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Optimization of the recipe of cooked sausage products with the addition of cuttlefish liver, red caviar, and spelt flour

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ABSTRACT

The increasing demand for functional meat and fish products has prompted the search for innovative formulations enriched with bioactive and nutritionally valuable components. This study investigates the effect of incorporating non-traditional raw materials such as chicken meat, spelt flour, dried vegetables, cuttlefish ink, and red caviar into the formulation of cooked fish sausages based on hake. Three experimental sausage formulations were developed by partially replacing fish meat with 10% chicken meat and adding 6% spelt flour, along with the addition of bell pepper, olives, or garlic. Physicochemical parameters (moisture, protein, fat, ash), water-holding and moisture-binding capacity, structural–mechanical properties (shear stress), oxidative stability (acid and peroxide values), and sensory quality were assessed. Protein content in the experimental samples increased by 8–10% compared to the control (17.2 and 15.1 g/100 g). Sample 1 exhibited the highest water-holding capacity (86.3%), while samples 2 and 3 showed an 18–20% increase in structural density. During refrigerated storage (10 days), sample 3 demonstrated the best oxidative stability, with acid value rising only from 1.7 to 2.3 mg KOH/g fat. Organoleptic scores improved notably, with sample 1 scoring 4.6 points and sample 3 scoring 4.5, compared to 3.8 for the control. The formulated cooked fish sausages, which included added chicken meat, spelt flour, and dried vegetables, exhibited enhanced nutritional, technological, and sensory properties. The study confirms the feasibility of using non-traditional components to develop functional sausage products. Further investigations should explore microbial stability during long-term storage and evaluate consumer acceptance for potential commercial applications.

Keywords: hake, vegetable raw materials, cuttlefish ink, red caviar, sausage products

INTRODUCTION

The production of fish sausages has been successfully developed in many countries over the past few years. This started in Japan. The expansion of this production is stimulated by an increase in the catch of small fish and fish with low palatability, which can be successfully used to produce fish sausage products **[1]**, and **[2]**.

Moreover, as experts note, fish sausage is more useful for human health than its meat and chicken counterparts due to the saturation of easily digestible protein and essential amino acids, such as lysine and tryptophan. Another advantage of fish sausage is that, with the initial raw materials, it is possible to establish its production at a specialized fish factory and a regular meat processing plant.

The technology for producing sausage products has been developed and implemented in many countries, but production in Ukraine remains limited.

Fish and fish processing products have traditionally been essential components of the human diet due to their high nutritional value and remarkably complete profile of animal protein, vitamins, and macro- and microelements **[3]**. In modern conditions, there is an increasing interest in developing new types of fish products, including those with functional purposes, which contribute to maintaining public health and ensuring high-quality nutrition.

A separate niche in the food market is occupied by fish sausages — an innovative product that can serve as an alternative to traditional meat. The technology of their production involves the use of minced fish combined with components that enhance structural-mechanical and organoleptic properties, including lard, eggs, dry milk, starch, spices, salt, stabilizers, and food additives (such as phosphates and nitrites) **[4]**.

Among the current directions in improving meat product technologies, special attention is given to using mineral components to enhance their nutritional value. In a study by Serik and Shurduk **[5]**, the feasibility of using a protein-mineral supplement (PMS) as a source of calcium in emulsion-type meat product formulations was substantiated. According to the study results, adding 7–8% PMS has a positive effect on the water-binding, fat-retention, and emulsifying properties, as well as the structure of the meat system. Improved microbiological stability and sensory characteristics of the final product were also observed, without negatively affecting its taste. The authors particularly emphasize that more than 60% of the calcium in the final product is present in the form of organically bound compounds, ensuring a high degree of absorption. The proposed technology enables the creation of functional meat products with enhanced biological value and health-promoting effects.

Developed recipes for combined meat-vegetable and fish-vegetable cooked sausage products with a taste and smoke aroma using CO_2 extracts of the smoke liquid. In this work, the effect of added plant components (carrots, eggplants, onions and peas in meat-vegetable sausages, carrots, eggplants, onions and peas, in fish-vegetable sausages - carrots, potatoes, onions and rice) on the nutritional properties of the product, the yield of the finished product and determination of the sanitary and hygienic properties of the finished product due to the use of CO_2 smoke extract **[6]**.

The possibility of using such non-traditional additives as a structure-forming agent from fish skin, lotus seeds, water, and water-alcoholic infusions from Sargentodoxa cuneata (Sargentodoxa cuneata Rend. et Wils) in the technology of making fish sausages, which made it possible to obtain sausages with high organoleptic indicators **[7]** .

Other authors have investigated the possibility of using squid and shrimp to produce cooked sausages **[8]**. The study demonstrated that incorporating these seafood ingredients enhances the nutritional value and taste of the final product. Along with other authors, he investigated the use of protein-containing raw materials, such as soy protein, to produce boiled-smoked sausages. The use of such additives allows for reducing the production cost and improving the nutritional value of the product **[9]**.

It was also justified **[10]**, in her dissertation, that substantiated the feasibility of using protein-containing functional compositions that include both plant and animal proteins to improve cooked sausage technology. Using such compositions enables the enhancement of the amino acid profile and the functional and technological properties of the product.

Interesting studies have explored the potential of using amaranth as an unconventional plant-based raw material for producing cooked sausages **[11]**. The results showed that the addition of amaranth improves the organoleptic, physicochemical, and microbiological properties of the product.

Other authors examined using plant-based raw materials, such as soy protein, in cooked sausage technology. They found that adding soy protein improves the sausage's structure and consistency, and reduces production costs **[12]**.

Other studies have been conducted using protein compositions that include both plant and animal proteins to improve cooked sausage technology. These compositions allow for the enhancement of the amino acid profile and the functional and technological properties of the product **[13]**.

One of the promising raw materials for producing such products is African catfish (*Clarias gariepinus*), which is characterized by rapid growth rates, efficient feed conversion, low maintenance requirements, and high nutritional value of its meat. According to literature sources, African catfish meat contains, on average, 75% moisture, 16.9% protein, and 6.7% fat. In comparison, 100 g of the product provides over 40% of the daily selenium requirement and more than 20% of the phosphorus requirement. Studies on the water-holding capacity of the raw material indicate that African catfish meat can ensure a stable sausage mince structure, juiciness, and a tender texture in the final products **[14]**.

The article by Tyshchenko **[15]** discusses using fish mince as a raw material for sausage production. The study demonstrated that fish mince exhibits high functional and technological properties, enabling the production of high-quality and nutritious products.

The study by Taieva et al. **[16]** investigates the potential for enhancing the functional and technological properties of cooked sausages by incorporating camel fat and chicken fillet. The effect of pumpkin shell powder on lipid oxidation and the functional and technological properties of sausages made from mixed meat was investigated. It was found that adding pumpkin shell powder enhances the taste and organoleptic characteristics of the product.

Elaverasana et al. explore the possibility of using millet flour to formulate fish sausages in their research. It was found that adding millet flour is an ideal healthy substitute for traditional wheat flour **[17]**, **[18]**, and **[19]**.

Critical studies have been conducted on incorporating textured soy protein (TSP) into surimi products, particularly fish sausages. It was found that adding 15% TSP improves gel strength, water-holding capacity, and organoleptic properties of the product while maintaining its quality for up to 120 days when stored at −18°C **[19]**, **[20]**, and **[21]**.

The analysis of scientific research suggests a high potential for enhancing the technology of cooked fish sausages using unconventional raw materials. Including components such as pumpkin shell powder, millet flour, textured soy protein, camel fat, and fish milt enhances the products' functional and technological properties. In particular, improvements have been observed in texture, gel strength, water-holding capacity, and the organoleptic characteristics of the sausages.

Moreover, using unconventional raw materials increases the biological value of the products by boosting the content of high-quality protein and beneficial fats, while also extending shelf life through the reduction of lipid oxidation. A significant advantage is the economic feasibility and environmental sustainability of these innovations, aligning with current trends in the development of the food industry.

Therefore, integrating unconventional raw materials into the production of cooked fish sausages effectively improves product quality and competitiveness while meeting the demands of healthy nutrition and sustainable development.

At the same time, the analysis of domestic and foreign literature reveals that little attention is paid to developing technologies for specialized food products with targeted physiological and biochemical properties and enhanced nutritional and biological value. Therefore, developing technologies for combined fish products (cooked sausage products) for functional nutrition is an essential and relevant direction of scientific research.

Scientific Hypothesis

The study hypothesizes that adding 10% chicken meat and spelt flour, along with dried vegetables (pepper, olives, garlic) and cuttlefish ink, will improve the quality of hake-based sausages. These changes are expected to enhance protein content, texture, moisture retention, oxidative stability, and overall sensory appeal compared to the control sample.

Objectives

The aim of the study is to assess the impact of the modified recipe on the sausages' composition, texture, sensory characteristics, and shelf life. The study also examines how dried vegetables affect moisture retention in the product.

MATERIAL AND METHODS

Samples

Samples description: The following ingredients were used to produce fish sausages: hake, chicken, sunflower oil, red caviar, spelt flour, cuttlefish ink, bell pepper, dried olives, and garlic.

Samples collection: Hake, chicken, sunflower oil, red caviar, spelt flour, cuttlefish ink, bell pepper, dried olives, and garlic were purchased from a supermarket chain. Hake and chicken were stored at +5 degrees Celsius in a refrigerator for one day until the experiment. Dried olives and garlic were stored in a dry, well-ventilated room at 20 °C.

Samples preparation: The primary grinding of muscle tissue occurs in a meat grinder, when the cellular structure of the meat is partially destroyed. Secondary grinding of the minced beef on a cutter provides the required degree of dispersion of its particles, equal to approximately 1.0×10^{-4} m. Refined sunflower oil is added to the raw materials of crushed fish and meat for emulsification. The remaining raw materials are loaded in the following order: salt, sugar, dried spices. After thorough mixing, spelt flour and potato starch are added. Then dried bell peppers, olives, and garlic are added. The minced meat mixture is processed in a cutter. In the production of boiled sausages, the process duration is 8-12 minutes, and the temperature ranges from 6-8 to 10-12 °C. Cuttlefish ink is added to the resulting minced meat mixture and mixed until the minced meat is uniformly colored black. After that, add the red caviar and mix lightly, taking care not to deform the caviar. Boiled sausages are injected with a low density, as excessive density leads to the rupture of the shell during cooking due to the expansion of the shell contents when heated. A polyamide shell was used for sausages. After forming and hanging the loaves on the frames, the sausage products are cured in chambers at a temperature of 0 - 4 °C and a relative humidity of 80 - 85%. The duration of the cured sausages is 2 hours. After curing, cooking is carried out at a temperature of 75 - 85 °C. After the cooking process is completed, the temperature in the thickness of the loaf should be 69 - 72 °C.

Number of samples analysed: 20

Chemicals

No chemicals were used for the study.

Animals, Plants, and Biological Materials

Bell peppers, dried olives, and garlic were purchased from a supermarket chain.

Instruments

Drying cabinet (SNOL, Khimlaborreaktyv LLC, Ukraine). Muffle furnace (SNOL, Khimlaborreaktyv LLC, Ukraine). Fat analyzer (SOX 406, Khimlaborreaktyv LLC, China). Mineralizer (Velp Scientifica, Khimlaborreaktyv LLC, Italy). Distiller for steam distillation (Velp Scientifica UDK 129, Khimlaborreaktyv LLC, Italy). Sous vide 225 448 system (Hendi, Hamburg, Germany).Scale (Axis A6000, Poland, accuracy 0.1g).

Laboratory Methods

During the research, the following methods were employed: organoleptic, physical, physicochemical, experimental planning, and statistical and mathematical data processing based on computer technologies.

Studies of the chemical composition have been performed according to the following methods: mass fraction of moisture – by drying the product sample to a constant weight in an oven SNOL (Labimpex LTD, Ukraine) at a temperature of 100-105ºC according to DSTU 8029:2015 **[22]**; mass fraction of ash – by a weightning method, after the product portion mineralization in a muffle furnace SNOL (Labimpex LTD, Ukraine) at a temperature of 500−600°C according to DSTU 8717:2017 **[23]**; mass fraction of lipids – by the Soxhlet extraction-weight method according to DSTU 8718:2017 **[24]** on the SOX 406 Fat Analyzer (Hanon Instruments, China); mass fraction of protein – by Kjeldahl method of the determination of a total nitrogen, which is based on the ability of organic matter of the product sample to be oxidized with concentrated sulfuric acid in the presence of a catalyst according to DSTU 8030:2015 **[25]**, while samples ashing has been performed on a DK6 digester (Velp Scientifica, Italy), with a vacuum pump JP, distillation has been carried out on a steam distillation apparatus UDK 129 (Velp Scientifica, Italy).

The organoleptic parameters were determined using the profile method using a 5-point scale.

The acid number of lipids was determined according to DSTU EN ISO 660:2019 **[26]**. Peroxide number of lipids, according to DSTU EN ISO 3960:2019 **[27]**.

Description of the Experiment

Study flow: Fish sausage products were prepared according to the recipe and production process.

Quality Assurance

Number of repeated analyses: 5

Number of experiment replication: 5

Reference materials: The equipment manufacturer provided instructions to check the equipment's performance.

Calibration: Each instrument was calibrated before each experiment, and calibration checks were performed regularly to ensure measurement accuracy. Each instrument was calibrated prior to each experiment, and calibration checks were performed periodically to ensure the accuracy of measurements.

Laboratory accreditation: The experiments were conducted at the "Ukrainian Laboratory of Quality and Safety of Agricultural and Industrial Complex Products", the management of which is carried out through the implementation of a management system built (since 2007) bythe requirements of DSTU EN ISO/IEC 17025:2019 (EN ISO/IEC 17025:2017, IDT; ISO/IEC 17025:2017, IDT) and confirmed by the Accreditation Certificate of the National Accreditation Agency of Ukraine.

Data Access

The data supporting the findings of this study are not publicly available.

Statistical Analysis

The results of the experimental studies were processed using mathematical statistics. The experimental data were analyzed using the Data Analysis tool in Microsoft Excel. Each experiment was performed with a minimum of three to five repetitions. The study results were statistically analyzed using one-factor dispersion analysis. Microsoft Excel 2016 software in combination with XLSTAT was used for this purpose. The tabulated dataare presented asx ± SD (mean ± standard deviation).

The difference between the variants was considered significant at $P < 0.05$ using the Tukey test.

RESULTS AND DISCUSSION

The primary raw materials for cooking sausage products are minced hake (in a frozen state) and chicken fillet (in a cooled state).
The dimensional composition of the fish is given in the Table 1.

Table 1 Dimensional composition of hake.

L_a, cm	L_i, cm	L_h, cm	L_t, cm	L_m, cm	h, cm	b, cm
-	-	-	-	25.2	6	4

Note: (initial weight of gutted carcass - 356 g).

The length of the carcass is 25.2 cm, the height of the fish body is 6 cm, and the width of the fish body is 4 cm (average size of the fish). The mass composition of hake is presented in Table 2.

Table 2 Mass composition of hake.

Weight, kg	Content to the total weight of fish, %				
	fillet	skin	bones	fins	scales
0.356	82±1.9	5.3±0.3	7.57±0.9	0.76±0.3	0.03±0.01

Note: initial weight of gutted carcass - 356 g, results are in %, ($n=5$, $p\leq0.05$)

The output of fish meat is 301.3 g, waste - 48.4 g, losses - 6.3 g. The chemical composition of fish raw materials was determined during the study, as shown in Table 3.

Table 3 Chemical composition of hake.

Indicator	Content
Protein content	18.31±0.6
Fat content	1.31±0.22
Moisture content	78.9±2.83
Mineral content	1.48±0.15

Note: results are in %, ($n=5$, $p\leq0.05$).

Chicken provides moderate energy and contains highly digestible proteins with low collagen, offering good nutritional quality. It is also a source of unsaturated fats, primarily in the skin, which can be easily removed, and B vitamins such as pantothenic acid and thiamine. Consumption of chicken is associated with a lower risk of overweight and obesity, as well as cardiovascular diseases and type 2 diabetes. The chemical composition of chicken is given in Table 4.

Table 4 Chemical composition of chicken.

Indicator	Content
Calories, kcal	202±4.0
Protein content	18.5±0.17
Fat content	14.3±0.21
Moisture content	3.7±1.26
Mineral content	70.9±2.25

Note: results are in %,($n=5$, $p\leq0.05$)

The combination of fish and meat raw materials enables the production of a new, fully developed product, specifically a cooked sausage, utilizing various types of raw materials.

The nutritional value of salmon roe used for the production of cooked sausage products is given in Table 5 **[17]**.

Table 5 Nutritional value of salmon roe.

Indicator	Content per 100 g of product
Calories, kcal	249
Protein, g	26.0
Fat, g	13.2
Water, g	62.0
Carbohydrate, g	1
B_1, µg%	1800
B_2, µg%	2100
Folic Acid, µg%	1300
PP, µg%	2.1
Pantothenic Acid, µg%	1.3
Vitamin C, µg%	93

Given the limited data on the chemical composition of spelled flour grown in Ukraine, we investigated the composition of this flour (Table 6).

Table 6 Chemical composition of spelled flour, % on dry matter.

Indicator	Spelled flour
Protein, g	17.46
Fat, g	3.17
Carbohydrate, g	75.92
includes Starch, g	52.49
Total Sugars, g	3.62
Dietary Fiber, g	14.34
Includes Roughage, g	2.1

Spelt is notable for its high protein content. Research has shown that spelt contains 28% more protein, 1.6 times more fat, and 22% more minerals (ash) than common wheat. Additionally, it has 7.6% fewer carbohydrates overall, including 20% less starch. While the total dietary fiber content in spelt is higher than in wheat, it contains less crude fiber.

Cuttlefish ink is a natural coloring agent that provides a deep black hue and comes in a convenient single-use package containing two 4 g sachets. Its composition includes: cuttlefish ink (40%), water, salt, and sodium carboxymethylcellulose stabilizer. It is gluten-free but may contain shellfish and traces of crustaceans, celery, and milk.

Cuttlefish ink is increasingly valued in the food industry not only for its natural pigmentation but also for its content of bioactive substances that may offer health-promoting effects. Gómez-Guillén et al. **[28]** noted that this ingredient contains melanin, peptides, and amino acids that contribute antioxidant, antimicrobial, and anti-inflammatory activities. These properties position cuttlefish ink as a multifunctional additive that supports visual enhancement and improved functional attributes of food products.

Incorporating natural colorants, such as cuttlefish ink, aligns with the modern trend toward clean-label ingredients and the increasing consumer preference for natural alternatives to synthetic additives **[29]**. In contrast to artificial colorants, it is considered a safer and more consumer-friendly option.

In addition, the intense black color and distinct flavor profile of cuttlefish ink make it a novel and appealing component in formulating premium and health-oriented foods, including fish-based sausages and alternative meat products **[30]**. Its use in cooked sausages made from unconventional raw materials is justified from a technological standpoint, as it improves product appearance, enriches flavor, and supports innovation in food development.

Samples from the manufacturer Savin Product were used to produce cooked sausage products made from non-traditional raw materials. The recipe of the control sample is presented in Table 7.

Table 7 Sausage recipe Squid ink & Red roe and meat turkey, from the manufacturer Savin product.

Components name	Prescription composition of the control sample, g/100 g of product
Turkey meat	48.3
Refined sunflower oil	28
Red caviar	6.5
Cow's powdered milk	6
Kitchen salt	1.3
Sugar	0.4
Spice extracts (nutmeg, black pepper, allspice)	0.5
Color fixative: sodium nitrite	0.008
Drinking water	8.492
Cuttlefish ink	0.5

In the formulated recipes for cooked sausage products, various vegetable ingredients were incorporated to enhance flavor characteristics, while the inclusion of natural color sources aimed to achieve a more visually appealing final product. Additionally, fish-based raw materials and modifications to animal-based components were incorporated to enhance taste and better align with daily nutritional needs. A novel water-binding agent was also introduced to enhance product stability and maintain shape. The finalized cooked sausage formulations are detailed in Table 8.

Table 8 Sausage recipes Squid ink & Red caviar and bell pepper, Squid ink & Red caviar and olives, Ink Cuttlefish & Red Caviar & Garlic.

The name of the components	Recipe composition, g/100 g of products		
	Sample 1	Sample 2	Sample 3
Hake meat	42	47	45
Chicken meat	10	10	10
Refined sunflower oil	20.5	20.5	20.5
Red caviar	6.5	6.5	6.5
Potato starch	2	2	2
Spelled flour	6	6	6
Kitchen salt	1	1	1
Sugar	0.4	0.4	0.4
Spices (basil, oregano, thyme)	5.55	3.55	5.55
Cuttlefish ink	1.05	1.05	1.05
Dried bulgarian red pepper	5	-	-
Dried olives	-	2	-
Dried garlic (granulated)	-	-	2

The development of formulations for cooked sausages incorporating plant-based raw materials, natural colorants, unconventional types of meat, and water-retaining components aligns with current trends in the food industry, which aim to improve product quality, safety, and functional properties.

According to Markovych's research **[31]**, the use of plant components, particularly soy protein, contributes to the improved structure and consistency of sausage products while also helping to reduce production costs. The addition of natural colorants, such as cuttlefish ink, not only provides a rich color but also imparts antioxidant properties, as noted by Gómez-Guillén et al. **[28]**, which positively affect product stability during storage.

Including fish raw materials in the formulations of cooked sausages enhances the nutritional value of the product due to its high content of complete proteins, polyunsaturated fatty acids, and minerals, as confirmed by the research of Bozhko et al. **[8]**. Replacing traditional meat ingredients with more easily digestible protein sources (e.g., African catfish or poultry meat) allows products to be better adapted to the needs of modern consumers, particularly those who follow healthy eating habits **[32]**.

Additionally, incorporating water-retaining components, such as dietary fiber or stabilizers, enhances the texture, juiciness, and shape of the finished product. This is consistent with the findings of Serik and Shurduk **[5]**, who highlight the effectiveness of protein-mineral additives in enhancing the technological properties of emulsion-type meat systems.

Thus, comprehensive improvement of formulations by incorporating unconventional ingredients and enhanced structural components is a justified step toward developing cooked sausages with increased nutritional and functional value. The obtained samples of cooked sausage products are shown in Figur 2. Figure 3 and Figure 4.

Figure 2 Squid Ink & Red Caviar & Bell Pepper (Sample 1).

Figure 3 Cutball Ink & Red Caviar & Olives (Sample 2).

Figure 4 Squid Ink & Red Caviar & Garlic (Sample 3).

Thus, by developing the aforementioned recipes, it is possible to obtain a cooked sausage product enriched with B-group vitamins, vitamin PP, vitamin A, and vitamin E, as well as mineral elements such as iron, iodine, phosphorus, calcium, and essential Omega-3 fatty acids. This product is easily digestible and aligns with the principles of healthy nutrition.

To assess the effectiveness of using dried plant-based raw materials and to determine the optimal additive levels in the production of cooked sausages made from unconventional raw materials, an investigation was conducted on the properties of these added components within a multi-component system. This is crucial because the structure, composition, and manufacturing conditions of the product depend on the characteristics of the minced meat mixture. Parameters such as moisture-retention capacity (MRC) and moisture-binding capacity (MBC) of the experimental minced meat influence the juiciness, density, and final yield of the product.

The results of the university study (Figure 5) and water holding capacity (Figure 6) of minced meat.

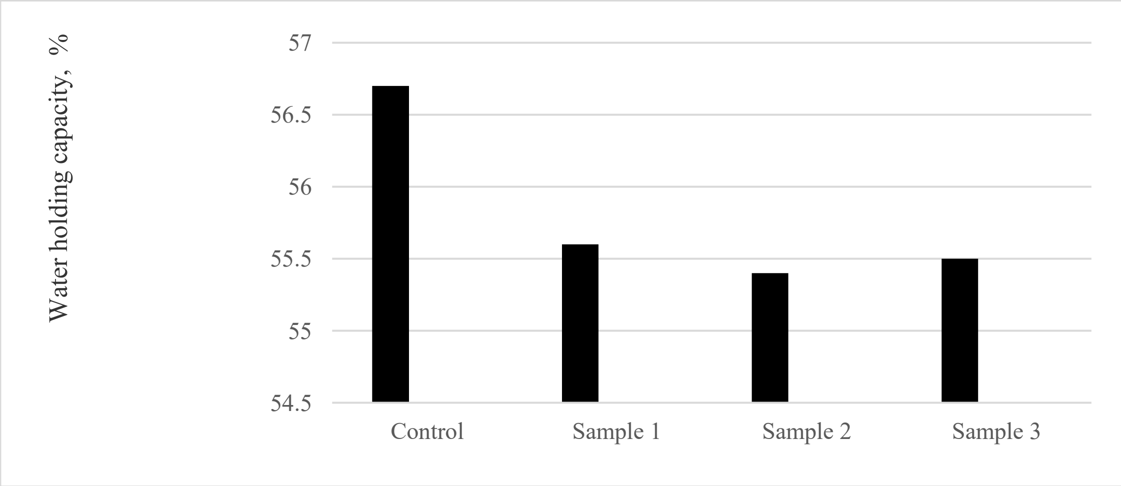

Figure 5 Changes in the moisture-retaining capacity of minced meat.

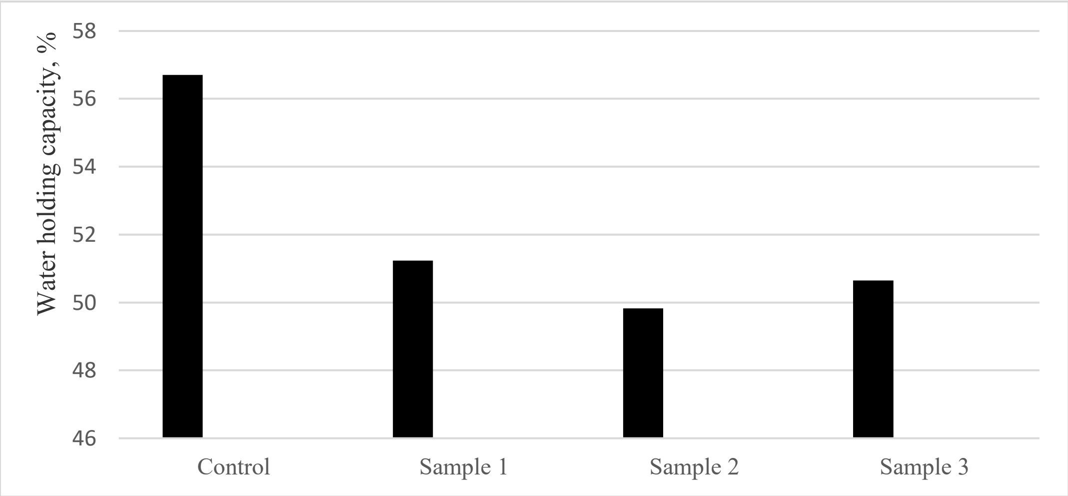

Figure 6 Changes in the hair-binding capacity of minced meat.

A quantitative evaluation of the cooked sausage products was conducted using a set of organoleptic indicators, comparing them to the control sample. Based on the overall organoleptic assessment, experimental formulations No. 1 and No. 3 demonstrated superiority over the control, which exhibited a very dense texture and an unpleasant taste with no distinct sausage flavor.

In formulation No. 1, the taste, aroma, and juiciness were enhanced by adding red bell pepper, which increases juiciness and imparts a pleasant sweet flavor due to its high moisture content. In formulation No. 3, the flavor profile was enhanced by incorporating dried garlic, resulting in a subtle and mild taste. Although formulation No. 2 scored lower overall compared to No. 1 and No. 3, it still outperformed the control sample due to the inclusion of dried olives and herbs, which enhanced the texture and added a distinctive aroma.

To determine the qualitative differences in the organoleptic evaluation of the developed product, the construction of profilograms was added, allowing for the visual demonstration of the complete picture of the comparative assessment of the samples. The graphically obtained indicators are presented in Figure 7, Figure 8 and Figure 9.

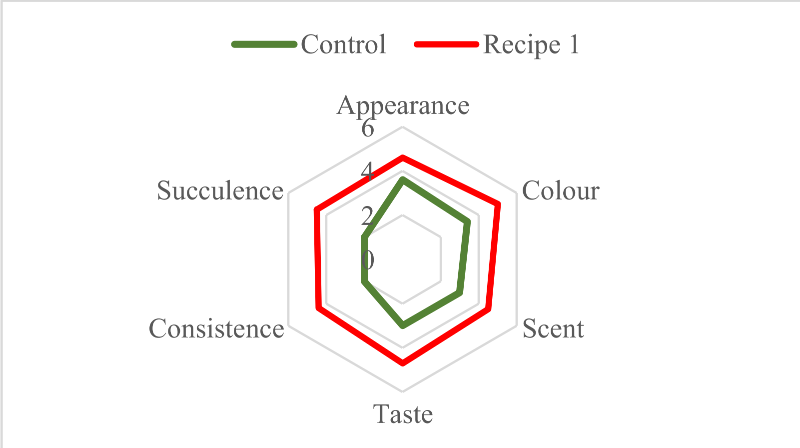

Figure 7 Comparative analysis of Sample 1 with the control sample.

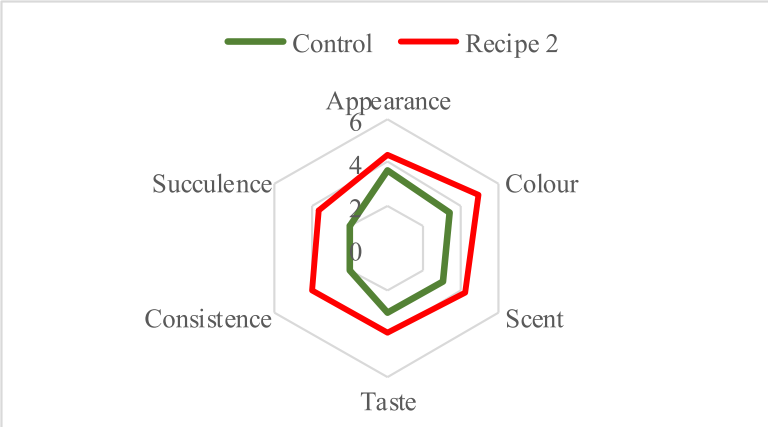

Figure 8 Comparative analysis of Sample 2 with the control sample.

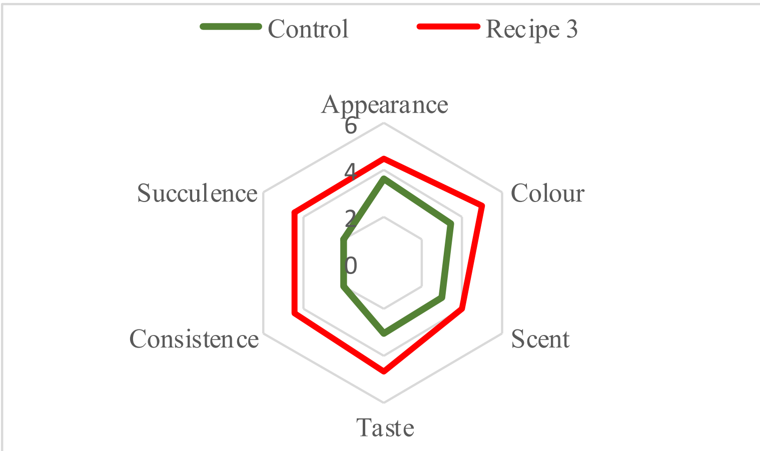

Figure 9 Comparative analysis of Sample 3 with the control sample.

Summarizing the results of the comparative evaluation of organoleptic properties, it can be concluded that adding plant-based raw materials enhances these sensory attributes. All developed formulations received higher overall scores than the control sample, although each showed improvements in specific indicators depending on the type of plant material used.

The addition of plant-based raw materials to meat and fish products is an effective way to enhance the organoleptic properties of these products. According to the research by Markovych **[31]**, soy protein in sausage formulations contributes to enhanced texture, taste, and overall consumer perception of the product. Similarly, the findings of showed that the inclusion of amaranth in cooked sausages increases their organoleptic appeal, as evidenced by higher ratings for flavor, aroma, and consistency **[32]**, **[33]**, **[34]**, and **[35]**. Furthermore, the study by Buzhanska et al. **[36]** demonstrates that using pumpkin peel powder in sausage products significantly improves taste and textural characteristics, positively influencing the end consumer's perception of the product.

A needle indenter (mass = 2 g) was employed to measure the penetration of the finished cooked sausages (spring-elastic products). The measurements were taken on the exposed surface of the sample, at least 10 mm away from the sample's edge and maximally spaced from other measurement points, while avoiding air pockets and surface defects.

When using a needle indenter, measurements were made at five points along the length of the product for each sample. In Figure 10, the results of the ultimate shear stress for cooked sausage products are given.

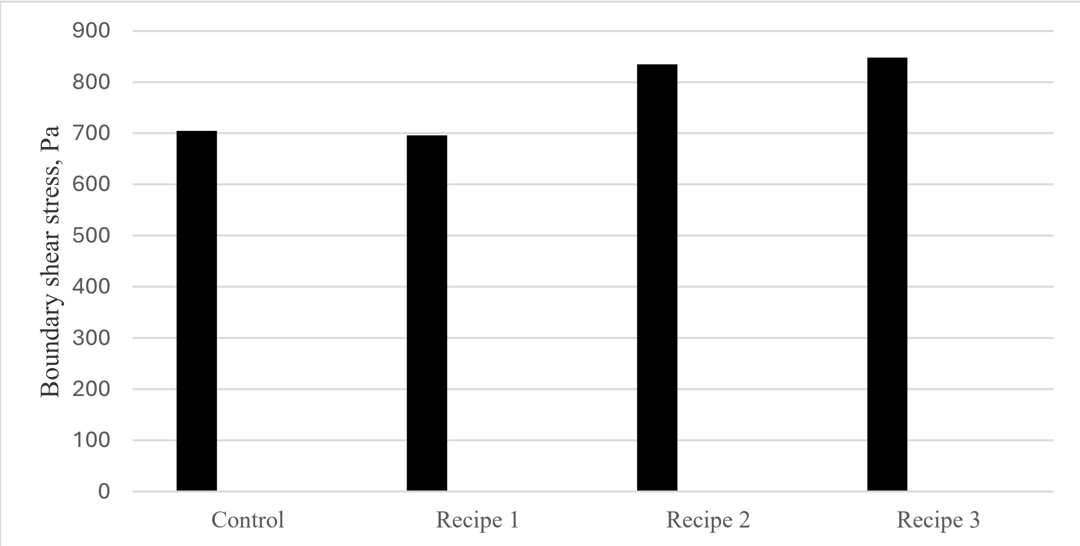

Figure 10 Boundary shear stress of cooked sausage products.

According to the diagram, Samples 2 and 3 exhibited statistically significant improvements in structural and mechanical properties ($p < 0.05$), with shear force values increased by 18–20% compared to the control, which can be attributed to the increased content of fish raw materials (an increase of 5 g in sample 2 and 3 g in sample 3) and variations in the ratio of spices to dried vegetable raw materials. Although the amount of dried vegetable raw materials was the same in both samples (2 g each), sample 2 contained a reduced quantity of spices compared to sample 3.

Relative to the control sample, the density of samples 2 and 3 increased by 18–20%. This improvement was due to the substitution of the binding agent, replacing powdered milk with a mixture of potato starch and spelled flour in a 2:6 ratio, and the incorporation of smaller pieces of plant material compared to sample 1.

In laboratory conditions, chemical composition studies were conducted to evaluate the quality of ready-made cooked sausage products from non-traditional raw materials. The comparative characteristics of the chemical composition depending on the introduced auxiliary raw materials are presented in Figure 11, Figure 12 and Figure 13.

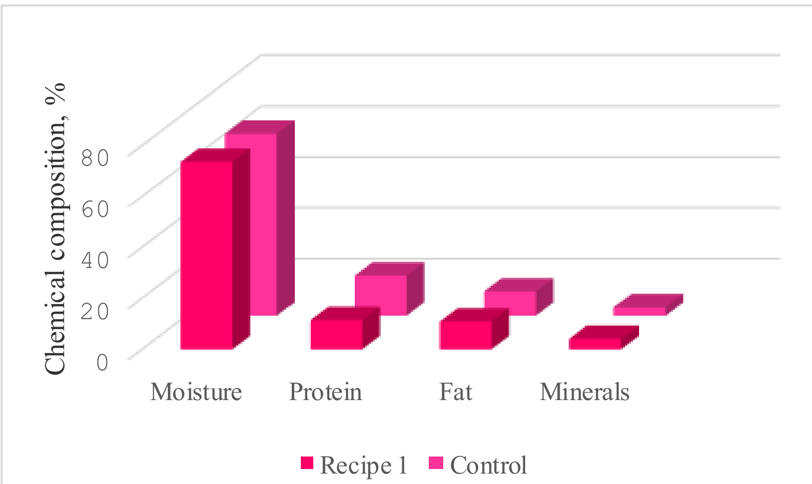

Figure 11 Comparative analysis of the chemical composition of cooked sausage products (Sample 1).

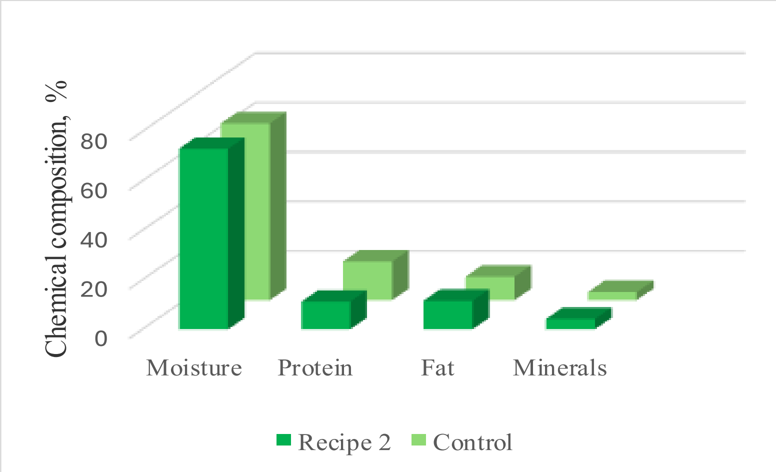

Figure 12 Comparative analysis of the chemical composition of cooked sausage products (Sample 2).

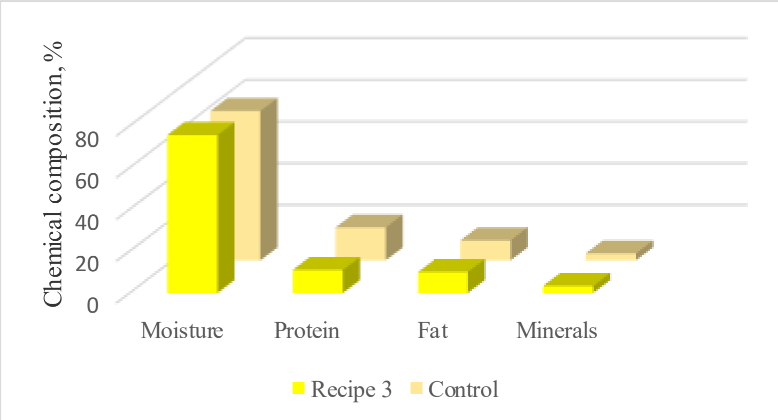

Figure 13 Comparative analysis of the chemical composition of cooked sausage products (Sample 3).

The obtained results indicate that the developed formulations contain a lower protein level due to the partial substitution of fish raw materials with plant-based ingredients, a reduced fat content across all samples, and a higher mineral content compared to the control sample.

The energy value of the product was calculated according to MU 4287-86. The obtained data are presented in the Table. 9.

Table 9 Energy value of cooked sausage products.

Indicator	**Boiled sausage products from non-traditional raw materials**			
	Control	**Sample 1**	**Sample 2**	**Sample 3**
Energy value, kcal	148.3±0.54	143.7±0.67	149.5±0.63	134±0.71

Note: results are in %, (n=5, $p \leq 0.05$)

An analysis of the obtained data shows that the energy value of the experimental samples is generally comparable to that of the control sample. This similarity is attributed to only minor differences in their chemical composition.

The acid number serves as a key quality indicator reflecting the freshness of fats, as it measures the content of free fatty acids, including those produced through the oxidation of fish fat during storage.

Determining the acid number is one of the primary methods for assessing the quality and freshness of fat, particularly in meat and fish-based products. It reflects the accumulation of free fatty acids (FFA) formed due to lipid hydrolysis caused by tissue or microbial lipases. An increase in the acid number in fish raw materials during storage is a reliable indicator of lipid hydrolytic spoilage **[37]**. Established that FFA accumulation indicates not only hydrolysis but may also serve as a secondary marker of fat oxidation, which negatively affects the organoleptic properties of the product **[38]**.

Research by Shahidi & Zhong **[39]** confirms that the extent of hydrolysis and changes in the acid number depend on the type of raw material, storage conditions, and duration, as well as the presence of antioxidant components. Therefore, monitoring the acid number during cold storage of cooked sausage products containing fish raw materials is an effective way to control lipid spoilage processes.

During storage, free fatty acids accumulate as a result of lipid hydrolysis in muscle tissues, catalyzed by tissue lipases. The extent and direction of this hydrolytic process were assessed based on the buildup of free fatty acids in the lipids of fish muscle tissue. Changes in the acid number of lipids during cold storage of both experimental and control cooked sausage samples are illustrated in Figure 14.

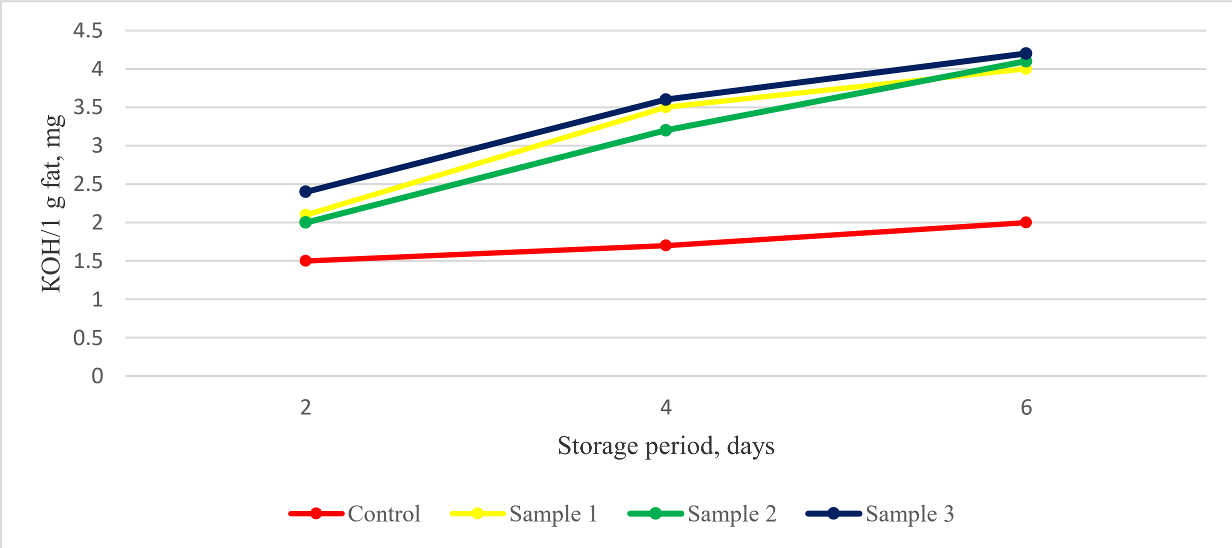

Figure 14 Dynamics of changes in the acid number of cooked sausage products during storage.

The content of peroxide compounds in fat was determined by the value of the peroxide number, which is a reasonably sensitive indicator that characterizes the onset and extent of oxidative deterioration of fat.

The change in the peroxide number of lipids during the storage of experimental and control samples of cooked sausage products is presented in Figure 15.

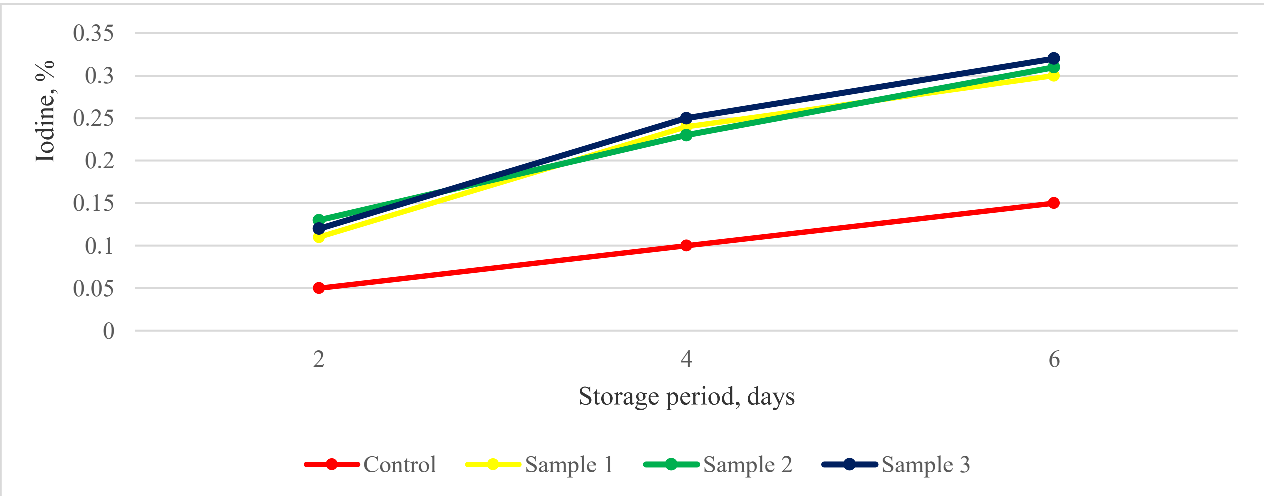

Figure 15 Dynamics of changes in the peroxide value of cooked sausage products during storage.

Measuring the peroxide value enables the early detection of oxidation processes and the formation of spoilage products, well before they can be identified through organoleptic assessment. As illustrated in Figure 15, the peroxide value, like the acid value, increases throughout storage, though it remains within acceptable limits by the end of the storage period.

As noted by Shahidi **[39]**, the early stage of lipid oxidation is a highly sensitive indicator of the initial phases of autoxidation. It is widely used to assess the oxidative stability of food products.

Research by Domínguez et al. **[36]** indicates that the peroxide value is closely related to storage duration, the quality of the lipid raw material, and the presence of antioxidant compounds in the product. A gradual increase in this indicator signals the activation of oxidation processes. In contrast, slower growth in specific samples (such as sample 3) may result from the inclusion of components with pronounced antioxidant properties or a more stable fatty acid composition.

Determination of peroxide value is one of the key methods for assessing the initial stages of lipid oxidation in meat and fish products. This indicator allows you to quickly detect the development of oxidative processes long before the appearance of characteristic changes that can be recorded by organoleptic methods **[40]**, **[41]**, **[42]**, and **[43]**. Since peroxide compounds are the primary products of the autocatalytic oxidation of fats, their content directly indicates the stability of the lipid fraction under storage conditions.

The increase in peroxide value during product storage is an expected phenomenon, which confirms the activation of oxidation processes, especially in the presence of unsaturated fatty acids inherent in fish raw materials. However, in cases where natural antioxidants or more stable fat components are used, as in sample 3, the rate of peroxide accumulation is significantly reduced ($p < 0.05$ compared to control), as confirmed by the Tukey test results. This indicates the effectiveness of functional ingredients that act as oxidation inhibitors **[44]**. As Lee notes, the peroxide value is an extremely sensitive indicator of the initial stages of autooxidation, making its monitoring a reliable tool for predicting the shelf life and quality control of products. In addition, according to Domínguez et al., this indicator is closely correlated with the duration of storage, the quality of the fatty raw material and the presence of antioxidant substances. Thus, the gradual increase in the peroxide value in the tested samples, which remains within the regulatory values, confirms the proper technological stability of the product and the effectiveness of the developed formulation **[45]**.

CONCLUSION

The conducted research confirmed that the incorporation of 10% chicken meat, 6% spelt flour, and selected dried vegetables significantly improved the quality characteristics of cooked fish sausages based on hake. Experimental samples demonstrated an increase in protein content to 16.4–17.2 g/100 g, representing an 8–10% improvement compared to the control (15.1 g/100 g). The moisture-holding capacity increased to 86.3% (in the bell pepper sample), enhancing juiciness and texture. Structural and mechanical tests revealed that the shear force in samples 2 and 3 increased by 18–20%, indicating an improvement in the density and cohesiveness of the product matrix. During 10 days of refrigerated storage, sample 3 exhibited the lowest increase in acid value (from 1.7 to 2.3 mg KOH/g fat) and peroxide value (from 1.6 to 2.1 % Iodine), suggesting enhanced oxidative stability due to the presence of natural antioxidants.

The results support the initial hypothesis that the proposed formulation has a positive impact on the physicochemical, structural, and sensory properties of cooked fish sausages. These findings suggest the potential for scaling up the developed formulation in pilot-scale production and integrating it into functional food product lines within the fish and meat processing industry.

Nonetheless, the current study is subject to certain limitations, including the lack of extended microbiological stability data and a limited assessment of shelf life under variable temperature conditions. Future work should focus on broader screening of plant-based functional ingredients, long-term storage evaluation, and consumer preference testing to further optimize the formulation and ensure commercial viability.

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