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STUDY OF DOUGH FERMENTATION PROCESS WITH FLAX SEEDS

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Abstract. Flax seeds are a valuable raw material for the production of functional bakery products. The article investigates the fermentation processes in wheat dough supplemented with whole and crushed flax seeds in dry and soaked states. For a holistic understanding of the fermentation process, the regularities of the kinetics and dynamics of gas formation in the experimental samples were analyzed. It was found that during fermentation in samples with whole flax seeds in dry and soaked states, the amount of carbon dioxide released slightly increases compared to the control. In the samples with crushed dry and soaked flax seeds, the total amount of carbon dioxide released is higher than in the control sample by 16.5% and 19.0%, respectively. In the sample with crushed flax seeds, the nature of the dynamics of carbon dioxide release differs from the control sample, namely, a one-stage fermentation is observed. At the same time, the peak of carbon dioxide release was observed almost 30 minutes later than in the control sample. This may be due to the fact that soaking flaxseed products produces viscous solutions of polysaccharides, which envelop the yeast cells during dough kneading and slow down the supply of nutrients to them. Based on the analysis of the dynamics of carbon dioxide emission, it is recommended to reduce the duration of dough fermentation for the sample with whole flax seeds to 90 minutes, and for the samples with crushed seeds and soaked flax products to 60 minutes, so that the most intense carbon dioxide emission in these experimental samples occurs during the period of proofing of dough pieces. It was found that the introduction of whole and crushed flax seeds in soaked form slows down the rise of the dough due to the thickening of the dough system with water-soluble and insoluble flax dietary fiber, reducing fermentation and the formation of sugars in the dough system.

Key words: dough, fermentation, whole flax seeds, crushed flax seeds, yeasts, polysaccharides of flax seeds.

Introduction. Formulation of the problem

Nutrition is one of the factors that influences the formation of a "healthy" lifespan and is the basis for the prevention of many non-communicable diseases [1-3].

Improving the nutrition of the population is possible by expanding the range of bakery products enriched with vegetable raw materials that have a wide range of positive effects on the human organism. In this regard, the importance of certain crops is gaining more weight. In the last decade, the role of flaxseed in the food industry has increased, as demand for it has reached a new level due to science that has assessed its importance for human health [4,5].

Flax seeds simultaneously contain several groups of compounds that give them functional properties: ω-3 polyunsaturated fatty acids, dietary fiber, lignans, tocopherols, and protein with high biological value [6,7].

The inclusion of flaxseeds in the human diet enhances protection against cardiovascular diseases by lowering plasma cholesterol [8-10], preventing certain types of cancer [11], and in people with prediabetes and diabetes, it helps to steadily moderate glucose levels and improve insulin sensitivity [12,13].

To impart functional properties to bakery products, scientists recommend adding both whole flax seeds [14] and its processed products: crushed flax seeds [15], flaxseed flour [16-19], flaxseed meal [20]. The inclusion of flaxseed and its products in the bread formula causes changes in the technological process of its production and the quality of finished products.

Analysis of recent research and publications

Flax seeds are a valuable raw material for the production of functional bakery products. Studies of the quality of bakery products enriched with flax seeds and its processed products are mainly aimed at assessing the taste, consumer, and antioxidant characteristics of products, their physicochemical characteristics and nutritional value [21-24]. At the same time, it is important to understand the influence of flax seeds and its products on the processes of formation of structural and mechanical properties of dough and the course of microbiological and physicochemical processes in semi-finished products, which together will determine the quality of finished products.

The authors of [25] found that the addition of yellow flax seeds to wheat dough, both in whole and in crushed form, reduces the amount of gluten in it. The reason for this, according to the authors, is the property of flax polysaccharides to become water-soluble during dough kneading and envelop the protein substances of flour, limiting their swelling. At the same time, whole seeds or particles of crushed seeds wedge into the gluten backbone and prevent the formation of a continuous gluten structure. In appearance, the gluten acquired a loose, unbound structure. In the case of crushed flaxseed, flaxseed oil, which enters the liquid phase of the dough, also has a certain effect on the protein substances of the flour. Disruption of the integral structure of gluten causes a decrease in gluten extensibility and a decrease in its elasticity. Such changes in the dough result in a decrease in the specific volume of finished products.

Study [26] found that the inclusion of crushed raw and roasted flax seeds in wheat bread increases the water absorption capacity of the dough and causes stickiness. Such changes are associated with the high water-absorbing capacity of flax seed mucilage, which in turn reduces the swelling of wheat flour gluten. To balance the rheological characteristics of the dough and the organoleptic characteristics of the products, the authors recommend a dosage of crushed raw and roasted flaxseeds of 10% by weight of flour.

Researchers in [27] found that the addition of flaxseed powder to the wheat dough formula reduces the amount and quality of gluten washed out of the dough from this mixture, reduces the specific volume and shape stability of bread. The reason for this, according to scientists, is the excessive activity of proteolytic enzymes in flax seeds. Therefore, the authors recommend using protease inhibitors in the technology of such products.

The authors of [28] enriched bread made from wheat flour with flaxseed flour obtained with separating seed hulls. Studies using a farinograph showed that the addition of flaxseed flour increased the water absorption capacity of the dough and the duration of its kneading. To obtain products without a significant deterioration in quality, it is recommended to replace 10% of wheat flour in the bread formula with flaxseed flour.

Studies in [29,30] found that with an increase in the dosage of flaxseed flour in wheat dough, dough stability and elasticity decrease, and the process of starch gelatinization is delayed.

Scientists at the University of Suceava (Romania) have investigated the possibility of using flaxseed flour from brown and yellow-seeded flax varieties in the production of wheat bread. The addition of flaxseed flour led to an increase in the falling number of the wheat-flax mixture and a slowdown in starch retrogradation. They recommended to include flaxseed flour in wheat bread in the amount of 5-15% by weight of flour [31].

Paper [32] considers the possibility of producing wheat bread with crushed flax seeds. The authors recommend a dosage of crushed flaxseed at 10% by weight of flour. At this dosage, despite the deterioration in gluten quality, products with good organoleptic and physicochemical characteristics are obtained. Scientists suggest that in the process of baking bread enriched with crushed flax seeds, lipid-protein complexes are formed, which helps to increase the elasticity of the crumb of the product.

Thus, the analysis of literature sources has shown that flax seeds and flaxseed products are now actively used in various forms in bakery products to impart functional properties to them. At the same time, improving the physiological properties of products is often accompanied by changes in organoleptic and physicochemical parameters. To explain such changes, researchers mainly focus on the structural and mechanical properties of semi-finished products. However, the quality of finished products also depends to a large extent on the course of fermentation processes. There is little research in this area, which makes it necessary and relevant to conduct it.

Purpose and objectives of the study. The aim of the study was to investigate the fermentation processes in wheat dough supplemented with whole and crushed flax seeds in dry and soaked states. In accordance with this goal, the main research **objectives** were formulated:

- to investigate the process of gas formation and alcohol accumulation in semi-finished products with whole and crushed flax seeds, which were introduced in dry and soaked states;
- to investigate the course of microbiological processes in semi-finished products with whole and crushed flax seeds in terms of dough rising power and the amount of yeast microbiota in it;
- to investigate the effect of whole and crushed dry and soaked flax seeds on the kinetics of sugars in the dough during its maturation.

Research materials and methods

The following raw materials were used for the study: top grade wheat flour (TM EuroMill, Ukraine), table salt (SE Artemsil, Ukraine), pressed bakery yeast "Lviv yeast" (PrJSC Enzym Company, Ukraine), yellow-seeded flax "Svitlozir" (Institute of Oilseeds of the National Academy of Agrarian Sciences of Ukraine, Ukraine).

The following reagents were used in this work: zinc sulfate (LLC "HIMPRODUCT TD", China), sodium hydroxide, standard titer (0.1N) 0.1 mol/l of sodium hydroxide, sulfuric acid, hydrochloric acid (RDE LLC Alfarus, Ukraine), potassium dichromate (LLC "Himproduct TD", Khazakhstan), potassium iodide (Klebrig TM, India), sodium thiosulfate (Biolik CJSC, Ukraine), copper sulfate (HEBEL TM, Poland), potassium-sodium tartrate (CHEMICO GROUP, China).

All raw materials and reagents complied with regulatory documents and were stored in the required conditions indicated on the labeling.

Model dough samples were prepared for research:

- control (without flax seeds);
- with the addition of whole dry seeds at 15% flax to the flour weight;
- with the addition of soaked whole seeds at 15% flax to the flour weight;
- with the addition of dry crushed flax seeds at 20% by weight of flour;
- with the addition of soaked crushed flax seeds at 20% by weight of flour;
- with the addition of a solution of mucilage obtained from flax seeds instead of the formulated amount of water.

The dosage of whole flax seeds at 15% by weight of flour and crushed seeds at 20% by weight of flour was established in [33] as contributing to the maximum possible enrichment of bread with physiologically functional substances of flax while ensuring its quality. Model dough samples made with soaked whole and crushed flax seeds were included in the study due to the fact that [34] proved the effectiveness of using the operation of preliminary soaking of flax seeds in the manufacture of wheat bread, which contributes to improving the condition of the crumb and increasing the specific volume. Flax polysaccharide solutions play a significant role in this, so to determine the effect of flax seed polysaccharides on the fermentation processes, the research also included a model sample in which the formulated amount of water for kneading the dough was replaced with a solution of mucilage extracted from flax seeds.

The moisture content of all dough samples was 43%.

Formula for the control dough sample: top grade wheat flour – 100 g, compressed yeast – 3 g, table salt – 1.3 g. The same amount of yeast and salt was added to all the test samples. The amount of water was set by calculation. Before kneading the dough, the salt was dissolved in water at 25±2°C, and a suspension was prepared from the yeast in a ratio of 1:3 with water. The dough was kneaded manually.

In the samples with dry whole or crushed flax seeds, wheat flour was pre-mixed with whole or crushed flax seeds before kneading the dough, after which the salt solution, yeast suspension and water were added and the dough was kneaded.

In the samples with soaked whole or crushed flax seeds, before kneading the dough, the flax seeds were pre-soaked: whole or crushed flax seeds were poured with water at 60°C in a ratio of 1:2 to water and left to hydrate for 90 minutes, after which the soaked whole or crushed seeds were added to the flour, a saline solution, yeast suspension and water were added, and the dough was kneaded.

For the experimental samples, flax seeds were crushed on a laboratory mill LZM-1, which is designed to grind laboratory samples of crop grains and other solid food products with a moisture content of no more than 18%. The crushed flax seeds were sieved through a wire sieve with a mesh size of 1.0 mm.

To prepare a solution of mucilage from flax seeds, whole seeds were weighed in an amount equal to the dosage in the dough samples with whole seeds, poured with water in the amount necessary for kneading the dough and left to hydrate for 90 minutes with periodic stirring. Then, the resulting mucilage solution was drained through a sieve and the total volume of the solution was leveled by adding water to the required calculated amount to obtain a dough with a moisture content of 43%. When kneading the test sample, the prepared mucus solution was used instead of water.

Gas formation in semi-finished products was determined by the volumetric method using the AG-1M device [35,36]. To determine the effect of flaxseed on gas formation in the dough, pieces of dough containing the same amount of flour were placed in the device. That is, the variable factor that will affect the process will be the amount of whole or crushed flaxseed added in dry or soaked state. For the rest of the below standardized methods, dough samples were kneaded according to the above instructions for preparing model dough samples from which a sample of semi-finished product was weighed according to the methods.

The amount of alcohol accumulated in semi-finished products during fermentation was determined by the iodometric method of Martin [36]. The determination was performed in the corresponding dough samples at the beginning and end of fermentation. The duration of fermentation of the dough samples was 120 min. The increase in alcohol during fermentation was calculated. The dough rising power was evaluated according to the standard method for determining the yeast rising power [35], while after the first rise of the dough in the mold, it was punched and placed back into the mold for the second rise, after which it was punched again and left in the mold for the third rise.

To determine the effect of flaxseed on the number of yeast microflora, extracts from dough samples were prepared after 120 minutes of fermentation and inoculated on wort agar in Petri dishes. Yeast counts were performed after 48 hours. The sugar content of semi-finished products was estimated by the express Schoorl iodometric method [36]. To determine the dynamics of sugar accumulation in the dough, two types of dough were kneaded: yeast-containing dough according to the instructions for the model samples and the same model samples, but without yeast. The amount of sugars formed during the maturation of the dough was determined by the difference between their content in the yeast-free dough after kneading and after 4 hours of fermentation. The amount of fermented sugars was determined by the difference between the total amount of sugars in the yeast dough after kneading, the amount of sugars formed in the yeast-free dough, and the amount of sugars contained in the yeast dough after 4 h of fermentation.

The results of the experimental studies were statistically processed using standard Microsoft Office software.

Results of the research and their discussion

Study of gas formation and alcohol accumulation in dough during fermentation.

Fermentation is one of the main processes that ensures dough maturation. Alcoholic fermentation prevails in wheat dough, the intensity of it depends on the activity of the yeast microbiota and its supply with products of enzymatic hydrolysis of flour biopolymers and other formula components [37].

According to the kinetics of carbon dioxide release (Fig. 1), it was found that in samples with whole flax seeds in the dry (WD) and soaked (WS) state the fermentation process is similar to the control sample for as long as 150 min. During further process, the amount of carbon dioxide released in these samples slightly increases compared to the control.

In the samples with crushed flaxseed in dry form (CD) and with soaked crushed flaxseed (CS), the total amount of carbon dioxide released is higher than in the control sample by 16.5% and 19.0%, respectively. At the same time, in the sample with CD, the intensification of carbon dioxide release after 90 min of fermentation is observed, and in the sample with CS it occurs after 60 min of fermentation. It is likely that the components of the crushed flax seeds are extracted into the liquid phase of the dough, and to a greater extent in the case of pre-soaking, thus improving the nutrition for the dough microbiota.

In the case of mucilage, there is a slight decline in carbon dioxide production compared to the control, probably due to the envelopment of yeast cells with a solution of flax seed polysaccharides, which creates a more viscous liquid phase of the dough and thus slows down the supply of nutrients to them.

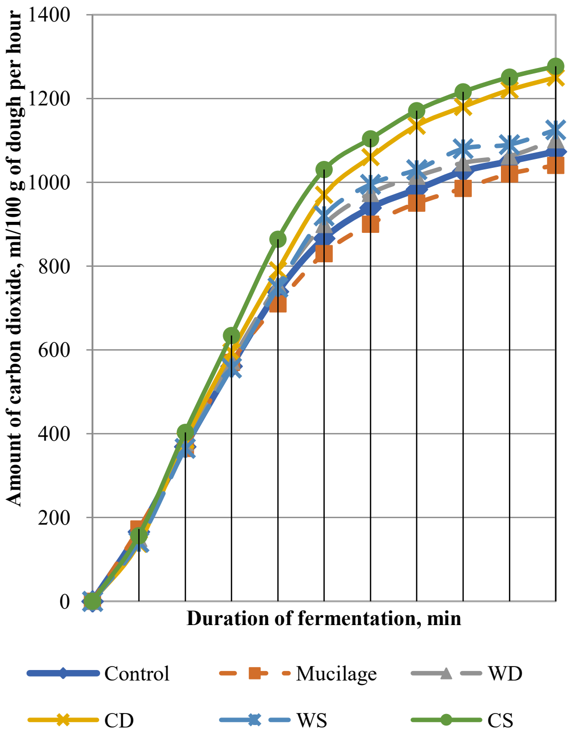

Fig. 1. Total gas formation in the dough

For a holistic understanding of the fermentation process, it is necessary to analyze the patterns of gas formation dynamics in the experimental samples. As can be seen from Fig. 2, a two-stage fermentation is observed in the control sample, and the yeast switches to maltose fermentation at 60 min of fermentation.

In the sample with the introduction of whole dry flax seeds, the dynamics of carbon dioxide emission also has two stages, but the first peak is reached 30 minutes later than in the control sample. The intensity of carbon dioxide emission in this sample at the beginning of fermentation was lower than in the control, but then it intensified and when the first peak of carbon dioxide emission was reached, its amount was 37% higher than in the control sample when the first peak was reached.

The analysis of the dynamics of carbon dioxide emission in the WS sample showed that the first peak of gas formation occurs at the same time as for the sample with dry seeds, but at a lower intensity of CO2 emission. It should be noted that in this sample, unlike the control and dry seed samples, the second peak is formed much later and is very low.

To explain the obtained patterns, it is necessary to understand the mechanism of flax seed hydrocolloids transition into the liquid phase of the dough. Flaxseed hydrocolloids are polysaccharides concentrated in flaxseed mucilage, which covers flaxseeds and gives them their shine. Flaxseed mucilage polysaccharides contain three high molecular weight polysaccharides: 75% (of the total mucilage content) of the most viscous neutral polysaccharide with a molar mass of $1.2 \cdot 10^6$ g/mol, 3.75% of the acidic polysaccharide AF1 with a molar mass of $6.5 \cdot 10^5$ g/mol, 21.55% of the acidic polysaccharide AF2 with a molar mass of $1.7 \cdot 10^4$ g/mol [38]. The acidic fraction is dominated by galacturonic acid, and traces of xylose have been found. The neutral fraction is almost free of galacturonic acid, xylose is the basis of this fraction. In addition to xylose and galacturonic acid, polysaccharide monomers include glucose, galactose, rhamnose, and fucose. Protein content is also of great importance for the properties of flax seed hydrocolloids [39]. The process of transition of polysaccharides into solution is accompanied by the simultaneous extraction of water-soluble fractions of proteins from the flax seed coat. The protein is believed to be mostly associated with polymers of the acidic fraction. It is not found in the neutral fraction. In addition, there is a sequential transition of protein-polysaccharide complexes representing the acidic fraction into the aqueous solution, and then directly of polysaccharide structures with a lower protein content. After 30 minutes of flaxseed hydration, its swollen hull partially moves away from the kernel and extractive substances from the kernel begin to pass into the solution [38].

Based on such theoretical data, it can be assumed that in the sample with whole flaxseeds, during the contact of the flax seed with the liquid phase of the dough, protein-polysaccharide complexes begin to be extracted from the seed surface, the protein component of these complexes improves the composition of the nutrient medium for yeast. The use of pre-soaking flax seeds probably contributes to a deeper swelling of the seed coat and greater extraction of proteins and carbohydrates from the seed coat and kernel. This contributes to a greater enrichment of the liquid phase of the dough with nutrients for the yeast, so in this sample the yeast switches to maltose fermentation at 180 minutes, while in the control and dry seed sample it takes 60 and 90 minutes, respectively.

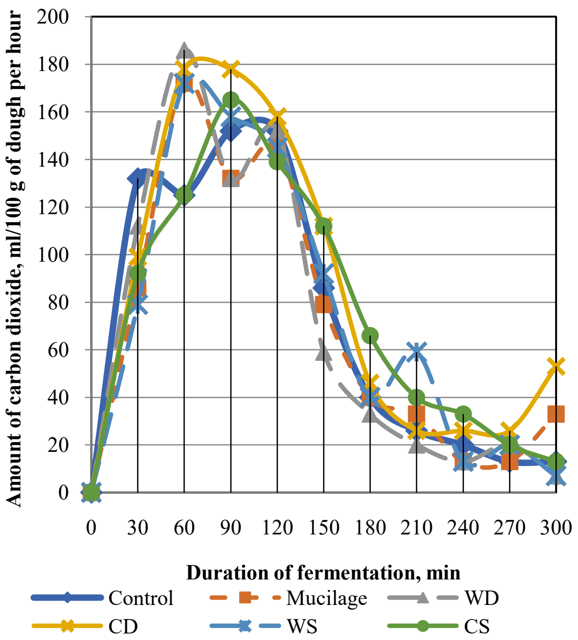

Fig. 2. Dynamics of carbon dioxide production in the dough samples

In the sample with crushed flax seeds, the dynamics of carbon dioxide production differs from the control sample, namely, a single-stage fermentation is observed. The peak occurred almost 30 minutes later than in the control sample. Probably, competitive extraction of water-soluble proteins and polysaccharides containing not only protein complexes but also sugars, in particular glucose, occurs from the crushed flax seeds. This improvement of the nutrient medium for the yeast ensures that it does not switch to maltose fermentation.

The use of soaking whole and crushed flax seeds results in a slightly lower intensity of carbon dioxide emission compared to dry samples. This may be due to the fact that the introduction of viscous solutions of polysaccharides during kneading creates a viscous medium around the yeast cell, which envelops it and slows down the supply of nutrients to it. At the same time, lipids are extracted from the crushed flax seeds into the liquid phase of the dough, and they also envelop the yeast cell and reduce its activity.

To achieve good product quality, it is necessary to stop the dough fermentation process 30–40 minutes before reaching the peak of carbon dioxide emission, so that the stage of proofing dough pieces falls within the maximum gas formation [40]. Based on this, it can be assumed that for a sample with whole flax seeds, the fermentation time will be 90 minutes, and for samples with crushed and soaked flax products, it will be reduced to 60 minutes.

The higher intensity of fermentation in the samples with crushed dry and soaked crushed flax seeds is confirmed by the data on the increase in alcohol content in these samples compared to the control (Fig. 3). Similar data on the accumulation of alcohol in the control and mucilage samples prove the fact that the introduction of polysaccharide solutions instead of water, despite the enrichment of the liquid phase of the dough, causes its significant thickening, which in turn impedes the access of nutrients to the yeast cell, and therefore no significant intensification of fermentation is observed. This explains the lower accumulation of alcohol in samples with soaked flax products compared to dry ones.

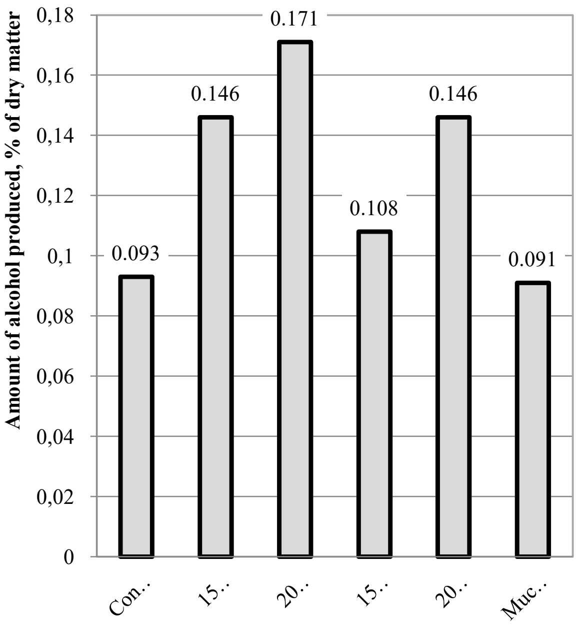

Fig. 3. Amount of alcohol produced during fermentation

Investigation of the dough's rising power and the amount of yeast microflora in it.

The vital activity of the yeast microflora in semi-finished products depends on the influence of the dough ingredients.

The effect of whole and crushed flax seeds added to the dough in a dry or soaked state on the fermentation activity of yeast was evaluated by their rising power.

The first rise of the dough in the mold was used to evaluate the zymase activity of the yeast, and the second and third rises were used to evaluate the maltase activity. The results of the research shown in Table 1 indicate that the introduction of mucilage prolongs the first rise of the dough to 73 minutes, compared to 51 minutes in the control. The introduction of whole flax seeds has almost no effect on the rate of the first rise of the dough, while its soaking and the introduction of CD and CS slow down the rise of the dough. In the case of crushed seeds, this may also be due to the fact that the crushed particles of the hulls during swelling bind some of the moisture and thereby increase the viscosity of the dough system, impairing the access of nutrients to the yeast cell.

The second and third rising of the dough showed that the soaking prolonged the dough's rising power in both the whole and crushed flaxseed samples by 3 and 7 minutes, respectively, compared to the dry whole and crushed samples.

Table 1 – Duration of dough rising, min

n=3, p≥0,95

Stage of study	Con-trol	Flaxseeds introduced, % of flour mass				Muci-lage
		15% whole flax		20% crushed flax		
		dry	soaked	dry	soaked	
First rising, min	51	50	66	64	71	73
Second rising, min	31	31	37	30	40	42
Third rising, min	39	29	26	29	26	19
Sum of the second and third risings, min	70	60	63	59	66	61

To determine the effect of flax seeds on the amount of yeast microbiota, extracts were prepared from the experimental dough samples after 120 min of fermentation and inoculated on nutrient medium. The results of counting yeast on the nutrient medium (Fig. 4) show that slightly more yeast (by 1.9–3.3%) is contained in samples with crushed flax seeds. It was also found that the largest increase in yeast (by 7.6%) was in the sample with yeast mucilage. It is likely that the introduction of yeast into the dough system with mucilage contributed more to its reproduction than to fermentation. This may be the reason why the yeast rising power at the beginning of fermentation was longer than in the control.

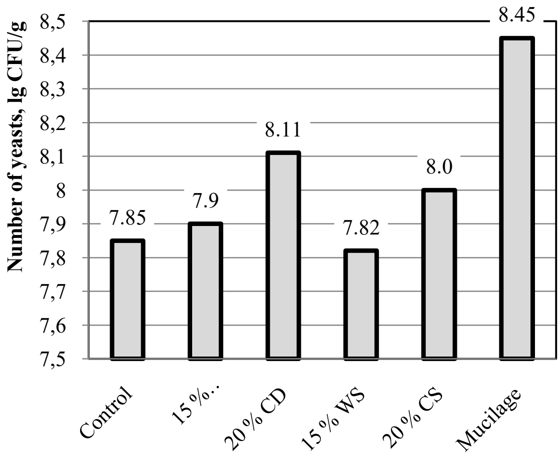

Fig. 4. Number of yeasts grown on nutrient medium

Gas formation in dough depends on the content of initial flour sugars, but is more likely to be shaped by its sugar-forming capacity, which is provided by the activity of amylases and the amylolytic degradability of starch. The intensity of fermentation processes depends on the accumulation of sugars in the dough during its maturation. Along with the process of maltose accumulation in the dough as a result of hydrolytic breakdown of starch, maltose is fermented by dough microorganisms.

The ratio between the intensity of sugar accumulation in the dough due to enzymatic hydrolysis of starch and the intensity of sugar fermentation by microorganisms determines the sugar content in the dough before processing and baking. The results of the study are shown in Table 2.

Table 2 – Accumulation and fermentation of sugars during dough fermentation, % of dry matter

n=3, p≥0,95

Indicators	Con-trol	15 % WD	20 % CD	15 % WS	20 % CS
Yeast-free dough					
Sugar content after kneading	1.25	1.23	1.24	1.24	1.26
After 2 hours of fermentation	2.03	2.22	1.84	1.66	1.78
Sugars produced	0.78	0.48	0.6	0.42	0.48
Fermented dough					
After kneading	1.27	1.11	1.25	1.23	1.24
After 2 hours of fermentation	0.79	0.67	0.85	0.83	0.92
Sugars fermented	1.26	1.05	1.0	0.82	0.8

It was found that in samples with the addition of soaked whole and crushed flax seeds, fermentation and accumulation of sugars was less intensive than in the corresponding samples with dry flax products. This is probably due to the thickening of the liquid phase of the dough by flaxseed polysaccharides, which swell unlimitedly to form a viscous colloidal solution that, by enveloping yeast cells, reduces their activity, and by enveloping starch grains, reduces their susceptibility to amylolysis.

Conclusion

Thus, according to the results of the research, it was found that the introduction of flax products into the dough affects the fermentation process in the dough system in two directions simultaneously. On the one hand, it enriches the liquid phase of the dough with proteins, carbohydrates and other nutrients and thus contributes to a certain increase in the total gas formation in the experimental dough samples, especially in the samples with crushed flax seeds, compared to the control. On the other hand, solutions of flax seed polysaccharides have a significant effect on the fermentation processes, as they envelop the yeast cells upon entering the dough system. These factors affect the kinetics and dynamics of dough fermentation. It was found that the introduction of flax products slightly increases the total gas formation in the dough compared to the control. Based on the analysis of the dynamics of carbon dioxide emission, it is recommended to reduce the duration of dough fermentation for the sample with whole flax seeds to 90 minutes, and for the samples with crushed and soaked flax products to 60 minutes. It was found that the introduction of whole and crushed flax seeds in soaked form slows down the rise of the dough due to the thickening of the dough system with water-soluble and insoluble flax dietary fiber, reducing fermentation and the formation of sugars in the dough system.

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ДОСЛІДЖЕННЯ ПРОЦЕСУ БРОДІННЯ ТІСТА З НАСІННЯМ ЛЬОНУ

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Анотація. Насіння льону є цінною сировиною для виробництва функціональних хлібобулочних виробів. У статті досліджено процеси бродіння в пшеничному тісті, в яке було внесено ціле та подрібнене насіння льону в сухому та зволоженому станах. Для цілісного розуміння перебігу процесу бродіння проаналізовано закономірності кінетики та динаміки газоутворення в дослідних зразках. Встановлено, що в процесі бродіння у зразках з цілим насінням льону у сухому та зволоженому станах кількість виділеного діоксиду вуглецю незначно зростає, порівняно з контролем. У зразках з подрібненим насінням льону у сухому вигляді та зі зволоженим подрібненим насінням льону загальна кількість виділеного вуглекислого газу вища, ніж у контрольному зразку на 16,5% та 19,0% відповідно. У зразку з подрібненим насінням льону характер динаміки виділення діоксиду вуглецю відмінний від контрольного зразку, а саме спостерігається одностадійність бродіння. При цьому досягнення піку виділення вуглекислого газу відзначається майже на 30 хв пізніше, ніж в контрольному зразку. Застосування зволоженого цілого та подрібненого насіння льону зумовлює дещо нижчу інтенсивність виділення вуглекислого газу, поряд із сухими зразками. Можливо причиною цього є те, під час замочування лляних продуктів утворюються в’язкі розчини полісахаридів, які під час замішування тіста огортають дріжджові клітини і уповільнюють надходження до них поживних речовин. На підставі аналізу динаміки виділення вуглекислого газу, рекомендовано скоротити тривалість бродіння тіста для зразку з цілим насінням льону до 90 хв, а для зразків з подрібненим насінням та замоченими лляними продуктами до 60 хв для того, щоб найбільш інтенсивне виділення вуглекислого газу у цих дослідних зразках припадало на період вистоювання тістових заготовок. Встановлено, що внесення цілого та подрібненого насіння льону в зволоженому вигляді зумовлює уповільнення підйому тіста внаслідок загущення тістової системи водорозчинними та нерозчинними харчовими волокнами льону, зниження зброджування та утворення цукрів в тістовій системі.

Ключові слова: тісто, бродіння, ціле насіння льону, подрібнене насіння льону, дріжджі, полісахариди насіння льону.