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Biological value of semi-smoked sausages with cedar oil cake

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Abstract:
Introduction. Development of novel meat products with better quality and biological value remains one of priority objectives of modern food industry. New meat products correspond with the principles of healthy diet due to their improved fatty acid profile and lower sodium content. The present research featured semi-smoked sausages with 15% of cedar oilcake and a low-sodium curing mix. The cedar nut oilcake is as a source of highly unsaturated fatty acids and high-grade protein. In addition to the physiological effect, the low-sodium curing mix increases the resistance of the combined fat phase to deterioration during storage.
Study objects and methods. Sausages of control and experimental formulations were made in laboratory conditions. The control formulation included raw second-grade beef, semi-fat pork (30% of fat), and traditional curing ingredients, i.e. sodium chloride and nitrite curing mix. In the experimental formulation, 15% of the semi-fat pork was replaced by cedar oil cake, and 30% of sodium chloride – by magnesium chloride. The samples were tested for fatty and amino acid composition, biological value of the lipid and protein phase, chemical composition, as well as physical, chemical, and sensory properties. Other research data included water activity, as well as acid, peroxide, and thiobarbituric value during storage at a temperature of 4 ± 2°C for 15 days.
Results and discussion. The study of fatty acid composition showed significant differences in the ratio of saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acids (PUFA, $P < 0.05$) in the samples. When 15% of pork was replaced by cedar oilcake, the amount of SFA decreased by 19.8%, while the content of MUFA and PUFA increased by 10.2% and 24.9%, respectively. These changes improved the indices of atherogenicity and thrombogenicity. The quality of the protein component also improved, as the utility coefficient of amino acids increased from 0.83 to 0.87, and the coefficient of comparable redundancy decreased from 7.2 g/100 g of protein to 5.35 g/100 g of protein. The sausages with cedar oil cake and low sodium chloride content received a high consumer evaluation. The hydrolysis of the lipid fraction was the same in both samples. The process of lipid oxidation was inhibited, which can partially be explained by a lower water activity.
Conclusion. The biological value, consumer quality, and storage stability of semi-smoked sausages could be improved by replacing fat-containing meat raw materials with cedar oil cake and reducing sodium chloride content. The new product demonstrated a better nutrition quality and can be recommended for mass production.

Keywords: Meat products, formulations, fatty acid composition, sodium, lipid oxidation, water activity

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INTRODUCTION

Contemporary domestic and foreign studies prove that diet can significantly improve health and quality of life. The specific character of raw materials and processing technology makes meat one of the most important food products [1, 2]. A healthy diet can prevent cardiovascular diseases, obesity, and hypertension. As a rule, a healthy diet implies reducing or eliminating the content of cholesterol, saturated fatty acids, and sodium, as well as enriching food products with biologically active components of plant origin.

Gorbatov All-Russia Meat Research Institute summarized and structured materials on the fatty acid composition of meat obtained from various farm animals and poultry. The study indicated a significant difference in their fat profile and a general tendency to an increased content of saturated fatty acids [3].

Semi-smoked sausages are meat products with a high content of fat component and sodium. However, they are extremely popular with consumers. As a result, domestic meat industry produces them in a large quantity and assortment [4]. Semi-smoked sausages are made from comminuted meat raw materials subjected to roasting, cooking, and smoking. The simple production technology, as well as their appearance and sensory indices, make semi-smoked sausages suitable for programmed formation of sensory properties, as well as nutritional and biological value.

The selection and justification of the fat component is extremely important when developing a new technology for semi-smoked sausages of improved quality and nutritional value. The fat component, its type and amount determine the total fat content, fatty acid composition, and flavor of the final product. A high content of saturated fatty acids in the fat component may decrease the biological value and digestibility of the fat, while a big amount of unsaturated acids increases the risk of oxidation during heat treatment and storage. The latter may lead to the formation of various organic compounds, e.g. aldehydes, ketones, hydroxy acids, etc. They possess a specific intense smell, which can affect the results of sensory evaluation and reduce product safety [5–8]. The specific smell of meat products also appears when lipids enter the Maillard reaction during heat treatment [9]. However, lipids are able to retain and enhance pleasant smells formed by other components of the formulation. Therefore, lipids can develop both programmed and unwanted tastes of the final product.

Domestic and foreign studies of the fat component in semi-smoked sausages feature various ways of reducing the mass fraction of fat and improving the fatty acid composition. As a rule, researchers propose two solutions. The first solution is to use low-calorie ingredients. The second solution is to replace animal fat with highly unsaturated vegetable oils or fat raw materials of plant origin. The second approach is more advantageous, since fat is involved in the formation of plastic consistency and aromatic properties of meat products.

Due to the differences in the physical properties of raw meat and vegetable oils, the latter cannot be directly used in sausage production. The problem is that direct replacement can misbalance the meat system and result in fat pockets in the final product [10–13]. This problem can be solved by changing the physicochemical properties of vegetable oils, e.g. by microencapsulation or emulsification. The changes should be aimed either at increasing the stability of the oils to oxidation, or at improving the water- and fat-holding properties of ground meat [14, 15].

Muguerza *et al.* replaced 20% of pork backfat with pre-emulsified olive oil in the formulation of Chorizo de Pamplona, a traditional Spanish dry fermented sausage. This reduced the total fat content by 53% and increased the proportion of MUFA. Similar results were obtained when pork fat was substituted by soybean oil. Olive and soybean oils reduced cholesterol content by 12.92% and 5.65%, respectively [16–18].

Korean scientists studied emulsified rice bran oil. Its fatty acid profile fully meets the requirements of the World Health Organization (WHO). The research in question used a combined fat phase that included 55% of bacon and 45% of rice bran oil. Such combination provided an optimal ratio of PUFA and SFA and did not reduce the stability of the meat emulsion [19, 20]. Linseed, rapeseed, perilla, canola, camellia, and grape seed oils also proved to have a positive effect on the ratio of SFA and USFA in various sausage products [11, 12, 21, 22].

There have been a lot of studies related to the use of plant materials to reduce the mass fraction of fat in meat products while enriching them with dietary fiber and USFA. By adding 3–6% of flax flour, it was possible to increase the amount of α-linolenic acid and improve the ratio of PUFA and SFA in minced beef cutlets [7]. When used in meat product formulations, raw materials with a high content of dietary fiber, e.g. bran of rice, oat, or wheat, decreased the mass fraction of fat and SFA [23–26]. The same effect was obtained by using soy, lemon, tiger nuts, and pea fibers [27–32].

Nuts and nut derivatives, e.g. oil, flour, oil meal, or oil cake, can serve as an alternative source of unsaturated fats. Oil cake is rich in fat and contains complete protein and antioxidant vitamins. There have been studies that featured fortifying meat products with hazelnuts and walnuts [24, 33]. Nuts of Siberian cedar pine and their products demonstrated an especially high biological value [35, 37].

The present research featured the biological value of semi-smoked sausages with cedar oilcake (CO) and a lower sodium content achieved by partial replacement of sodium chloride with magnesium chloride. The product with the combined fat phase was tested for stability during refrigerated storage.

STUDY OBJECTS AND METHODS

The study featured semi-smoked sausages (for formulations – see Table 1). The control and the experimental formulations differed in the basic and auxiliary raw materials. In the experimental formulation, 15% of semi-fat pork with a fat content of ≤ 30% was replaced by 15% of cedar oil meal. The chemical composition of cedar oil cake makes it a balanced complex of proteins, lipids, nutrients, vitamins, and dietary fibers. Oil cake proteins possess a high biological value and all essential acids, including high amounts of tryptophan, lysine, and sulfur-containing amino acids [36]. Oil cake looks like a cream-colored powder, free of foreign matters; its structure flakes and is easy to deform. Oil cake is oily to the touch and has a sweet taste and a light smell of cedar nuts. The amount of cedar oil cake in the formulation and the choice of the final product were based on the available data on the use of nuts in various meat products.

Nitrite and edible salt (sodium chloride) were used as curing ingredients for the control sample. In the

Table 1 Formulations of semi-smoked sausage

Ingredients	Samples	
	without oil cake (control)	with oil cake (experimental)
Critical ingredients, kg		
Trimmed second-grade beef	50.0	50.0
Semi-fat trimmed pork	50.0	35.0
Cedar oil cake	–	15.0
Auxiliary ingredients, kg/100 kg		
Nitrite salt	1.250	1.062
Edible salt (sodium chloride)	1.450	1.146
Magnesium chloride	–	0.492
Granulated sugar	0.100	0.100
Black pepper	0.120	0.120
Allspice	0.060	0.060
Red pepper	0.060	0.060
Nutmeg	0.050	0.050
Fresh garlic	0.100	0.100

experimental formulation, the curing mix included nitrite salt and edible salt, 30% of which was replaced with magnesium chloride. This replacement was aimed at reducing the sodium in the product. According to WHO, its consumption exceeds the physiological need, thus leading to nutritionally dependent diseases [38]. From the technological point of view, the replacement of edible salt with sodium chloride makes the fat component resistant to oxidation, especially if the proportion of unsaturated acids is high.

In both the experimental and the control formulations, nitrite salt was added in an amount that provided the standard content of sodium nitrite, i.e. 0.075% from the weight of the raw meat.

The sausages were produced from chilled second-grade trimmed beef and semi-fat pork. The raw meat was ground using a meat grinder plate with the bore diameter of 2–3 mm for beef and 8–12 mm for pork. The ground meat was mixed with 2.7% of curing ingredients (from the weight of the raw material). The resulting materials were stored for ripening at 0–4°C for 24 h. The ripened raw meat was used to prepare sausages. Cedar oil cake was subjected to no prior preparation. It was stored at –12°C and briefly heated at room temperature before being introduced into the formulation.

The formulations of the experimental and the control samples were combined in the mixer in the following order: beef, pork, cedar oil cake (in the experimental sample), sugar, spices, and garlic. The components were mixed for 6–8 min until smooth. The temperature of the ground meat after the mixing did not exceed 12°C.

The ground meet was molded into an artificial protein sausage casing. The sausages were kept in a hanging room for 4 h at 2–4°C. After that, the sausages underwent heat treatment: first, they were dried at 60°C for 30–40 min, then cooked at 70 ± 2°C, and, finally, smoked at 72–74°C until the surface obtained the required reddish-brown color. Subsequently, the sausages were cooled to ≤ 6°C and stored at 2–6°C for 15 days.

A comparative analysis of the parameters of the biological value and quality was performed based on the sensory properties and the chemical, fatty acid, and amino acid compositions. During storage, a set of experiments was performed to study the oxidative damage to the lipid fraction by determining acid, peroxide, and thiobarbituric values, as well as water activity.

Research methods. The sensory evaluation was done by tasting. It involved a nine-point scale, as required by State Standard 9959-2015[I].

As for the chemical composition of the sausages, the mass fraction of protein was determined by the Kjeldahl method (State Standard 25011-2017[II]), the mass fraction of fat – by the Soxhlet method (State Standard 23042-2015[III]), the mass fraction of ash – by the mineralization of the batch weight (State Standard 31727-2012 (ISO 936:1998)[IV]), the mass moisture content – by roasting the sample to constant batch weight (State Standard 33319-2015[V]).

The fatty acid composition was determined by gas chromatography using an Agilent 7890A chromatograph. The mass fraction of methyl ethers of fatty acids was defined in relation to their total amount, as required by the State Standard 51483-99[VI]. High purity nitrogen was used as the carrier gas, while grade A hydrogen was used as auxiliary.

The obtained results made it possible to calculate the ratios of SFA, MUFA, and PUFA, as well as the indices of atherogenicity and thrombogenicity using the Wilbrich and Southhein formula [39, 40].

The amino acid composition was determined by capillary electrophoresis using a Kapel'-105M system. The balance of the amino acid composition was established by the method of test values: the total of the essential amino acids (EAA), the utility coefficient of the essential amino acids (U), and the coefficient of comparable redundancy.

The peroxide value (PV) was determined by direct titration of peroxides formed during the oxidation of the fat fraction with a sodium thiosulfate solution.

[I] State Standard 9959-2015. Meat and meat products. General conditions for sensory assessment. Moscow: Standartinform; 2010. 23 p.
[II] State Standard 25011-2017. Meat and meat products. Methods for determining protein. Moscow: Standartinform; 2018. 14 p.
[III] State Standard 23042-2015. Meat and meat products. Methods for determining fat. Moscow: Standartinform; 2016. 9 p.
[IV] State Standard 31727-2012. (ISO 936:1998). Meat and meat products. Method for determining the mass fraction of total ash. Moscow: Standartinform; 2013. 12 p.
[V] State Standard 33319-2015. Meat and meat products. Method for determining the mass fraction of moisture. Moscow: Standartinform; 2016. 6 p.
[VI] State Standard 51483-99. Vegetable oils and animal fats. Using gas chromatography to determine the mass fraction of methyl ethers of individual fatty acids to their total. Moscow: Standartinform; 2008. 11 p.

Table 2 Fatty acid composition of semi-smoked sausages

Acid	Notation	Mass fraction, % of total fatty acids	
		without cedar oil cake (control)	with cedar oil cake (experi-mental)
Saturated fatty acids (SFA)			
Capric	$C_{10:0}$	0.05 ± 0.001	–
Lauric	$C_{12:0}$	0.62 ± 0.040	0.18 ± 0.010
Myristine	$C_{14:0}$	1.73 ± 0.080	1.48 ± 0.020
Palmitic	$C_{16:0}$	25.5 ± 0.980	20.1 ± 1.290
Margarine	$C_{17:0}$	0.61 ± 0.040	0.53 ± 0.060
Stearin	$C_{18:0}$	11.68 ± 1.09	10.1 ± 0.830
Arachic	$C_{20:0}$	0.27 ± 0.030	0.17 ± 0.070
Geneukosan	$C_{21:0}$	0.16 ±	–
Monounsaturated fatty acids (MUFA)			
Palmitoleic	$C_{16:1,\omega\text{-}7}$	3.77 ± 0.040	3.11 ± 0.060
Heptadecene	$C_{17:1}$	0.33 ± 0.020	0.30 ± 0.010
Elaidic	$C_{18:1,\omega\text{-}9,т}$	0.10 ± 0.001	0.18 ± 0.003
Oleic	$C_{18:1,\omega\text{-}9,цис}$	39.64 ± 0.73	44.33 ± 0.61
Gadolein	$C_{20:1}$	0.17 ± 0.003	0.61 ± 0.050
Polyunsaturated fatty acids (PUFA)			
Linoleic	$C_{18:2,\omega\text{-}6}$	7.96 ± 0.250	9.61 ± 0.540
Eicosapentaenoic	$C_{20:2}$	–	0.26 ± 0.005
α- Linolenic	$C_{18:2,\omega\text{-}3}$	0.20 ± 0.030	–
γ- Linolenic	$C_{18:3,\omega\text{-}6}$	–	0.85 ± 0.040
Arachidonic	$C_{20:5,\omega\text{-}6}$	1.11 ± 0.030	0.86 ± 0.040
USFA, %	–	40.62 ± 0.56	32.56 ± 1.11
MUFA, %	–	44.01 ± 0.32	48.53 ± 0.64
PUFA, %	–	9.27 ± 0.330	11.58 ± 0.59
USFA/ MUFA	–	0.92	0.67
USFA/PUFA	–	4.38	2.82
PUFA/USFA	–	0.23	0.36
Atherogenicity index	–	0.62	0.44
Thrombogenicity index		1.46	1.05

A sample of semi-smoked sausage was crashed to extract fat with chloroform in the presence of anhydrous sodium thiosulfate. The resulting extract was dissolved in glacial acetic acid and titrated with a 0.01N sodium thiosulfate solution in the presence of a saturated solution of potassium iodide and starch. The PV value was expressed in mmol ½ O/kg [41].

The acid value was determined by direct titration in a neutral alcohol-ether mix of free fatty acids with a 0.1N sodium hydroxide solution in the presence of phenolphthalein. The extraction of fat from the crashed samples was performed similarly to the method that was used to determine PV, i.e. extraction from a crashed sample with chloroform [41].

The thiobarbituric value (TBV) was determined by a modified distillation method: a colored complex formed as a result of the interaction of malondialdehyde with 2-thiobarbituric acid. The crushed sample was heated in distilled water where hydrochloric acid was added. The resulting distillate was mixed with a solution of thiobarbituric acid and heated in a water bath to develop a color reaction. The color intensity of the resulting solutions was measured using a spectrophotometer at a wavelength of 538 nm (green filter) [41].

The mass fraction of chlorides was established by argentometric titration. The method is based on the determination of chlorine ions by titration of an aqueous extract from the sample with a solution of silver nitrate in the presence of chromic acid potassium.

The content of sodium ions in the finished product was determined with the help of an ELIS-112Na ion-selective electrode (Russia). The range of determination of Na^+ ion activity equaled 1.0–3.5 pNa. The test involved a 150-MI pH meter.

Water activity (A_w) was determined by the cryoscopic method using an AVK-4 water activity analyzer (Russia). To determine the water activity, the test sample was cooled, while its temperature was measured using the precision meter. Then, a special program was used to analyze the process thermogram and determine the cryoscopic temperature, which was converted into values of the water activity indicator. The results were processed using a personal computer [42].

The values were obtained after triplicate tests of homogeneous sausage material. The arithmetic mean and standard deviation were used to define the standard error of the mean and the confidence limits. The calculation took into account the Student's coefficient t (n, p) at the confidence level of 95% ($P = 0.05$) and the number of measurements.

RESULTS AND DISCUSSION

The biological value was assessed by comparing the fatty acid and the amino acid compositions of the semi-smoked sausages with and without cedar oil cake. Table 2 shows the fatty acid composition.

The fatty acid composition in the control formulation had the following ratio of fatty acids: USFA:MUFA:PUFA – 40.62%:44.01%:9.27%

When 15% of semi-fat pork was substituted by cedar oil cake, it led to a significant decrease in the total content of USFA, which was 19.8% relative to the control formulation. MUFA and PUFA increased by 10.2% and 24.9%, respectively. SFA decreased in the following manner: palmitic acid – by 21%, lauric acid – by 70%, and arachinic acid – by 37%, if compared with the control formulation. The experimental sample revealed neither capric nor genicosanoic USFA.

The experiment revealed a significant increase in MUFA, which has a beneficial effect on blood lipoproteins and prevents coronary heart disease. Therefore, an increase in MUFA means a higher biological value of the semi-smoked sausages with cedar oil cake [3]. The total increase in MUFA occurred after the cis-oleic acid increased from 39.64% in the control formulation to 44.33% in the experimental formulation.

Table 3 Content of essential amino acids in semi-smoked sausages

Essential amino acids	Ideal protein, FAO/WHO scale	Samples			
		without cedar oil cake (control)		with cedar oil cake (experimental)	
		Protein, g/100 g	Amino-acid score, %	Protein, g/100 g	Amino-acid score, %
Valine	5.0	5.78	115.60	5.37	107.40
Isoleucine	4.0	4.48	112.00	4.38	109.50
Leucine	7.0	6.88	98.20	6.64	94.80
Lysine	5.5	8.05	146.30	7.68	139.60
Methionine + Cysteine	3.5	3.89	111.40	3.44	98.30
Threonine	4.0	4.48	112.00	4.19	104.70
Tryptophan	1.0	1.18	118.00	1.41	141.00
Phenylalanine+ Tyrosine	6.0	7.56	126.00	5.80	96.60

The tests also demonstrated a change in the ratio and composition of PUFA. When 15% of semi-fat pork was replaced with cedar oil cake, the content of linoleic acid (omega-6) increased by 20.7%. In addition, long-chain eicosapentaenoic (omega-3) and γ-linolenic (omega-6) acids were registered in the product, the latter being the precursor of dihomo-γ-linolenic, or eicosatrienoic, acid. The fatty acid composition of sausages with cedar oil cake demonstrated a bigger total amount of long chain UFA. These fatty acids have a lower melting point compared to SFA of a similar chain length.

The comparison of the indices of atherogenicity and thrombogenicity was in favor of the experimental formulation, which makes the final product anti-atherosclerotic.

The sausage formulation did not fully correspond with the modern concept of balanced nutrition in terms of SFA:MFA:PUFA ratio (30:60:10) [43]. However, a greater amount of essential PUFA and a decrease in SFA is one of the main arguments in favor of using cedar oil cake as the main raw material.

Similar results were obtained by replacing beef fat with walnuts, walnut pasta, and hazelnuts [44, 45]. These studies also showed that a decrease in SFA improved the fatty acid composition of meat products.

Table 3 demonstrates the amino acid composition of the sausages under study.

Therefore, cedar oil cake makes it possible to obtain a product of high biological value. The scores for essential amino acids were high: lysine – 139.6%, tryptophan – 141.0%, and sulfur-containing amino acids – 98.3%. The total content of essential amino acids in the sausage with cedar oil cake was 38.91 g/100 g protein. This amount was lower than in the product with only meat raw materials, which was 42.3 g/100 g protein. However, it was higher than in ideal protein (36 g/100 g protein). Leucine appeared the first limiting amino acid in the experimental sample: its score was 94.8%.

Table 4 Biological value of protein in semi-smoked sausages

Indicatiors	Samples	
	without cedar oil cake (control)	with cedar oil cake (experimental)
Total essential amino acid, g/100 g protein	42.30	38.91
Utility coefficient, unit fraction	0.83	0.87
Comparable redundancy coefficient, g/100 g protein	7.20	5.35

In addition, the biological value of the new semi-smoked sausages proved that cedar oil cake improved the amino acid ratio (Table 4). As a result, the utility coefficient of amino acid composition increased, and the proportion of amino acids not used for anabolic purposes decreased. In terms of the content of potentially utilizable essential amino acids, the amount of protein in the product was equivalent to their amount in 100 g of reference protein.

The obtained data showed that cedar oil cake can be recommended for semi-smoked sausage production. The analysis of fatty acid and amino acid composition proved that such replacement increased the biological value of the final product. A comprehensive assessment of the quality of the semi-smoked sausages was based on sensory and physicochemical parameters (Table 5 and 6).

The nine-point panel evaluation of the semi-smoked sausages involved such parameters as appearance, inner color, smell, taste, and texture. Each of nine panelists evaluated randomly encoded samples of sausages in triplicate. The score of each sensory property was calculated based on the opinion (evaluation) of each panelist (Table 5).

The obtained data proved that cedar oil cake and a lower amount of sodium chloride had a positive effect on the smell and taste of the semi-smoked sausage. The panelists noted that the usual meaty smell was accompanied with a faint smell of cedar nuts. In general, they evaluated the taste as milder and pointed out a specific pleasant aftertaste, which made them give the sample a higher score. The new curing mix decreased the salty flavor. The fine structure of the oil cake resulted in its better distribution in the meat,

Table 5 Sensory evaluation of semi-smoked sausages

Samples	Appearance	Inner color	Smell	Taste	Texture	Total
Without cedar oil cake (control)	7.4 ± 0.3	7.4 ± 0.1	6.5 ± 0.3	6.3 ± 0.5	7.2 ± 0.2	6.9 ± 0.7
With cedar oil cake (experiment)	7.9 ± 0.6	8.0 ± 0.5	8.8 ± 0.2	8.5 ± 0.6	7.8 ± 0.1	8.2 ± 0.2

Table 6 Physicochemical characteristics the semi-smoked sausages

Indicator	Samples	
	without cedar oil cake (control)	with cedar oil cake (experimental)
Mass fraction of protein, %	16.2 ± 0.37	17.4 ± 0.34
Mass fraction of fat, %	23.4 ± 0.29	25.2 ± 0.27
Mass fraction of moisture, %	56.8 ± 0.24	52.2 ± 0.21
Mass fraction of chlorides, %	2.8 ± 0.05	2.8 ± 0.08
Mass fraction of sodium, %	1.13 ± 0.07	0.76 ± 0.04
Energy value, kcal	248	284

thus preserving the texture of the sausage even when the percentage of cedar oil cake was relatively high. The panelists described the texture as dense. A slight decrease in the inner color intensity did not affect the score for this indicator. The total score for sausages with cedar oil cake was 8.2 points, which corresponded with "excellent" on the nine-point scale. The sausages made without cedar oil cake received 6.9 points and were evaluated as "good". According to the results of the sensory evaluation, the semi-smoked sausages with cedar oil cake and low salt content received high consumer characteristics.

The obtained results were consistent with other studies. For instance, almond and walnut had a positive effect on the sensory properties of various meat products, e.g. chopped semi-finished products and emulsified sausages. However, if the percentage of the new component exceeded 25%, the final product acquired a specific taste, while the structure became heterogeneous, especially in case of coarse-ground nuts [46–49].

Table 6 shows the physicochemical parameters of the sausages. The nutritional values of both samples conformed to the requirements of regulatory documents for this group of products. The analysis revealed no significant differences in the chemical composition of the samples. However, the sausage with cedar oil cake had a higher mass fraction of protein and fat than the control sample.

The partial replacement of sodium chloride with magnesium chloride led to a decrease in the sodium. The daily reference intake for sodium is 2 g per day for an adult. In the control sample of the semi-smoked sausage, the sodium content was 1.13%, which corresponds to 56.5% of the daily reference intake. In the experimental product, it was 0.76%, or 38% of the daily requirement. The obtained experimental data confirmed the high nutritional value of the developed formulation.

Ground meat used in semi-smoked sausages is a complex system with a high content of pro-oxidants, which contributes to the formation of free radicals. Free radicals, in their turn, are most active against MUFA and PUFA, the amount of which increased in the formulation with cedar oil cake. However, cedar oil cake contains natural antioxidants that can inactivate free radicals. Tocopherol is one of the most significant antioxidants. According to our previous study, its content in cedar meal is 11.43 mg/100 g [36]. The smaller amount of sodium chloride is one more protective mechanism in the developed formulation. The effect of competing factors on the lipid oxidation process of the combined fat phase requires further research when it goes about semi-smoked sausages.

The amount of primary and secondary oxidation products was determined on days 1 and 15 of refrigerated storage at 2–6°C and 70–80% of relative humidity. The hydrolysis of fat facilitates the development of oxidation processes. As a result, assessment of acid value had to be performed simultaneously (Table 7).

The hydrolysis process in both samples revealed a similar development pattern. After the expiry date, the acid value increased by 2.3 times in the control sample and by 2.2 times in the experimental sample. In both cases, the acid value was significantly lower than the standard. In addition, the intensity of the hydrolysis process decreased in the experimental sample.

The oxidative changes in the combined lipid fraction of the experimental formulation vs. the control formulation were determined according to accumulation of primary oxidation products. By the end of storage, the peroxide value increased by 28.3% in the experimental

Table 7 Indicators of oxidative damage in semi-smoked sausages

Samples	Storage time, days	Acid value, mg KOH	Peroxide value, mmol½ O/kg	Thiobarbital value, mgMA/kg
Without cedar oil cake (control)	0	0.75 ± 0.063	2.36 ± 0.130	0.250 ± 0.009
	15	$1.73^{a} \pm 0.046$	$3.4^{a} \pm 0.350$	$0.298^{a} \pm 0.007$
With cedar oil cake (experimental)	0	0.68 ± 0.036	2.29 ± 0.110	0.246 ± 0.006
	15	$1.54^{ab} \pm 0.024$	$2.94^{ab} \pm 0.120$	$0.282^{ab} \pm 0.008$

The a–b values in the columns differed significantly ($P < 0.05$)

Table 8 Water activity in semi-smoked sausages

Samples	Storage time, days	Water activity (A_w), units.
Without cedar oil cake (control)	0 15	0.9652 ± 0.0031 0.9694 ± 0.0030
With cedar oil cake (experimental)	0 15	0.9461 ± 0.0033 0.9437 ± 0.0032

sample and by 44.0% in the control sample. Therefore, cedar oilcake and low sodium chloride content slowed it down without reversing it. The results must have been caused by the effect of cedar tocopherols, which are most active against radicals attacking double bonds of USFA. Lipid peroxidation is triggered by the removal of a hydrogen atom from a free PUFA or an acid within phospholipids. When heme iron becomes non-heme, reactions start branching, and the process is reinitiated. Stabilization of heme-containing meat proteins is caused by a decrease in sodium chloride, which inhibits the oxidation process [50].

However, in spite of the fact that the samples differed significantly in peroxide values, the obtained results do not guarantee that the lipid oxidation rate reduced in the formulations with cedar oil cake and low sodium content. Peroxides and hydroperoxides are unstable intermediate reaction products, which quickly turn into the products of secondary oxidation. Hence, peroxide value is a variable value and does not fully reflect the degree of oxidative changes [51].

Thiobarbital value is a more objective indicator of oxidative spoilage. It describes the amount of malonic aldehyde that is formed during storage. The process of accumulation of secondary oxidation products was less intensive in the sausages with cedar oil cake and lower salt content over the entire storage period. The thiobarbital value increased by 19.2% in the control sample without cedar oil cake and by 14.6% in the experimental sample with cedar oil cake. This increase could be associated with more intense hydrolytic processes and lipid peroxidation during storage, as well as with aerobic storage conditions [52].

The obtained results indicated the stabilization of the lipid fraction of the semi-smoked sausages with cedar oil cake and low sodium content, since no extraneous rancid taste and aroma were registered.

Water activity is one of the product stability parameters. Water activity values for the semi-smoked sausages under study during storage are presented in Table 8.

The decrease in the water activity in the experimental sample compared with control could be explained by lower moisture content. In addition, magnesium chloride has a more pronounced effect on the moisture retention in the product, as described in [53, 54].

CONCLUSION

The research showed that 15% of cedar oil cake introduced into the traditional formulation of semi-smoked sausages to substitute 15% of pork increased the biological value of the product. Its fatty acid composition improved due to a decrease in saturated fatty acids, including palmitic acid. The mono- and polyunsaturated fatty acids increased, including long-chain eicosapentaenoic and γ-linolenic acids. The parameters of hydrolytic and oxidative changes in the combined fat phase demonstrated a greater stability during storage. This improvement could be explained by two facts. First, the composition of cedar oil cake had natural antioxidants. Second, sodium chloride was partially replaced with magnesium chloride (30%) in the curing mix. This replacement also decreased the amount of sodium in the composition of the final product.

According to the sensory evaluation, cedar oil cake and lower content of sodium chloride had a positive effect on the taste, smell, and texture of the sausage. The new sausages contribute to a healthy diet while their prospective production can be of practical use to meat industry.

CONTRIBUTION

G.V. Gurinovich supervised the project. All the authors took part in research, data processing, writing, and updating the article: I.S. Patrakova, S.A. Seregin, A.G. Gargaeva, O.Ya. Alekseevnina, O.M. Myshalova, M.V. Patshina.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest related to the publication of this article.

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