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IMPROVING THE QUALITY OF RYE-WHEAT BREAD ENRICHED WITH FLOUR FROM EXTRUDED KERNELS OF SUNFLOWER SEEDS FOR FOOD SUPPLIES TO MILITARY PERSONNEL

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Bakery products have an unstable heterogeneous structure that needs stabilization. The nutrient composition of these products, in most cases, is unbalanced: it is characterized by a high content of calories and carbohydrates. At the same time, the content of protein, fat, dietary fiber (fiber), vitamins, macro- and microelements is low. This leads to the search for raw materials with high functional and technological potential and with an attractive nutrient profile. The expediency of using in the technologies of bakery products a secondary product of processing sunflower seeds – flour from the extruded kernel of sunflower seeds (FESSK) has been proved. Its nutrient profile has been investigated. A high protein content (38.73 %) with a well-balanced amino acid composition (10 essential and 9 non-essential amino acids) increases the biological value of FESSK. The content of fat (4.87 %), rich in unsaturated fatty acids (16 fatty acids), enriches the nutritional profile of FESSK. The high ash content (8.0 %) (22 elements were found) and the presence of 12 vitamins (92.3 % of the total amount of vitamins) indicates a high biological value of FESSK. It was found that the addition of FESSK in the amount of 10.0 % to the mass of wheat flour increases the humidity by 0.5–1.2 %; reduces acidity by 0.5–1.2°; increases porosity by 7.0–11.0 %; increases the specific volume by 1.12–1.26 cm^3/g. It reduces crumbliness of the crumb by 2.0–2.2 times, QMAFAnM – by 4.0–4.8 times, and increases the period of preservation of bread freshness by 1.57–1.77 times

Keywords: flour from extruded kernel of sunflower seeds, rye-wheat bread, nutrient profile, quality indicators

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1. Introduction

Scientific research on the development of innovative technologies of food products with high nutritional value and extended period of freshness preservation is important [1, 2]. The results of such studies are needed by practice to improve the food supply of the population and military personnel during a special period. In the diets of servicemen and the population of Ukraine there is a deficiency of macro- and micronutrients, protein, polyunsaturated fatty acids, vitamins, dietary fiber, biologically active substances. There is an imbalance in the food consumed. This can be explained by the entry into the processing of defective raw materials, the deterioration of the ecological situation, violations in the structure of nutrition, that is, the reasons leading to an increase in the number of people suffering from various

diseases, including alimentary [2, 3]. Improving the food structure of Ukrainians, ensuring the quality and safety of food products have become the most important priorities of this country's domestic policy. The development of the sector of production of healthy food products is focused on the postulates of nutrition. In particular, on the development of technologies that make it possible to obtain on the basis of the rational use of natural raw materials food products that contribute to the improvement of the nutritional structure and are intended for the prevention of diseases associated with the alimentary factor [3, 4]. One of the main tasks of the food industry in Ukraine is the sustainable development of the production of its raw materials and food. Their volumes should be sufficient to provide food to the population of the country. An important task is the use of new advanced technologies for deep and complex processing of food raw materials. Further improvement of the nutritional standards of military personnel in a special period also depends on the level of innovation in the food supply system [1, 3].

Secondary resources of the oil and fat industry are actively used in solving food, environmental, and energy problems, being an additional source of substances of natural origin. A significant amount of secondary resources is formed in the process of processing sunflower seeds – the main oilseed crop of Ukraine, namely sunflower cake and meal. The most valuable properties of secondary products of sunflower seed processing such as cake/meal/flour are high protein content, low cost, and the absence of toxic and anti-nutrients in them. However, these secondary products of sunflower seed processing, especially meal and cake, are used mainly for agricultural needs [2, 4]. In particular, as feed additives for poultry and livestock. Sunflower seed kernels have a rich chemical composition. They contain up to 20 % of proteins, up to 50 % of lipids, dietary fiber, minerals, and other substances. Therefore, they are a good source of nutrients and can be used in food technology [2, 5].

Analysis of the results of the study of the chemical composition showed that sunflower seeds (varieties Dzherelo R-453, Master, Buzuluk; hybrids Mercury, Melin, Altair) prevail in the total volume of gross harvest of sunflower seeds in Ukraine. It is a promising raw material for obtaining a complex of foods of high nutritional value, namely, oil, lecithin, dietary protein, secondary products (cake/meal/flour) and a complex of natural antioxidants, including chlorogenic acid [2, 3].

A promising source of valuable nutrients (essential fatty acids, essential amino acids, vitamins, minerals, etc.) is FESSK. It is a raw material component that improves the functional and technological properties of tite semi-finished products. It improves biological and nutritional value; indicators of the quality of finished products. The most valuable properties of FESSK are high protein content (~39.0 %) with a balanced amino acid composition. Presence of essential amino acids, essential polyunsaturated fatty acids; a significant amount of antioxidants: vitamin E – 15.4 mg % and chlorogenic acid – 0.321 %. Additionally, the absence of toxic and anti-nutrients, low cost. All this makes FESSK a useful raw material ingredient [6]. That is, FESSK is a promising raw material with a complex effect that can be used in food production [6].

In this regard, the use of flour from the extruded kernel of sunflower seeds in food technologies, bread and bakery products, is relevant.

2. Literature review and problem statement

The EU Council highlighted the global food crisis provoked by the Russian invasion of Ukraine (Evropeyska Pravda, 20.06.2022). These are supply chain disruptions and logistical complications due to restrictions imposed during special conditions, rising food prices due to global inflation, and low productivity of food systems. At the same time, among the EU partner countries, the problem of lack of nutrients in the diet of the population of Ukraine has reached its maximum value. Changes in the economy of the country and partner countries of the EU in a special period led to the fact that over the past 1.0 years, purchasing power has decreased significantly [7]. And consumers save primarily on food, buying cheap products of dubious quality and insufficient biological and nutritional value. Indeed, the cost of high-quality raw materials has increased, and therefore it becomes necessary to use new sources of raw materials and enrich them, first of all, products of mass consumption – bread and bakery products [1, 6, 7].

Works [3, 4, 7] report the results of research on improving the nutritional properties of bakery product. It is indicated that bread is a staple food consumed daily, so its quality must meet all medical and biological requirements. But in industry, up to 50 % of the total volume of flour with reduced properties is processed; large bakeries use continuous technologies that have a number of drawbacks, including those that affect the quality of bread. In [2, 5, 6] it is shown that these indicators of the quality of bread depend on a number of factors, the main of which is the quality of the main and additional raw materials used in the production of bread. It was noted that the need of the population and military personnel for bakery products for medical, dietary, and preventive and functional purposes, especially in areas of hostilities and environmental distress, is not sufficiently met. There is also a problem in the production of bread and bakery products for long-term storage. Therefore, it is necessary to pay attention to the selection of the range, the creation of new recipes that provide the specified nutritional properties of finished products.

Specialists of the agro-industrial sector proved that in Ukraine a large acreage is taken by sunflower [7]. This vegetable raw material is known as oil crop. It contains up to 20 % of proteins and other valuable substances, therefore it can serve as a basis for use as a multifunctional food component. But this requires additional research on functional and technological properties. In addition, secondary products of the oil and fat industry – cake, meal, flour – are not sufficiently used.

The expediency of using secondary products of processing oilseeds, in particular sunflower flour, in the production of flour products is associated with an increase in biological value and an improvement in the technological and taste qualities of the products obtained [5]. Their disadvantages are the lack of a complex action. There are known works to improve the biological value of bakery products by enriching them with sunflower processing products – protein isolate [8] and protein concentrate [9]. The disadvantage of these enrichers is the narrow direction of action.

Recent works [10, 11] have shown that bread enriched with nutrients from sunflower seeds and products of its processing had several advantages: increased biological and nutritional value, improved organoleptic characteristics. But

during its production there were certain difficulties. This significantly reduced the consumer attractiveness of finished products. The introduction of 5 % or more of sunflower flour or protein isolate from sunflower seeds or meal contributed to the deterioration of the organoleptic properties of bread – darkening of the crumb. Papers [12, 13] proved the expediency of using in the technology of bakery products of secondary products of processing sunflower seeds: cake/meal/flour. But the introduction of sunflower cake/meal/flour more than 4.75 %, namely 5.0–12.5 %, worsened the texture of finished products. In [14] it is shown that partial replacement of wheat flour by 2.5–7.0 % of sunflower flour helps extend the period of freshness preservation and improve the nutritional value of finished products. But the introduction of sunflower flour into the bread recipe of 7.5–15.0 % contributed to the deterioration of the crumb consistency (insufficiently developed porosity).

Studies [15, 16] show the use of secondary products of processing sunflower seeds in the technologies of bakery products with extended periods of freshness. But high temperature regimes of processing sunflower seeds and obtaining oil and secondary products lead to deep denaturation of seed proteins. As a result, the functional properties of oil and secondary products of sunflower seed processing are reduced. This helps reduce the biological and nutritional value of bread and bakery products. Works [5, 17] proved the expediency of using protein products of processing sunflower seeds in the production of bread. But the proposed technology of processing sunflower seeds excludes the possibility of obtaining sunflower secondary products without additional processing. In addition, these protein foods have a reduced biological value.

Promising is the complex technology of processing the collapsed kernel of sunflower seeds, which involves the production of FESSK, enriched with physiologically valuable essential fatty acids. FESSK also contains such ingredients in demand in food technologies as vegetable protein with a balanced amino acid composition and lecithin (manufacturer NAUTECH PLUS LLC, Ukraine) [6].

Therefore, the scientific substantiation of the use of FEKSS for bakery products with high quality and nutritional value and an extended period of freshness preservation has great practical prospects in the food industry.

3. The aim and objectives of the study

The aim of this study is to determine the effect of FESSK on the quality indicators of rye-wheat bread. This will make it possible to improve the nutritional properties and extend the shelf life of bakery products.

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

– to determine the chemical composition and functional and technological characteristics of flour from the extruded kernel of sunflower seeds (FESSK);

– to investigate the influence of FESSK on the organoleptic indicators of prototypes of rye-wheat bread;

– to investigate the influence of FESSK on the physical-chemical indicators of prototypes of rye-wheat bread;

– to investigate the influence of FESSK on the structural and mechanical parameters of prototypes of rye-wheat bread in the process of their storage;

– to investigate the influence of FESSK on the microbiological indicators of prototypes of rye-wheat bread in the process of their storage.

4. The study materials and methods

The influence of FESSK on the organoleptic, physical-chemical, structural-mechanical, and microbiological parameters of rye-wheat bread was investigated in order to improve its quality and nutritional value.

The object of study: technology of bread from a mixture of rye and wheat flour.

The subjects of research:

– FESSK, obtained with the help of innovative integrated technology of processing sunflower seeds, manufacturer LLC "NAUTECH PLUS", Ukraine;

– sample 1, control – rye-wheat bread "Darnytskyi" DSTU 4583:2006 with quality indicators: crumb moisture – no more than 44,5 %; acidity not more than – 8.5°; porosity – not less than 58,0 %;

– sample 2 – rye-wheat bread with partial replacement of wheat flour of the highest grade (WFHG) with FESSK in the amount of 7.5 % by weight of WFHG;

– sample 3 – rye-wheat bread with partial replacement of WFHG with FESSK in the amount of 10.0 % by weight of WFHG;

– sample 4 – rye-wheat bread with partial replacement of WFHG with FESSK in the amount of 12.5 % by weight of WFHG.

To implement the tasks, generally accepted [18–21] and standard research methods according to DSTU-P 4583:2006 and DSTU 7517:2014, as well as instrumental methods of biochemical, physicochemical, and microbiological analysis were used. The content of crude fat and moisture was determined using the NMR-relaxometer minispec mq-20 (Bruker, Germany) according to DSTU 7491:2013. The mass fraction of the protein was determined using the quantitative identification system N_2/protein DKL8 (VELP SCIENTIFICA, Italy) in accordance with DSTU 7491:2013. The biological value of the protein complex was studied by experimental determination of the amino acid composition using the capillary electrophoresis system "KRAPEL-105M", the manufacturer Lumex. The relative biological value (RBV) of protein products was determined by an express method using Tetrahymena pyriformis ciliates, a strain of WH14, in accordance with the recommendations from [18]. The mass fraction of fiber was determined at the fiber analysis plant FIBRETHERM FT12 (Gerhardt, Germany) in accordance with DSTU 7491:2013. The mass fraction of fat in the protein complex was determined at the automatic installation for solid-liquid extraction SOXTHERM SOX414a (Gerhardt, Germany) according to the user manual and DSTU 7491:2013. The fatty acid composition of lipids was determined on a gas chromatograph with a flame-ionization detector and the integrator "Crystal 5000". The content of calcium and magnesium was established by the complexometric method. Statistical processing of the results of the experiment was carried out according to the Student's method. The organoleptic and physical-chemical properties of rye-wheat bread were determined by standard methods [19, 20]. The structural and mechanical properties of bread crumb (elasticity, %; modulus of elasticity E, Pa; shrinkage, %) were determined by measuring its plastic-elastic properties on an automated penetrometer AP-4/2. With the help of this device, the general deformation of the bread crumb (ΔH_{gen}) was determined, which characterizes its compressibility; plastic deformation (ΔH_{pl}), or elasticity and elastic deformation (ΔH_{el}), or shrinkage according to the

methods from [19, 20]. To characterize the process of staleness of bread, a method was used to determine the modulus of elasticity E, which characterizes the depth of immersion of the cone-shaped penetrometer indenter under load in the crumb of bread [19, 20]. Crumbliness was determined in % of the crumbs formed in relation to the mass of the crumb taken [19, 20]. The shape resistance of wheat bread was determined by the formula: SR=H/P (H – height, cm; *P* – perimeter, cm). The specific volume (V_{sv}, cm^3/g) was determined by dividing the value of the volume of bread by its mass. It was expressed with an accuracy of 0.01 cm^3/g. The volume of bread (in cm^3) was measured three times using the RZ-BIO device. The device works on the principle of measuring the volume of bulk filler squeezed out with bread [19, 20]. The list of microbiological indicators by which the quality control of finished bakery products was carried out was established, guided by the requirements of DSP 4.4.5.078 and MBT No. 5061-89. The quantity of mesophilic aerobic and facultative-anaerobic microorganisms (QMAFANM, CFU/g) and the presence of intestinal bacteria were determined (BGKP-coliforms) in 0.001 g). Staphylococcus aureus, Proteus, bacteria of the genus Salmonella, and other pathogenic microorganisms were determined in 25 g [21] and, respectively, DSanPiN 4.2-180-2012 and DSTU 8446: 2015.

5. Results of studies of the effect of flour from the extruded kernel of sunflower seeds on the nutritional properties of rye-wheat bread

5. 1. Determination of the chemical composition and physical-chemical indicators of flour from the extruded kernel of sunflower seeds

We investigated the features of the chemical composition of FESSK. Due to the fact that FESSK has an attractive nutrient profile, it was used to increase the nutritional value of rye-wheat bread. A comparative analysis was carried out on the chemical composition of the main raw materials – WFHG and peeled rye flour (PRF) (Table 1).

FESSK was studied for GMO content. It was found that FESSK does not contain genetically modified DNA, which has target sequences of the 35S promoter and the NOS terminator.

Table 2 gives the physical-chemical indicators of the quality of FESSK.

Analysis of physical and chemical quality indicators presented in Table 2 shows that FESSK is characterized by a high protein content (38.73 %). And a well-balanced amino acid composition (which increases the biological value of flour). FESSK contains 76.35 % soluble proteins. This is an important factor in stabilizing food systems – foams, emulsions; the formation of gels. Because soluble proteins create a high homogeneous dispersion of molecules in such systems and promote intersurface interactions. The fat content (4.87 %), rich in unsaturated fatty acids, increases the nutritional value of sunflower flour. FESSK has a low acid number (0.093 mg KOH/g), including after 6 months of storage (0.091 mg KOH/g). This indicates a low level of hydrolysis and oxidation of fat, high quality, and stability of FESSK during storage. The acid number grows negligible – only by 1.1 %. This is due to the antioxidant action of natural antioxidants, in particular α-tocopherol, chlorogenic acid, etc. They contribute to an increase in the period of induction, the destruction of hyperoxides without the formation of free radicals, which leads to chain break (decontamination of free radicals in chain oxidation reactions) and slow down the oxidation rate [15].

Table 3 gives the results of determining the amino acid profile of FESSK, WFHG and PRF.

Table 1

Comparative chemical composition of FESSK, WFHG and PRF

Product	Protein, g	Fats, g	Sugar, g	Starch, g	Fiber, g	Ash, g	Ca, mg	Mg, mg
FEKSS	38.7	4.87	3.7	12.5	11.9	8.0	367	317
WFHG	12.0	1.9	3.4	70.7	0.12	0.58	21	19
RRF	10.7	1.6	5.6	65.8	0.20	1.6	34	60

Table 2

Physical-chemical indicators of FESSK quality, $P \leq 5{,}0$ %

Name of the indicator	Content
Mass fraction of moisture, %	4.72±0.24
Mass fraction of volatile substances, %	3.48±0.16
Mass fraction of dry matter, %	91.80±4.19
Mass fraction of crude protein in terms of dry matter, %	38.73±1.94
The mass fraction of soluble proteins in flour to the total protein content, %	76.35±3.11
Mass fraction of crude fat in terms of dry matter, %	4.87±0.25
Acid value of crude fat once/after 6 months. storage, mg KOH/g	0.091±0.004/0.093±0.004
Mass fraction of crude fiber, %	11.87±0.55
Mass fraction of total ash, in terms of dry matter, %	8.0±0.35
Mass fraction of starch, %	12.53±0.59
Mass fraction of chlorogenic acid, %	0.321±0.016
Mass fraction of vitamin E, mg/kg	15.40±0.77

Table 3

Content of essential amino acids in FESSK, WFHG and PRF, P≤5.0 %

Amino acid	Mass fraction, mg per 100 g of product		
	FEKSS	Wheat flour	
		of the highest grade	peeled rye
Sum of amino acids	7416±12.14	3471±6.12	3013±5.16
including: valine	1070±4.22	471±3.42	343±3.11
isoleucine	710±3.14	430±3.48	242±1.85
leucine	1343±4.02	806±3.56	406±3.24
lysine	693±3.01	250±1.98	231±1.85
methionine+cystine	785±3.00	353±2.18	362±2.19
threonine	886±3.66	311±2.04	281±2.39
tryptophan	337±2.11	100±1.01	88±0.96
phenylalanine+tyrosine	1592±4.34	750±2.98	475±3.51

The analysis showed (Table 3) that the total amount of essential amino acids in FESSK is 2.44–2.48 and 3.15–3.19 times more than in rye and wheat flour.

Due to the fact that in addition to proteins and minerals, physiologically functional ingredients include unsaturated fatty acids, a comparative analysis of the fatty acid composition of FESSK, rye and wheat flour was carried out in our work (Table 4).

Table 4

Fatty acid content in FESSK, WFHG and PRF, P≤5,0 %

Fatty acid	Amount of fatty acid in terms of flour fat, mg/g		
	FESSK	Flour	
		wheat of the highest grade	peeled rye
Palmitic, C16:0	0.44±0.01	0.13±0.01	0.08±0
Stearic, C18:0	0.34±0.01	0.01±0	0.01±0
Oleic, C18:1(ω–9)	10.95±0.85	1.13±0.1	0.81±0.1
Linoleic, C18:2 (ω–6)	36.88±1.02	1.81±0.1	0.97±0.1
Linolenic, C18:3(ω–3)	0.10±0.01	0.03±0	0.02±0

As can be seen from Table 4, FESSK has a richer fatty acid profile than wheat and rye flour. The study of the nutrient composition of FESSK is promising for finding economic ways to improve the nutritional quality of bread and bakery products; increasing the profitability of secondary products of sunflower seed processing. Previous studies have established that FESSK is a powder that consists of homogeneous particles (90–110) microns [6]. This predetermines the relative ease of its introduction into the formulation of flour products, in which the typical particle size of wheat and rye flour is ≤200 microns (usually ~100 microns).

Thus, judging by the presented characteristics, FESSK is a very valuable raw material for the baking industry, the decisive task of which is to create bakery products with increased nutritional value and an extended period of freshness.

Indicators of oxidative spoilage of FESSK, calculated taking into account the oil content in sunflower flour, are within the normal range (Table 2); foreign, metal-magnetic impurities, and pest infestation are absent. In general, the results of the study of safety indicators and nutritional value of FESSK make it possible to classify the studied sample of FESSK as standard food raw materials.

5. 2. Investigation of the influence of flour from the extruded kernel of sunflower seeds on the organoleptic characteristics of rye-wheat bread

Sensory analysis of prototypes of rye-wheat bread revealed an increase in the integrated quality indicator with a partial replacement of WFHG with FESSK in the amount of 7.5 %; 10.0 %; 12.5 % of the amount of WFHG by (0.07±0.01); (0,18±0,01); (0.05±0.01) points, respectively (Table 5).

Moreover, in the production of rye-wheat bread with a partial replacement of WFHG by 7.5 % FESSK, the quality indicators of products compared to the control almost did not change. When replacing WFHG with 12.5 % FESSK, the texture of the products becomes dry and brittle. The best organoleptic characteristics have products when replacing WFHG with 10.0 % FESSK, that is, with a ratio (in %) WFHG: FESSK =90:10 (Fig. 1).

At the same time, *the texture* is preserved; products acquire a pleasant nutty *flavor*. Improved: *appearance* – correct, with a convex surface shape; smooth, crackless surface. *Consistency* – finely supported, elastic, delicate, and *appearance on a break* – a structure with small evenly distributed pores.

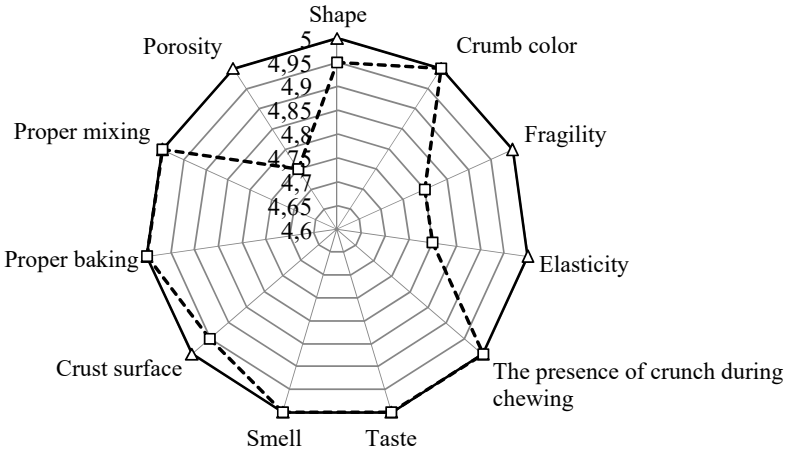

Fig. 1. Organoleptic indicators of bread samples: –□– – "Darnytskyi" (control); –△– – with flour mixture (in %) "WFHG: FESSK =90:10"

Experimentally, the optimal mass fraction of FESSK in the technology of rye-wheat bread, which accounted for 10.0 % of the amount of WFHG, was established. The mass fraction was established taking into account the nutritional properties of bread and based on the calculation of the cost of finished products.

Table 6 gives the results of organoleptic analysis of rye-wheat bread with a partial replacement of WFHG with FESSK in the optimal amount – 10.0 % by weight of WFHG compared with the control sample.

Table 5

Evaluation of organoleptic indicators of prototypes of rye-wheat bread, R≤5.0 %

Prototypes of rye-wheat bread	Organoleptic indicators of rye-wheat bread					
	Taste	Color	Porosity	Appearance and surface of bread	Smell	Complex indicator
Sample 1 – control	5.00±0.02	5.00±0.02	4.90±0.01	4.92±0.01	5.00±0.02	24.82±0.01
Sample 2 – 7.5 % FESSK	5.00±0.02	5.00±0.02	4.92±0.01	4.97±0.02	5.00±0.02	24.89±0.01
Sample 3 – 10.0 % FESSK	5.00±0.02	5.00±0.02	5.00±0.01	5.00±0.01	5.00±0.02	25.00±0.01
Sample 4 – 12.5 % FESSK	5.00±0.02	5.00±0.02	4.97±0.01	4.98±0.01	5.00±0.02	24.95±0.01

Table 6

The results of organoleptic analysis of the quality of rye-wheat bread with the addition of FESSK in the optimal amount – 10.0 % by weight of WFHG compared with the control sample, $P \leq 5.0$ %

Indicator	Prototypes of rye-wheat bread	
	Sample 1 – control	Sample 3 – 10,0 % FESSK
Shape, condition of the surface of the crust, K_v=2	9.01±0.04	9.61±0.04
Color of crusts, K_v=2	9.41±0.04	9.61±0.04
Crumb color, K_v=3	14.42±0.05	14.42±0.05
The nature of porosity, K_v=3	13.81±0.05	14.41±0.05
Crumb elasticity, K_v=3	12.02±0.05	13.82±0.05
Aroma (smell), K_v=3	13.81±0.06	15.01±0.06
Taste, K_v=3	13.81±0.06	15.01±0.06
Chewability, K_v=1	4.01±0.02	4.81±0.02
Total quality indicator $\Sigma X_i \times K_v$*	90.31±0.08	97.71±0.08

*Note: * K_v – coefficient of weight, X_i – i-th quality indicator.*

As follows from the data (Table 6), prototypes were estimated at 90.21–97.61 points, depending on the amount of FESSK. The determining indicators of the increase in total points in relation to the control sample were the aroma and taste of bread.

5. 3. Investigation of the influence of flour from the extruded kernel of sunflower seeds on the physical-chemical parameters of rye-wheat bread

To assess the impact of FESSK on the quality of finished products, the physical-chemical indicators of prototypes of rye-wheat bread were determined: mass fraction of crumb moisture, specific volume, acidity and porosity of the crumb. Table 7 gives the physical-chemical indicators of prototypes of rye-wheat bread enriched with FESSK, compared with the control.

The mass fraction of crumb moisture is an indicator that is closely related to the quality and durability of bread during storage. Excess moisture contributes to the course of enzymatic and chemical reactions, activates the activity of microorganisms, including those that lead to spoilage of bread, in particular its molding.

Important indicators of the quality of bread are porosity and acidity. The porosity of bakery products shows the ratio of the pore volume to the total crumb of bakery products and is expressed as a percentage. Visually, the dependence of the porosity of prototypes of rye-wheat bread on the amount of addition of FESSK is given in Table 7.

Acidity characterizes the freshness and taste of bread. Bread and bakery products with low acidity are stored longer. It is worth noting that the acidity level of rye-wheat bread with the addition of FESSK is lower compared to the control (Table 7).

From the data in Table 7 it follows that the partial replacement of WFHG with FESSK in the amount of 7.5–12.5 % by weight of WFHG improves the physical-chemical characteristics of rye-wheat bread. Prototypes of rye-wheat bread, enriched with FESSK, had good elasticity and developed uniform porosity; pores of the same size with thin walls; the crumb did not crumble and did not bend.

In addition, the minimum content of phenolic compounds in FESSK ensures its light color, which indicates the possibility of introducing FESSK into bakery products made from rye-wheat flour without deteriorating the color of the crumb, as well as in other food products.

Table 8 shows experimental data of partial replacement of WFHG with FESSK in the amount of 7.5–12.5 % by weight of WFHG. The crumbliness, shape resistance and contamination with spores of mycelial fungi (penicills, aspergillus, mukorovi, etc.), which cause molding of bread and bakery products, were investigated.

The increase in specific volume (Table 7) and shape resistance (Table 8) of bread enriched with FESSK is associated with the ability of sunflower seed components (in particular, lipids, glucolipids, and lipoproteins) to complexation and structure formation. That is, the partial replacement of WFHG with FESSK contributes not only to increasing the nutritional value of the finished product but also to improving its quality indicators.

Table 7

Dependence of the physical-chemical indicators of prototypes of rye-wheat bread on the partial replacement of WFHG with FESSK, P≤5.0 %

Prototypes of rye-wheat bread	Physical and chemical indicators			
	Crumb moisture, %, not more than	The acidity of the crumb, degree, not more than	Porosity, %, not less	Specific volume, cm^3/g
Sample 1 – control	41.0±0.06	8.5±0.08	58.0±0.2	4.09±0.02
Sample 2 –7.5 % FESSK	41.5±0.06	8.0±0.08	65.0±0.2	5.21±0.02
Sample 3 –10.0 % FESSK	42.0±0.06	7.5±0.08	68.0±0.2	5.32±0.02
Sample 4 –12.5 % FESSK	42.2±0.06	7.3±0.08	69.0±0.2	5.35±0.02

Table 8

Dependence of the indicators of quality and safety of prototypes of rye-wheat bread on the partial replacement of WFHG with FESSK, $P \leq 5.0$ %

Prototypes of rye-wheat bread	Quality and safety indicators				
	Crumbliness of the crumb, %, immediately (after 12 days)	Shape resistance immediately (after 3 days)	The appearance of mold (at 7 °C) during storage		
			5 days	10 days	13 days
Sample 1 – control	2.5 (6.5)±0.01	0.46 (0.42)±0.001	+	+	+
Sample 2 –7.5 % FESSK	2.0 (3.5)±0.01	0.60 (0.58)±0.001	–	–	+
Sample 3 –10.0 % FESSK	1.5 (3.0)±0.01	0.65 (0.63)±0.001	–	–	–
Sample 4 –12.5 % FESSK	1.3 (2.8)±0.01	0.67 (0.61)±0.001	–	–	–

5. 4. Investigation of the influence of flour from the extruded kernel of sunflower seeds on the structural and mechanical properties of bread

Table 9 shows the results of determining the deformation of the crumb of prototypes of rye-wheat bread (ΔH_{gen}, mm) during storage for 12 days.

Table 9

Dependence of crumb deformation of prototypes of rye-wheat bread on partial replacement of WFHG with FESSK during storage, $P \leq 5.0$ %

Prototypes of rye-wheat bread	Crumb deformation, mm, storage during			
	0 hour	6 hours	72 hours	12 days
Sample 1 – control	8.0±0.2	7.0±0.2	4.5±0.2	1.5±0.1
Sample 2 – 7.5 % FESSK	11.5±0.3	10.8±0.3	9.7±0.3	6.5±0.2
Sample 3 – 10.0 % FESSK	11.5±0.3	11.0±0.3	10.2±0.3	7.0±0.2
Sample 4 – 12.5 % FESSK	11.5±0.3	11.2±0.3	10.4±0.3	7.3±0.2

Data analysis of Table 9 shows that the staleness of bread using FESSK is slower compared to control. That is, the partial replacement of WFHG with FESSK contributes to the extension of the shelf life of bread.

5. 5. Investigation of the effect of flour from the extruded kernel of sunflower seeds on the microbiological parameters of bread

Table 10 gives the microbiological indicators of prototypes of rye-wheat bread immediately after baking and after storage for 72 hours and 10 days (when determining the spores of bacteria Bac. Subtilis).

Data in Table 10 confirm the bacteriostatic effect of FESSK and the microbiological safety of prototypes of rye-wheat bread enriched with FESSK, and compliance with the standards established for this type of product [21].

Our studies allowed us to establish a rational amount of FESSK, which is 10.0 % of the amount of WFHG. To make a recipe for a new bakery product – rye-wheat bread with a partial replacement of WFHG with FESSK.

Thus, FESSK extends the period of preservation of freshness and improves the quality indicators of rye-wheat bread, significantly increasing its nutritional value.

6. Discussion of results of the study of the effect of extruded sunflower kernel flour on the quality of bread

When assessing the possibility of introducing FESSK into bakery products in order to increase their nutritional and biological value and consumer characteristics, we studied the quality indicators of FESSK, namely: organoleptic, physical-chemical characteristics, chemical composition, and safety indicators. The proposed innovative food ingredient FESSK has no deviations in taste and smell, is characterized by an unexpressed, with a slight grassy tinge of taste inherent in sunflower seeds without a specific oily taste.

As can be seen from the above data (Table 1), in FESSK, in comparison with wheat and rye flour, the content of protein, minerals, including calcium and magnesium, is much higher.

Table 10

Dependence of the microbiological indicators of prototypes of rye-wheat bread on the partial replacement of WFHG with FESSK

Name of the indicator	Standard	Prototypes of rye-wheat bread			
		Sample 1 – control	Samples 2 – 7.5 % FEKSS	Samples 3 – 10.5 % FEKSS	Samples 4 – 12.5 % FEKSS
QMAFAnM, CFU/g, immediately/after 72 hours	1.0×10^3	$1.0\times10^3/1.2\times10^3$	$0.25\times10^3/0.30\times10^3$	$0.20\times10^3/0.24\times10^3$	$0.18\times10^3/0.23\times10^3$
S.aureus, immediately/after 72 hours	not allowed per 1.0 g	absent per 1.0 g	absent per 1.0 g	absent per 1.0 g	absent per 1.0 g
BGKP, immediately/after 72 hours	not allowed per 0.001 g	absent per 0.001 g	absent per 0.001 g	absent per 0.001 g	absent per 0.001 g
Proteus, immediately/after 72 hours	not allowed per 0.1 g	absent per 1.0 g	absent per 1.0 g	absent per 1.0 g	absent per 1.0 g
Salmonella, L.monocy-togenes, immediately/after 72 hours	not allowed per 25.0 g	absent per 25.0 g	absent per 25.0 g	absent per 25.0 g	absent per 25.0 g
The number of spores of bacteria Buc. Subtilis, CFU/g, immediately/after 72 hours	0.4×10^3	$0.20\times10^3/0.26\times10^3$	$0.15\times10^3/0.19\times10^3$	$0.10\times10^3/0.14\times10^3$	$0.08\times10^3/0.12\times10^3$
Number of bacterial spores Bac. Subtilis, CFU/g, immediately/after 10 days	0.4×10^3	$0.20\times10^3/0.40\times10^3$	$0.15\times10^3/0.30\times10^3$	$0.08\times10^3/0.19\times10^3$	$0.06\times10^3/0.17\times10^3$

Table 2 shows that the carbohydrate component of FESSK is represented by fiber (11.87 %) and starch (12.53 %). The results satisfy the requirements of consumers regarding the content of fiber (dietary fiber). Dietary fiber has a number of beneficial effects: it contributes to normal intestinal motility and maintain good microflora in it; to a decrease in blood pressure and glucose and cholesterol levels; reabsorption of bile acids and digestion of starch. Starch is the main source of carbohydrates in human nutrition; it envelops the intestinal mucosa, absorbing (absorbing) substances harmful to the body; promotes good absorption by the body of certain trace elements, in particular zinc, iron. FESSK contains a significant amount of antioxidants: vitamin E (α-tocopherol) 15.40 mg/kg and chlorogenic acid (0.321 %). α-tocopherol also exhibits the properties of an immunomodulator, having a positive effect on cellular respiration processes. Chlorogenic acid affects the metabolism of oxalic acid in the human body, prevents gout, lowers blood sugar levels. High ash content (8.0 %) indicates a richer mineral composition of FESSK compared to whole sunflower seeds (2.68–4.87 %) [2].

We would especially like to draw attention to such a property of FESSK as gluten content (mass fraction of gluten, mg/kg less than 5), which makes it possible to attribute it to gluten-free products.

When studying the FESSK composition of protein, obtained by innovative resource-saving integrated technology of processing sunflower seeds, it was revealed that the proposed technology does not lead to a significant change in the native composition of amino acids of the protein part of the sunflower kernel. The content of essential amino acids in the protein complex of FESSK is ~38.73 %. In FESSK, the predominant amino acid is lysine, in addition, a higher content of the amino acids leucine and threonine, deficient for all varieties of wheat and rye flour, is noted (Table 3). It should be noted the balance of the amino acid composition of proteins FESSK (ACC of essential amino acids approaches 100 %).

When assessing the indicators that determine the physiological value of the oil (Table 4) contained in FESSK, it was found that the lipid part has fat-soluble physiologically valuable nutrients in its native form, as well as replaceable and essential fatty acids. The predominant fatty acids in FESSK are oleic, C18:1 (ω–9) (19.32 %) and linoleic, C18:2 (ω–6) (65.05 %). They make up (84.37±4.22) % of the total amount of fatty acid profile of FESSK, that is, they are the main components of flour fat. At the same time, the ratio C18:2(ω–6)/C18:1(ω–9)=3,4:1 is a balanced ratio of unsaturated fatty acids of the family ω–6, ω–9 especially for diet food (according to the British Food Foundation, this ratio is from 3:1 to 5:1) [16]. Linoleic, C18:2(ω–6) and linolenic, C18:3(ω–3) acids are essential fatty acids and play an important role in maintaining health, triglyceride and cholesterol levels, normalize blood pressure. The content of linolenic acid is 0.17 %. Similar results were obtained in the works of other authors [2, 16, 17]. Consumption of bakery products using FEKSS helps increase the level of linoleic, linolenic, and oleic acids in the human body. This makes extruded sunflower kernel flour an important dietary source of unsaturated fatty acids, in particular linoleic, linolenic, and oleic.

The organoleptic analysis of prototypes of rye-wheat bread with the addition of FESSK (Tables 5, 6) showed an improvement in the quality of bread with a partial replacement of WFHG with FESSK in the above dosages. Bread with the introduction of FESSK had a more pleasant taste, a pronounced aroma, well-developed porosity, and a large volume compared to control. During the experiment, a rational mass fraction of FEKSS was determined, which is 10.0 % of the amount of WFHG.

The physical-chemical indicators of rye-wheat bread are better in samples with FESSK (Table 7): the moisture content of the crumb increases by 0.5–1.2 %; the acidity of the crumb decreases by 0.5–1.2°; porosity increases by 7.0–11.0 %; the specific volume increases by 1.12–1.26 cm^3/g. This is due to surfactant properties; moisture- and fat-retaining capacity of proteins, lipids and lipo- and glycoproteins FESSK. Addition of FESSK in the amount of 7.5 %; 10.0 %; 12.5 % by weight of wheat flour helps reduce the crumbliness of rye-wheat bread by 1.0–1.3 % (Table 8) and increase in shape resistance – by 1.0–1.5 % (Table 8).

Bread that uses FESSK molds 5–8 days later compared to the control (Table 8). This is due to the bacteriostatic action of terpenoids of sunflower seeds (in particular, thymol, borneol, camphene), which inhibit growth and destroy pathogenic microbes, fungi, micelles. When storing prototypes of rye-wheat bread for 12 days (Table 9), the compression of the crumb is reduced for control – by 5.3 times, for sample 2 – by 1.77 times, for sample 3 – by 1.64 times, for sample 4 – by 1.57 times. That is, the staleness of bread using FESSK is slower.

Experimental data (Tables 8, 10) confirm the antimicrobial effect of FESSK and the microbiological safety of prototypes of rye-wheat bread enriched with a secondary product of sunflower seed processing – FESSK.

Thus, the results of our studies make it possible to substantiate the feasibility of using FESSK in the technology of rye-wheat bread with high nutritional value, in particular, for the partial replacement of wheat flour. At the same time, the optimal amount of FESSK is 10.0 % of the amount of wheat flour.

Taking into account previous studies on the chemical composition and functional and technological properties of FESSK [6], the results of this study can be used in the development of technologies for a wide range of flour products, in particular bakery, flour confectionery (cookies, gingerbread, crackers, muffins, cakes, etc.). However, to determine the functional and technological capabilities of flour mixtures "WFHG+FESSK" in the production of flour products, additional research is needed – mathematical, methodological, experimental. It is necessary to assess the impact of the innovative raw material ingredient (FESSK) on the functional and technological properties and nutritional characteristics of certain types of flour products.

7. Conclusions

1. A comparative analysis of the chemical composition of FESSK, wheat flour, and rye flour found that FESSK has a significantly higher content of protein, minerals, including calcium and magnesium.

FESSK contains a significant amount of antioxidants: vitamin E – 15.4 mg% and chlorogenic acid – 0.321 %, which affects the metabolism of oxalic acid in the human body. The presence of gluten in FESSK in the amount of ~5 mg/kg makes it possible to attribute it to gluten-free products.

The content of essential amino acids in the protein complex of FESSK is more than ~38.73 %. In FESSK, the predominant amino acid is lysine, in addition, a higher content

of the amino acids leucine and threonine, deficient for all varieties of wheat and rye flour, is noted.

In FESSK, fat-soluble physiologically valuable nutrients in native form, as well as replaceable and essential fatty acids, are preserved as much as possible. The predominant fatty acids in FESSK are oleic, C18:1 (ω–9) (19.32 %) and linoleic, C18:2 (ω–6) (65.05 %).

2. The data of organoleptic analysis confirm the improvement in the quality of rye-wheat bread using FESSK by an average of 5.0–7.0 % compared to the control. A rational amount of FESSK has been established – 10.0 % of the amount of WFHG.

3. The effect of the addition of FESSK on the physical-chemical indicators of prototypes of rye-wheat bread was revealed.

The use of FESSK contributes to an increase in the moisture content of the crumb by 0.5–1.2 %; reducing the acidity of the crumb by 0.5–1.2°; increase in porosity by 7.0–11.0 %; increase in specific volume by 1.12–1.26 cm^3/g; increase in shape resistance by 1.0–1.5 %; decrease in crumbliness by 1.0–1.3 %.

4. The influence of the addition of FESSK on the structural and mechanical parameters of prototypes of rye-wheat bread in the process of their storage was investigated.

When storing prototypes of bread for 12 days, the compression of the crumb is reduced for control – by 5.3 times, for sample 2 – by 1.77 times, for sample 3 – by 1.64 times, for sample 4 – by 1.57 times. That is, the staleness of bread with the addition of FESSK is slower.

5. The effect of the addition of FESSK on the microbiological indicators of prototypes of rye-wheat bread during their storage was revealed.

The level of total microbial contamination of both freshly baked rye-wheat bread and bread stored for 72 hours (and 10 days) at a temperature of 20 °C did not exceed the permissible levels and amounted to: after baking and cooling – the number of microorganisms (QMAFAnM) in 1 g of samples 2–4 compared to the control decreases by 4.0–4.8 times both immediately and after 72 hours; the number of spores of bacteria Bac. Subtilis grows after 10 days: in control by 2 times, and in samples 2–4 – by 1.2 times. All prototypes during storage for 72 hours (and 10 days) at a temperature of 20 °C met the requirements of microbiological standards established for this type of product in Ukraine [21].

That is, FESSK has an antimicrobial effect and helps increase the quality and shelf life of rye-wheat bread.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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