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Fermentation activity of rye sourdough as a quality factor of wheat-rye bread

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Abstract. The purpose of the article was to determine the best fermentation activity of rye sourdough starter for the production of wheat-rye bread for health purposes. Natural sourdough bread is popular in the Ukrainian flour market due to its high taste and nutritional value. The developed recipe of wheat-rye sourdough bread contained high-grade wheat flour, rye flour, rye bran, olive oil, salt and sugar, as well as rye sourdough on different days of its fermentation. The sensory analysis was performed and the organoleptic characteristics of wheat-rye sourdough bread were determined. A sensory profilogram of model compositions of wheat-rye bread was constructed and, based on the results of expert evaluation, the model composition with the best organoleptic characteristics was determined. According to the experiment, the starter of the sixth day of fermentation allowed to achieve the highest gas retention capacity and optimal spreading of the dough ball. In the process of fermentation in all the tested samples, an increase in the active acidity of the dough was observed, which affected its quality characteristics. The moisture content and porosity of the finished product obtained with the sourdough starter of the sixth day of fermentation increased by 2.3% and 7.4%, respectively, compared to the values recorded for bread with the sourdough starter of the fourth day of fermentation. There was a slight increase in the fragility of the finished product due to an increase in its porosity. Wheat-rye bread with rye sourdough was beneficial due to dietary fiber, which improved digestion, normalises the microflora, reduces the risk of heart disease, and vitamins and minerals that strengthen the immune system and support energy metabolism

Keywords: moisture; porosity; recipe; organoleptic evaluation; nutritional value

Introduction

In Ukraine, human life and health are defined as the highest social value. S. Kvasha *et al.* (2024) argued that food security was a systemic element of national security, which guaranteed effective management of

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the food system, ensuring that food needs were met in the proper quantity and quality for every citizen of the country. Similarly, O. Ivanishcheva & O. Pakhomskaya (2021) pointed out that food quality and safety were one of the key indicators of population well-being. In this context, the production of bakery products with functional properties was of particular relevance.

Modern bakeries were faced with the task of expanding the range of products aimed at preventing diseases and maintaining consumer health. This required the development of new recipes and the enhancement of current production processes to guarantee the addition of biologically active substances to bakery goods. Therefore, an innovative approach to the baking industry was becoming an important tool in improving the quality of life of the population.

Sourdough starter cultures had attracted considerable attention of scientists. K. Papadimitriou *et al.* (2019) studied its impact on bread quality, focusing on the prospects for using alternative raw materials, innovative fermentation technologies, and expanding the range of bakery products. O. Naumenko & V. Chizh (2022) divided sourdoughs into four types depending on the preparation process and the metabolic activity of the bacteria and yeast they contain. Type I starters were a mixture of flour and water to which a pre-fermented starter was added. It was usually a viscous with a pH range of 3.8 to 4.5, which was fermented at a temperature of 20°C to 30°C. A primarily liquid blend of flour and water, the Type II starting culture fermented for up to five days at temperatures higher than 30°C. Type III sourdough was made by drying a flour and water mixture to induce dormancy in microorganisms. Before use, it was reactivated and re-suspended in water, most often it was used for large-scale baking. Type IV sourdough (mixed), consisted of a mixture of types I and II.

Scientists N. Hernández-Parada *et al.* (2023) noted that the ratio of lactic acid bacteria and yeast, their growth and metabolic activity, which determined the physical, chemical, biochemical and sensory characteristics of sourdough bread, depend on the fermentation and storage temperature of the sourdough. Most often, a temperature equal to 30°C was used for fermentation of sourdough. At the same time, A.S. Amr & A.M. Alkhamaiseh (2022) emphasised that the growing popularity of sourdough bread was driven by consumer demand for a natural product with a rich taste,

balanced properties, and a long shelf life, which met modern ideas of healthy eating.

The authors V. Bandura & K. Teplyuk (2024) devoted their study to the development of a recipe for the latest technologies of bakery products with a low sugar content. In particular, it was proposed to introduce stevia extract into the recipe of bakery products, which can reduce the sugar content in products and give them functional properties. C.B. Munch-Andersen *et al.* (2024) investigated the impact of fermentation temperature on the pH stability of starter cultures and the shift in microflora during the fermentation of bean flour starter cultures. The findings demonstrated that fermentation can raise the nutritional content and quality of goods made from beans.

I.T. Akamine *et al.* (2023) investigated microorganisms from sourdough that produce enzymes (glutenase, amylase, cellulase, peptidase) that contribute to the reduction of allergenic molecules in wheat flour, while preserving its baking properties. The results of the study opened up opportunities for the development of innovative starter cultures with improved properties and increased nutritional value.

The aim of this study was to evaluate the effect of the fermentation time of rye sourdough on the quality and nutritional properties of wheat-rye bread.

Materials and Methods

The research was carried out in 2024 at Lutsk National Technical University. Model samples of craft wheat-rye bread on rye sourdough were made according to the recipe indicated in Table 1. To determine the best fermentation property of rye sourdough, samples of dough were prepared from premium wheat flour, rye flour and rye bran with the addition of rye sourdough on the fourth (sample 1), fifth (sample 2), sixth (sample 3) and seventh (sample 4) days of its fermentation. Sampling of flour used as the main raw material in the recipe was carried out in accordance with GOSTU 46.004-99 (1999) and DSTU 8791:2018 (2019). For the production of bread and bakery products, it was necessary to use flour that had a good ability to form dough with appropriate structural and mechanical properties. This ability was characterised by an indicator of the strength of flour – a physical property that can be assessed by the spread of a ball of dough during proofing. Accordingly, the strength of flour affected the quality of finished bakery products and determined their volume, texture and porosity.

Table 1. Recipe for wheat-rye bread on rye sourdough

Raw material	Mass, kg	Moisture, %	Dry matter weight, kg
Premium wheat flour	46.0	14.0	39.6
Rye flour	30.0	14.0	25.8
Rye bran	3.0	14.0	2.6
Sourdough (rye flour)	21	50.0	10.5

Table 1. Continued

Raw material	Mass, kg	Moisture, %	Dry matter weight, kg
Olive oil	5.0	–	–
Food salt	3.0	–	3.0
Granulated sugar	6.0	–	6.0
Together	114		87.5

Source: developed by authors

The study was carried out using physicochemical and organoleptic methods in accordance with regulatory documents DSTU 7045:2009 (2010) and DSTU 9188:2022 (2023). Using sensory testing techniques, the organoleptic properties of wheat-rye bread on rye sourdough were ascertained by H.T. Lawless & H. Heymann (2010). The assessment was carried out by the method of expert assessments on a 5-point scale. Figure 1 displayed cross-sectional prototypes created using the recipe listed in Table 1.



Figure 1. Sections of test samples of bread

Note: a – sample 1; b – sample 2; c – sample 3; d – sample 4

Source: developed by the authors

According to the method described by V. Drobot et al. (2021), the influence of the fermentation time of the starter culture on the structural and mechanical properties of the dough was experimentally determined, and the gas-forming ability of the dough was determined according to the method described by Z.I. Kucheruk & O.S. Tsukanova (2014). Active acidity was determined using a generally accepted technique by D. Hasenay et al. (2006). Using the approach outlined by C. Simons (2018), the moisture content of wheat-rye bread samples was ascertained, also in compliance with DSTU 7045:2009 (2010). The approach outlined by T.V. Bozhko et al. (2019) was used to investigate the porosity of bread. For this purpose, the Zavyalov method was used using Zhuravlev's device (Ukraine), by weighing three cylindrical samples with a volume of $27 \pm 0.5 \text{ cm}^3$ each, which was designed to isolate a sample of a certain volume from a bakery product, according to the results of weighing which the porosity of bread was determined by calculation. Bread staleness was assessed using the method of T.A. Sylchuk (2004). The research was conducted in accordance with standards of The Declaration of Helsinki (2013).

Results and Discussion

To determine the best fermentation activity of rye sourdough, dough samples were prepared according to the recipe given in Table 1, changing the type of sourdough depending on its fermentation time. The spread of the dough ball was used to examine, how the various sourdough fermentation activities affected the dough's viscosity. The dough sample was shaped into 50 mm-diameter balls. The dough ball's diameter was measured after the fermentation procedure, which lasted four hours at 30°C , was finished. The dough balls' diameter changed during the fermentation process, as seen in Figure 2. The diameter of the dough ball changed the least in sample 1, indicating that the starter was not active enough. Sample 3 had the highest sourdough activity, as seen by the dough ball's biggest diameter. Additional variations in the dough ball's diameter were negligible. V. Drobot et al. (2021) also investigated the effect of different amounts of rice flour on the viscosity of the dough by changing the volume of the dough ball during its fermentation process. It was found that the diameter of a ball of dough with rice flour during fermentation decreased by 3.7–18.5%, depending on the dosage. In this study, an increase in the diameter of the dough ball with an increase in the fermentation activity of the starter culture has been experimentally established.

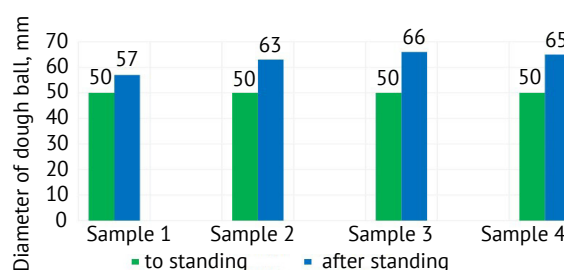


Figure 2. Changing the diameter of the dough ball
Source: developed by authors

During the study of the gas-forming capacity, the change in the volume of dough samples during fermentation was determined. The initial volume of dough samples was measured by placing them in a measuring cylinder. The dough was left to ferment for 4 hours in a proofing cabinet at 30°C . After the fermentation process was completed, the volume of dough samples was determined (Table 2).

Table 2. Dough volume before and after fermentation

No. sample	Dough volume, cm ³				
	0	60	120	180	240
1	10.0	11.3	12.8	15.7	19.1
2	10.0	11.5	16.4	21.1	22.3
3	10.0	12.2	17.1	22.2	24.5
4	10.0	12.5	16.6	22.6	23.9

Source: developed by authors

The dough of sample 3 had the highest gas retention capacity, while sample 4 had a slightly lower value. The study found that the sourdough reaches its maximum activity on the sixth day of fermentation, so it is during this period that it is most advisable to use it to obtain a finished product. The gas-forming ability of the dough was determined according to the method described by Z.I. Kucheruk & O.S. Tsukanova (2014) and their experimental studies showed that with an increase in the amount of xanthan to 0.3% to the weight of starch, the specific volume of the dough improves, and with the amount of xanthan 0.5% to the weight of starch, this figure decreases, which may be due to the inhibition of fermentation. It was demonstrated in this study that, when the starter's fermentation activity increased, so did the dough's volume.

Understanding the acidity of the dough and bread medium was crucial for comprehending the chemical reactions that take place during baking and for advancing the technology used to produce bakery goods. The final product's quality, especially its taste and texture, can be better controlled as a result of these scientific advancements. Thus, the authors I. Banu *et al.* (2011) found that the pH value of the starter culture differs for samples of dark rye flour and whole grain rye flour that were fermented at 30°C and 37°C for 24 hours using different microbiological cultures. The pH value varies depending on the composition of the flour and the physicochemical properties. Rheological analysis of samples carried out by R. Mürniece *et al.* (2023) showed that the pH value varies between 4.09 and 5.15 for rye bread and from 4.26 to 4.89 for barley bread made by brewing flour and without brewing, respectively. This indicates the effectiveness of fermentation of the dough by brewing with a high content of reducing sugars.

Because wheat flour was used in the recipe, the active acidity values of the dough samples for wheat-rye bread on rye sourdough created in this study were greater than the initial data from the literature (pH 6.1-6.3). It had been demonstrated that the dough's acidity reduces in all samples throughout the fermenting process. This indication dropped to 5.2 in samples 1 and 2, then declines to 5.4 in samples 3 and 4. (Fig. 3). Therefore, using starting cultures increases the dough's acidity buildup, which speeded up its maturation and enriches goods with organic acids, minerals, and dietary fiber found in flour. In addition, studies by authors K.S. Aplevicz *et al.* (2013) and

A. Korzhenivska *et al.* (2019) experimentally confirmed a decrease in the pH value of dough and bread with increasing fermentation time. Laboratory tests of this research also confirmed this pattern.

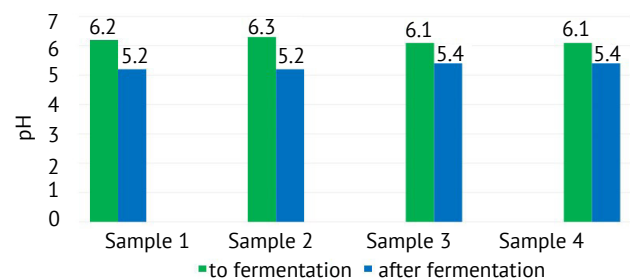


Figure 3. Diagram of changes in the acidity of dough during its fermentation

Source: developed by authors

Two important measures of the quality of wheat-rye sourdough bread were the crust's moisture content and the crumb's porosity. As noted by M. Gharekhani *et al.* (2021), these qualities relied on the type of starting culture, and how long it was stored after baking. The researchers discovered that as the crumb's storage time increased, its moisture content gradually dropped. When examining the porosity of sourdough bread samples from microbiological cultures, I. Banu *et al.* (2011) determined that this indicator is lower for bread made from whole grain rye flour compared to bread made from dark rye flour. Figure 4 displayed the findings of identifying these markers for the research samples.

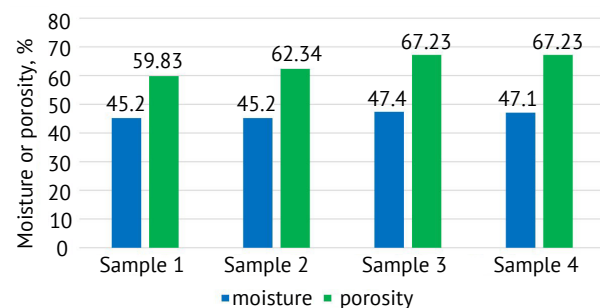


Figure 4. Calculated values of moisture and porosity of bread crumb

Source: developed by authors

The moisture content of bread made from a mixture of rye and wheat flour should be no more than

41.0-53.0% (DSTU 4583:2023, 2024). Sample 3 had the highest moisture content (47.4%), whereas samples 1 and 2 had the lowest (45.2%). The moisture content of each examined sample was within allowable bounds. The porosity of bread made from a mixture of rye and wheat flour according to (DSTU 4583:2023, 2024) must be not less than 46.0%. The porosity of the final product increases as the sourdough's activity increases, according to the study of the bread crumb's porosity values. The porosity of bread samples 3 and 4 was the

highest and amounted to 67.23%. This was a 7.4% increase compared to sample 1.

The length of time that bread and bakery goods were preserved was one of the most crucial markers of their freshness. Numerous factors affect bread's freshness, including its composition, the way the dough was prepared, and the addition of ingredients that slow down the staleness process, which can be measured using the fragility indicator. The estimated average values of brittleness of bread samples were given in Table 3.

Table 3. Average values of bread brittleness

Sample	Brittleness, %		
	3 hours after baking	24 hours after baking	48 hours after baking
1	0.9	2.5	3.5
2	1.1	3.1	4.4
3	1.4	3.2	5.5
4	1.4	3.3	5.6

Source: developed by authors

Samples 3 and 4 lost freshness the fastest (the maximum brittleness value 48 hours after baking was 5.5% and 5.6%, respectively) due to the higher porosity of the finished products. Sourdough-made wheat-rye bread had a long-lasting freshness, a strong scent, and a mildly sour taste. The specialists' organoleptic examinations and data from the literature verified that the bread had an elastic texture and a porous crumb with thin pore walls. The results of sensory evaluation of bread samples carried out by D. Djukić *et al.* (2014) showed that depending on the method of kneading, bread with different organoleptic and physicochemical parameters can be obtained. Optimising the rye

sourdough fermentation process helped provide a rich profile of flavour and volatile chemicals that enhance the bread's sensory qualities, when added. The process of reproduction resulted in the activation of beneficial components and the formation of new compounds with various functional qualities that improved the bread's quality. The biodiversity of lactic acid bacteria (LAB) for fermentation was investigated by L. de Vuyst & M. Vancaeyt (2007), while M.G. Gänzle *et al.* (2023) showed that recent advancements had modified the selection criteria for starter cultures and expanded tools for assessing their metabolic potential. The results of expert evaluation of bread samples were presented in Table 4.

Table 4. Organoleptic parameters of bread samples

No. sample	Sample 1	Sample 2	Sample 3	Sample 4
Indicator	From wheat and rye flour, rye bran and sourdough on the fourth day of fermentation	From wheat and rye flour, rye bran and sourdough on the fifth day of fermentation	From wheat and rye flour, rye bran and sourdough on the sixth day of fermentation	From wheat and rye flour, rye bran and sourdough on the seventh day of fermentation
Surface condition	Smooth, slightly rough, without undermining, with small cracks	Smooth, slightly rough, without undermining, with small cracks	Smooth, slightly rough, without undermining and cracks	Smooth, slightly rough, without undermining and cracks
Crust colour	Light brown	Light brown	Light brown	Light brown
Colour of the crumb	Light brown with brown bran blotches	Light brown with brown bran blotches	Light brown with brown bran blotches	Light brown with brown bran blotches
Porosity	With uneven pores, thin-walled and small	With uneven pores, thin-walled and small	With uniform pores, thin-walled and small	With uneven pores, thin-walled and large
Taste	Characteristic of products made from wheat and rye flour and bran, a slightly sour taste characteristic of rye products	Characteristic of products made from wheat and rye flour and bran, a slightly sour taste characteristic of rye products	Characteristic of products made from wheat and rye flour and bran, a slightly sour taste characteristic of rye products	Characteristic of products made from wheat and rye flour and bran, a slightly sour taste characteristic of rye products
Smell and aroma	Characteristic of products made from wheat and rye flour and bran	Characteristic of products made from wheat and rye flour and bran	Characteristic of products made from wheat and rye flour and bran	Characteristic of products made from wheat and rye flour and bran

Source: developed by authors

All of the bread samples that were analysed had smooth, somewhat rough surfaces, and samples 3 and

4 showed no signs of undermining or cracking, according to the experts. Every sample had a light brown

crust, and the crumbs had light brown bran blotches throughout. In sample 3, the porosity is fairly uniform with thin-walled and small pores, in samples 1, 2 and 4 it is uneven with small and large pores. All of the samples under study had a taste that was typical of goods derived from wheat and rye flour and bran, with rye items having a somewhat sour flavour. Products created from wheat and rye flour and bran also had a distinct scent and aroma. According to the results of the expert evaluation, sample 3 received the highest overall score: its porosity was rated at 4.9, and all

other indicators were rated at 5. Sample 4 was the best rated for crust and crumb colour, taste, smell and aroma, but received 4.9 points for surface condition and 4.8 points for porosity. Sample 2 received the highest scores for crust colour, smell and aroma, while taste was rated at 4.8 and surface condition, crust colour and porosity at 4.9. The lowest scores were for sample 1: surface condition, crumb colour and taste received 4.9 points, while crust colour, porosity, smell and aroma received 4.8 points. A sensory profiogram of bread samples was presented in Figure 5.

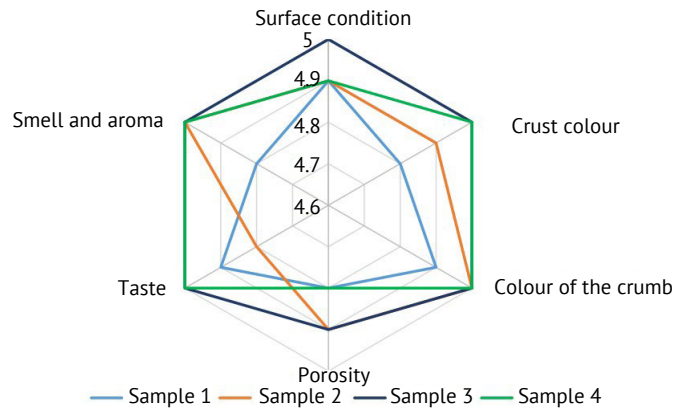


Figure 5. Sensory profiogram of bread samples

Source: developed by authors

The calorie content of wheat-rye sourdough bread is slightly higher compared to bread baked using yeast. S. Plessas (2021) and A.S. Subaşı & R. Ercan (2023) emphasised that sourdough starter enriches bakery products with dietary fibre, vitamins, in particular vitamin A, group B, PP, and minerals: potassium, calcium, magnesium, sodium, phosphorus, and others. A technological plan for making wheat-rye bread on rye

sourdough was created as a result of fermentation process analysis and experimental research, and it was shown in Figure 6. Based on the findings of research on the physical and chemical features of raw materials and final products, as well as the effectiveness of employing rye sourdough, this plan considered the ideal criteria for attaining the desired taste qualities and quality of the final product.

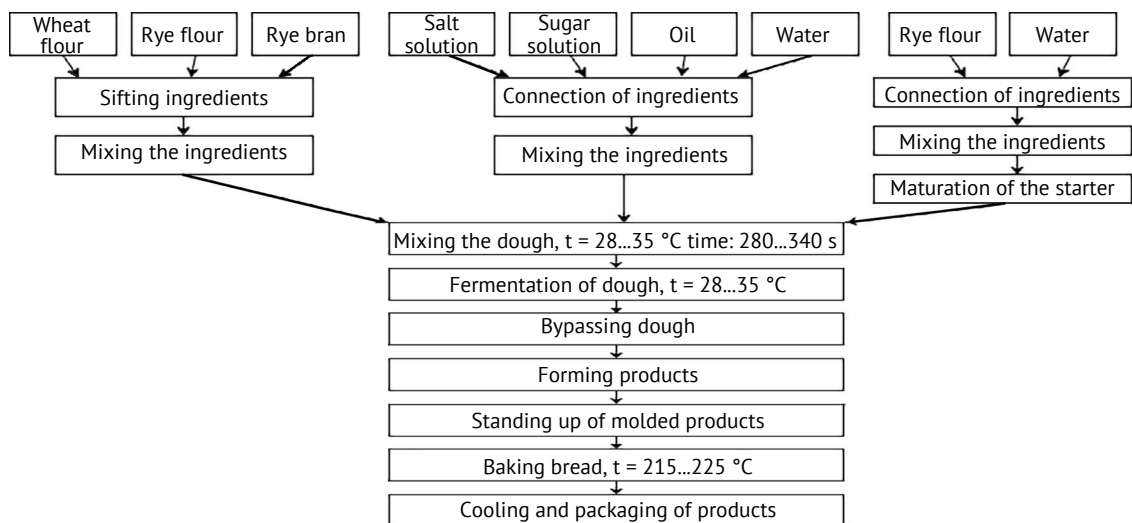


Figure 6. Technological scheme of bread production

Source: developed by authors

The rye sourdough was prepared as the first step in making sourdough bread. Water and rye flour were used to make it. According to experimental research, the starting culture from the sixth day of fermentation was the most active, and using it produced satisfactory quality indicators for the final product. Then dry ingredients, namely premium wheat flour, rye flour and bran, were prepared, sifted and passed through a magnetic separator to remove impurities from them. Next, the purified dry components in the quantities determined by the recipe were served for mixing to obtain a homogeneous mixture. Water, vegetable oil, and premade table salt and sugar solutions were added to the container separately. After adding sourdough to the mixture, the dough was kneaded for 280-340 s and allowed to ferment for 40-50 min at 28-35°C. Once the dough was prepared, it was kneaded and used to create bread with a specific mass and shape. The formed products were placed on a baking sheet and left to stand in a proofing cabinet for 40...60 min. The next step was to bake bread in a convection oven at a temperature of 215...225°C for 25...30 min. Finished products were cooled, packaged and stored for transportation to retail chains.

The authors I. Shevchuk *et al.* (2016) investigated the directions of regional food security policy of developed countries in the context of interrelated economic, social and environmental components, emphasising the importance of innovations in this area. In this context, the developed technology of bread production will contribute to strengthening food security both at the regional and national levels. Determining the ideal sourdough fermentation period was one of the most important aspects of bread quality. As noted by M. Sluková *et al.* (2021), the prolonged fermentation of rye sourdough had a positive effect on the texture of the bread, as well as on the characteristic sour taste and distinct aroma of the bread. Studies by Z. Alkay *et al.* (2024) demonstrated, how sourdough fermentation impacted a variety of nutritional elements, such as dietary fiber, vitamins, phenolic compounds, glycemic index, salt reduction, mineral bioavailability, and the digestibility of starch and protein. Sourdough fermentation increased nutrient availability, which benefited customers' general health and wellbeing. R. Laatikainen (2023) highlighted that the employment of various sourdough fermentation techniques resulted in a more noticeable sour flavour and improved bread texture, and that the selection of yeast strains and bacteria that affect bread flavour was crucial. According to M. Gharekhani *et al.* (2021), bread with reduced hardness and more flexibility was made possible by starters fermented by lactic acid bacteria that had high levels of EPS synthesis, proteolytic activity, and acidification qualities. V. Chechitko (2024) noted that during fermentation, some microorganisms can become probiotics, which were beneficial for the

intestinal microflora. The paper by R. Mūrniece & D. Klava (2022) focused on the selection of LAB strains that produce exopolysaccharides (EPS) in rye sourdough. A lengthy sourdough fermentation period and the use of scorching rye flour were crucial because they influenced the quantity of sugars needed for fermentation and the substrate needed to produce EPS, which enhanced the bread's quality and postponed its staleness. The impact of the sourdough period on bread quality parameters as moisture, porosity, shelf life, and fragrance and aroma was validated by this study.

Conclusions

Fermentation processes play a key role in the production of bread, as they significantly affect its physicochemical and organoleptic properties. Specifically, the length of fermentation, the type of starter culture, and the flour composition can alter the dough's pH as well as the final product's texture, flavour, and scent. Numerous studies pointed to the significance of these factors for improving the quality of baked goods.

As a result of the research, it was found that the best quality indicators of wheat-rye dough and finished products were achieved, when using sourdough on the sixth day of its fermentation. In comparison to products made on the sourdough on the fourth day of fermentation, the dough's maximum gas-retaining capacity was reached during this time, the dough ball spread optimally, and the final products' moisture and porosity increased by 2.3% and 7.4%, respectively. A slight increase in the fragility of products was due to an increase in their porosity.

The resulting bread samples had a mild sour taste, pronounced aroma and long-term freshness. Their crumb was porous, with thin pore walls, which gave the bread an elastic texture. These signs indicated the high quality of bread. As a result of experimental research and analysis of literature sources, a technological scheme for the production of wheat-rye bread on rye sourdough had been developed. The resulting wheat-rye bread was of high quality, enriched with dietary fiber, vitamins: vitamin A, group B, PP, and minerals – potassium, calcium, magnesium, sodium, phosphorus thanks to rye sourdough.

Further research will be aimed at testing the addition of vegetable and fruit powders to wheat-rye bread, which will increase the range of health bread.

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Conflict of Interest

None.

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Бродильна активність житньої закваски як фактор якості пшенично-житнього хліба

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Анотація. Метою статті було визначення найкращої ферментаційної активності житньої закваски для виробництва пшенично-житнього хліба для оздоровчих цілей. Натуральний заквасний хліб популярний на українському ринку борошняних виробів завдяки високим смаковим і поживним властивостям. Розроблений рецепт пшенично-житнього хліба містив борошно пшеничне вищого ґатунку, житнє борошно, житні висівки, оливкову олію, сіль і цукор, а також житню закваску на різних стадіях її ферментації. Було проведено сенсорний аналіз і визначено органолептичні характеристики пшенично-житнього хліба. Побудовано сенсорну профілограму модельних зразків пшенично-житнього хліба, і, за результатами експертної оцінки, визначено модельну композицію з найкращими органолептичними властивостями. За результатами експерименту, закваска шостого дня ферментації забезпечила найвищу газоутримувальну здатність і оптимальне розтікання тістового шару. У процесі ферментації у всіх досліджуваних зразках спостерігалось підвищення активної кислотності тіста, що впливало на його якісні характеристики. Вміст вологи та пористість готового виробу, отриманого із закваскою шостого дня ферментації, збільшилися на 2,3 % та 7,4 % відповідно порівняно з хлібом на заквасці четвертого дня ферментації. Відзначено незначне збільшення крихкості готового виробу через зростання його пористості. Пшенично-житній хліб на житній заквасці був корисним завдяки вмісту харчових волокон, що покращують травлення, нормалізують мікрофлору, знижують ризик серцевих захворювань, а також вітамінів і мінералів, які зміцнюють імунну систему та підтримують енергетичний обмін

Ключові слова: вологість; пористість; рецепт; органолептична оцінка; поживна цінність