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INVESTIGATION OF FLAXSEED MEAL PROTEINS AND THEIR INFLUENCE ON WHEAT DOUGH

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З метою збагачення білковими речовинами, що збалансовані за амінокислотним складом, обґрунтовано доцільність використання шроту льону в рецептурі хлібобулочних виробів, які є основою раціонів харчування, в тому числі і в закладах ресторанного господарства.

В результаті вивчення мікроструктури клейковини встановлено, що порівняно з контролем стінки клейковини у зразку з шротом насіння льону потовщуються, а розміри пор зменшуються. Завдяки цьому підвищуються пружні характеристики клейковини.

Експериментальними дослідженнями вилучення фракцій білків за розчинністю встановлено, що основними білками шроту є альбуміни і глобуліни. Необхідно зазначити, що значна кількість білкових речовин шроту насіння льону 14.34 % знаходилась у нерозчинному осаді.

Встановлено, що білки шроту льону впливають і на процес перетворення фракційного складу білка в пшеничному тісті під час його дозрівання. Досліджено, що вміст азоту клейковини зменшується на 17.0 % внаслідок переходу частини азоту клейковини до водорозчинної та проміжної фракцій. Це призводить до збільшення вмісту азоту цих фракції в дослідному зразку, порівняно з контрольним і дозволяє стверджувати про зміни реологічних властивостей тіста, оскільки такі властивості залежать від співвідношення цих фракцій.

При дослідженні суміші борошна з шротом льону встановлено, що у разі збільшення дозування шроту від 2.5 до 7.5 %, водопоглинальна здатність, зростає, що пов'язано з більш високою гідратаційною здатністю альбуміну і глобуліну шроту насіння льону, ніж клейковинних білків. Зростає розрідження, і тим більше, чим більша тривалість замісу, що пов'язано з утворенням рідкої фази тіста водорозчинними білками шроту.

Зважаючи на хімічний склад, шрот льону здатний бути джерелом білкових речовин для збагачення ними продуктів харчування. Однак, його використання обумовлює зміну біохімічних процесів, що потребує корегування з метою забезпечення необхідної якості виробів

Ключові слова: шрот насіння льону, борошно пшеничне, білки, фракційний склад, амінокислоти, клейковина

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1. Introduction

The priority function of the activity of restaurants is catering. Thanks to quality nutrition, the human body is able to resist the adverse effects of the environment. Therefore, one of the important tasks of catering is the development of new products with high nutritional, biological value and health properties.

In recent years, the quality and structure of nutrition have deteriorated significantly. Animal protein, unsaturated fatty acids, vitamins, macro- and micronutrients, and dietary fiber are in deficit, especially in low-income populations [1].

Environmental deterioration along with poor nutrition has led to the progressive growth of many non-contagious diseases of global character. Among such diseases, commonly known as "diseases of civilization", the most common are diabetes, cardiovascular diseases, musculoskeletal disorders, cancer, and shorter life expectancy. Thus, according to statistics, the average life expectancy of a person reaches 66 years for men and 72 years for women [2].

In the world practice in the last decades, the concept of health food rationing through the use of functional products was formed. According to scientific research, functional foods include products that have a beneficial effect on human health if consumed regularly at effective doses. Such products contain functional ingredients that exert a biologically significant positive effect on the human body, which helps to adapt to environmental influences, prevent diseases and early aging [3].

The main types of functional ingredients include dietary fiber (soluble and insoluble), vitamins (A, E, B, etc.), minerals (such as Ca, Fe, I, Se), lipids containing unsaturated fatty acids (ω_3, ω_6), antioxidants, oligosaccharides (as a substrate for beneficial bacteria), some types of beneficial microorganisms (bifidobacteria, etc.).

From a medical, biological and hygienic point of view, the content of functional ingredients in food should be sufficient for providing 20–50 % of the average daily need of the body in these ingredients. But this is ensured with the usual level of product use. In special-purpose products, this content may be higher [4].

Along with functional ingredients, the enrichment of food with high-grade proteins is important. Protein in the human body can only be formed from the protein of food. The average standard daily physiological norm of protein for an adult is 80–100 g. Meeting the needs of the human body in protein is one of the main problems of nutrition. Protein deficiency decreases the activity of oxidative enzymes, which weakens the body's antioxidant system [5].

As a source of functional ingredients, along with various nutraceuticals, plant material rich in biologically active substances can be used. In vegetable raw materials proteins, vitamins, minerals are in the form of natural compounds, that is, in a form that is easily absorbed by the body. The complexity of their chemical composition causes the enrichment of the product simultaneously with proteins, vitamins, mineral compounds, and other important components [6].

Bakery products have always been considered traditional cereal products, which are available to all segments of the population and are the basis of diets. The production of bakery products from high-quality flour impaired the physiological and functional properties of these products, because in the manufacture of high-quality flour, most of the functional ingredients of grain are removed. Therefore, the main task of food industry specialists is providing these products with functional properties [7].

Vegetable raw materials are the carrier of a number of functional ingredients in an easily digestible form. Existing scientifically grounded baking technologies are based on the use of flaxseed meal, which is a semi-fat flour [8–13]. It is obtained as a by-product of oil technology by cold pressing. The meal contains 33.6 % protein, 9–10 % lipids. During interaction with water, the meal will swell and form mucus, which gives it antibacterial and anti-sclerotic properties.

Recent investigations have increasingly revealed the chemical composition of flax seeds, their biological value, technological properties, medical and hygienic value [14, 15].

According to investigations [16], flax meal is the source of most vitamins such as B_1, B_2, B_6, niacin (PP), pantothenic (B_3) and folic acid (B_9), biotin (B_7), tocopherol (vitamin E). Of particular importance is the content of thiamine (B_1). This product is a natural source of selenium. It is established (Table 1) that flax meal contains 1.5 times more protein than flax seeds, carbohydrates – 1.6 times and 4 times less fat, which determines its calorie content by 32 % less.

Table 1

Chemical composition of flax seeds and flaxseed meal [16]

Raw material	Mass fraction of moisture, %	Ash content, %	Fat, %	Protein, %	Carbohydrates, %	Energy value, kcal
Flax seeds	8.7	3.6±0.3	40.1±0.3	22.2±0.4	25.4±0.3	537
Flaxseed meal	11.2	5.6±0.05	10.5±0.1	32.6±0.3	40.4±0.5	365

The value of flax meal is due to the chemical composition [16]. It contains 32.6 % protein (with high PDCAAS (protein digestibility corrected amino acid score), 37.6 % dietary fiber, high ash content (5.6 %) correlates with sufficient mineral content of calcium (256 mg), magnesium (461 mg), zinc (3.23 mg). The composition of lipids is dominated by polyunsaturated fatty acids. Meal proteins are capable of meeting the body's daily requirement for essential amino acids in a bigger amount (Table 2) than wheat flour proteins. Thus, the PDCAAS of these proteins by lysine is higher 4.0 times, methionine – 3.7; tryptophan – 6.1. These proteins have a higher PDCAAS score for other essential amino acids, indicating the high ability of flax meal proteins to improve the quality of wheat flour proteins.

Table 2

Content of essential amino acids in 100 g of meal and flour and their degree of daily requirement satisfaction of amino acids (PDCAAS) [16]

Amino acid	Daily need for an adult, g	Content, g/100 g		Degree of daily requirement satisfaction of PDCAAS, % (100 g)	
		meal	flour	For the meal	For flour
Lysine	4.1	1.46	0.30	35.6	7.3
Threonine	2.4	1.33	0.29	55.4	12.0
Valine	2.5	1.24	0.27	49.6	10.8
Methionine+ Cystine	1.8	1.36	0.28	75,5	15.5
Leucine	4.6	2.24	0.67	48.6	14,5
Isoleucine	2.0	1.06	0.28	53.0	14.0
Tyrosine+ Phenylalanine	4.4	2.51	0.82	57.0	18.6
Tryptophan	0.8	0.78	0.07	97.5	8.7

The specificity of the chemical composition of flaxseed meal, namely the high content of proteins, lipids, dietary fibers, requires substantiation of the feasibility of its use to adjust the chemical composition of bakery products in order to give them functional properties and establish the parameters of the technological process of production of these products in order to ensure traditional quality.

Currently, a large amount of bread is made in private mini-bakeries, directly in specialized shops of restaurants and cafes, supermarkets. Therefore, it is important to search and develop innovative technologies of bread products with the purpose of giving them biological value and adaptation in these establishments.

2. Literature review and problem statement

Functional ingredients such as insoluble dietary fiber (cellulose), lignin, hemicellulose contribute to the excretion of heavy metals and toxic substances. Investigations [17] show that the addition of raw and fried flaxseed flour increases the antioxidant capacity due to the formation of melanoids. Products undergoing heat treatment tend to reduce the amount of phenols and flavonoids. In addition, the energy value of finished products is greatly increased. But along with the improvement of functional and antioxidant properties, the quality of finished products deteriorated. In this case, with an increase in the dosage of flaxseed flour by more than 20 %, there was a decrease in the specific volume, elasticity, cookies became browner in color, worse chewed, were sticky. The authors attribute the cause of these impairments to an increase in the amount of protein and dietary fibers that have a greater ability to bind water. The effect of flaxseed flour on bakery products is similar. However, such a conclusion is not confirmed by the studies and is only an assumption.

Flax proteins are the basis for new prospects on health promotion and disease prevention through the manufacture of nutritional products and functional foods. Currently, using the chemometric approach [18], the physicochemical properties of flax meal proteins have been analyzed. Investigations have shown a decrease in the risk of breast cancer among premenopausal women, which is associated with a higher content of flaxseed meal containing high amounts of protein and lignans. The sequence of results assures the impact of the meal on the risk assessment of the disease. However, these studies found no relationship between the risk of breast cancer and the intake of flax meal proteins and lignans and how these substances affect technological processes in food production. The change in the chemical composition of raw materials leads to a change in technological processes, so this requires adjustment of dosage of flaxseed meal.

In order to overcome this problem, [19] investigated the replacement of wheat flour with flax meal in the manufacture of cookies. The authors claim that increasing the meal dosage results in an improvement in the functional and antioxidant properties of cookies, since the protein, mineral, fiber content increases in the test samples compared to the control. Investigations have shown that if the concentration of flax meal in the mixture increased, the cookies became darker in color and if the dosage is bigger, the more intense the dark color spread. The basic component analysis showed that the best physicochemical and organoleptic parameters were in the cookie samples with a dosage of 10 % by weight of flour. However, these studies did not present results on the effects of flaxseed meal on the baking properties of wheat flour and gluten quality during dough formation and on wheat flour proteins during dough maturation.

But work has been carried out in this direction [20] and the analysis of existing investigations also confirms that the use of flaxseed meal and sprouted flax seed in the development of cupcakes increases the functional properties and nutritional value of the products. In addition, the authors argue that the germination of flax seeds causes an improvement in the content of fiber, protein and fat. The authors investigated various combinations of adding low-fat and germinated flax seeds to wheat flour in quantities of 5, 10, 15, 20, 25, 30 %. Studies have shown that increasing the dosage of the tested ingredients leads to an increase in water absorption for both flax meal and sprouted flax seeds. With the increase in the dosage of flaxseed products, the authors observed a decrease in the specific volume of cupcakes and texture. The investigations suggested a dosage of 15 % for the meal and 10 % for the germinated seeds, which characterizes the best level of organoleptic characteristics and texture properties, the cupcakes were more resistant to storage due to the presence of slime in the flax. However, these studies do not allow us to understand the impact of flax meal on the dough formation process, which would allow us to study the change in product quality more, because flax meal differs significantly in chemical composition from flax seeds. And the question remains about the effect of flax meal on wheat flour proteins in the process of dough maturation.

The above examples of using flax seeds in various food industries, including in restaurants, show great attention to this unconventional raw material.

Protein properties are mostly dependent on their fractional composition. The ratio of protein fractions determines their impact on the flow of technological process, structural and mechanical properties. Thus, according to [21], proteins of flax seeds are dominated by proteins of water-soluble and salt-soluble fractions and do not contain alcohol-soluble. In [22], the investigation of the fractionation of low fat flaxseed flour was carried out. In addition to water-soluble and salt-soluble fractions, proteins of an alcohol-soluble fraction were found in this sample. According to studies [13, 23], all four fractions are present in flax seeds. Therefore, there are reasons to believe that differences in the characteristics of the fractional composition of flaxseed proteins in literature sources necessitate research in this direction.

However, it should be noted that the fractional composition of flax meal proteins was not investigated in these literature sources [13, 21–23], and the chemical composition of seed and meal proteins differs, as evidenced by the data in Table 1. This means that the study of the process of separation of protein fractions of flax meal and protein properties is very important for understanding the unique functionality of flaxseed meal and, thus, the study of using the specified meal for catering establishments.

Wheat flour is included in the formulation of a large number of food products, so the fractional composition of its proteins affects the flow of technological processes. This means that, from a practical point of view, the addition of flaxseed meal to bakery products causes a change in the organoleptic properties [24] of finished products and the structural and mechanical properties of dough and finished products [25].

Despite the practical significance of such results, the effect of flaxseed meal on dough protein or gluten protein, which affects the rheological properties of the dough, has not been considered.

However, investigations [26] about the effect of flaxseed flour on the microstructure of ready-made cupcakes were conducted. Disturbances of the protein molecule were observed to a greater extent with the higher dosage of flax flour. This can be caused by water-soluble mucus and flax fiber. However, research data cannot convince that flax meal would have a similar effect on the microstructure of gluten by adding flax meal to the samples.

There is also no data in the production of bakery products about the effect of flaxseed meal on the water absorption capacity and gluten of wheat flour, which are one of the main indicators of the baking properties of flour. To a large extent, the ability of flour to absorb moisture depends on the ability of proteins, starch grains, and pentosans to bind water. The yield of the dough and, accordingly, the output of high-quality finished products depend on the value of water absorption capacity. This leads to research in this area.

Analysis of the literature indicates that effective improvement of the formulations of existing products and the development of new types of food with increased biological value require research using protein quality assessment techniques that do not require significant time and expense.

3. The aim and objectives of the study

The study aimed to determine the interaction of flaxseed meal proteins with wheat flour proteins and to determine the effect on the structural properties of the dough and the quality of finished products.

To achieve this goal, the following objectives were set:

– to determine the fractional composition of flaxseed meal proteins;

– to study the patterns and depth of the processes of protein conversion in wheat dough during its maturation;

– to investigate the effect of flaxseed meal on the properties of wheat gluten protein;

– to determine the effect of flaxseed meal protein on the water absorption capacity of wheat flour;

– to investigate the effect of flaxseed meal on the organoleptic characteristics of finished products.

4. Materials, equipment and methods for the investigation of flax meal proteins and influence on the dough processes

The studies were conducted in the laboratory of clinical and biological research of the State Scientific-Research Control Institute of Veterinary Medicinal Products and Feed Additives (Lviv, Ukraine), laboratories of the bakery and confectionery technology department (National University of Food Technologies, Kyiv, Ukraine), the Center for Quality Assessment of Raw Materials and Finished Products (Kyiv, Ukraine), laboratory of biochemistry of Lviv State University of Physical Culture (Lviv, Ukraine).

In the investigations, flaxseed meal of the production of LLC Zhytomyrbioproduct (Zhytomyr region, Ukraine) obtained by the method of “cold pressing” with a chemical composition containing proteins 32.6 %, food fibers 37.6 %, lipids 10 % was used.

The fractional composition of proteins was determined by using the method of extraction of fractions by solubility (albumins, globulins, prolamins, glutelins), proposed by an American researcher.

Albumins from aqueous solutions were precipitated by salting out a saturated solution of ammonium sulfate salts ($(NH_4)_2SO_4$). The principle of salting out is that the electrolyte ions are hydrated by subtracting water from the biopolymer.

Globulins are insoluble in pure water. These proteins are dissolved in aqueous solutions of various salts. For this purpose, a 10 % NaCI solution was used in the investigations. Dialysis using semipermeable membranes was used to isolate globulins from the saline solution.

Prolamins were dissolved in 70 % ethanol solution, and glutelins were dissolved in a 0.2 % alkali solution.

During investigations of the effects of flaxseed meal on the state of the protein in the dough, the determination of its fractional composition was performed by a well-known method.

Dough samples were prepared without adding flaxseed meal (control) and adding 7.5 % flaxseed meal to the flour. Such a dosage was adopted for a more pronounced effect of this raw material on the state of flour proteins compared to the lower dosage. In the dough samples after kneading and after 180 min of fermentation by the Kjeldahl method, the total nitrogen content, gluten nitrogen, nitrogen of water-soluble and intermediate fractions were determined. Nitrogen of the intermediate fraction was determined by the difference between total nitrogen, gluten nitrogen and nitrogen of water-soluble fractions.

The effect of flaxseed meal on the properties of wheat flour gluten was investigated using a JEOL JSM-IT-200 (Japan Electron Optics Laboratory, Japan) scanning microscope based on the principle of interaction of the characteristic X-ray spectrum with the object under investigation.

Gluten samples were prepared from the dough with 7.5 % of flaxseed meal with and without flour (control). Pieces of gluten samples weighing 4 grams were used. Samples were prepared by freezing, freeze-drying, breaking and ash spraying in a vacuum chamber into the fracture site. Microscopy of the samples was carried out at 500 times magnification. The sample area was observed using an optical image displayed on a computer screen. The most expressive areas were photographed.

To determine the effect of flaxseed meal on the water absorption capacity of wheat flour, Farinograph-AT (Brabender, Germany) was used. In addition, the curve, which is crossed by the recorder of the device, determines the time of dough formation, elasticity and elongation, stability of the dough. During the research, samples of wheat flour of the 1st grade were prepared, and 2.5; 5.0; 7.5 % of flaxseed meal were added. The control was a sample that does not contain this meal.

In order to check the change in the microstructure of gluten due to the influence of flaxseed meal on the quality of finished products, trial baking of the dough samples was carried out with a dosage of 7.5 % flax meal. A test sample without meal served as control. Due to the increased water absorption capacity of the dietary fiber of the meal in the test sample containing 7.5 % of flax meal compared to the control, the dough moisture was increased by 1.5 % against the humidity of the control sample.

5. Results of the study of flaxseed meal protein and the impact on dough proteins and quality of finished products

5. 1. Results of the study of the fractional composition of flaxseed meal proteins

The essence of the method consists in the sequential extraction of flax meal protein substances with distilled water, followed by 10 % sodium chloride solution, then 70 % ethyl alcohol and at the end 0.2 % alkali solution. Proteins are precipitated with acetic acid. The precipitate is filtered.

As a result of researches, it is established (Table 3) that the main proteins of flaxseed meal (FSM) are albumins and globulins. Their content is 66.64 %. Prolamines and glutelins are only 19.02 %, while in wheat flour 75.12 %. But, unlike the results of the studies published in [21, 22], the obtained data of the fractional composition allow to confirm the presence of all four protein fractions.

Table 3

Fractional composition of proteins, %

Raw material	Albums	Globulins	Prol-amines	Glutelins	Insoluble precipitate
Wheat flour of the first grade	9.30±0.6	8.37±0.4	29.30±1.3	45.82±1.3	7.21±0.2
Flaxseed meal	36.54±1.2	30.10±1.2	6.15±0.6	12.87±0.8	14.34±1.3

It should be noted that a significant amount of flaxseed meal protein substances of 14.34 % was in the insoluble precipitate. Obviously, this is due to the specific structure of flax meal prolamins and glutelins, due to which they cannot be completely separated by the solvents provided by Osborne methods.

It should be noted that during the process of oil removal, flaxseed proteins form compounds with its other constituents. Obviously, such a mechanism of formation of compounds is the factor by which this method fails to separate the protein into fractions.

But at the same time, the cause of the sediment in the investigation may be that glutelins are poorly understood because they are difficult to isolate purely. The most studied is wheat grain glutelin, which is part of gluten, rice oryzenin and corn glutelin.

5. 2. Results of the study of the depth of protein transformation processes in wheat dough during maturation

To solve the following problem, we studied the patterns and depth of the processes of protein transformation in the dough during its maturation. The state of the protein was characterized conditionally dividing into separate fractions, namely: protein gluten, washed out of the dough, protein gluten, which is not washed in the form of gluten and does not go into the solution – intermediate fraction and water-soluble nitrogen compounds. This fraction also includes non-protein nitrogen, including amino acid nitrogen.

The rheological properties of the dough depend on the ratio of these fractions. Technically important is an intermediate fraction of the protein, which is highly hydrated gluten. Protein in this state is mobile, evenly distributed throughout the mass of the dough and gives it certain elastic properties.

The results of the study are presented in Table 4. It was found that the content of total nitrogen in the dough with flaxseed meal after mixing was higher than in the control by 14 % due to the protein of the meal.

Table 4

Fractional composition of dough proteins, mg/100 g dry substances

Fraction	Without FSM (control)	With the addition of 7.5 % of FSM	% of total: Without FSM (control)	% of total: With the addition of 7.5 % of FSM
Total nitrogen	2.213	2.522	100	100
Gluten Nitrogen				
after mixing	1.660	1.380	75.0	54.7
after 180 min of fermentation	1.569	1.100	70.9	43.6
Water-soluble nitrogen				
after mixing	0.251	0.466	11.2	18.6
after 180 min of fermentation	0.298	0.590	13.5	23.4
Intermediate fraction				
after mixing	0.302	0.676	13.7	26.7
after 180 min of fermentation	0.346	0.832	15.6	33.0

It was found that gluten nitrogen content decreased by 17.0 % due the transition of gluten nitrogen to water-soluble and intermediate fractions. The nitrogen content of the water-soluble fraction in the test sample is higher than in the control by 85.6 %, and the intermediate by 2.2 times.

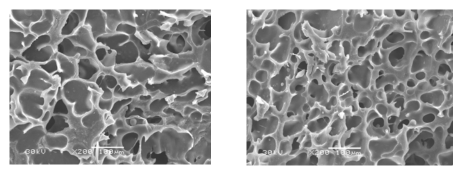
After 180 min of dough fermentation due to the deepening of the enzymatic hydrolysis of the protein and the interaction between the flour constituents and flaxseed meal, the content of gluten in the dough with this raw material is reduced by 30.0 %, compared with the control sample. The content of water-soluble and intermediate nitrogen fractions increased by 97.9 % and 2.4 times, respectively.

Such differences in the fractional composition of the protein are explained by the introduction of soluble proteins into the dough with flax meal and the formation of complexes of flour proteins and flax meal mucus, which do not take part in the formation of gluten and do not pass into the solution and form an intermediate fraction.

It can be predicted that a significant increase in the flaxseed dough of the water-soluble and intermediate nitrogen fraction will weaken the consistency of the dough, increase the ductility, which will be tested by baking.

5. 3. Results of the study of the effect of flaxseed meal on the properties of wheat gluten protein

As a result of studying the microstructure of gluten, it is established (Fig. 1) that, compared to the control, the walls of gluten with flaxseed meal (FSM) thicken. Based on these results, we can conclude that there is an interesting pattern associated with improving the elastic characteristics of gluten.



a b

Fig. 1. Microstructure of gluten dough: a – control; b – with FSM

It should be noted that along with the thickening of the gluten walls, there are smaller pore sizes in the experimental gluten samples (Fig. 1). This is indirect evidence that due to the formation of complexes of flax mucus with the gliadin fraction of flour proteins, as more active, which are removed during gluten washing, glutenin content increases in gluten, which leads to its strengthening and wall thickening.

5. 4. Results of the study of the effect of flaxseed meal protein on the water absorption capacity of wheat flour

Water absorption capacity is one of the main indicators of baking properties of flour. To a large extent, the ability of flour to absorb moisture depends on the ability of proteins, starch grains, and pentosans to bind water. The yield of the dough and, accordingly, the output of high-quality finished products depend on the value of water absorption capacity.

Experimental data about the change in water absorption capacity of the test samples obtained by mixing the dough on Farinograph-AT are presented in Table 5.

Table 5

Indicators of the effect of flaxseed meal on wheat flour of the first grade

Test samples	Indexes: Consistency, units	Water absorption capacity, $cm^3/100$ g	Duration of formation, min	Elasticity, units	Stability, min	Rarefaction during kneading, 15 min. units
Control without meal	500	59.6	2.5	140	5.0	45
2.5 % meal		61.5	4.5	135	4.5	60
5.0 % meal		65.2	5.0	120	4.0	75
7.5 % meal		69.3	5.5	80	3.5	95

Table 5 data indicate that the water absorption capacity of grade 1 flour is 59.6 %. During studying the mixture of flour with flaxseed meal, it was found that in the case of increasing the dosage of flaxseed meal from 2.5 to 7.5 %, the water absorption capacity of the samples is increased. Thus, the water absorption capacity of the dough after adding 2.5; 5.0 and 7.5 % of flax meal to flour increased compared to 3.2 %; 9.4 and 16.3 %, and mixing time was 4.5; 5.0 and 5.5 min, respectively.

5. 5. Results of the study of the effect of flaxseed meal on the quality of finished products

The results of previous investigations have found that flax meal in chemical composition and technological properties is different from wheat flour and has an effect on the microstructure of gluten, baking properties of flour, in particular, its water absorption capacity, elasticity. It is obvious that the inclusion of this raw material in the bread recipe should also affect the quality of finished products. In this regard, trial baking was carried out, which makes it possible to determine the influence of its quantity on the quality of bakery products.

Experimental data of bread quality indicators are presented in Table 6.

Table 6

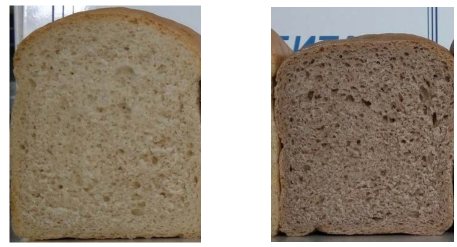
Indicators of technological process and bread quality

Indexes	Control	7.5 % of flaxseed meal added to flour
Dough		
Moisture content, %	42.5	44.0
Acidity, deg initial final	 1.7 2.3	 2.3 2.9
Duration of fermentation, min	170	170
Maturation time, min	48	63
Gas formation during dough fermentation and maturation of dough pieces cm^3/100 g of dough	980	840
Bread		
Specific volume, cm^3/h	2.82	2.51
Porosity, %	72	68
Acidity, deg	2.0	2.2
Form stability H/D	0.45	0.36
Surface condition	Smooth without cracks and disruption	
Crust color	Light with golden tinge	Brown with gray tinge
Crumb color	Light	Gray with brownish tinge
Crumb elasticity	Elastic	Less elastic
Preservation of freshness after 24 h, %	70	75
Taste and aroma	Characteristic of wheat bread	Peculiar to wheat bread with herbal taste

According to these studies, it is established (Table 6) that, compared to the control, the addition of flax meal leads to the prolongation of maturation of the dough pieces by 15 minutes. After maturation, these pieces had a smaller volume than the control. This is due to the decrease in fermentation intensity, which is confirmed by the lower CO_2 release during the fermentation period of the dough and maturation of the test pieces, due to the decrease in the fermentation activity of yeast in the presence of flax meal. Thus, the total gas production in the sample with 7.5 % of flax meal decreased by 13.3 %.

A significant decrease of the fermentation activity of yeast is associated with an increase in the viscosity of the liquid phase of the dough, caused by the mucus of flaxseed meal, the deterioration of nutrients access to the yeast cell.

After kneading, the dough with the meal is somewhat sticky, but in the process of fermentation its adhesive properties are improved, the dough is characterized by good plasticity, less bursting.



a *b*

Fig. 2. Results of trial baking: *a* — control; *b* — with flaxseed meal

The results of trial baking confirmed the thickening of the walls and the reduction of pore size, which was found during the study of the microstructure of gluten with flax meal. This is due to the formation of complexes of flax mucus with the gliadin fraction of flour proteins, the content of glutenin fraction in gluten increases, which leads to its strengthening and thickening of the pore walls.

Trial baking also confirmed the results of the investigation of protein substances. Due to the increase in the content of water-soluble proteins introduced with flax meal, there is rarefaction and weakening of the dough and increase in plasticity. This is confirmed by the increase of the water-soluble and intermediate nitrogen fraction in the flax meal dough, as established by the preliminary investigation of the fractional composition of protein substances.

Due to the excessively active course of protein disaggregation processes, the structural and mechanical properties of the dough deteriorate, adversely affecting the gas and shape-forming ability, as well as the volume, shape stability and porosity of bread.

It was found that in the case of adding 7.5 % of meal to flour, the bread quality decreased markedly: the specific volume decreased by 12.0 %, porosity by 6 % absolute, shape stability decreased and organoleptic parameters also changed. The crust got grayish, the crumb darkened. With the flax meal dosage of 7.5 %, the crumb darkened (Fig. 2), porosity was not uniform enough, thick-walled, and crumb elasticity decreased. This is not in conflict with the pre-established data in the study of water absorption capacity.

There was a specific herbaceous taste in the finished bread, but the smell of the bread was pleasant. However, the sample with flaxseed meal preserves freshness better, which is obviously caused by the introduction of dietary fibers into the dough with FSM that have high water absorption and water-holding capacity.

6. Discussion of the results of the study of flaxseed meal protein and effects on dough proteins

During determining the fractional composition of flaxseed meal proteins, as follows from the obtained results (Table 3), it should be noted that a significant amount of flaxseed meal protein 14.34 % was in the insoluble precipitate, apparently due to the specific structure of prolamines and glutelins, due to which they cannot be completely separated by the solvents provided by Osborne methods.

This is not at odds with the practical data well known in [22, 23], whose authors, incidentally, also associate any protein release with a solvent with a disruption of the natural structure of the protein molecule, because the solvent destroys or alters non-covalent bonds, that is, the release of protein from plant material is always accompanied by initial denaturation. From a practical point of view, such conclusions may be considered appropriate because they suggest that even the extraction of proteins with water is associated with a disruption of the hydrophobic interaction, the transition of metal salts into solution occurs and the ionic equilibrium of the protein molecule is impaired. And when gluten proteins are isolated with a 0.2 % alkali solution, there is a break even of disulfide bonds. But in contrast to the results of the studies reported in [27], data were obtained regarding the uneven distribution of fractional groups of proteins with a predominance of glutelin fraction (40 %) in flax L. humile, whereas in wild flax L. hispanicum and L. angustifolium all four fractions are in fairly equal proportions. It is found that the ratio of protein fractions in wild varieties of L. hispanicum and L. anustifolium is fairly uniform, with prolamin and glutelin fractions dominating in L. bienne and L. grandiflorum. These results affirm that considerable variation in the qualitative composition of proteins in different annual wild species is evident, which is obviously due to the breadth of the response rate characteristic of the Linum genus. From a theoretical point of view, the results of the investigation in this paper alow to confirm that the mechanism of protein extraction is determined, which is a certain advantage of this study. However, it should be noted that the results of the determination (Table 3) indicate the ambiguous effect of solvents on protein fractions. This is manifested, first of all, in the discrepancy between the results of published investigations [13, 21–23]. Such uncertainty imposes certain limitations on the use of the results obtained, which may be interpreted as the disadvantage of this study.

As a result of subsequent studies, during determining the patterns and depth of the processes of protein transformation in the dough during its maturation, it is established (Table 4) that gluten nitrogen content is less by 17.0 % due to the transition of gluten nitrogen to water-soluble and intermediate fractions. The nitrogen content of the water-soluble fraction in the test sample is greater than in the control by 85.6 %, and the intermediate one by 2.2 times. Such differences in the fractional composition of the protein are explained by the introduction of soluble proteins into the dough with flaxseed meal and the formation of complexes of flour proteins and flax meal mucus, which do not participate in the formation of gluten and do not pass into the solution and form an intermediate fraction.

In the dough after mixing, the intensive swelling of the protein substances of flour continues, the activity of proteolytic enzymes, which cause the disaggregation of protein molecules, hydrolysis of polypeptide chains, increases. The content of water-soluble protein substances increases in the dough, resulting in rarefaction.

These processes are significantly influenced by the ingredients of the dough. Due to the excessively active course of protein disaggregation processes, the structural and mechanical properties of the dough deteriorate, adversely affecting its gas and shape-forming capacity, as well as the volume, shape stability, and porosity of bread. This was confirmed by the results of trial baking.

As a result of studying the microstructure of gluten, it was found that, compared to the control, the gluten walls with flaxseed meal thickened, which was associated with an increase in the elastic properties of gluten. Due to the glutenin content increase in gluten, the walls and pores are strengthened and thickened. This is in agreement with the investigation [20], which indicates that the protein molecule is disrupted more if the dosage of flax meal is greater. The authors attribute the cause of this disorder to water-soluble mucus and flax meal fiber. Adding flax meal allows making similar conclusions, because flax meal and flour are by-products of flaxseed processing in the manufacture of oil.

It should be noted that a higher hydration capacity of albumin and globulin of flaxseed meal than gluten proteins is associated with increased water absorption. The advantage of this study is that it is not inconsistent with the previously established practical data, because their content in flaxseed meal is more than 66.64 %. Mucous polysaccharides bind and retain more water than flour polysaccharides. Due to the peculiarities of its structure, a large amount of water is bound by flax meal fiber. Such findings are confirmed by the study in the development of cupcakes [19]. It has been found that increasing the dosage of the investigated ingredients leads to an increase in the absorption of water for both flax meal and germinated flax seeds.

With the increase of flax meal in the dough, its stability and elasticity decrease. The elasticity of the dough is reduced by 3.8 % with the addition of 2.5 % of flax meal, and with the addition of 7.5 % by 22.3 %. The rarefaction grows if the duration of mixing increases. This is due to the fact that water-soluble proteins and water-soluble dietary fiber of the meal cause an increase in the formation of the liquid phase of the dough, which leads to rarefaction.

The results of trial baking make it possible to emphasize that the peculiarities of the chemical composition of flaxseed meal, together with the ability to give the products physiological and functional (health) properties, affect the technological process and product quality. Thus, the addition of flax meal causes a decrease in fermentation intensity, prolongs maturation, which leads to a deterioration of bread quality. These findings are consistent with the studies [9, 13, 19], which also indicate the change in the organoleptic properties of finished products and structural and mechanical properties of dough and finished products due to the specificity of the chemical composition of flax meal. In this case, the products are better kept fresh due to the presence of mucus in the flax meal.

At this stage, the studies are complete. Further research will focus on improving the technological process, selecting technological measures to improve the structural and mechanical properties of the dough and finished products, the results of which will be published in periodicals. At this stage, it can be concluded that in order to enrich bread with biologically active substances, it is advisable to add flaxseed meal in the amount of 7.5 % to flour. Adding 2.5–3 % of flaxseed meal to flour practically does not affect the quality of bread, but this amount is not enough to create a functional product. Dosing more than 10 % of flax meal significantly impairs the technological process and reduces bread quality.

7. Conclusions

1. As a result of investigations of the fractional composition of flaxseed meal proteins, it has been established that the specific structure of prolamins and glutelins leads to the formation of a significant amount of insoluble sediment. This is also due to the disruption of the natural structure of the protein molecule due to the separation of protein by the solvent. The solvent breaks down non-covalent bonds, so the release of protein from plant material is always accompanied by the initial stage of denaturation.

2. It is established that the use of 7.5 % of flaxseed meal in flour with the deepening of enzymatic hydrolysis of protein and interaction between flour and meal components leads to a decrease in gluten nitrogen content in the dough by 30.0 %, compared with the control sample. Due to the transition of gluten nitrogen to water-soluble and intermediate fractions, the nitrogen content of these fractions increases. A significant increase of water-soluble and intermediate nitrogen fraction in the flaxseed dough leads to a weakening of dough consistency.

3. As a result of studying the microstructure of gluten, it was found that the use of flaxseed meal leads to the strengthening of gluten and thickening of the pore walls. Investigations have shown that compared to the control, there is a decrease in pore size in the sample. This will definitely affect the ramifications of the gluten frame.

4. It is found that the high hydrophilic property of flax meal proteins and food fibers causes an increase in the water absorption capacity of the dough. The formation of the liquid phase of the dough increases, leading to rarefaction. With increasing the dosage of the meal, the stability and elasticity of the dough decrease, and dough formation is longer.

5. Studies have shown that the addition of 7.5 % flax meal to flour in the dough causes a decrease in fermentation intensity, prolongs maturation, which leads to a deterioration in the quality of bread. The quality of bread markedly reduced. Specific volume decreased by 12.0 %, porosity by 6 % absolute, shape stability decreased, and organoleptic parameters of its quality also changed. The crust became grayish, the crumb darkened. The porosity was not uniform enough, thick-walled, and the elasticity of the crumb decreased. There was a specific herbaceous taste in the finished bread, but the smell of the bread was pleasant. However, the flaxseed meal sample retained freshness better because of the high water absorption and water-holding capacity of flaxseed meal.

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