Доведено, що за хімічним складом насіння кунжуту переважає пшеничне борошно за вмістом моно- та поліненасичених жирних кислот, мінеральних речовин, повноцінного за амінокислотним складом білка, харчових волокон та вітамінів. Для розширення асортименту хлібобулочних виробів з оздоровчими властивостями рекомендовано використовувати у рецептурі пшеничного хліба кунжутне борошно в кількості до 10 % до маси борошна. Встановлено, що у разі внесення кунжутного борошна розроблений виріб більшою мірою, ніж пшеничний хліб, покриває потребу організму в білках – в середньому на 7 % та забезпечує організм людини більшою на 15,5 % кількістю жирів, з переважаючим вмістом ненасичених жирних кислот, зокрема ω-6 та ω-9 – кислотами, та в мінеральних речовинах, зокрема кальції, магнії – на 26 та 30 %.

Визначено закономірності впливу кунжутного борошна на формування структурно-механічних властивостей тіста. Встановлено, що внесення в тісто кунжутного борошна призводить до зниження кількості клейковини в тісті та її пружних властивостей, покращує пластичні властивості тіста, що зумовлює скорочення тривалості замішування тіста. Зважаючи на зниження питомого об'єму тіста з додаванням кунжутного борошна після 180 хв бродіння, рекомендовано, щоб тривалість бродіння тіста у разі його використання за безопарного способу тістоприготування не перевищувала 120 хв.

Встановлено, що внаслідок внесення 10 % кунжутного борошна готові вироби містять до 3 % жиру. Виходячи з цього, можна рекомендувати заміновати кунжутним борошном маргарин в діючих рецептурах хлібобулочних виробів, якого міститься до 3 %.

Доведено, що вироби з додаванням кунжутного борошна краще зберігають свіжість, що підтверджено зменшенням кришкуватості, збільшенням загальної деформації м'якушки та її гідрофільних властивостей, а також містять більше ароматичних сполук, ніж хліб з пшеничного борошна

Ключові слова: пшеничний хліб, кунжутне борошно, черствіння, клейковина, структурно-механічні властивості тіста

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STUDYING THE EFFECT OF SESAME FLOUR ON THE TECHNOLOGICAL PROPERTIES OF DOUGH AND BREAD QUALITY

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1. Introduction

As stated in the annual statistical report of the WHO Global Health Observatory, life expectancy indicators have grown worldwide over the period from 2000 onwards [1]. At the same time, according to data by the World Health Organization, the health status of population all over the world, given the current environmental and socio-economic conditions, tends towards deterioration and is characterized by the increasing number of persons suffering from different diseases. The total number of deaths from non-infectious diseases has increased due to the growth of the population and its aging [2]. Therefore, one of the tasks of WHO is to reduce by one-third, to the year of 2030, premature mortality from non-infectious diseases through prevention, treatment, and supporting the health and well-being of population [3]. One of the factors that affect the formation of the "healthy" life expectancy is nutrition. In this regard, of significant relevance is the problem of providing the population not only with full and healthy food products, but also functional ones. Such products contain ingredients that increase resistance to disease, they are able to regulate physiological processes in the human body, making it possible to keep an active lifestyle over a long time.

On a global scale, there are constant efforts to create products of functional purpose, which have both a wide range of action and a narrow focus on a specific organ, disease, or a category of population [4].

One of the possible ways to improve the structure of nutrition of this country's population is to use in the manufacture of bakery products the alternative raw materials, food additives, complex baking improvers [5]. Such raw materials must contain a significant amount of easily digestible protein, vitamins, unsaturated fatty acids, minerals, and nutrients.

Functional properties of baked goods can be improved through the introduction of the products of processing to their formulations, specifically oil-bearing crops, particularly sesame seeds.

In this regard, it is an important task to investigate influence of shredded sesame seeds on the quality of wheat bread and to establish its optimal dosage to bread for rendering it functional properties and ensuring at the same time the traditional quality of products.

Given this, it is a relevant task to conduct a study into the influence of shredded sesame seeds on the quality of wheat bread and to establish its optimal dosage for rendering functional properties to bread and ensuring at the same time the traditional quality of products. It is also important to define patterns in the formation of structural-mechanical properties of dough and to devise recommendations regarding the parameters of the bread making technological process for the case of using sesame flour, as well as to study the bread staling processes for the case of dosing sesame flour.

2. Literature review and problem statement

Sesame is cultivated in the world as a source of oil and protein whose content in sesame seeds reaches 58 % and 26 %, respectively [6]. The proteins of sesame seeds are characterized by high biological value. They are rich in methionine and especially in tryptophan. However, the proteins of sesame seed are limited for lysine, albeit to a lesser extent than the proteins of wheat. In terms of solubility in the group composition of proteins, sesame seeds are dominated by salt-, water- and alkali-soluble [7].

The fat-free flour from sesame seeds, obtained after the extraction of oil, is used to receive the isolates and concentrates of sesame proteins. The research into their fortifying wheat bread has shown that if one adds 16 % of protein products from sesame seeds, the quality of bread did not worsen while their nutritional value improved due to the enrichment with amino acids, mineral substances; the digestibility of bread improved as well [8]. However, the derived protein isolates and concentrates of sesame proteins lack valuable polyunsaturated fatty acids that are contained in seeds. That does not make it possible to fully ensure the improvement of the nutritional value of bakery products in the case of using such products of sesame processing. Studies into the influence of sesame protein products on animals showed a decrease in cholesterol, triglycerides and lipoproteins in their blood serum [9]. Thus, it may be a prerequisite for the use of sesame seeds in the production of bakery products for special purposes.

The oil of sesame seeds in terms of fat-acid composition refers to the olein-linoleic type, in which the weight percentage of oleic acid is 41–45 %, linoleic – 42...44 %, of the total content of fatty acids. The ω-3 sesame oil contains neither long-chain fatty acids nor fatty acids. Consumption of sesame oil helps reduce the absorption of cholesterol in the lymphatic system of thin intestines [10, 11]. Experimental research on animals revealed anti-carcinogenic effect of sesame oil at chemical carcinogenesis, as well as the inhibition of the growth of human colon cancer cells under in vitro conditions [12]. The high content of linoleic acid and dietary fiber in sesame seed ensures its capability to reduce the level of cholesterol in the blood plasma of humans [13, 14]. A study into health state of women aged from 50 to 70 who consumed 50 g sesame seeds per day over 5 weeks showed lower levels of total cholesterol and improvement in the hormonal status of women this age [15]. These studies render relevance to using the seeds of sesame for the enrichment of bakery products. The above studies, however, fail to tackle the technology for applying sesame seeds in order to enrichment food products.

The positive impact of sesame oil on the human body is associated with its antioxidant properties and its special fat-acid composition. Kapadiya and others [16] explain the antioxidant properties of oil by the presence of vitamin E and fat soluble lignans. The sesame oil is marked by the predominance of γ-tocopherol over other isomers of vitamin E. At the same time, the lignans of seeds contribute to the preservation of vitamin E, preventing its oxidation. The cited data characterize the antioxidant properties of the oil, rather than their change in the case it is used as a component of food products.

Lignans make up to 1.5 % of the sesame seed weight. The main lignans in sesame seeds are sesamin and sesamolin. The content of lignans in sesame seeds is even higher than that in the seeds of flax, which is considered their richest source. The lignans of sesame seeds under the influence of microflora of the intestines are turned into enterolactones that produce an estrogenic effect [17].

The antioxidant properties of sesame seeds and the presence of biologically-active substances in them contribute to slowing down the processes of aging, which was confirmed by the results of a study of animals whose diet included sesame seeds [18]. Consequently, an analysis of the above sources points to their antiatherosclerotic and anti-carcinogenic potential. To enrich food products with the seed components, it is appropriate to use the whole seeds. The products of seed processing, such as oil, protein foods, extracts, will provide better nutritional and physiological value of products in one direction only (the protein value or fat-acid composition).

The combination of a given set of nutrients provides for the sesame unique nutritional properties and defines its prospects to adjust the chemical composition of bakery products in order to ensure their functional properties.

In European countries, sesame seeds are commonly used for the decoration of bakery products. At present, sesame seeds are actively included to the composition, balanced by the content of major nutrients, of multigrain mixtures, which are intended for use in bakery production [19], and premixes for manufacturing various assortment of bakery products (Schapfen Muhle (Germany), Leipurin (Finland), "Diamant" Austria, etc.).

The addition of whole sesame seeds to bread formulation causes deterioration of the structural-mechanical properties of dough, reducing the volume of products and accelerating their staling. That is why, in order to enrich wheat bread with the physiologically-functional ingredients from sesame seeds, it was proposed to use them in the shredded form.

Paper [20] proposed using the shredded sesame seeds in combination with the seeds of flax, cedar nuts, peach puree, for the production of sweet bread of enhanced nutritional value. The authors of this paper suggested applying the shredded sesame seeds in the technology of sweet rusks. However, the defined patterns of its effect on the quality of products and the progress of the technological processes would probably have significant differences predetermined by the difference in technology for making products with long shelf life and plain wheat bread. Authors of [21] use the shredded sesame seeds in the formulation of wheat bread "Sesame"; however, the main factor that determines the quality of this product is the introduction, along with sesame flour, of a large number of dry wheat gluten. This factor, first, does not make it possible to identify the impact of the sesame flour on the products quality and the technological process. Second, the addition of food additives increases the cost of products. Therefore, it is advisable to study the application of the shredded sesame seeds that would enrich wheat bread, as a separate ingredient.

It is advisable to establish the optimal dosage of the shredded sesame seeds to the formulation of wheat bread to maximize the possible introduction of physiological-functional ingredients with it, and to ensure traditional quality of products. In addition, to explore the influence of sesame flour on the quality of gluten, structural-mechanical characteristics of dough, aas well as the staling processes of finished goods.

3. The aim and objectives of the study

The aim of present work was to substantiate the appropriateness of using the shredded sesame seeds, consequently sesame flour, to enrich wheat bread with its physiological-functional ingredients and to obtain products of good quality.

To accomplish the aim, the following tasks have been set:

– to establish the optimum dosage of the shredded sesame seeds for obtaining products of traditional quality, enriched with the physiological-functional nutrients;

– to explore the influence of sesame flour on the structural-mechanical properties of dough and the quality of gluten;

– to study the influence of sesame flour on the staling processes of wheat bread.

4. Materials and methods to study the influence of sesame flour on the quality of wheat bread

4. 1. Examined objects and materials used in the experiment

Wheat bread was baked from the first-grade wheat flour using the straight-dough techniques for the following formulation:

– first-grade wheat flour – 100 kg;

– baking pressed yeast – 3.0 kg;

– food salt – 1.5 kg.

In our research we used sesame flour (SF) received by shredding the sesame seeds at a laboratory mill. The grain size of sesame flour was close to the grain size of brown wheat flour.

Comparative evaluation of the chemical composition of sesame seeds [22] and the first-grade wheat flour reveals (Table 1) that contains 1.7 times more protein than wheat flour, 36 times more fats, 1.6 times more non-starched polysaccharides.

Table 1

Chemical composition of sesame seeds and the first-grade wheat flour, %

Components	First-grade wheat flour	Sesame seeds
Proteins, %	11.6	19.4
Carbohydrates, %	73.3	17.8
incl. dietary fiber, %	3.5	5.6
starch, %	70.1	10.2
sugars, %	1.8	2.0
Fats, %	1.35	48.7
Ash-content, %	0.7	4.8
Mineral substances, mg/100 g potassium	176	497
calcium	26	1474
magnesium	49	540
phosphorus	122	720
Vitamins, mg/100 g thiamine (B_1)	0.16	1.27
α-tocopherol (E)	1.8	2.3
riboflavin (B_2)	0.08	0.36
niacin (PP)	2.2	4.0
pyridoxine (B_6)	0.74	0.8

The proteins of sesame seeds are rich in hydrogen sulfide amino acids – methionine + cystine, which possess antioxidant properties (their amino acid score is 129 against 72 in wheat flour), aromatic amino acids – phenylalanine + tyrosine, which can improve the activity of the nervous system (their amino acid score is 138 against 119 in wheat flour), and are especially rich in tryptophan, whose content in the proteins of sesame is 2.5 times higher than that in the proteins of wheat flour (its amino acid score is 155 against 67 in wheat flour) (Table 2). The proteins of sesame seed are limited for lysine, albeit to a lesser extent than the proteins in wheat.

Sesame seed oil consists of 13.5 % of saturated fatty acids and 86.5 % of the unsaturated fatty acids: monounsaturated fatty acids, which are almost entirely represented by oleic acid and the polyunsaturated fatty acids – linoleic (Table 3).

Sesame seeds contain B group vitamins (B1, B2, PP), as well as vitamin E, and can supplement wheat flour with them, because they contain more of these vitamins than in wheat flour.

Sesame seeds has a significantly larger ash content than wheat flour – by 6.7 times, which correlates with its high content, compared with wheat flour, of potassium – by 2.8 times; magnesium – by 11 times; phosphorus – by 6.0 times, and calcium – by 57 times.

Nutritional properties of sesame seeds are not limited to the presence of essential nutrients and are also determined by the presence of biologically active substances, mainly lignans.

Table 2

Amino acid composition of the proteins of sesame seeds and wheat flour

Amino acid	Content of essential amino acids, g/100 g protein			Amino acid score	
	Protein reference (defined by FAO/WHO)	Sesame protein	Wheat flour protein	Sesame protein	Wheat flour protein
Essential amino acids					
Lysine	5.5	2.83	2.69	52	49
Threonine	4.0	3.96	2.54	99	64
Valine	5.0	4.58	2.55	92	51
Methio-nine + cystine	3.5	2.88 1.65	1.32 1.22	129	72
Leucine	7.0	6.89	6.03	98	86
Isoleucine	4.0	4.02	2.52	101	63
Phenyl-alanine + Tyrosine	6.0	3.71 4.58	2.63 4.70	138	119
Tryptophan	1.0	1.55	0.67	155	67
Total		36.65	26.87		

Table 3

Fat-acid composition of lipids, g

Fatty acid title	Sesame seeds
Fat content of seed – 48.7 %	
Saturated fatty acids	6.6 (13.5 %)
Palmitic	4.2
Stearic	2.1
Arachidic	0.1
Monounsaturated fatty acids	21.0 (43.1 %)
Palmitoleic	0.1
Oleic (Omega-9)	20.9
Polyunsaturated fatty acids	21.1 (43.4 %)
Linoleic (Omega-6)	21.1

Thus, sesame flour is significantly different in chemical composition from wheat flour and would contribute to the enrichment of bread with physiological-functional ingredients.

4. 2. Methods of research into quality of wheat bread with sesame flour

We baked bread at the laboratory to examine the indicators of the technological process, biochemical, physical-chemical changes in dough and quality indicators of bread. The dough was prepared using a straight-dough technique; mass fraction of the dough moisture content was 42 %. Before mixing the dough, sesame flour was mixed with wheat flour. We mixed dough in a dual-speed dough making machine. We treated the dough manually; the aging of dough semi-finished pieces was performed at the thermostat at a temperature of (38±2) °C and relative humidity (78±2) %, up to readiness. The products were baked in a cabinet-type baking oven at 220...240 °C.

The gas-forming ability of semi-finished products was determined using the device AG-1M [23].

The elastic characteristics of the dough was examined using the pharinograph made by Brabender (Sweden) and the alveographer made by Chopin (France). The indicators from a pharinograph make it possible, along with a characteristic of the structural-mechanical properties of dough, to determine the amount of water required to produce the dough of the preset consistency. The quality of bread was estimated based on the physical-chemical (specific volume, shape stability, structural-mechanical properties of crumb) and organoleptic parameters (physical appearance, state of the surface of crust, structure of porosity, taste, flavor). We measured how long the products retain freshness based on a change in the structural and mechanical properties of crumb. We determined its total deformation after 48 h of storage using the penetrometer AP 4/1. An integrated quality score was assessed based on a point estimation of the quality of bakery products [23].

The degree of product staling was studied based on the swelling of bread crumb and its friability. The staler the bread, the lower the swelling of crumb. The degree of staling is represented by the magnitude of specific swelling per cm^3 of the swollen weight per 1 g of dry matter of the examined sample [24].

The content of aromatic substances in bread was determined based on the number of bisulfite-binding compounds [24].

Results of the experimental research were statistically processed employing the standard software package Microsoft Office.

5. Results of studying the quality of wheat bread with the addition of sesame flour

To estimate the quality of bread with the addition of sesame flour (SF) and its optimal dosage, we conducted a trial laboratory baking.

During study, we prepared dough from the first-grade flour with the introduction of 5; 10; and 15 % sesame flour by weight of the flour. A sample without sesame flour, prepared in line with the formulation described above, served as control. The dough was prepared using a straight-dough technique. Duration of fermentation of all samples of dough was 170 min. Research results are given in Table 4.

Based on the results of the trial laboratory baking, we established that in case of adding sesame flour the starting acidity of dough, compared to control, grows by 0.2–0.7 degrees, due to the presence of fatty acids in sesame. However, we observed no intensification of acidity accumulation in the process of dough maturation.

The samples of dough with the added sesame flour demonstrated the lower, compared with control, intensity of fermentation, confirmed by the smaller release of CO_2 during fermentation of the dough and aging of the dough pieces. Thus, the total gas evolution in samples from the 5-% sesame flour decreased by 6.5 %, from 10.0 % – by 12.0 %, from 15 % – by 16.5 %.

Aging duration of dough pieces with sesame flour reduces, compared with control, by 5–12 min.

The obtained finished products' crust with the added SF is colored more intensely than that in control. When adding 5 to 10 % of the shredded sesame seeds of the weight of flour, the products had uniform, thin-walled porosity, and an elastic crumb. The taste and flavor of these products were inherent to wheat bread with a pleasant tender aroma of sesame. When dosing the shredded sesame seeds in the amount of 15 % by the weight of flour, we obtained products with a less elastic crumb and too strong taste and flavor of sesame.

Table 4

Indicators of the technological process and products quality

Indicator	Control	Sesame flour, introduced as % to the weight of flour		
		5	10	15
Dough				
Dough moisture content, %	42.5	41.8	41.7	42.0
Acidity, degrees starting resulting	 1.4 2.1	 1.6 2.3	 1.9 2.6	 2.1 2.8
Fermentation duration, min	170			
Aging duration, min	55	50	45	43
Amount of carbon dioxide released during fermentation and aging of dough semi-finished products, cm^3/100 g of dough	840	785	740	700
Bread				
Surface state	Smooth, no cracks and fractures			
Crust color	Light		Light brown	
Crumb color	Light		Light, hardly visible inclusions of sesame flour	
Crumb elasticity	Elastic			Less elastic
Taste and flavor	Inherent to wheat bread	Inherent to wheat bread with pleasant nutty flavor and sesame aroma		Inherent to wheat bread with intense flavor and sesame aroma
Specific volume, cm^3/g	2.86	2.80	2.73	2.64
Porosity, %	72	71	70	69
Acidity, degrees	2.0	2.1	2.3	2.4
Shape stability H/D	0.46	0.44	0.43	0.40

It is established that the specific volume of finished products with the introduction of sesame flour reduces by 2.0, 4.5, and 7.5 %, respectively, as the dosage grows.

The shape stability and porosity of products reduce in accordance with the increased dosage of sesame flour.

An integrated index of products quality based on the organoleptic indicators showed 96.6 points for the examined sample against 89 points for control (Table 5).

The main factor that determines the formation of volume, porosity, structure of crumb for bakery products, as well as the behavior of dough under its processing, is the structural-mechanical properties of the dough.

Bread baking dough possesses at the same time the elastic and viscous-plastic properties, occupying an intermediate place between a perfectly elastic body and the true viscous liquid.

Table 5

Organoleptic estimates of products based on a 100-point scale, taking into consideration the significance factor of quality indicators

Indicator	Significance factor	Estimate, points	Estimate with respect to significance factor	Estimate, points	Estimate with respect to significance factor
		Bread from the first-grade wheat flour		Bread with added SF, 10 % to the weight of flour	
Bread volume	0.15	5	0.75	4.8	0.75
Shape regularity	0.14	4.5	0.63	4.7	0.66
Crust color	0.05	4	0.2	5	0.2
Surface state	0.05	4.5	0.23	4.8	0.24
Crumb color	0.06	5	0.3	5	0.3
Porosity structure	0.08	4.0	0.32	4.8	0.39
Crumb elasticity	0.12	4.0	0.48	4.7	0.57
Flavor	0.11	4	0.44	5	0.55
Taste	0.12	4.5	0.54	4.8	0.58
Crumb chewiness	0.12	4.7	0.56	5.0	0.6
Bread quality based on the totality of all indicators recalculated for 100 points	–	–	89	–	96.6

The balance between elastic and elastic-plastic characteristics of dough determines its structural-mechanical properties, particularly gas-forming ability. Therefore, to elucidate the causes of quality deterioration in the products with sesame flour, we determined the capability of semi-finished products with sesame flour to retain carbon dioxide, that is, their gas-forming ability.

Table 6

Dough specific volume, cm^3/g, n=3, $p \leq 0.95$

Fermentation duration, min.	Control	Sesame flour, introduced as % to the weight of flour		
		5	10	15
0	1.0	1.0	1.0	1.0
60	2.3	2.6	2.4	2.3
120	2.6	2.8	2.7	2.5
180	2.8	3.0	2.8	2.6
240	**3.0**	2.7	2.6	2.3

It was established (Table 6) that when adding a dosage of 5 % of SF to the flour weight, specific volume of the dough after 4 hours of fermentation was smaller than that of the control sample by 10 %; 10.0 % – by 16.5 %, 15 % – by 23.3 %. This leads to a decrease in the volume of bread and its porosity.

However, an analysis of the change in the specific volume of dough during its fermentation showed that after 60 min of fermentation specific volume of the dough with the introduction of 5 and 10 % of SF to the weight of flour was larger than that of the control sample. The improvement of the shape-retaining ability of the dough with sesame flour, compared with control, is also observed at minute 120 and minute 180 of fermentation. When adding sesame flour in the amount of 15 % to the weight of flour, specific volume of the dough was the same as that in control, probably due to the increase in the plastic properties of the dough. After 180 minutes of fermentation, specific volume of all samples of dough with sesame flour reduces.

During our research, we prepared the samples of dough with the added 10 % of SF. A sample that does not contain SF served as control.

The research results are given in Tables 7, 8, and Fig. 1.

Table 7

Structural-mechanical properties of dough based on pharinograph (n=3, p≤0.95)

Indicators	Control without flour	10 % of SF introduced
Consistency, unit of the device	500	500
Water-absorbing capacity, cm^3/100 g	61.1	61.4
Forming duration, min	6.5	4.5
Elasticity, unit of the device	70	60
Stability, min	3.0	4.0
Dilution for kneading, unit of the device	30	40

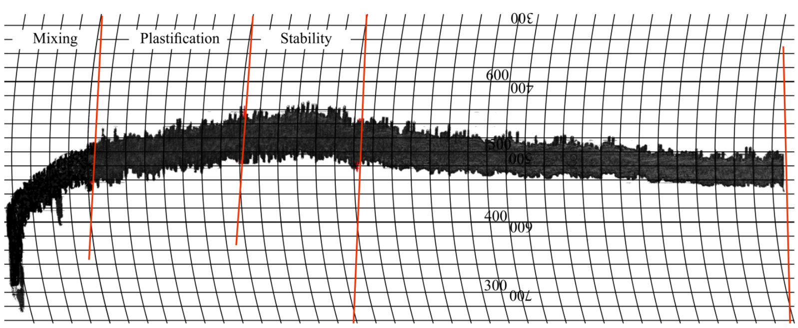
Table 8

Effect of sesame flour on plastic-elastic properties of dough (based on alveographer), n=3, p≤0.95

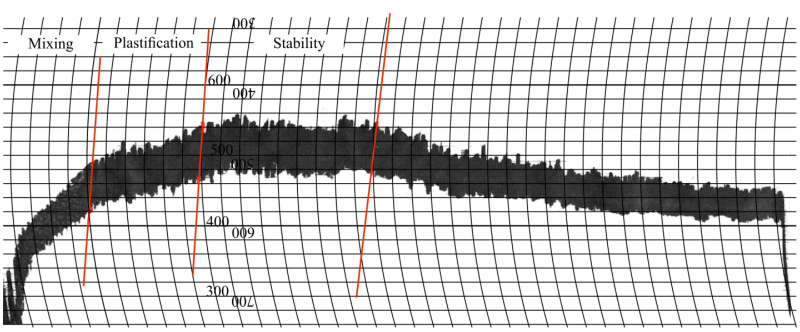
Indicators	Control	SF % introduced to the weight of flour	
		5	10
Elasticity, P, mm	60	49	38
Elongation, L, mm	50	55	49
P/L	1.2	0.89	0.77
Specific work of deformation, W, 10 conditional units	223	187	174

Results of studying the structural and mechanical properties of dough, acquired from pharinograph, indicate that the introduction of sesame flour does not improve the water-absorbing capacity, however, it reduces the duration of kneading the dough. It should be noted that the duration of dough kneading can be conditionally divided into two stages: mixing the ingredients and the plasticization of dough. When adding the sesame flour, the duration of mixing the ingredients was the same as that in control while that of the plasticizing – decreased. The dough with sesame flour had better stability; however, at the end of mixing we observed somewhat larger dilution of the dough system with added sesame flour than that in control.

The study using an alveographer indicates that the introduction of SF is accompanied by a decrease in the elasticity of dough and in the specific work of deformation. The samples with sesame flour had, compared to control, greater elongation. The elongation of dough is largely dependent on its plasticity. Given that, it is possible to predict better gas-forming ability of those samples of dough that demonstrated a larger indicator when an alveographer was used. That confirms the results obtained about a change in the specific volume of dough in the case of adding sesame flour.



a



b

Fig. 1. Pharinograms of dough: *a* – control (without adding SF); *b* – adding 10 % of SF to the weight of flour

The colloidal system, which the dough is, is characterized by the viscous-plastic properties, along with the elastic-plastic ones.

The main feature of the fat-containing raw materials is the ability to plasticize the structure of dough. The mechanism of plasticization of polymers implies breaking by the molecules of a plasticizer part of the intermolecular bonds and their interaction with appropriate groups of polymers. This reduces the interaction forces between proteins. Active plasticizers of protein are fats.

An indirect indicator based on which one assesses changes in viscosity that occur in dough with added sesame flour is a possible spreading of the ball of dough during fermentation, since it is caused by the displacement of the layers of dough as a result of the decrease in the internal friction of the system.

The results of studying the spreading of a ball of the dough after 3 h of fermentation, shown in Fig. 2, indicate that an increase in the addition of sesame flour to dough leads to an increase in its spreading, as compared with control. This is contributed to by the high content of fat in sesame flour, which provides the dough with greater plasticity and decreases viscosity of the dough system.

Thus, when adding sesame flour in the amount of 10 % to to the weight of flour, the diameter of a ball of dough in 3 hours of fermentation was larger, compared to control, by 4.5 %, 10.0 % – by 8.2 %; and 15 % – by 11.8 %.

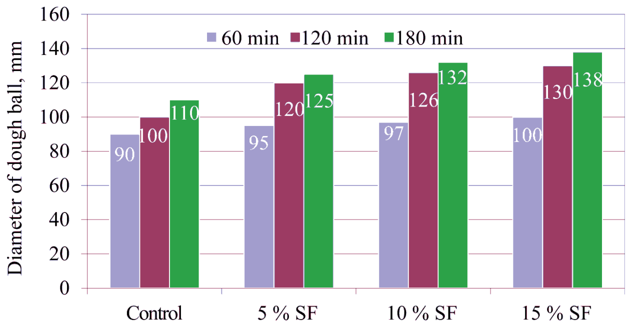


Fig. 2. Spreading of a ball of dough with added sesame flour

The most informative indicator that characterizes the state of the protein-proteinase complex is gluten. It is known that the hydrated proteins of gluten, gliadin and glutenin, form continuous sponge-mesh structure in dough – the frame of dough, which ensures its plastic and elastic properties, provides for the retention of CO_2 during fermentation, preserves the shape of dough semi-finished products during aging and baking.

The proteins of gluten during dough kneading absorb 31.2 % of all water, which significantly affects the ratio of solid and liquid phase in dough. A decrease in the amount of water absorbed by proteins leads to the dilution of dough. The absorption of proteins of water gluten is affected by the formulation components.

It was established (Table 9) that, compared with control, the addition of sesame flour reduces the amount of crude gluten, its hydration ability, increases elastic properties and reduces elongation.

Table 9

Amount and quality of gluten in dough n=3, p≤0.95

Indicator	Control	Added sesame flour, % to the weight of flour	
		5.0	10.0
Amount, %	28.3	27.8	27.3
Elongation, cm	11	10	9
Plasticity, unit of the device, index deformation gluten	63	60	57
Hydration ability, %	192	187	182
Elasticity	good	good	good

An important indicator of consumer properties of finished products is the freshness of bread.

Fresh bread must have good plasticity of the entire product, soft and elastic crumb, pleasant taste and flavor. However, these indicators change during its storage and bread loses appeal to the consumer. When stored, bread dries out, first the crust and the under-crust layers of crumb. This makes the product hard. Along with the drying, there occurs the aging process of colloidal systems of crumb, starch, and proteins; bread goes stale.

Changes in the elasticity of crumb as a result of staling, its increased friability and decreased hydrophilic properties are the main indicators, which characterize the degree at which bread retains freshness over a certain period of its storage.

The staling of bread slows down when its formulation is introduced with raw materials or additives with high water-absorbing and water-retaining properties, surface-active substances, fats.

Since sesame flour is rich in fat and protein substances, its introduction, therefore, will exert a certain influence on the processes of bread staling.

During our study, we determined the structural and mechanical properties of crumb using the penetrometer AP-4/I, its friability, as well as water-absorbing capacity of the following samples of bread: control (without sesame flour), with sesame flour in the amount of 5 % to the weight of flour, and with sesame flour in the amount of 10 % to the weight of flour.

When studying the structural and mechanical properties of the crumb, we determined the overall deformation of crumb. Based on a change in the total deformation, we calculated the percentage at which products retained freshness in 24 and 48 hours.

The study has shown (Table 10) that the total deformation in samples with the added sesame flour was greater than that in control. This is explained by the improvement in the elasticity of products' crumb due to the introduction of fat along with sesame flour. In the process of storing, these samples, in 24 hours, demonstrated freshness that was 5 and 7 % better than that of control.

Table 10

Indicators of deformation for the crumb of bread with SF, n=3, p≤0.95

Indicators	Control (without SF)	SF, introduced as % to the weight of flour	
		5	10
Crumb deformation, units of the device, in 4 hours:			
total	73	78	85
in 24 hours:			
total	50	57	64
Degree of retaining freshness, %	68	73	75
in 48 hours:			
total	35	40	46
Degree of retaining freshness, %	48	51	54

The structural-mechanical properties of crumb of the samples of products with the addition of sesame flour changed slower in the process of storing. Thus, after 48 hours of storage, the total deformation of control sample decreased by 52 %, whereas that of the samples with sesame flour – by 48 and 45 %, respectively.

Along with studying the structural-mechanical properties of the crumb, we determined changes in its friability during storage of bread.

The research results, shown in Fig. 3, indicate that products with the added sesame flour demonstrated less friability than that of control. In 24 hours of storing, the friability of samples from the 5 and 10 % sesame flour was less than that of control by 9 % and 12 %; and after 48 hours – by 14 % and 18 %.

Thus, the data that characterize how products retain freshness for friability correlate with the data obtained using the penetrometer.

Research into hydrophilic properties of the bread crumb showed (Table 11) that, compared to control, the samples of bread with the added sesame flour had higher water-absorbing ability in the process of storing, indicating their decreased staling.

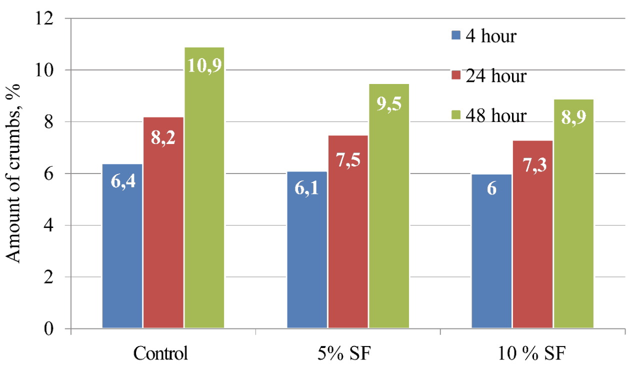


Fig. 3. Friability of bread during storage

Table 11

Hydrophilic properties of bread, % on dry matter, n=3, $p \leq 0.95$

Storage duration	Control (without SF)	Samples of bread with the added sesame flour, % to the weight of flour	
		5	10
4	351	401	453
24	277	282	293
48	228	243	259

When bread is store, along with staling, there occurs a decrease in the intensity and expressiveness of its flavor. Aromatic substances are partially weathered off the crust, part of them migrates to the crumb to be eventually adsorbed on its components, which leads to the loss of flavor.

A commonly applied method for studying the flavor of bread is a method for determining its content of carbonyl compounds, which is based on the binding of aldehydes and ketones by sodium bisulfite. In this work, we employed this method to determine the content of bisulfite binding substances in the sample of bread containing 5 and 10 % of sesame flour. A sample of bread without sesame flour served as control.

In the samples of products with the addition of sesame flour, when compared with the control sample, the crust was better colored and, consequently, it contained more bisulfite binding substances.

The study has shown (Table 12) that the bread with sesame flour in the amount of 5 % and 10 % to the weight of flour, in 4 hours after baking, contains more aromatic compounds than control. Thus, the crust demonstrated 17 % and 23 % more aromatic compounds, respectively; the crumb – 19 % and 26 %, respectively.

This can be explained by the that along with sesame flour, bread is additionally introduced with protein substances that enter the reaction of melanoidin formation. Both the crust and the crumb of products with sesame flour lost the flavor slower during storage.

These data correlate with the organoleptic perception of the taste and flavor of products with sesame flour. Their taste was pleasant, and the flavor – distinctly nutty.

Table 12

Content of bisulfite binding substances, mg-equiv./100 g of bread, n=3, $p \leq 0.95$

Indicator	Control without SF	Added sesame flour, % to the weight of flour	
		5	10
In crust, in hours:			
4	13.5	15.9	16.7
24	9.4	11.5	13.9
48	8.3	9.4	11.3
In crumb, in hours			
4	5.1	6.1	6.5
24	5.2	6.4	6.8
48	4.3	5.6	5.8

An analysis of data (Table 13) shows that the product with SF meets the need of the body in essential substances by a greater extent than control.

The product with the addition of SF better satisfies the need of the human body in the essential amino acids compared to wheat bread and provides the organism with a larger amount of unsaturated fatty acids, specifically ω-6 and ω-9 acids.

6. Discussion of results of using sesame flour in the formulation of wheat bread

It was established that it is advisable to include sesame flour to the formulation of the first-grade wheat bread in the amount of up to 10 % to the weight of flour. When dosing increases, the products acquire very pronounced unpleasant taste and aroma of sesame seeds; the crumb is not elastic.

Expert evaluation has shown that the introduction of sesame flour to the formulation of bread improves the shape, surface state, color of the crust and crumb, its elasticity, the taste and flavor of products. This is explained by that the fatty components of sesame flour improves the elasticity of crumb, contribute to the formation of thin-walled porosity. Protein components of sesame flour enter the reaction of melanoidin formation and improve the color of the crumb. In combination, all that contributed to the improvement in the quality of products, which is confirmed by that the points increased by 7.6 units.

It is established that following the introduction of sesame flour in the amount of 10 % the finished products contain up to 3 % of fat. Given this, one can recommend replacing the margarine contained in the existing formulations in bakery products in the amount of up to 3 % with sesame flour. Scientists believe that the replacement of solid fats, rich in saturated fatty acids and trans-isomers of fatty acids, with oils, rich in oleic or linolenic acid, improves the profile of lipoprotein in terms of risk of the coronary heart disease. Therefore, an alternative strategy to improve the profiles of lipoproteins in the blood and to reduce the risk of coronary heart disease is to change the composition of fatty acids in fatty products of mass consumption [25].

Table 13

Meeting the daily need in nutrients under condition of consuming 277 g of bread

Components	Daily need	277 g of bread contain		Meeting the daily need, %	
		Bread from the first-grade flour	Bread with SF in the amount of 10 % to the weight of flour	Bread from the first-grade flour	Bread with SF in the amount of 10 % to the weight of flour
Proteins, g	59	22.4	26.5	38	45
Essential amino acids, mg					
Valine	3,500	576.2	750.7	16.5	21.4
Isoleucine	3,500	548.2	731.3	15.7	21
Leucine	500	1,357.3	1,615	271	323
Lysine	4,000	576	709	14.5	17.7
Methionine + Cystine	3,000	576	750.7	19.2	25
Threonine	2,500	567.8	731.2	22.7	29
Tryptophan	1,000	155	210.5	15.5	21
Phenylalanine + Tyrosine	3,000	1,731	2,038.7	57.7	68
Fats, g	60	2.6	11.9	4.3	19.8
including: mono unsaturated fatty acids	–	0.2	4.3	–	–
polyunsaturated fatty acids	11.0	1.08	5.2	9.8	47
General carbohydrates, g	344	141	145	41	42
including dietary fiber, g	25	6.7	7.8	26.8	31.2
Mineral substances, mg					
Potassium	3750	355	452	9.5	12
Calcium	1100	61	346	5.5	31.5
Magnesium	350	96	199	27	57
Phosphorus	1200	246	385	20.5	32
Vitamins, mg					
Thiamine (B_1)	1.3	0.33	0.58	25.4	44.5
Riboflavin (B_2)	16.0	0.16	0.25	1.0	1.6
Niacin (PP)	16	4.5	5.3	28	33
Folic acid	0.2	0.14	0.16	70	80
Tocopherol (E)	15	3.4	3.9	23	26
Energy value, kcal	2150	642	700	29.8	38.6

We observed in the dough with sesame flour a reduction in the intensity of fermentation, compared to control, which is probably due to the deterioration of the fermenting activity of yeast. The reason for this might be a lower supply of nutrients to the cells of the yeast cell as a result of its covering with the fat from sesame flour.

It is established that the specific volume, shape stability and porosity of the products reduce with the increased dosing of sesame flour. The reason for this could be not only a reduction of the intensity of fermentation of the examined samples of dough, but also the reduction in their gas-retaining capacity. However, an analysis of change in the specific volume of dough when adding sesame flour in the amount of 5 and 10 % to the weight of flour revealed the improvement, compared with control, in the shape-retaining capacity of the examined sampled of dough at minute 60, 120, and 180 of fermentation. This is probably because in the process of preparing the dough the lipids of sesame form lipoprotein complexes with the protein of flour, while the fat is distributed along the gluten films, thereby filling the micropores. This improves gas-retaining capacity of dough, as well as its structural-mechanical properties.

A decrease in the specific volume of all samples of dough with sesame flour after minute 180 of fermentation is probably due to that the introduction of lipids with sesame flour predetermines a larger reduction in the viscosity of the dough system compared to control. Therefore, when baking products using the traditional straight-dough technique, we obtained products of smaller volume due to the fact that the phase of aging and baking coincided with a period of deterioration in the capability of dough to retain carbon dioxide. So, when using sesame flour, one can recommend that the dough fermentation should last no longer than 120 min.

The results of the analysis of pharinograms showed that when sesame flour was added, the duration of dough plasticizing decreased at the expense of improvement in the plastic properties of dough as a result of the distribution of fat among the gluten films of the dough system. The dough acquired greater stability, probably due to the formation of complexes of fat from sesame flour with the proteins of wheat flour.

The fats that enter the dough with sesame flour are partially bound to the flour proteins, forming the complexes. However, the major proportion of lipids, when entering the hydrophilic structure of dough, block the polar groups of proteins, preventing their interaction with water. Therefore, the introduction of sesame flour leads to a decrease in the hydration capacity of these samples of dough, compared with controls. This is also a reason for reducing the amount of gluten in the dough. Thus, 2 % and 3.7 % less gluten is washed out of the dough with 5 and 10 % of sesame flour, respectively, compared to control.

The lipids of sesame flour are represented mainly by the unsaturated fatty acids, therefore, they are actively involved in the oxidative processes and exert the corresponding effect on the structure of the proteins of dough. As a result, the gluten of dough, when adding sesame flour, acquires a greater elasticity, compared with the control sample, as evidenced by data on elasticity derived from index deformation gluten.

Adding sesame flour to the formulation of wheat bread predetermines the lengthening of its freshness, probably due to that the fat of sesame flour is adsorbed at the surface of starch grains by the hydrophobic part of the molecule, which results in the increased number of hydrophilic parts. This in turn causes reduced adhesion between grains of starch. The fat disrupts the continuous structure of gluten and starch and prevents the formation of a solid and hard mass. The fats that slow down the aging process of the starch gel make the process of staling less noticeable. Their introduction also causes a decrease in the moisture content, osmotically associated with starch. This phenomenon is attributed to the formation of a complex from starch and fat, which prevents the penetration of water into the micro voids of starch grains.

The product with added SF meets the organism needs in proteins better than wheat bread –by 7 % on average, including the essential amino acids, and provides the body with a larger amount of fat, by 15.5 %, with the predominant content of unsaturated fatty acids, particularly ω-6 and ω-9 acids, and mineral substances, specifically calcium, magnesium – by 26 % and 30 %. Therefore, the product with SF is capable of giving the body physiological-functional ingredients and thus could be assigned to products with health properties.

However, still unclear is the degree of digestion of proteins from products, enriched with sesame flour. It is also expedient to conduct research into the impact of different grain size of sesame flour on the quality of products.

It is promising in the future to study the establishment of technological measures without the use of food additives to improve the quality of the finished products, enriched with sesame flour. That relates to the deterioration in the quality of finished products, specifically the reduction of specific volume, when using the shredded sesame seeds, as compared with control.

7. Conclusions

1. It was established that it is advisable to include sesame flour to the formulation of wheat bread in the amount of up to 10 % to the weight of flour. The product with added sesame flour meets better the need of human body in the proteins than wheat bread –by 7 % on average, including the essential amino acids, and provides the organism with a larger amount of fat, by 15.5 %, with the predominant content of the unsaturated fatty acids, such as ω-6 and ω-9 acids, and in mineral substances, specifically calcium, magnesium – by 26 % and 30 %.

2. It was established that the introduction of sesame flour to dough leads to a decrease in the amount of gluten in the dough and its elastic properties. The samples of dough with added sesame flour demonstrate improved plastic properties, which predetermines the shorter kneading of dough. Given the reduction in the specific volume of the dough with added sesame flour after 180 minutes of fermentation, we recommend that the duration of fermentation of the dough using a straight-dough technique of preparation should not exceed 120 min.

3. It was established that products with the addition of sesame flour are better in retaining freshness, which was confirmed by a decrease in friability, an increase in the total deformation of the crumb and its hydrophilic properties; they also contain more aromatic compounds than bread baked from wheat flour.

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