bread made from wheat and sorghum flour in a ratio of 90:10 and 85:15 had a specific volume of bread 2% higher than control. Porosity is 2% lower; acidity is 0.2 degrees higher, the structural-mechanical properties of the bread corresponded to the control level.

During sensory evaluation, bread with sorghum flour was characterized by developed thin-walled porosity, had an

elastic crumb, a characteristic taste and smell. It should be noted that a characteristic nutty flavor appeared, but this does not reduce the taste of the bread, as well as a slightly brown color.

It was found that an increase in the proportion of sorghum flour in a mixture with wheat flour and sorghum flour from 5 to 15% led to a decrease in the protein content in bread from 8.0 to 15.8% per 100 g of product. In bread prepared with sorghum flour, the amino acid composition of proteins significantly improved, the amino acid score of protein for lysine increased. The content of water-soluble B vitamins increased: thiamine – by 5.8–17.6% and riboflavin – by 13.3–21.6% compared to a sample of bread made from Pioneer wheat flour. The developed bakery products from the mixture of Pioneer flour and "Kazakhstanskoe 20" sorghum flour can be used in special diets and healthy eating.

Research into the effect of "Kazakhstanskoe 20" sorghum flour on the rheological and baking properties of the dough, the quality and nutritional value of bread allowed us to develop technologies for making high-quality and nutritionally valuable bread.

The advantage of these technologies is their simplicity and efficiency in commercialization.

The addition of 5 to 15% sorghum flour during bread making significantly increases the nutritional value and provides prospects for further expansion of the range of bakery products, including gluten-free ones.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Acknowledgments

The authors would like to thank the administration and staff of Muehlenchemie (Almaty) for their support in conducting the study.

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