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Elena A. Kuznetsova^{1, 2}Maksim B. Rebezov^{3, 4} ✉Nikolay I. Bondarev¹Davaasuren Lkhagvadolgor⁵¹Orel State University named after I.S. Turgenev, Orel, Russia²Bashkir State Agrarian University, Ufa, Russia³Gorbatov Federal Research Center for Food Systems, Moscow, Russia⁴Ural State Agrarian University, Yekaterinburg, Russia⁵Mongolian University of Science and Technology (School of Technology, Darkhan), Ulaanbaatar, Mongolia

✉ rebezov@yandex.ru

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Е.А. Кузнецова^{1, 2}М.Б. Ребезов^{3, 4} ✉Н.И. Бондарев¹Д. Лхагвадолгор⁵¹Орловский государственный университет им. И.С. Тургенева, Орёл, Россия²Башкирский государственный аграрный университет, Уфа, Россия³Федеральный научный центр пищевых систем им. В.М. Горбатова Российской академии наук, Москва, Россия⁴Уральский государственный аграрный университет, Екатеринбург, Россия⁵Монгольский университет науки и технологии, Школа технологии в Дархане, Улан-Батор, Монголия

✉ rebezov@yandex.ru

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Development of an innovative starter culture for use in whole grain bread technology

ABSTRACT

Relevance. Probiotic-based starter cultures are used to improve the quality and safety of whole-grain bread. *The aim of the study* is to use plant substrates with prebiotic properties as fermentation media. Whole-grain buckwheat flour, rich in antioxidants, essential amino acids, vitamins and minerals, can serve as such a substrate. Fermentation using probiotic starter cultures in whole grain bread technology increases the bioavailability of active compounds, nutritional value and microbiological safety of the product.

Methods. Experimental data are presented on the effect of whole-milled buckwheat flour on the growth of lactic acid bacteria and a probiotic yeast strain during the production of thick starter cultures. The antagonistic properties of starter microorganisms against *Bacillus subtilis* and mold fungi of the genera *Aspergillus*, *Penicillium*, *Mucor*, and *Rhizopus* were studied, along with the fermentative activity of the starter. The optimal dosage of thick buckwheat probiotic starter for whole wheat bread production was determined, along with the amino acid composition and antioxidant activity of the resulting bread.

Results. It was found that starter strains developed better in a medium made from the Bashkir Red-Stem buckwheat variety. Antagonistic activity of the studied lactic acid bacteria and yeast strains was observed against *Bacillus subtilis* VKM-B-501 and certain mold strains of *Aspergillus*, *Penicillium*, *Mucor*, and *Rhizopus*. The most promising lactic acid bacteria strains were selected for creating a thick buckwheat probiotic starter. The starter was deemed suitable for baking applications. The optimal amount of thick buckwheat probiotic starter was 40% of the mass of dispersed wheat grain. Using this starter in whole wheat bread technology resulted in bread with enhanced antioxidant activity and a more balanced amino acid profile.

Key words: buckwheat grain, probiotics, antagonistic activity, thick buckwheat starter, whole grain bread

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Разработка инновационной закваски для использования в технологии цельнозернового хлеба

РЕЗЮМЕ

Актуальность. Для повышения качества и безопасности цельнозернового хлеба используются закваски на основе пробиотиков. *Задача исследования* — использование в качестве сред для ферментации растительных субстратов с пребиотическими свойствами. В качестве такого субстрата может служить цельнозерновая гречневая мука, богатая антиоксидантами, незаменимыми аминокислотами, витаминами и минералами. Ферментация с использованием пробиотических заквасок в технологии цельнозернового хлеба повышает биодоступность активных соединений, пищевую ценность и микробиологическую безопасность продукта.

Методы. Представлены экспериментальные данные о влиянии цельнозерновой гречневой муки на рост молочнокислых бактерий и пробиотического штамма дрожжей при производстве густых заквасок. Изучены антагонистические свойства заквасочных микроорганизмов по отношению к *Bacillus subtilis* и плесневым грибам родов *Aspergillus*, *Penicillium*, *Mucor* и *Rhizopus*, а также ферментативная активность закваски. Определены оптимальная дозировка густой гречневой пробиотической закваски для производства цельнозернового хлеба, аминокислотный состав и антиоксидантная активность полученного хлеба.

Результаты. Установлено, что заквасочные штаммы лучше развиваются на питательной среде, приготовленной из гречихи сорта Башкирская красноперея. Антагонистическая активность изученных штаммов молочнокислых бактерий и дрожжей отмечена по отношению к *Bacillus subtilis* VKM-B-501 и некоторым штаммам плесневых грибов родов *Aspergillus*, *Penicillium*, *Mucor* и *Rhizopus*. Для создания густой гречневой пробиотической закваски отобраны наиболее перспективные штаммы молочнокислых бактерий. Закваска признана пригодной для хлебопекарного применения. Оптимальное количество густой гречневой пробиотической закваски составило 40% от массы диспергированного зерна пшеницы. Использование этой закваски в технологии цельнозернового хлеба позволило получить хлеб с повышенной антиоксидантной активностью и более сбалансированным аминокислотным составом.

Ключевые слова: гречневая крупа, пробиотики, антагонистическая активность, густая гречневая закваска, цельнозерновой хлеб

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Introduction/Введение

Sourdough fermentation positively influences the nutritional value of grain-based products by slowing starch digestion and enhancing protein assimilation, which regulates the levels of bioactive compounds including vitamins and minerals [1–3].

Sourdough dominated by lactic acid bacteria has attracted research interest for its potential to improve the overall quality of grain products [4–6].

Probiotics and prebiotics can exert a synergistic effect, as prebiotics promote the growth and activity of probiotics [7–9].

Inulin, lactulose, oligofructose, and polydextrose are proven prebiotics that enhance the proliferation of probiotic strains [10].

Currently, there is a growing interest in unconventional plant-based raw materials rich in prebiotics. Due to its composition, buckwheat seeds are a valuable source of nutrients and have a beneficial impact on human health. A buckwheat-based diet lowers serum cholesterol, improves diabetic conditions by reducing sugar absorption, and supports the growth of beneficial gut bacteria. D-chiro-inositol found in buckwheat helps reduce insulin resistance and enhances insulin action [11]. The nutritional value of buckwheat flour rich in complex carbohydrates, proteins, essential vitamins, minerals, and antioxidants makes it a promising source of prebiotic components for human nutrition and probiotic bacteria [12–15].

Buckwheat is known to possess prebiotic properties. Methanol extracts from buckwheat accelerate the growth of lactic acid bacteria in carbon-free media while inhibiting *Clostridium perfringens* and *Escherichia coli*. This suggests how gut bacteria may respond to buckwheat [16]. Naturally fermented buckwheat cultures or products have proven to be excellent substrates for probiotic bacteria, especially *Lactobacillus* strains. Buckwheat has been shown to reduce populations of *Ruminococcaceae*, *Lachnospiraceae*, *Helicobacteraceae*, *Clostridium*, and *Escherichia*, while increasing *Peptoclostridium*, *Prevotellaceae*, *Lactobacillus*, *Bifidobacterium*, *Enterococcus*, and *Eubacteriaceae* [17].

Studies confirm that aqueous suspensions of buckwheat groats serve as effective prebiotic substrates for lactic acid bacteria, maintaining their viability during storage. Specifically, a 5% buckwheat flour suspension supported active growth of *Lactobacillus* and *Streptococcus thermophilus*: after 24 hours of fermentation, 7 out of 14 strains reached concentrations of 9.00 log CFU/mL. The metabolic activity of *L. casei* strains (2K and Y) in buckwheat substrate varied: despite similar cell counts after fermentation, pH values differed [18]. It was also shown that buckwheat-based beverages provide a suitable medium for the growth of *Lactobacillus* and *Bifidobacteria* populations. Fermented buckwheat groats acquire

beneficial properties and may be used to prevent lifestyle diseases such as diabetes, obesity, and cancer [19].

Several researchers associate whole grain consumption with improved health outcomes. Two major risk factors for cardiovascular disease total cholesterol and low-density lipoproteins in serum did not increase with the consumption of whole grain products, suggesting a cardioprotective role [3, 20, 21].

From a quality improvement perspective, sourdough with lactic acid bacteria as the dominant microflora is of greater research interest than pure yeast fermentation [4, 22–24].

Using sourdough in bread production leads to hydrolysis of dietary fibers, reduced lipid oxidation, improved digestibility of proteins and starch, and increased vitamin content and mineral bioavailability [25]. Phytic acid in grains exists as complexes with metal cations and proteins. Its enzymatic breakdown requires an optimal pH level, which can be achieved through natural fermentation. This degradation significantly increases the amount of soluble iron, zinc, and calcium in fermented grain products [26].

Although the health effects of sourdough bread consumption are not fully understood, Abbondio *et al.* [27] provide evidence that sourdough bread intake can significantly alter gut microbiota taxonomy and the metabolic functions of key microbial groups, including *Bacteroides* and *Clostridium*.

Some studies have examined the effect of adding buckwheat sourdough to wheat bread at levels of 10–20% of total flour. This approach shortens the technological process, improves rheological and sensory properties, and enhances the quality and nutritional value of bread [28–30].

The aim of this study was to develop an innovative starter culture based on whole-milled buckwheat grain and probiotic strains for use in the production of whole wheat bakery products.

Materials and methods /

Материалы и методы исследования

The study focused on common buckwheat (*Fagopyrum esculentum* Moench) of two varieties: Bashkir krasnostebel'naya and Dikul. Pure cultures of *Saccharomyces boulardii* Y 3925 yeast and *Lactobacillus brevis* B78 lactic acid bacteria were used from the industrial microorganism museum collection. Additional strains included *Streptococcus thermophilus* TC 14, TC 91, *Lactobacillus acidophilus* AP Ac, and AP A97 from the pure culture museum of the Federal State Scientific Institution "VNIMI". All strains were stored in lyophilized form at 4–8 °C. Before inoculation, microorganisms were acclimated at room temperature (22 °C) for 2 hours¹. All microbiological work was conducted under aseptic conditions in a laminar flow cabinet.

¹ GOST ISO 7218-2015 Microbiology of food and animal feed. General requirements and recommendations for microbiological testing.

Saccharomyces boulardii Y 3925 yeast cultures were revived on Sabouraud medium, while lactic acid bacteria were cultured on MRS medium.

To assess antagonistic activity, pure cultures of *Bacillus subtilis* VKM-B-501, *Aspergillus flavus* VKM-F-1024, *Aspergillus candidus* VKM-F-3908, *Penicillium crustosum* VKM-F-4080, *Penicillium expansion* VKM-F-275, *Mucor mucedo* VKM-F-1257, *Mucor racemosus* var. *sphaerosporus* VKM-F-541, and *Rhizopus stolonifer* VKM-F-2005 were used. Antagonistic activity was studied using the agar diffusion method with supernatants of culture fluids.

Thick buckwheat sourdough was prepared by milling buckwheat grain to particle sizes under 0.35 mm using an SM 200 mill. A suspension was made by mixing flour with water at a 1:3 ratio. Lactic acid bacteria and yeast biomass were washed from culture media and added to the suspension. The mixture was incubated at 30–32 °C for 48 hours until reaching an acidity of 8–10 °C in a thermostat. During fermentation, the mass increased 2–3 times. The sourdough was stored in sealed containers under refrigeration.

For bread preparation, soft winter wheat grain of the Mironovskaya 808 variety was cleaned and soaked for 10 hours. Excess water was drained, and the grain was twice dispersed using a Homogenizer 1094 (Tekator). Sourdough was added in varying amounts (20 to 60%). Additionally, 4% dry wheat gluten (based on dispersed wheat mass) was added to improve bread quality. Dough was manually kneaded, fermented in a chamber at 35 °C and 75–80% humidity, and baked at 220 °C. Proofing and baking were done using PRSH-1 and PRSH-11 ovens. Control bread was prepared using the straight dough method per GOST 31805–2018². Organoleptic and physicochemical analyses were conducted four hours post-baking.

Lactic acid bacteria counts were measured using a DEN-1B densitometer and McFarland turbidity standards.

Reducing sugars were determined by the semi-micro titrimetric method of K.N. Chizhova and A.N. Sonkina, based on copper oxide reduction in Fehling's solution³.

α -Amino nitrogen content was measured by titration, based on the formation of soluble copper complexes with amino acids and peptides, followed by iodometric titration³.

Antioxidant activity was measured spectrophotometrically in ethanol extracts at 515 nm, using the DPPH radical inhibition method described by Silva *et al.* [31].

Free and protein-bound amino acids were quantified after hydrolysis in sealed ampoules with 6N HCl for 24 hours, using ion-exchange chromatography and electrochemical detection on a Chromaspek amino acid analyzer.

Results and discussion /

Результаты и обсуждение

Demand for health-promoting foods has increased, and whole grain sourdough bread fits this category. To select suitable lactic acid bacteria strains for sourdough, microbial growth was studied in media made from whole-milled buckwheat of two varieties after 24 and 48 hours of incubation. Results are shown in Table 1.

The Bashkir krasnostebel'naya variety proved more suitable due to its higher content of bioactive compounds. These compounds enhance probiotic bacterial growth, resulting in 7.8–21.6% higher counts compared to the Dikul variety. Since *S. boulardii* yeast is included in the sourdough, selecting lactic acid bacteria that allow for alcoholic fermentation is crucial. *S. boulardii* tolerates low pH better than other *Saccharomyces* species, making it suitable for sourdough and fermented dairy products⁴. Although *Lactobacillus acidophilus* AP Ac grew well, it produced excessive lactic acid, lowering pH to 4.3 after 48 hours, and was excluded from the sourdough formulation.

A key criterion for selecting lactic acid bacteria strains for sourdough used in grain bread is antagonistic activity against spore-forming bacteria and storage molds. These contaminants enter bread production via raw materials (flour, yeast, additives) and equipment surfaces [32]. Spore-forming bacteria and molds are typically concentrated in the outer grain layers and are especially common in whole grain bread [33, 34].

The antagonistic activity of selected lactic acid bacteria and yeast strains was tested against *Bacillus subtilis* VKM-B-501 and mold strains of *Aspergillus*, *Penicillium*, *Mucor*, and *Rhizopus* (Table 2). The results confirmed that the studied strains exhibited inhibitory effects on these microorganisms, indicating

Table 1. The number of lactic acid bacteria during growth in the starter medium

A strain of lactic acid bacteria	24 hours of temperature control		48 hours of temperature control	
	Number of bacteria (CFU/ml)	pH	Number of bacteria (CFU/ml)	pH
Bashkir krasnostebel'naya buckwheat				
<i>Streptococcus thermophilus</i> TC 14	1,66×10 ⁹	5,1	2,25×10 ⁹	4,8
<i>Streptococcus thermophilus</i> TC 91	1,69×10 ⁹	5,2	2,29×10 ⁹	4,5
<i>Lactobacillus acidophilus</i> AP Ac	3,05×10 ⁹	6,0	3,55×10 ⁹	4,3
<i>Lactobacillus acidophilus</i> AP A97	2,58×10 ⁹	5,8	3,15×10 ⁹	4,5
<i>Lactobacillus brevis</i> -B78	2,10×10 ⁹	5,9	3,14×10 ⁹	4,6
Dikul buckwheat				
<i>Streptococcus thermophilus</i> TC 14	1,55×10 ⁹	5,0	2,00×10 ⁹	4,8
<i>Streptococcus thermophilus</i> TC 91	1,57×10 ⁹	5,0	2,06×10 ⁹	4,7
<i>Lactobacillus acidophilus</i> AP Ac	2,98×10 ⁹	5,6	3,30×10 ⁹	4,6
<i>Lactobacillus acidophilus</i> AP A97	2,07×10 ⁹	5,8	2,59×10 ⁹	4,6
<i>Lactobacillus brevis</i> -B78	1,88×10 ⁹	5,9	2,78×10 ⁹	4,6

² GOST 31805–2018 Bakery products made from wheat flour. General specifications.

³ Eliseeva S.I. Quality control of raw materials, semi-finished products and finished products at bakeries. Moscow: Agropromizdat. 1987; 128.

⁴ Soboleva E.V. Substantiation of the use of *Saccharomyces cerevisiae* yeast strain RCAM 01730 in the technology of wheat bread with increased microbiological resistance. Dissertation for the degree of Candidate of Technical Sciences. St. Petersburg. 2014; 142.

their potential to improve the microbiological safety of read.

It was established that when the supernatant of the culture fluid of *Saccharomyces boulardii* VKPM-Y-3925 was introduced into wells, zones of inhibition were observed against *Bacillus subtilis*, the causative agent of potato disease in bread. Similar findings were reported by E.V. Soboleva [33], who studied the antagonistic effect of *Saccharomyces boulardii* strain RCAM 01730 against *Bacillus subtilis* VKM 120.

Experimental research revealed that the probiotic strains suppressed the development of typical mold strains responsible for spoilage of bakery products. Overall, the yeast strain *Saccharomyces boulardii* VKPM-Y-3925 exhibited stronger antagonistic activity against the tested mold cultures compared to the lactic acid bacteria strains. The studied *Streptococcus thermophilus* strains showed no antagonistic activity against *Aspergillus flavus*.

These findings confirm the antagonistic activity of the probiotic strains against the studied mold fungi and spore-forming *Bacillus* bacteria, indicating their potential use in imparting antimicrobial properties to bakery products. Based on the combined properties studied, the following microorganisms were selected for the sourdough formulation: homofermentative lactic acid bacteria *Streptococcus thermophilus* TC 14, *Lactobacillus acidophilus* AP A97, heterofermentative *Lactobacillus brevis*-B78, and yeast *Saccharomyces boulardii* VKPM-Y-3925.

The characteristics of the resulting thick buckwheat probiotic sourdough (Table 3) demonstrate its suitability for baking applications.

The developed thick probiotic sourdough, based on probiotic microorganisms and whole-milled buckwheat flour of the Bashkir Red-Stem variety, was applied in whole wheat bread technology. Prior to this, the fermentative activity of the sourdough microorganisms was studied by tracking the accumulation dynamics of free amino nitrogen and reducing sugars over two hours of fermentation (Fig. 1).

It was found that during two hours of fermentation, the levels of amino nitrogen and reducing sugars in the dough decreased by 27.3% and 12%, respectively, indicating active consumption of these compounds by the sourdough microorganisms. These experimental results confirm the high fermentative activity of the sourdough strains.

To determine the optimal sourdough dosage for whole grain bread technology, trial baking

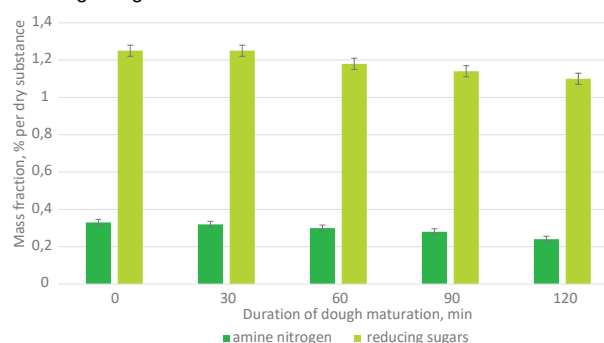
Table 2. The effect of lactic acid bacteria and *S. boulardii* strains on the development of test cultures of mold pathogens and potato bread disease

Test cultures	The diameters of the growth inhibition zones of the test cultures of microorganisms under the influence of the studied bacteria and yeast <i>S. boulardii</i> , mm				
	<i>Streptococcus thermophilus</i> TC 14	<i>Streptococcus thermophilus</i> TC 91	<i>Lactobacillus acidophilus</i> AP A97	<i>Lactobacillus brevis</i> -B78	<i>Saccharomyces boulardii</i> VKPM-Y-3925
<i>Bacillus subtilis</i> VKM-B-501	6,5 ± 0,6	8,1 ± 0,6	10,3 ± 0,6	9,3 ± 0,6	11,7 ± 0,6
<i>Aspergillus candidus</i> VKM-F-3908	8,0 ± 0,6	9,1 ± 0,6	8,5 ± 0,6	7,8 ± 0,6	11,3 ± 0,6
<i>Aspergillus flavus</i> VKM-F-1024	the zone is missing	the zone is missing	8,0 ± 0,6	8,3 ± 0,6	9,7 ± 0,6
<i>Penicillium expansion</i> VKM-F-275	6,8 ± 0,6	7,2 ± 0,6	6,3 ± 0,6	8,7 ± 0,6	12,3 ± 0,6
<i>Penicillium crustosum</i> VKM-F-4080	8,7 ± 0,6	9,7 ± 0,6	the zone is missing	10,3 ± 0,6	11,7 ± 0,6
<i>Mucor mucedo</i> VKM-F-1257	the zone is missing	6,7 ± 0,6	8,3 ± 0,6	the zone is missing	10,7 ± 0,6
<i>Mucor racemosus</i> var. <i>sphaerosporus</i> VKM-F-541	the zone is missing	6,3 ± 0,6	10,7 ± 0,6	9,2 ± 0,6	the zone is missing
<i>Rhizopus stolonifer</i> VKM-F-2005	9,5 ± 0,6	10,1 ± 0,6	the zone is missing	8,3 ± 0,6	9,3 ± 0,6

Table 3. Characteristics of the Sourdough

Indicator	Thick Buckwheat Sourdough
Moisture content, %	49.86 ± 0.1
Titrated acidity, deg	13.4 ± 1.0
Fermentation activity, min	5.0 ± 1.0
Lifting force on the ball, min	30.0 ± 1.0
The number of microorganisms in the studied semi-finished product	
Total	134x10 ⁶
Yeasts	58x10 ⁶
Bacteria	76x10 ⁶

Fig. 1. Changes in Free Amino Nitrogen and Reducing Sugars During Dough Fermentation



experiments were conducted using varying amounts of thick buckwheat probiotic sourdough during dough preparation. The results of these experiments, assessing the impact of sourdough quantity on bread quality indicators, are presented in Table 4.

The studies showed that increasing the sourdough quantity improved the physicochemical properties of the finished bread: moisture content decreased, and specific volume and crumb porosity increased. However, sensory qualities declined due to increased acidity in the crumb. The resulting whole wheat bread had a proper shape with a domed top crust, a smooth,

Table 4. Optimal Quantity of Thick Buckwheat Probiotic Sourdough

Bread Quality Indicator	Sourdough Amount (% of flour mass)				
	20	30	40	50	60
Taste	Characteristic bread flavor, slightly sweet		Characteristic, pronounced		Sour
Mass fraction of moisture, %	47.1	47.8	46.3	45.6	45.0
Acidity, degree	6.3	6.9	7.6	8.2	9.4
Porosity, %	48.0	49.4	51.8	51.9	52.0
Specific volume, cm ³ /g	1.48	1.50	1.51	1.52	1.53

glossy surface free of cracks, and a uniform crumb structure with medium and small pores. The bread had a characteristic aroma and flavor typical of whole grain bakery products. Thus, the study concluded that the optimal amount of thick buckwheat probiotic sourdough is 40% of the mass of dispersed wheat grain.

The antioxidant activity of the developed whole wheat bread using thick buckwheat probiotic sourdough was determined to be 28.8% DPPH radical inhibition, compared to 9.8% in control bread made according to GOST 31805.

The amino acid composition of the developed whole grain bread was also analyzed and is presented in Table 5.

The data show that the amino acid profile of the developed bread improved. The content of isoleucine and lysine increased, as did the combined total of cystine and methionine. The total amino acid content in the developed bread was 6.8% higher than in the control bread made according to GOST 31805.

To assess the microbial stability of the whole wheat bread made with thick buckwheat probiotic sourdough, the bread was cooled and stored under provoked conditions (temperature = 37 ± 1 °C, relative humidity = 90%) until signs of potato disease and mold appeared. Observations were conducted over 120 hours.

It was found that bread made with the developed sourdough was less susceptible to microbial spoilage compared to the control bread. The first signs of potato disease — characteristic odor and changes in crumb elasticity — appeared after 60 hours in the control sample. In contrast, the sourdough bread showed no signs of spoilage during the observation period.

Visible mold mycelium appeared on the surface of the control bread after 68–70 hours, while it appeared on the sourdough bread only after 98 hours — 28–30 hours later. This indicates that the use of thick buckwheat probiotic sourdough in whole grain bread technology helps prevent microbial spoilage of the final product.

The fermentative activity of the sourdough was also evaluated. The selected strains demonstrated high fermentative capacity, contributing to the development of desirable sensory properties in the final bread product. The optimal dosage of thick buckwheat probiotic sourdough was determined to be 40% of the mass of dispersed wheat grain.

Table 5. Amino Acid Composition of Whole Wheat Bread with Thick Buckwheat Probiotic Sourdough

Amino Acid, mg / 100 g	Grain wheat bread according to GOST 31805	Grain wheat bread with buckwheat probiotic thick Sourdough
Aspartic acid	418	667
Glutamic acid	2118	2076
Serine	296	356
Histidine	205	221
Glycine	386	411
Threonine	224	310
Arginine	436	536
Alanine	292	398
Tyrosine	146	177
Cystine + Methionine	268	297
Valine	411	398
Phenylalanine	428	427
Isoleucine	253	289
Leucine	538	517
Lysine	243	318
Proline	842	649
The sum of amino acids	7504	8047

This proportion provided the best balance between fermentation efficiency and bread quality. Bread produced with the developed sourdough showed improved antioxidant activity and a more balanced amino acid profile compared to control samples. The inclusion of buckwheat-based sourdough enhanced the nutritional value of the bread, making it a functional food product suitable for health-conscious consumers.

Conclusions /Выводы

An innovative sourdough starter was developed using whole-milled buckwheat flour and pure probiotic strains: lactic acid bacteria *Streptococcus thermophilus* TC 14, *Lactobacillus acidophilus* AP A97, *Lactobacillus brevis*-B78, and yeast *Saccharomyces boulardii* VKPM-Y-3925. It was established that the starter strains of microorganisms grew best in a fermentation medium made from the Bashkir krasnostebel'naya buckwheat variety.

Antagonistic activity was observed in the studied strains of lactic acid bacteria and yeast against the spore-forming bacterium *Bacillus subtilis* VKM-B-501 and mold strains *Aspergillus flavus* VKM-F-1024, *Aspergillus candidus* VKM-F-3908, *Penicillium crustosum* VKM-F-4080, *Penicillium expansion* VKM-F-275, *Mucor mucedo* VKM-F-1257, *Mucor racemosus* var. *sphaerosporus* VKM-F-541, and *Rhizopus stolonifer* (syn. *Rhizopus nigricans*) VKM-F-2005.

The characteristics of the resulting thick buckwheat probiotic sourdough demonstrated high fermentative activity and suitability for baking applications. Trial baking experiments determined that the optimal amount of thick buckwheat probiotic sourdough is 40% of the mass of dispersed wheat grain.

Incorporating the optimal dosage of the developed innovative sourdough into whole wheat

bread technology resulted in bread with enhanced antioxidant activity and a more balanced amino acid profile. The use of this sourdough technology helps prevent microbial spoilage of the finished product.

The author is responsible for the work and the presented data.

The author contributed 100% to the work.

The author participated in writing the manuscript and is responsible for plagiarism.

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The proposed technological solutions will expand the range of whole grain bakery products with increased nutritional value, suitable for functional nutrition applications.

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БИБЛИОГРАФИЧЕСКИЙ СПИСОК

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ОБ АВТОРАХ

Елена Анатольевна Кузнецова^{1,2}

- доктор технических наук, доцент, завкафедрой промышленной химии и биотехнологии¹
 - доктор технических наук, доцент, профессор кафедры технологии общественного питания и переработки растительного сырья²
- elkuznetcova@yandex.ru
<https://orcid.org/00000-0001-7165-3517>

Максим Борисович Ребезов^{3,4}

- доктор сельскохозяйственных наук, профессор, главный научный сотрудник³
 - доктор сельскохозяйственных наук, профессор кафедры биотехнологии и пищевых продуктов⁴
- rebezov@ya.ru
<https://orcid.org/0000-0003-0857-5143>

Николай Ильич Бондарев¹

доктор биологических наук, доцент, профессор кафедры промышленной химии и биотехнологии
nik.in@list.ru
<https://orcid.org/0009-0001-1198-0345>

Даваасурен Лхагвадолгор⁵

кандидат технических наук, старший преподаватель кафедры технологии
lkhagvadolgorg@stda.edu.mn
<https://orcid.org/0009-0005-3640-2188>

¹Орловский государственный университет
 им. И.С. Тургенева,
 ул. Комсомольская, 95, Орёл, 302026, Россия

²Башкирский государственный аграрный университет,
 ул. 50-летия Октября, 34, Уфа, 450001, Россия

³Федеральный научный центр пищевых систем
 им. В.М. Горбатова Российской академии наук,
 ул. им. Талалихина, 26, Москва, 109316, Россия

⁴Уральский государственный аграрный университет,
 ул. им. Карла Либкнехта, 42, Екатеринбург, 620075, Россия

⁵Монгольский университет науки и технологий,
 Школа технологии в Дархане,
 8-я улица Бага Тойруу, 34, Улан-Батор, 46/520, Монголия

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ABOUT THE AUTHORS

Elena Anatolyevna Kuznetsova^{1,2}

- Doctor of Technical Sciences, Associate Professor, Head of the Department of Industrial Chemistry and Biotechnology¹
 - Doctor of Technical Sciences, Associate Professor, Professor of the Department of Public Catering Technology and Processing of Plant Raw Materials²
- elkuznetcova@yandex.ru
<https://orcid.org/00000-0001-7165-3517>

Maksim Borisovich Rebezov^{3,4}

- Doctor of Agricultural Sciences, Professor, Chief Researcher³
 - Doctor of Agricultural Sciences, Professor of the Department of Biotechnology and Food Products⁴
- rebezov@ya.ru
<https://orcid.org/0000-0003-0857-5143>

Nikolai Ilyich Bondarev¹

Doctor of biological sciences, Docent, Professor of the Department of Industrial Chemistry and Biotechnology
nik.in@list.ru
<https://orcid.org/0009-0001-1198-0345>

Davaasuren Lkhagvadolgorg⁵

Candidate of Technical Sciences, Senior Lecturer at the Department of Technology
lkhagvadolgorg@stda.edu.mn
<https://orcid.org/0009-0005-3640-2188>

¹Orel State University named after
 I.S. Turgenev,
 95 Komsomolskaya Str., Orel, 302026, Russia

²Bashkir State Agrarian University,
 34 50-letiya Oktyabrya Str., Ufa, 450001, Russia

³Gorbatov Federal Research Center for Food Systems,
 Moscow, Russia,
 26 Talalikhin Str., Moscow, 109316, Russia

⁴Ural State Agrarian University,
 42 Karl Liebknecht Str., Yekaterinburg, 620075, Russia

⁵Mongolian University of Science and Technology
 (School of Technology, Darkhan),
 34 8th Baga Toiruu Str., Ulaanbaatar, 46/520, Mongolia