Проведено дослідження жирнокислотного складу м'ясомісткої напівкопченої ковбаси з м'ясом качки Пекінської та визначено біологічну ефективність жиру продукту. Вивчено ефективність застосування екстракту розмарину на перебіг окислювальних процесів у напівкопченій ковбасі з високим вмістом ненасичених жирних кислот.

Експериментально встановлено високий вміст мононенасиченої ЖК С18:1 ω-9 (олеїнової) – 40,37 г/100 г жиру. Вміст ω-3 ПНЖК у м'ясо-місткій напівкопченій ковбасі із м'яса качки Пекінської становить 1,22 г/100 г жиру, що задовольняє рекомендовану добову потребу в ессенціальних ЖК на 27 %. Співвідношення між родинами ЖК ω-3/ω-6 в розроблених продуктах становить від 1:11 при рекомендованих фізіологічних нормах ідеального складу жирів в м'ясному продукті 1:10.

Дослідження підтверджують високу антиоксидантну активність екстракту розмарину та ефективне гальмування процесу окислення ліпідів в м'ясомістких ковбасних виробах. Внесення екстракту розмарину в кількості 0,02–0,06 % уповільнює гідролітичне окислення ліпідів фаршу на 29,13–35,00 %, гальмує перекісне окислення ліпідів в м'ясо-місткій напівкопченій ковбасі, знижуючи кількість перекисів практично в п'ять разів.

Підтверджено, що стабілізація перекісного окислення ліпідів в м'ясо-місткій напівкопченій ковбасі із м'яса качки Пекінської з високою концентрацією ненасичених жирних кислот як наслідок має зменшення концентрації вторинних продуктів окислення. Кількість альдегідів і кетонів була найменшою в кінці терміну зберігання готових виробів і становила 0,38–0,80 мг МА/кг продукту, що в 2,54–3,94 рази нижче, ніж в контрольному зразку. Найбільший стабілізаційний ефект отриманий при внесенні екстракту розмарину у кількості 0,06 %, що дозволяє знизити показники оксилювального псування жиру більше ніж в два рази

Ключові слова: м'ясомістка напівкопчені ковбаса, м'ясо качки, ненасичені жирні кислоти, екстракт розмарину

UDC 637.5.05/07
DOI: 10.15587/1729-4061.2020.205201

THE EFFICIENCY OF STABILIZING THE OXIDATIVE SPOILAGE OF MEAT-CONTAINING PRODUCTS WITH A BALANCED FAT-ACID COMPOSITION

N. Bozhko
PhD, Associate Professor
Department of Biophysics, Biochemistry, Pharmacology and Biomolecular Engineering
SumDU Medical Institute
Sanatorna str., 31, Sumy, Ukraine, 40018
Sumy State University
Rymskoho-Korsakova str., 2, Sumy, Ukraine, 40007
E-mail: natalybozhko@ukr.net

V. Pasichnyi
Doctor of Technical Sciences, Professor, Head of Department*
E-mail: Pasww1@ukr.net

A. Marynin
PhD, Associate Professor, Head of Laboratory
Problem Scientific and Research Laboratory
National University of Food Technologies
Volodumurska str., 68, Kyiv, Ukraine, 01601
E-mail: andrii_marynin@ukr.net

V. Tischenko
PhD, Associate Professor
Department of Technology of Milk and Meat**
E-mail: tischenko_1958@ukr.net

I. Strashynskyi
PhD, Associate Professor*
E-mail: sim2407@i.ua

O. Kyselov
PhD, Associate Professor
Department of Biochemistry and Biotechnology**
E-mail: oleksandr.kyselov@snau.edu.ua

*Department of Technology of Meat and Meat Products
National University of Food Technologies
Volodumurska str., 68, Kyiv, Ukraine, 01601
**Sumy National Agrarian University
Herasyma Kondratieva str., 160, Sumy, Ukraine, 40021

Received date 10.05.2020
Accepted date 13.06.2020
Published date 30.06.2020

1. Introduction

Meat and meat products occupy an important place in healthy nutrition, providing the human body with protein with a balanced amino acid composition, essential mineral substances, specifically iron in easily accessible form, vitamins [1]. Meat is also a source of significant amount of fat in human diet, and it is this component that attracts the

most attention in recent years due to the health of people who consume meat. Meat contains a relatively large amount of saturated fatty acids (SFA), while the meat of industrial animals (lamb and beef) differs by a low quantity of polyunsaturated fatty acids. If such a balance is constant in the human diet, there is a risk of a number of diseases, including cardiovascular disease [2, 3].

However, the fatty acid composition of meat is a variable component that can vary during the cultivation of the animal and at the industrial meat processing. It is possible to improve the balance of fatty acids through modeling the formulations of meat and meat-containing products and introducing new promising ingredients to their composition.

Therefore, it is a relevant task for the modern meat industry to devise meat-containing products with a balanced fat-acid composition and to apply technological methods to prevent the oxidation spoilage of the specified products during storage.

2. Literature review and problem statement

The quality of food products is one of the main criteria for consumers who adhere to a healthy lifestyle and care about their health. According to recent studies, one of the factors to which the attention is primarily drawn is the content of fat and the fat-acid composition of a product. It is known that fatty acids in meat have predominantly medium and large length chains, that is, contain from 12 to 22 carbon atoms in the molecule with the main structure of CH3-(CH2) n-COOH [4]. About 40 % of fatty acids are saturated (SFA), meaning each carbon has two attached hydrogen atoms. Approximately 40 % have one double bond (monounsaturated fatty acid, MUFA), where each adjacent carbon atom is attached to one hydrogen atom. And a lesser part, approximately 2–25 %, have more than one double bond (polyunsaturated fatty acids, PUFA). The principal fatty acid in all meat products is oleic acid (18:1 cis-9), which has a concentration of over 30 % of the total fatty acids.

Among PUFA, linoleic acid has the largest quantity in meat (18:2n-6), which is an essential fatty acid, that is, it is consumed completely with a diet [5]. Among the ω-3 family, the most common fatty acid is the -linolenic acid (18:3n-3), which can be transformed into the long chains of n-3 fatty acids, such as eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3). These fatty acids of ω-6 and ω-3 long chains play an important physiological role in the body due to their transformation into eicosanoids, which, in addition to other activities, control thrombosis and inflammation of tissues [6, 7].

Saturated fatty acids, which have in their chain less than 18 carbon atoms, raise the level of low-density lipoprotein cholesterol, which increases the risk of atherosclerosis and leads to the development of cardiovascular diseases in humans [8, 9].

On the other hand, mono- and polyunsaturated fatty acids reduce the cholesterol levels of low-density lipoproteins in the blood [10]. Based on the research findings, the dietary recommendations were developed regarding the fat-acid composition of human nutrition [11]. The WHO states that the total fat content should not exceed 15–30 % of the total energy in the nutrition; SFA, about 10 %; ω-6 PUFA, about 5–8 %, and ω-3 PUFA, 1–2 % [11].

It is possible to resolve the issue of balanced fat intake by using a more balanced fat-acid composition of meat. According to data from [12], among farm animals, the largest content of saturated fatty acids is typical of lamb and beef, 60.0–62.0 and 58.13 %, respectively, slightly less – in pork, 43.54 %, and turkey – 40.40 %. The lipid fraction of pork contains the highest level of MUFA (36.59 %), then, in descending order, the lipid fractions of beef, turkey, lamb. Comparing the ratio of fatty acids in different types of meat from industrial animals and poultry shows that the most balanced is poultry meat. Consequently, one of the ways to solve the issue related to the fatty acid composition in the diet is the creation of meat and meat-containing products using a formulation that includes poultry meat.

The authors of [12] found that the largest amount of PUFA is in the lipid fraction of horse meat (22.17 %), almost three times less – in the lipid fraction of beef and lamb (7.25 and 6.75 %, respectively), and about twice less in the lipid fraction of pork (11.49 %). Unlike plant-based fats, animal fats are characterized by the high content of arachidonic acid (0.36–1.69 %).

The balance of the fatty acid composition is estimated by the ratio PUFA/SFA whose rational range should vary from 0.2 to 0.4, and the ratio of unsaturated fatty acids to saturated ones – 2.3:1. The fatty acid composition of lipids of the pork muscular tissue, as well as horse and turkey meat, is more balanced than that of lamb and beef. Thus, according to [12], this ratio in the pork and turkey meat is more balanced and is 0.25 and 0.30, respectively. Thus, there is an issue related to the unbalanced ratio of fatty acids in the composition of traditional meat products, which can be resolved by developing new products whose formulations may include raw materials with the best fatty acid composition, in particular, Peking duck meat [13].

According to data from [14], the content of the saturated fatty acids in Peking duck meat is 26.85±3.38 % of the total content of fatty acids, monounsaturated – 30.22±2.65, and polyunsaturated – 42.47±5.97 %. That is, the concentration of saturated fatty acids in this kind of meat is almost half as opposed to pork, beef, and turkey. Accordingly, the level of PUFA is higher and exceeds this indicator in pork by more than three times. Estimating the PUFA/SFA ratio in duck meat showed that it is 1.58, and that of the unsaturated to saturated fatty acids is 2.7:1. This confirms that the meat of duck is a valuable resource of fat, which has the optimally balanced fat-acid composition and which can be used in the development of meat and meat-containing products in order to improve the biological efficiency of fat.

It is possible to modify the fatty acid profiles in meat products with high biological value in two ways. The first direction is a pre-slaughter way through the feeding ration. The second way is the addition to the meat systems of raw materials with a high content of PUFA (meat of duck, turkey), or additional sources of essential fatty acid, such as a mixture of vegetable oils and fats (olive, avocado) [15, 16].

On the other hand, the high content of polyunsaturated fatty acids in meat products can lead to the development of lipid oxidation, which, in turn, adversely affects the taste and color of the finished product [17, 18]. Once the ratios of the ω-6 and ω-3 to fatty acids become more favorable, sensitivity to oxidation of lipids is increased and the oxidative stability decreases. Therefore, the use of natural oxidation inhibitors is a prerequisite for commercial success for meat products with improved biological value [19, 20].

Natural antioxidants can be applied through technological techniques of animal feeding or direct implementation of

technological strategy in the process of meat processing [21]. However, when introducing antioxidants in the diet of animals, there is a series of difficulties related to that the concentration of antioxidant compounds in the plant feed changes significantly and, consequently, their dosage in the diets varies depending on the type, zone, and plant cultivation technology, etc. [22, 23].

The technological strategy of meat processing implies the use of antioxidants directly in meat and, especially, meat-containing foods. In addition, this can be achieved through (or by) coating the packaging materials with plant extracts to improve the oxidative stability of products [24, 25], the use of a modified gas environment, and the "elements of active packaging" [26]. For a long time, the meat processing industry has used the synthetic antioxidants butyloxyanisole and butylhydroxytoluene, which showed high efficiency [27]. However, recent studies prove the fact that they have a side toxicological effect. The efficacy of various natural antioxidants to reduce oxidative spoilage of lipids, discoloration, and suppression of the growth of microbes on meat products has been proven [29–31]. Phenolic compounds are the main constituents of plant materials that promote their antioxidant activity. Plants, fruits, and their extracts, having a high concentration of phenolic compounds, are seen as effective sources of antioxidants to suppress oxidation in meat and meat-containing products [32, 33]. However, the issue of the use of natural antioxidants in meat-containing products with high content of unsaturated fatty acids remains unresolved.

All this allows us to argue that it is advisable to study the fatty acid composition and biological efficiency of a specially created product with a balanced fatty acid composition.

3. The aim and objectives of the study

The aim of this study is to analyze the fatty acid composition and biological value of fat in the developed semi-smoked sausage with Peking duck meat to further determine the rosemary extract (RE) effectiveness in the technology of semi-smoked products with the high lipid content.

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

– to determine the fat-acid composition and analyze the biological efficiency and fat balance of the developed semi-smoked sausage with Peking duck meat;

– to investigate the influence of RE on the course of oxidative processes in a semi-smoked sausage made from Peking duck meat (acid number, peroxide number, thiobarbituric number); to establish the rational level of RE concentration, which is effective for inhibiting the oxidative processes in a semi-smoked sausage with Peking duck meat.

4. Materials and methods to study the fat-acid composition of sausage and the effectiveness of rosemary extract

A semi-smoked sausage was prepared for our study in line with the technology given in [34]. The formulation of the sausage included the boned Peking duck meat, pork heart with tendon removed, side fat, chicken skin, all of which were crushed in a grinder with a diameter of the grid holes of 16–25 mm. To the minced meat, we added dry whey, a soy isolate pre-hydrated with 1:4 drinking water, the plant-fiber preparation fiber 110. All ingredients were mixed; salt and spices were added to the minced meat. After filling the natural shell with the prepared minced meat, the finished sausages were subjected to sedimentation at 4–8 °C for 2 hours. Next, the sausages were dried and fried at a temperature of 90 °C for an hour, cooled, and cooked at t=(80±5) °C for 40...50 minutes. After cooling at t<20 °C for 2 hours, the sausages were smoked at t=(43±7) °C, τ=12...24 hours. After smoking, the sausage was dried at t=10...12 °C and the relative humidity of 76.5±1.5 % for 24 hours. After finishing the technological process, the sausage was stored at a temperature not higher than 12 °C for 20 days.

Our experiment on the use of natural antioxidants involved a rosemary extract (Food Ingredients Mega Trade, USA). In the manufacture of the minced meat of the sausage, the rosemary extract (RE) was added according to the following scheme: No. 1 – RE 0.02 %; No. 2 – RE 0.04 %; No. 3 – RE 0.06 % to the mass of the raw materials; control was a sample without the addition of antioxidants.

We determined the fatty acid composition of semi-smoked sausages by gas-liquid chromatography using the automated gas chromatograph Kupol-55 [35]. To determine the fat-acid composition of the sausages, a sample was prepared by extracting the lipids. The extract was concentrated at a rotary evaporator at a temperature not higher than 40 °C. After heating in a water bath for 50 min., the extract was diluted with water at a ratio of 1:1. Next, we derived hexane extracts. Hexane was evaporated at a rotary evaporator, thereby yielding chromatographically pure methyl esters of fatty acids, which were dissolved in hexane and analyzed at the chromatograph Kupol-55 (Russia) in the column SP 2560 (USA) with a length of 100 m.

The acidity number was determined by the titration of the batch with sodium hydroxide, concentrated in the presence of an alcoholic solution of phenolphthalein [36]. In a conical flask with a capacity of 150–200 cm^3, we weighed 3–5 g of the studied minced meat with an error not more than 0.001 g. The batch was heated in a water bath; we added 50 cm^3 of the neutralized ester-alcohol mixture, and stirred. Next, we added 3–5 drops of the alcohol solution of phenolphthalein with a mass fraction of 1 %. The resulting solution, at constant shaking, was quickly titrated with a solution of potassium hydroxide with a molar concentration of 0.1 mol/dm^3 before the appearance of clear pink color, which persists for 1 min. The acidity number was calculated from the following formula:

$$X=(V\times K\times 5{,}61)/m, \quad (1)$$

where V is the volume of a solution of potassium hydroxide of the molar concentration 0.1 mol/dm^3, which was used on titration; K is the correction factor to an alkali solution for conversion to precise (0.1 mol/dm^3) solution; 5.61 is the quantity of milligrams of potassium hydroxide, contained in 1 cm^3 (0.1 mol/dm^3) of solution; m is the mass of a minced meat batch, g.

A method for determining PV is based on extracting the batch by a mixture of chloroform and ice acetic acid and subsequent titrating by a solution of sodium hypophosphite with a pre-added starch solution [36].

We added to the conical flask with a tight stopper 0.8–1 g of the batch, weighted with an accuracy of no more

than 0.0002 g, melted it in a water bath, and poured against a wall of the flask 10 cm^3 of chloroform and 10 cm^3 of ice acetic acid. WE then quickly added 0.5 cm^3 of saturated fresh potassium iodide solution. We covered the flask with a stopper, agitated the content with rotary motions, and put it in a dark place for 3 minutes. After aging, the flask was added with 100 cm^3 of distilled water, which in advance was added with 1 cm^3 of a solution of starch of mass fraction 1 %. We titrated with a solution of sodium hyposulfite of the molar concentration 0.01 mol/dm^3 until the disappearance of blue color.

To check the purity of the reagents, we conducted control determination without a batch. The peroxide number was calculated from the following formula:

$$X=(V-V_1)\times K\times 0{,}00127\times 100/m, \quad (2)$$

where V is the volume of a sodium hyposulfite solution of molar concentration 0.01 mol/dm^3, used on titration during the main experiment involving a batch of the minced meat, cm^3; V_1 is the volume (0.01 mol/dm^3) of a sodium hyposulfite solution, used on titration during the control experiment (without a batch of the minced meat), cm^3; K is the correction factor to a sodium hyposulfite solution for conversion to the precise (0.01 mol/dm^3) solution; 0.00127 is the number of grams of iodine equivalent to 1 cm^3 (0.01 mol/dm^3) of a sodium hyposulfite solution; m is the mass of a batch of the examined minced meat, g.

We determined TBARS by measuring the intensity of coloring a mixture of the distillate of the examined sample with a solution of thiobarbituric acid (1:1) after aging in a water bath over 35 minutes, at the spectrophotocolorimeter "Specol -11" (Germany) with a wavelength of 535 nm [36].

We placed 50 g of the minced meat batch in a porcelain mortar, used a glass cylinder to measure 50 cm^3 of distilled water, added to the mortar, and rubbed the mixture with a pestle to a homogeneous state. The prepared sample was quantitatively transferred to a Kjeldahl flask, we flushed 47.5 cm^3 of distilled water remaining in the mortar, and added 2.5 cm^3 of hydrochloric acid. Distillation was carried out in a Kjeldahl apparatus (Fig. 4), collecting 50 cm^3 of the distillate in a measuring flask with a tight stopper. We took 5 cm^3 of the distillate, placed it in a flask with a tight stopper, added 5 cm^3 of thiobarbituric acid, covered with a tight stopper, mixed, and put in a boiling water bath for 35 min., checking the time by a stopwatch.

Simultaneously, a control experiment is carried out, using 5 cm^3 of distilled water instead of the distillate. Next, the solutions were cooled in running cold water for 10 min, checking the time by a stopwatch, and measured the optical density at a wavelength of (535±10) nm relative to the control solution.

The thiobarbituric number, mg, MA (malonic aldehyde)/kg, of the product was calculated from the following formula:

$$X=D\times 7{,}8, \quad (3)$$

where D is the optical density of a solution; 7.8 is the coefficient of proportional dependence of MA density on its concentration in a solution. This coefficient is a constant quantity.

The absolute error of measurements was determined using a Student criterion, confidence interval P=0.95, the number of repeated determinations is 3–4, the number of parallel samples of the examined samples is 3.

5. Results of determining the fat-acid composition of sausage and the anti-oxidation efficiency of rosemary extract

5. 1. Determining the fat-acid composition and analysis of the biological efficiency of the semi-smoked sausage with Peking duck meat

The developed semi-smoked meat-containing sausage with Peking duck meat contained a total fat percentage of 31.03 g/100 g in the finished product. Fig. 1–4 show the results of studying the fat-acid composition of the meat-containing sausage with Peking duck meat.

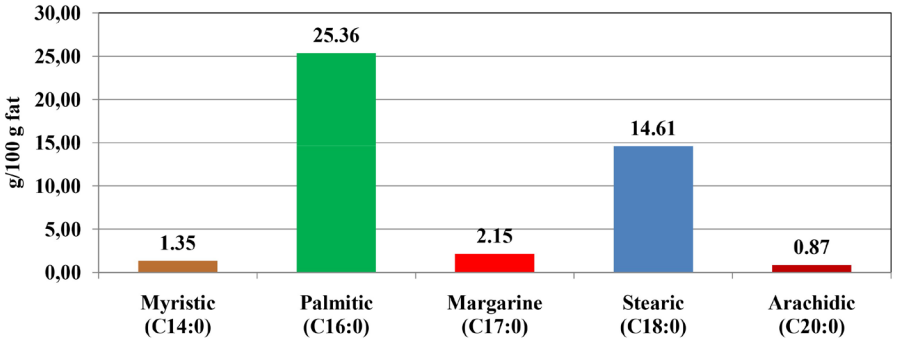

Fig. 1. The concentration of saturated fatty acids in a semi-smoked sausage, g per 100 g fat

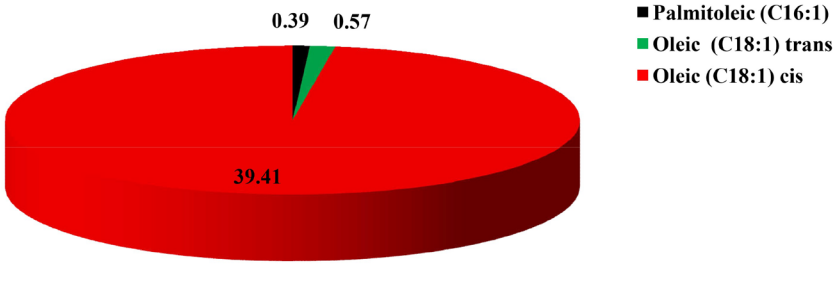

Fig. 2. The concentration of monounsaturated fatty acids in a semi-smoked sausage, g per 100 g fat

The fat-acid composition of the meat-containing semi-smoked sausage is represented mainly by palmitic (25.36 %), stearic (14.61 %), and myristic (1.35 %) acids, the unsaturated oleic (39.41 %), linoleic (13.52 %), α-linolenic (0.72 %) acids.

The overall level of SFA in the sausage was 40.37 % in the fat of the product or g/100 g, which is dominated by palmitic (25.36 g/100 fat) and stearic (14.61 g/100 g fat) acids.

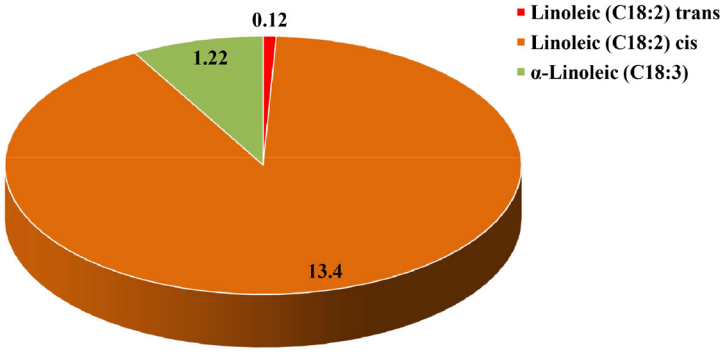

Fig. 3. The concentration of polyunsaturated fatty acids in a semi-smoked sausage, g per 100 g fat

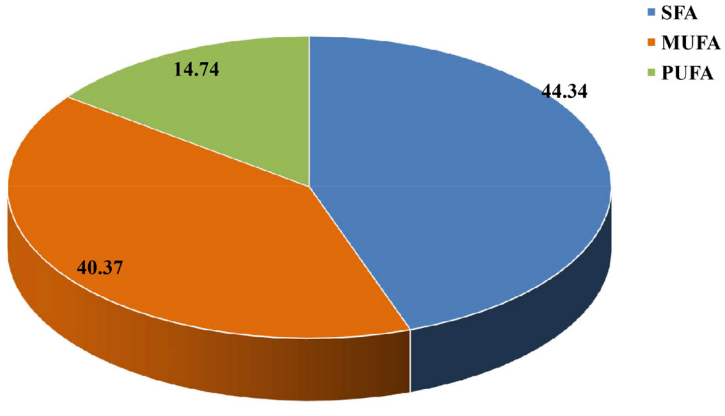

Fig. 4. The total amount of SFA, MUFA, PUFA in a semi-smoked sausage, % of total fat content

The total amount of PUFA was 14.24 g/100 g of fat, including the high content of linoleic acid (13.40 g/100 g), which belongs to the ω-6 family. Among the sausage PUFA, we detected α-linolenic acid, which belongs to the ω-3 family, whose concentration in the fat of the product is 1.22 g/100 g.

The indicators of the biological effectiveness of lipids in meat-containing boiled sausages are given in Table 1 compared with hypothetical ideal fat (reference).

It has been established experimentally that the concentration of the ω-3 PUFA in the developed sausage is high enough and is 1.22 g/100 g fat. This meets the recommended daily requirement for 81 % if 300 g of the product is consumed. The meat-containing semi-smoked sausage made from Peking duck meat can be considered as a source of the ω-3 PUFA for inclusion in the daily diet of an adult.

5. 2. Studying the influence of RE on the course of oxidative processes in a semi-smoked sausage made from Peking duck meat

The results of studying the dynamics of acidity number during storage of meat-containing sausages with the addition of rosemary extract are shown in Fig. 5.

It was established that the examined samples demonstrated the tendency to reduce the concentration of free fatty acids on the fifth day of storage. At the end of the storage duration, after 20 days, AV in the samples with rosemary extract reached from 1.65±0.09 mg KOH in sample No. 3 to 1.80±0.11 in sample No. 1, which is 29.13 % less compared with the control.

The results of studying the dynamics of the peroxide number during the storage of meat-containing sausages with the addition of rosemary extract are shown in Fig. 6.

It was determined that the introduction of rosemary extract contributes to inhibiting the accumulation of peroxide products of oxidative processes, as evidenced by the study results. Studying the dynamics of peroxidation in the samples demonstrated that among the samples of the semi-smoked sausage PV grew more intensively in the sample without an additive, while adding a rosemary extract in all three concentrations slowed the oxidative processes. The greatest stabilizing effect was demonstrated by the extract additive in a concentration of 0.06 %. PV in this sample at the end of the examined duration equaled 0.13±0.01 % J_2, whereas in control this indicator amounted to 0.65±0.00 % J_2.

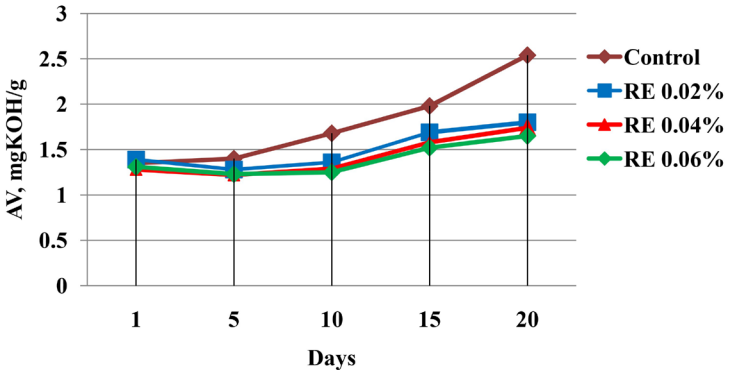

Fig. 5. Dependence of acidity number on the concentration of rosemary extract in sausages, mg KOH

Table 1

Indicators of the biological efficiency of lipids in the meat-containing boiled products

Indicators of the biological efficacy of lipids	Reference [37]	Semi-smoked meat-containing sausage
The content of ω-3 fatty acids, g/100 g of product	1.0–2.0	1.22
The level of meeting the recommended daily need in the ω-3 PUFA, %	1.5 g (100 %)	81 %
The content of linoleic fatty acid, g/100 g of product	11.3–16.3 g	13.52
The level of meeting the recommended daily need in linoleic acid, %	13.8 g (100 %)	97.98 %
The content of α-linolenic fatty acid, g/100 g of product	1.1–1.6 g	1.22
The level of meeting the recommended daily need in α- linoleic acid, %	1.4 g (100 %)	87.14 %
The content of the ω-6 fatty acids, g/100 g of product	5.6	13.52
The ratio of fatty acids ω-3/ω-6	1:5–1:10	1:11

The results of studying the effect of the bioflavonoids of a rosemary extract on the accumulation rate of secondary products of oxidation during storage of meat-containing sausages are shown in Fig. 7.

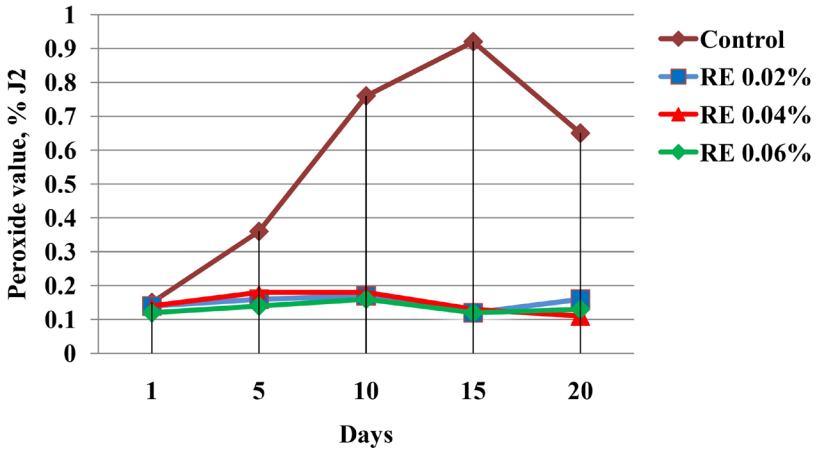

Fig. 6. Dependence of a peroxide number value on the concentration of rosemary extract in sausages, % J_2

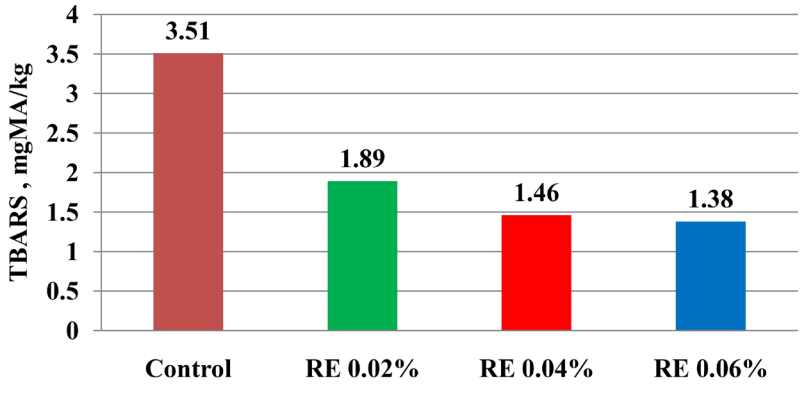

Fig. 7. The effect of flavonoids from the extract of rosemary on TBARS of meat-containing sausages, mg MA/kg

At the end of storing, TBARS in the samples with the addition of RE was 0.38–0.80 mg MA/kg of the product, which is 2.54–3.94 times lower than that in the control sample of the sausage without the addition of an antioxidant. Introducing RE in the amount of 0.06 % had the greatest effect.

6. Discussion of results of studying the fat-acid composition of sausage and the effectiveness of rosemary extract

The development of a semi-smoked meat-containing sausage involved Peking duck meat in order to create a product balanced in terms of the fat-acid composition. Compared with the meat of broiler chickens or turkey, duck meat has a higher level of lipids [37, 38]. Duck meat is a good source of polyunsaturated fatty acids, especially from 20 and 22 carbon atoms [39]. There are also studies that prove that there is a positive correlation between the amount of lipids in duck meat and aroma intensity [40].

Our analysis of data on the fat-acid composition of the meat-containing semi-smoked sausage with Peking duck meat, which is illustrated in Fig. 1–4, confirms that the product contains the concentration of the cis-isomer of oleic acid in the sausage at the level of 39.41 g/100 g fat, and 0.57 % of trans-isomer. As is known, trans-fatty acids of natural origin can amount to 6 % of fat in meat and dairy products [41]. The natural and industrial sources of the trans isomers of fatty acids differently affect the human body. Natural trans isomers are not a risk factor for cardiovascular disease because, unlike industrial, they do not help reduce the high-density lipoproteins and increase the lipoproteins of low density [42, 43]. They are also not related to coronary heart disease [44].

According to the results from Fig. 3, the ratio of the concentration of linoleic to linolenic FA meets the recommended one, which makes it possible to characterize the product as intended for healthy nutrition and for people with diseases of lipid metabolism.

Based on the results of our study (Table 1), the ratio of the ω-6/ω-6 FA fluctuated within 1:11, which practically corresponds to the recommended physiological norms of nutrition for a healthy person. It is known that the fatty acids from ω-3 family demonstrate anticarcinogenic and antiallergic effects on human health [45].

When increasing the ratio of PUFA to SFA, there is an increase in the risk of oxidative spoilage of meat-containing products, especially those with long shelf life. This issue is solved by the use of natural oxidation inhibitors, specifically rosemary extract.

Our analysis of the diagram in Fig. 5 confirms that the introduced extract of rosemary inhibits the hydrolysis of fat in systems with a high content of unsaturated fatty acids due to the high concentration of flavonoids in the extract. This agrees with the studies into the rosemary extract efficiency in the beef cutlet technology [46]. The most effective in terms of inhibiting the hydrolytic decomposition of acyl glycerides is the rosemary extract in a concentration of 0.06 % to the mass of the raw materials.

When storing a meat-containing semi-smoked sausage with the high content of PUFA, adding the extract of rosemary caused the inhibition of the process of formation and accumulation of the secondary products of lipid oxidation, which is confirmed by data in Fig. 7. This is due to the property of the flavonoid and polyphenolic compounds to inhibit free radical oxidation. The antioxidant activity of regenerative-active polyphenols delays the onset of autooxidation by suppressing the formation of free radicals. The relative efficacy of polyphenols depends on the oxidation-reduction potentials, the stability of phenoxy-radical, stability (the degree of oxidation inhibitor to lose or break down during processing) and distribution in meat systems [32, 47]. The efficacy of phenolic molecules as inhibitors of oxidation contributes to the resonance stability of the oxidized form in food matrices [48].

7. Conclusions

1. We have determined the fat-acid composition and analyzed the biological efficiency and proper balance of fat in the

developed semi-smoked sausage with Peking duck meat. Using Peking duck meat in the technology of semi-smoked meat-containing sausage makes it possible to obtain a product with a high content of unsaturated fatty acids, including essential, and the recommended ratios of the ω-3/ω-6 fatty acids.

2. Our study of the RE influence on the course of oxidative processes in a semi-smoked sausage made from Peking duck meat has confirmed the high antioxidant activity of rosemary extract and the effective inhibition of the process of oxidation of lipids in meat-containing sausage products. The rational level of RE concentration has been established, which is effective for inhibiting the oxidative processes in the semi-smoked sausage with Peking duck meat. The largest effect has been obtained when introducing an extract of rosemary in the amount of 0.06 % to the mass of the raw materials, which makes it possible to reduce indicators of the oxidative spoilage of fat by more than twice.

References

1. Wood, J., Enser, M., Whittington, F., Richardson, R. (2007). Fatty Acids in Meat and Meat Products. Food Science and Technology, 87–107. doi: https://doi.org/10.1201/9781420006902.ch5
2. Wood, J. D., Enser, M. (2017). Manipulating the Fatty Acid Composition of Meat to Improve Nutritional Value and Meat Quality. New Aspects of Meat Quality, 501–535. doi: https://doi.org/10.1016/b978-0-08-100593-4.00023-0
3. Innes, J. K., Calder, P. C. (2020). Marine Omega-3 (N-3) Fatty Acids for Cardiovascular Health: An Update for 2020. International Journal of Molecular Sciences, 21 (4), 1362. doi: https://doi.org/10.3390/ijms21041362
4. Lisitsyn, A. B., Chernukha, I. M., Lunina, O. I. (2017). Fatty acid composition of meat from various animal species and the role of technological factors in trans- isomerization of fatty acids. Foods and Raw Materials, 5 (2), 54–61. doi: https://doi.org/10.21603/2308-4057-2017-2-54-61
5. Mapiye, C., Aldai, N., Turner, T. D., Aalhus, J. L., Rolland, D. C., Kramer, J. K. G., Dugan, M. E. R. (2012). The labile lipid fraction of meat: From perceived disease and waste to health and opportunity. Meat Science, 92 (3), 210–220. doi: https://doi.org/10.1016/j.meatsci.2012.03.016
6. Briggs, M. A., Bowen, K. J., Kris-Etherton, P. M. (2017). 23 Omega-3 Polyunsaturated Fatty Acids and Health. Food Lipids, 603–626. doi: https://doi.org/10.1201/9781315151854-24
7. Shahidi, F., Ambigaipalan, P. (2018). Omega-3 Polyunsaturated Fatty Acids and Their Health Benefits. Annual Review of Food Science and Technology, 9 (1), 345–381. doi: https://doi.org/10.1146/annurev-food-111317-095850
8. Wyness, L., Weichselbaum, E., O'Connor, A., Williams, E. B., Benelam, B., Riley, H., Stanner, S. (2011). Red meat in the diet: an update. Nutrition Bulletin, 36 (1), 34–77. doi: https://doi.org/10.1111/j.1467-3010.2010.01871.x
9. Li, J., Sun, Q. (2019). Consumption of saturated fatty acids and coronary heart disease risk. International Journal of Cardiology, 279, 27–28. doi: https://doi.org/10.1016/j.ijcard.2019.01.022
10. Vissers, L. E. T., Rijksen, J., Boer, J. M. A., Verschuren, W. M. M., van der Schouw, Y. T., Sluijs, I. (2018). Fatty acids from dairy and meat and their association with risk of coronary heart disease. European Journal of Nutrition, 58(7), 2639–2647. doi: https://doi.org/10.1007/s00394-018-1811-1
11. Burlingame, B., Nishida, C., Uauy, R., Weisell, R. (Eds.) (2009). Fats and Fatty Acids in Human Nutrition. doi: https://doi.org/10.1159/isbn.978-3-8055-9262-8
12. Lisitsyn, A. B., Chernukha, I. M., Ivankin, A. N. (2013). Comparative study of fatty acid composition of meat material from various animal species. Scientific Journal of Animal Science, 2 (5), 124–131.
13. Bozhko, N., Tischenko, V., Pasichnyi, V., Polumbryk, M., Haschuk, O. (2018). Development of meat-containing minced semi-finished products based on the locally produced raw materials. Eastern-European Journal of Enterprise Technologies, 4 (11 (94)), 49–54. doi: https://doi.org/10.15587/1729-4061.2018.140052
14. Huda, N., Aronal, A. P., Ahmad, R. (2012). Amino Acid and Fatty Acid Profiles of Peking and Muscovy Duck Meat. International Journal of Poultry Science, 11 (3), 229–236. doi: https://doi.org/10.3923/ijps.2012.229.236
15. Mancini, S., Preziuso, G., Dal Bosco, A., Roscini, V., Parisi, G., Paci, G. (2017). Modifications of fatty acids profile, lipid peroxidation and antioxidant capacity in raw and cooked rabbit burgers added with ginger. Meat Science, 133, 151–158. doi: https://doi.org/10.1016/j.meatsci.2017.07.003
16. Papamandjaris, A. A., Macdougall, D. E., Jones, P. J. H. (1998). Medium chain fatty acid metabolism and energy expenditure: Obesity treatment implications. Life Sciences, 62 (14), 1203–1215. doi: https://doi.org/10.1016/s0024-3205(97)01143-0
17. Wood, J. D., Richardson, R. I., Nute, G. R., Fisher, A. V., Campo, M. M., Kasapidou, E. et. al. (2004). Effects of fatty acids on meat quality: a review. Meat Science, 66 (1), 21–32. doi: https://doi.org/10.1016/s0309-1740(03)00022-6
18. Kausar, T., Hanan, E., Ayob, O., Praween, B., Azad, Z. (2019). A review on functional ingredients in red meat products. Bioinformation, 15 (5), 358–363. doi: https://doi.org/10.6026/97320630015358
19. Falowo, A. B., Fayemi, P. O., Muchenje, V. (2014). Natural antioxidants against lipid–protein oxidative deterioration in meat and meat products: A review. Food Research International, 64, 171–181. doi: https://doi.org/10.1016/j.foodres.2014.06.022
20. Bozhko, N., Tischenko, V., Pasichnyi, V., Marynin, A., Polumbryk, M. (2017). Analysis of the influence of rosemary and grape seed extracts on oxidation the lipids of peking duck meat. Eastern-European Journal of Enterprise Technologies, 4 (11 (88)), 4–9. doi: https://doi.org/10.15587/1729-4061.2017.108851
21. Gobert, M., Bourguet, C., Terlouw, C., Deiss, V., Berdeaux, O., Comte, B., Durand, D. (2009). Pre-slaughter stress and lipoperoxidation: protective effect of vitamin E and plant extracts rich in polyphenols given to finishing cattle. In the Proceedings of the 11th International Symposium on Ruminant Physiology, 814–815.
22. Moyo, B., Oyedemi, S., Masika, P. J., Muchenje, V. (2012). Polyphenolic content and antioxidant properties of Moringa oleifera leaf extracts and enzymatic activity of liver from goats supplemented with Moringa oleifera leaves/sunflower seed cake. Meat Science, 91 (4), 441–447. doi: https://doi.org/10.1016/j.meatsci.2012.02.029

23. Nkukwana, T. T., Muchenje, V., Masika, P. J., Hoffman, L. C., Dzama, K., Descalzo, A. M. (2014). Fatty acid composition and oxidative stability of breast meat from broiler chickens supplemented with Moringa oleifera leaf meal over a period of refrigeration. Food Chemistry, 142, 255–261. doi: https://doi.org/10.1016/j.foodchem.2013.07.059
24. Ahn, J., Grun, I., Mustapha, A. (2007). Effects of plant extracts on microbial growth, color change, and lipid oxidation in cooked beef. Food Microbiology, 24 (1), 7–14. doi: https://doi.org/10.1016/j.fm.2006.04.006
25. Bozhko, N., Tishchenko, V., Pasichnyi, V., Svyatnenko, R. (2019). Analysis of the effectiveness of natural plant extracts in the technology of combined meatcontaining bread. Ukrainian Food Journal, 8 (3), 522–531. doi: https://doi.org/10.24263/2304-974x-2019-8-3-9
26. Pasichnyi, V., Ukrainets, A., Ukrainets, A., Khrapachov, O., Khrapachov, O., Marynin, A. et. al. (2018). Research into efficiency of pasterization of boiled sausage products in order to improve their storage term. Eastern-European Journal of Enterprise Technologies, 6 (11 (96)), 21–28. doi: https://doi.org/10.15587/1729-4061.2018.147946
27. Fasseas, M. K., Mountzouris, K. C., Tarantilis, P. A., Polissiou, M., Zervas, G. (2008). Antioxidant activity in meat treated with oregano and sage essential oils. Food Chemistry, 106 (3), 1188–1194. doi: https://doi.org/10.1016/j.foodchem.2007.07.060
28. Karre, L., Lopez, K., Getty, K. J. K. (2013). Natural antioxidants in meat and poultry products. Meat Science, 94 (2), 220–227. doi: https://doi.org/10.1016/j.meatsci.2013.01.007
29. Carpenter, R., O'Grady, M. N., O'Callaghan, Y. C., O'Brien, N. M., Kerry, J. P. (2007). Evaluation of the antioxidant potential of grape seed and bearberry extracts in raw and cooked pork. Meat Science, 76 (4), 604–610. doi: https://doi.org/10.1016/j.meatsci.2007.01.021
30. Doolaege, E. H. A., Vossen, E., Raes, K., De Meulenaer, B., Verhé, R., Paelinck, H., De Smet, S. (2012). Effect of rosemary extract dose on lipid oxidation, colour stability and antioxidant concentrations, in reduced nitrite liver pâtés. Meat Science, 90 (4), 925–931. doi: https://doi.org/10.1016/j.meatsci.2011.11.034
31. Umaraw, P., Chauhan, G., Mendiratta, S. K., Verma, A. K., Arya, A. (2020). Effect of oregano and bay as natural preservatives in meat bread for extension of storage stability at ambient temperature. Journal of Food Processing and Preservation, 44 (4). doi: https://doi.org/10.1111/jfpp.14375
32. Masoodi, F. A. (2016). Advances in use of natural antioxidants as food additives for improving the oxidative stability of meat Products. Madridge Journal of Food Technology, 1 (1), 10–17. doi: https://doi.org/10.18689/mjft-1000102
33. Ukrainets, A. I., Pasichny, V. M., Zheludenko, Y. V. (2016). Antioxidant plant extracts in the meat processing industry. Biotechnologia Acta, 9 (2), 19–27. doi: https://doi.org/10.15407/biotech9.02.019
34. Bozhko, N., Tishchenko, V., Pasichniy, V., Verteleckaja, N. (2018). Development of sausages from the peking duck meat. Prohresyvni tekhnika ta tekhnolohiyi kharchovykh vyrobnytstv restorannoho hospodarstva i torhivli, 1 (27), 112–122.
35. Bozhko, N., Tischenko, V., Pasichnyi, V., Moroz, O. (2019). Research of nutritional and biological value of the semi smoked meatcontaining sausage. Food Science and Technology, 13 (4), 96–103. doi: https://doi.org/10.15673/fst.v13i4.1561
36. Bozhko, N., Tischenko, V., Pasichnyi, V., Marynin, A., Polumbryk, M. (2017). Study of oxidation processes in duck meat with application of rosemary and grape seed extracts. EUREKA: Life Sciences, 4, 10–15. doi: https://doi.org/10.21303/2504-5695.2017.00374
37. Biswas, S., Banerjee, R., Bhattacharyya, D., Patra, G., Das, A. K., Das, S. K. (2019). Technological investigation into duck meat and its products - a potential alternative to chicken. World's Poultry Science Journal, 75 (4), 609–620. doi: https://doi.org/10.1017/s004393391900062x
38. Baéza, E. (2006). Effects of genotype, age and nutrition on intramuscular lipids and meat quality. Proceedings of the 2006 Symposium COA/INRA Scientific Cooperation in Agriculture. Tainan, 79–82. Available at: http://www.angrin.tlri.gov.tw/%5C/INRA/o5.pdf
39. Ali, M. S., Kang, G.-H., Yang, H.-S., Jeong, J.-Y., Hwang, Y.-H., Park, G.-B., Joo, S.-T. (2007). A Comparison of Meat Characteristics between Duck and Chicken Breast. Asian-Australasian Journal of Animal Sciences, 20 (6), 1002–1006. doi: https://doi.org/10.5713/ajas.2007.1002
40. Chartrin, P., Méteau, K., Juin, H., Bernadet, M. D., Guy, G., Larzul, C. et. al. (2006). Effects of Intramuscular Fat Levels on Sensory Characteristics of Duck Breast Meat. Poultry Science, 85 (5), 914–922. doi: https://doi.org/10.1093/ps/85.5.914
41. Stender, S., Astrup, A., Dyerberg, J. (2012). A trans European Union difference in the decline intransfatty acids in popular foods: a market basket investigation. BMJ Open, 2 (5), e000859. doi: https://doi.org/10.1136/bmjopen-2012-000859
42. Gayet-Boyer, C., Tenenhaus-Aziza, F., Prunet, C., Marmonier, C., Malpuech-Brugère, C., Lamarche, B., Chardigny, J.-M. (2014). Is there a linear relationship between the dose of ruminant trans-fatty acids and cardiovascular risk markers in healthy subjects: results from a systematic review and meta-regression of randomised clinical trials. British Journal of Nutrition, 112 (12), 1914–1922. doi: https://doi.org/10.1017/s0007114514002578
43. De Souza, R. J., Mente, A., Maroleanu, A., Cozma, A. I., Ha, V., Kishibe, T. et. al. (2015). Intake of saturated and trans unsaturated fatty acids and risk of all cause mortality, cardiovascular disease, and type 2 diabetes: systematic review and meta-analysis of observational studies. BMJ, h3978. doi: https://doi.org/10.1136/bmj.h3978
44. Fernández-Ginés, J. M., Fernández-López, J., Sayas-Barberá, E., Pérez-Alvarez, J. A. (2005). Meat Products as Functional Foods: A Review. Journal of Food Science, 70 (2), R37–R43. doi: https://doi.org/10.1111/j.1365-2621.2005.tb07110.x
45. Remacle, C., Reusens, B. (Eds.) (2004). Functional foods, ageing and degenerative disease. Woodhead Publishing, 792. doi: https://doi.org/10.1533/9781855739017
46. Movileanu, I., Núñez de González, M. T., Hafley, B., Miller, R. K., Keeton, J. T. (2013). Comparison of Dried Plum Puree, Rosemary Extract, and BHA/BHT as Antioxidants in Irradiated Ground Beef Patties. International Journal of Food Science, 2013, 1–7. doi: https://doi.org/10.1155/2013/360732
47. Shah, M. A., Bosco, S. J. D., Mir, S. A. (2014). Plant extracts as natural antioxidants in meat and meat products. Meat Science, 98 (1), 21–33. doi: https://doi.org/10.1016/j.meatsci.2014.03.020
48. Domínguez, R., Pateiro, M., Gagaoua, M., Barba, F. J., Zhang, W., Lorenzo, J. M. (2019). A Comprehensive Review on Lipid Oxidation in Meat and Meat Products. Antioxidants, 8 (10), 429. doi: https://doi.org/10.3390/antiox8100429