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Quality assessment of common CARp *(Cyprinus Carpio)* products depending on method of processing and storage methods: an experimental research

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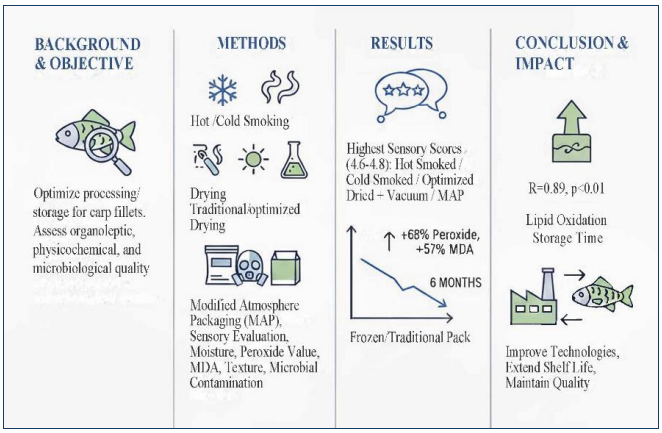
Abstract

Background: With global fish production exceeding 178 million tonnes and up to 35% lost to spoilage, improving processing and storage is vital to maintain quality. Freshwater species like carp, rich in moisture and unstable fats, rapidly deteriorate during storage, demanding precise preservation methods. **Objective:** The study aimed to determine the effect of processing methods and storage conditions on the organoleptic, physicochemical, and microbiological quality of carp products. The subject of the study was carp fillets that were subjected to freezing, hot and cold smoking, and traditional and optimised drying. **Methods:** After processing, the samples were stored in three types of packaging: vacuum, modified atmosphere (gas mixture), and traditional (polyethylene and paper). The organoleptic evaluation was conducted by qualified and certified sensory panellists following the international standard and additionally determined moisture content, peroxide number, malondialdehyde content, texture hardness and total microbial contamination. **Results:** The highest sensory scores (4.6-4.8 points) were achieved by meat processed by hot smoking or optimised drying and packaged in a vacuum or modified atmosphere. The frozen meat gradually lost its texture and flavour properties, and after six months in traditional packaging the sensory score dropped to 2.5-2.8 points. At the same time, the peroxide number increased by 68% on average and the malondialdehyde content by 57%. **Conclusions:** A strong positive correlation between the storage time and the level of lipid oxidation was recorded (correlation coefficient of 0.89 with a significance level of less than 0.01). The results of the study can be used to improve the technologies of processing and packaging freshwater fish in production conditions to extend the shelf life without loss of quality.

Keywords: Sensory testing. Heat treatment. Vacuum packaging. Dehydration. Lipid oxidation. Microbiological stability. Physicochemical parameters.

Graphical Abstract



Introduction

The problem of maintaining the quality of fish products during processing and storage is one of the key challenges of modern food technology, given the high biological value of fish, its rapid susceptibility to

perishability and growing consumer demands for safety and stability of organoleptic characteristics. Globally, fish provides nearly 15% of the total animal protein consumed by the human population, with an estimated 178 million tonnes of production in 2021, of which over 70% was used for direct human consumption **[1]**. However, approximately 30-35% of fish and seafood products are lost annually due to inadequate post-harvest handling, temperature abuse, and microbial spoilage, representing a substantial nutritional and economic burden **[2]**.

Meat from freshwater fish, such as carp, bream and perch, is an important source of easily digestible protein, polyunsaturated fatty acids, vitamins and minerals, which makes it important in the diets of the population **[3-5]**. In Central and Eastern Europe, per capita consumption of freshwater fish has increased by 18% over the past decade, yet spoilage during storage still leads to losses exceeding 15 kg per capita per year in small-scale fisheries **[6]**. However, the specific physicochemical properties of this raw material, such as high humidity (typically 70-80%), unstable lipids, and relatively low buffering capacity, contribute to the rapid development of microorganisms and autolysis processes. These biochemical and microbiological mechanisms not only accelerate quality degradation but also heighten the risk of toxin formation, emphasising the necessity of improving preservation, packaging, and cold-chain technologies for fish products.

This study is noteworthy because it provides workable ways to improve the quality and shelf life of freshwater fish, especially carp, which is a very perishable but significant source of vital nutrients. The study offers information crucial for enhancing industrial fish processing technologies by investigating the combined effects of processing techniques and packaging circumstances. The outcomes help to guarantee food safety, lower post-harvest losses, and preserve nutritional and sensory quality over extended storage. Additionally, the use of energy-efficient processing and sustainable packaging facilitates the shift to ecologically conscious food production systems, which is consistent with international norms for resource conservation and sustainable development.

Even though there are many studies that focus on different aspects of fish preservation, like smoking, freezing, or packaging, there are still very few integrated analyses that assess how particular processing techniques interact with various storage conditions to affect the overall quality of freshwater fish products. The majority of the research that is now accessible concentrates on either marine species or specific technological factors, offering fragmented insights that are insufficient for creating all-encompassing quality management plans for freshwater species like carp. The combined effects of processing intensity, packing environment, and storage length on the physicochemical, sensory, and microbiological stability of carp products are also not well documented empirically. In order to validate the best processing and packaging combinations that guarantee consumer safety and long-term sensory appeal, this information gap highlights the necessity for a comprehensive approach that connects technological characteristics with quantifiable markers of product quality.

The relevance of organoleptic monitoring of freshwater fish meat was highlighted in the study by Fotina et al. **[7]**, which established the effectiveness of using organic acids to stabilise the textural characteristics and improve the palatability of aquatic organisms. In practical terms, the results of this study are of practical importance for raw material processing technologies. The topic of freshwater fish safety in market conditions was covered by Liasota et al. **[8]** in the study on risk-based approaches to product quality control depending on storage conditions, regional specifics, and the surveillance system.

The focus on physicochemical changes during the process of cooling and freezing fish was demonstrated by Duarte et al. **[9]** and Walayat et al. **[10]**, which provided evidence of a decrease in texture quality and degradation of flavour components in products with a long shelf life. A critical reflection on sensory assessment methods is provided in the publication by Bernardo et al. **[11]**, which analyses the strengths and weaknesses of the Fish Quality Index as a universal method for monitoring changes in fish quality. The negative effect of prolonged freezing on the sensory and textural properties of fish was confirmed by Xie et al. **[12]**, who showed a correlation between increased levels of thiobarbituric acid reactive substances (TBARS) and deterioration in the toughness of tilapia fillets. A summary of available research shows that there is a need for a comprehensive approach to studying the impact of heat treatment, packaging type, and storage time on the quality of freshwater fish meat. At the same time, there is a lack of empirical data on the effect of smoking, drying and storage on sensory, physicochemical, and microbiological parameters within the same experimental model.

The study aimed to determine changes in the organoleptic, physicochemical, and microbiological properties of carp meat, depending on the method of heat treatment, type of packaging, and storage time. To achieve this goal, the following tasks were set:

- compare the sensory characteristics of samples

after hot and cold smoking, drying and freezing;

- determine the impact of vacuum packaging, modified gas atmosphere and traditional packaging on the chemical stability of products during storage;
- establish statistical relationships between oxidation rates, the number of microorganisms and sensory scores at different stages of storage.

Materials and Methods

The study was conducted between April and December 2024. The object of the study was carp *(Cyprinus carpio*) meat obtained from fish farms in the Kyiv region certified in accordance with national veterinary and hygiene standards. Prior to capture, standardised conditions were provided, including controlled temperature conditions in water bodies (18-22°C), a constant stocking density (up to 2.5 kg/m³), and a unified feeding ration, which included complete granular feed with a standard protein and fat composition (35% protein, 6% fat). These conditions minimised the impact of external factors on the quality of fish meat. The fish were caught in September 2024. For the study, 50 specimens of carp with an average length of 35-40 cm were selected, which met the inclusion criteria: no external damage, no signs of spoilage and a muscle tissue pH value of 6.4-6.8.

A sample size of 50 carp specimens was chosen to guarantee accurate results under various storage and processing circumstances. With a 95% confidence level, a power analysis verified that this sample size would produce statistically significant results. To evaluate treatment differences, one-way ANOVA and Tukey's test were employed, guaranteeing that the sample size was sufficient for trustworthy findings.

After capture, the fish were humanely slaughtered in accordance with veterinary regulations, including stunning and bleeding, followed by manual evisceration. The carcasses were then thoroughly washed under running potable water and filleted using standardised hygienic procedures. To ensure homogeneity of the samples, the fillets were cut into portions with an average thickness of 2 cm.

The carp fillets were frozen by the shock method at a temperature of -40°C using a Liebherr GNP 2956 freezer (Germany). For the experiment, 15 fish were used, each yielding two fillets, resulting in a total of 30 fillets. Each fillet was divided into uniform portions of equal weight. Freezing was performed prior to packaging: the fillets were first frozen in open form to avoid moisture condensation and then packed under three different conditions – vacuum, modified atmosphere (50% CO_2, 40% N_2, 10% O_2), and traditional packaging (polyethylene bag with food-grade paper). All samples were stored at -18°C for 1, 3, and 6 months.

Two smoking technologies were used in the study: hot smoking (at 80-90°C) and cold smoking (at 25-30°C). Both processes were conducted in a Smokey Oak S-200 smokehouse (Poland) using beech wood as the smoking material. A total of 20 carp specimens were used, yielding 40 fillets, which were evenly divided between the two smoking methods (20 fillets per method). To assess the effect of smoking duration on the aroma intensity, separate batches of fillets were processed for different time intervals. For hot smoking, three groups were formed and smoked for 4, 6, and 8 hours, respectively. For cold smoking, the durations were 8, 12, and 14 hours. Each smoking duration was carried out as a separate process and not as a continuous smoking session with intermediate sampling. This design allowed for the evaluation of different smoking intensities as standalone processing treatments. After smoking, the fillets were cooled to +4°C for no more than 2 hours and then packed under three different packaging conditions: vacuum (stored at +2°C), modified atmosphere (stored at +4°C), and traditional packaging (stored at +4°C). Samples were stored for 1, 3, and 6 months, although it should be noted that the 6-month storage of smoked fish exceeds typical commercial shelf life and was conducted solely for experimental purposes to observe long-term stability. For the assessment of aroma development (see Figure 1), separate samples were taken from each time point corresponding to the specific smoking durations described above. No sampling was performed during an ongoing smoking process.

The fillets were dried in two ways: by traditional natural drying at a temperature of 20-25°C and relative humidity of 60-65% for 7-10 days; and by optimised dehydration at a temperature of 35-40°C in a Binder ED 53 drying oven (Binder ED 53, Binder GmbH, Tuttlingen, Germany) until a moisture content of 25-30% was reached within 48-60 hours. A total of 15 carp were used (7-8 fish per drying method). After drying, the samples were cooled to room temperature (22±1°C), packaged using three different packaging methods (vacuum, modified atmosphere, traditional), and stored at +20°C under stable humidity conditions (55-60%) for 1, 3, 6, and 12 months, depending on the experimental design.

The choice of processing methods was based on their prevalence in industrial fish processing and their ability to significantly affect product shelf life, organoleptic properties and microbiological stability. Freezing ensures long-term storage at low temperatures, smoking provides the desired flavour

profile and suppresses microflora, and drying reduces water activity, creating unfavourable conditions for bacterial growth. Comparing these methods in combination with different packaging options identified the best technological solutions for the long-term preservation of carp products.

To ensure objective comparison between different processing methods and storage conditions, a control group was included in the experimental design. To compare the evaluation results, a control group of fresh carp fillets that had not been subjected to any processing was used. These samples were obtained from the same batch of 10 carp as the experimental groups. Filleting was performed immediately after slaughter, and sensory evaluation took place within 3 hours of filleting to preserve the freshness of the product. Each panellist received an individual coded sample, ensuring that every fillet portion was evaluated only once to avoid cross-panel bias. Before tasting, all samples – except for the smoked ones – were brought to a temperature of +4°C and subjected to standard culinary preparation: cooking for 10 minutes in water without the addition of salt or spices. Smoked products were tasted without any additional processing. This approach ensured consistent serving conditions and enabled an objective comparison of the sensory characteristics across all treatment groups.

The organoleptic evaluation was carried out by 10 qualified tasters (panellists) aged 30 to 50 years, selected following ISO 8586:2023 **[13]**. All participants had at least 5 years of experience in sensory testing and were previously instructed in the evaluation methodology. Before the main testing, all tasters underwent a calibration assessment to verify the sensory sensitivity and reproducibility of the results. All tasters provided voluntary written consent to participate in the study following the requirements of ISO 11136:2014 **[14]**. The evaluation was carried out on a 5-point scale according to ISO 4121:2003 **[15]**, considering four main parameters: texture, taste, smell, and colour. According to this scale: 1 point – unacceptable quality; pronounced defects such as unpleasant odour, pungent taste, undesirable colour, or textural disintegration; 2 points – poor quality, with significant deviations from the norm, but the sample is still considered suitable for consumption; 3 points – satisfactory quality; minor defects are noticeable, but sensory characteristics are generally acceptable; 4 points – good quality, with only slight deviations from the reference sample and pleasant organoleptic properties; 5 points – excellent quality; the sample is free of defects and exhibits a clearly defined, typical smell, taste, colour, and texture. It is generally assumed that a score of 3 or higher indicates that the product is acceptable for consumption. Additionally, a 9-point scale adapted from ISO 13299:2016 **[16]** was used to assess odour intensity during the smoking duration study: 1 point – no or very low odour; 5 points – moderate intensity, typical of smoked products; 9 points – extremely intense aroma, possibly pungent or overly concentrated. The average score for each group was calculated based on the individual ratings provided by 10 sensory panellists.

To ensure the safety of sensory panellists, microbiological screening was conducted prior to each tasting session. Samples with total viable counts (TVC) exceeding 5.0 log colony forming units (CFU)/g or with confirmed presence of *Listeria* spp. or *Escherichia coli* were excluded from organoleptic evaluation. In particular, smoked products stored for six months underwent full microbiological testing before being considered for sensory analysis. Only samples that complied with basic food safety criteria and hygiene regulations were presented to the panel. Furthermore, all tasters were instructed not to ingest the products during evaluation. The assessment was limited to smell, texture, and visual appearance, following spitting and rinsing protocols recommended in ISO 8586:2023 **[13]**, to minimise any risk of accidental ingestion of potentially compromised products.

Tastings were conducted in a specially equipped sensory laboratory with controlled conditions: temperature 20±2°C, neutral lighting, and no foreign odours. The samples were coded with a random three-digit number and presented to the tasters in a randomised order with the taste buds cleansed between tests (water, unsalted bread). The average scores were used for further statistical analysis. The physical and chemical analysis included the determination of malondialdehyde (MDA) (TBARS) by spectrophotometric method (Lambda 25, PerkinElmer, USA), peroxide value according to ISO 3960:2017 **[17]**, and moisture content by the gravimetric method at 105°C to a constant weight. Meat hardness was measured using a TA.XT Plus texture analyser (Stable Micro Systems, Great Britain) at a deformation rate of 1 mm/s. Microbiological studies (total number of microorganisms, CFU/g (colony-forming units per gram)) were carried out on Plate Count Agar A (PC) by ISO 48331:2013 **[18]**.

Statistical Analysis

The SPSS 26.0 software was used for statistical data processing. A one-way analysis of variance (ANOVA) with Tukey's test (significance level $p<0.05$) was used to identify differences between processing methods. The correlation between the shelf life and organoleptic/chemical parameters was assessed by

Pearson's coefficient, and the normality of the distribution was checked by the Shapiro-Wilk test. Measurement errors did not exceed 5%. Compliance with ethical requirements was ensured following the provisions of DSTU ISO 7218:2015 (2017) for the microbiological control of food products. The study did not involve animal experimentation or invasive human exposure, so no ethics committee approval was required.

Results and Discussion

The results of the study reflect changes in the organoleptic characteristics of carp meat depending on the method of heat treatment, the type of packaging and the storage time. Parameters such as texture, taste, smell and colour were assessed on a 5-point scale. The evaluation of organoleptic parameters identified characteristic changes in the quality of fish meat associated with different processing methods: freezing, smoking (hot and cold) and drying. Compared to fresh fillet samples cooked immediately after capture, frozen carp meat showed a decrease in organoleptic scores for all parameters, most notably in terms of smell and colour. This indicates that freezing affected not only the texture but also the aroma profile and appearance of the product, resulting in an overall decrease in consumer appeal **[19]**. However, the taste remained at an acceptable level, which indicates the relative stability of the flavour components under the recommended storage conditions.

Smoking, especially hot smoking, had a positive effect on the flavour and colour of the meat. The highest scores for odour intensity were recorded for hot-smoked samples. This method contributed to the formation of stable flavour compounds and improved the appearance, which resulted in high organoleptic scores. While cold smoking showed slightly lower values, it provided a more delicate flavour profile, which may be desirable for certain consumer categories. This correlated with the results of Ekelemu et al. **[20]**, who showed that smoking in combination with spices not only enhanced the flavour but also significantly extended the shelf life of smoked fish. Similar conclusions are presented by Oli et al. **[21]**, determining that smoke treatment significantly reduces moisture and at the same time increases organoleptic stability compared to fresh samples, while maintaining taste appeal.

Drying resulted in a decrease in all organoleptic parameters, including texture, due to moisture loss and increased stiffness. The worst scores were obtained for samples without process optimisation (i.e., conventional drying), where the lowest overall quality was recorded (Table 1). At the same time, lowering the drying temperature in the optimised mode significantly improved both the taste and texture characteristics of the product compared to the traditional method. Similar results were obtained by Aktaruzzaman et al. **[22]**, demonstrating that the combination of preheating and dense packaging ensures the preservation of the textural and flavour characteristics of tilapia products during storage. The benefits of advanced temperature-controlled drying were also highlighted by Tavares et al. **[23]**, demonstrating the effectiveness of physical innovative technologies in preventing the spoilage of fresh fish.

Table 1. Comparative evaluation of organoleptic characteristics of carp fillets subjected to different processing methods (mean±SD, n=10 panelists, 5-point scale).

Processing method	Texture (±SD)	Taste (±SD)	Odour (±SD)	Colour (±SD)	Overall score (±SD)
Fresh (control, day 0)	4.80±0.20	4.90±0.10	4.70±0.15	4.90±0.10	4.83±0.14
Frozen (1 month)	3.60±0.25	3.80±0.30	3.10±0.28	3.20±0.22	3.43±0.26
Smoked (hot, 6 h, day 0)	4.20±0.18	4.10±0.15	4.50±0.20	4.60±0.17	4.35±0.18
Smoked (cold, 12 h, day 0)	4.00±0.22	3.70±0.25	3.90±0.23	4.10±0.20	3.93±0.22
Dried (traditional, day 0)	3.20±0.30	3.10±0.27	3.00±0.25	3.50±0.29	3.20±0.28
Dried (optimised, day 0)	3.80±0.18	3.80±0.20	3.70±0.17	3.90±0.15	3.80± 0.18

Note: all samples in this table were evaluated within 3 hours after processing to ensure comparability of fresh sensory characteristics. Hot smoking was performed for 6 hours at 80-90°C, cold smoking for 12 hours at 25-30°C. Traditional drying was carried out for 7-10 days at 20-25°C and 60-65% RH; optimised drying was conducted in a drying oven at 35-40°C until 25-30% moisture was reached within 48-60 hours. Scores represent the mean ± standard deviation of ratings given by 10 certified sensory panelists following ISO 4121:2003 **[15]**. According to the scale used, a score of 3.0 or higher indicates that the product is acceptable for consumption. Source: compiled by the authors.

Comparative analysis demonstrated that the organoleptic properties of fish meat varied significantly depending on the processing method. Fresh carp fillet samples after minimal heat treatment received high marks for their natural texture and typical smell but were slightly inferior to smoked versions in terms of taste. Freezing resulted in a decrease in quality, mainly due to a deterioration in texture and smell, while hot smoking provided a high level of taste and aroma. Drying, especially without prior optimisation, had a

negative impact on texture and flavour, but improvements in technology ensured partial compensation for these losses. Similarly, Omoruyi and Omosoh **[24]** reported the effectiveness of combined methods (heat treatment + dehydration) in ensuring the stability of sensory parameters of fish semi-finished products, which confirms the relevance of the approaches used in this study. To visualise the dynamics of aromatic characteristics depending on the processing method and the duration of thermal exposure, a graph was constructed and presented in Figure 1, which shows the relationship between the intensity of the smell and the hours of smoking.

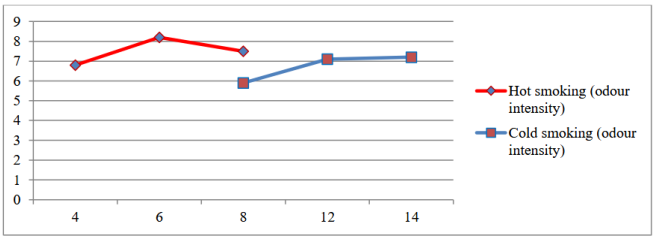


Figure 1. Dependence of fish meat odour intensity on the duration of smoking under different thermal processing conditions. Note: X-axis – smoking duration (in hours); Y-axis – odour intensity (on a 9-point scale). Data for hot smoking (80-90°C) include durations of 4, 6, and 8 hours; data for cold smoking (25-30°C) include 8, 12, and 14 hours. No hot smoking was performed beyond 8 hours – the 14-hour value applies only to cold smoking. Odour intensity was assessed using a 9-point scale by 10 sensory panelists immediately after smoking. Source: compiled by the authors.

The analysis of the graphical dependence of odour intensity on the duration of smoking shows differences in the effect of hot and cold methods on the aromatic properties of fish. In the case of hot smoking, a rapid increase in odour intensity was observed for up to 8 hours, after which the values began to decline. Such dynamics indicate that beyond the optimal interval (6-8 hours), excessive accumulation of smoke components, in particular phenols, leads to an overload of the aroma profile and the appearance of undesirable notes.

Cold smoking is characterised by a gradual increase in odour intensity, which reaches a maximum of 12 hours. After that, the curve stabilises without a significant decrease. This profile is characteristic of delicate processing, which contributes to the formation of a balanced flavour with mild character. In contrast to hot smoking, there is no sharp decline in quality after the peak point, which underlines the stability of the method within the technologically acceptable time.

Thus, hot smoking is effective in achieving intense flavour in a relatively short time but requires precise control of the duration, while cold smoking provides a lasting flavour with longer exposure. The choice of method depends on the target sensory profile and the type of fish being processed.

The study results demonstrated that the processing method has a decisive influence on the organoleptic properties of carp meat. Freezing reduces the quality of texture, colour and smell, although it ensures partial preservation of taste characteristics **[25,26]**. Smoking, especially hot smoking, provides pronounced aromatic and visual benefits, while cold smoking creates a more delicate sensory palette. Drying without optimisation leads to a significant deterioration in texture, but adjusting humidity and temperature can improve quality **[27]**. In general, the most attractive characteristics for the consumer were recorded in hot-smoked samples under optimal technological conditions. The relevance of combining organoleptic, chemical and microbiological methods of quality control for fish products was confirmed by Yu et al. **[28]**, substantiating the benefits of an integrated approach to monitoring the freshness and safety of fish products without freezing.

Storage of processed fish requires precise control of temperature, humidity and time to preserve its nutritional and organoleptic quality **[29, 30]**. The study analysed changes in the physicochemical, textural, microbiological and sensory characteristics of freshwater fish meat depending on the duration of storage using three main processing methods: freezing, smoking and drying.

Storage of fish at -18°C was accompanied by a gradual deterioration of its texture and chemical composition, especially in samples packed traditionally. After 1 month of exposure, these samples showed a partial disruption of the muscle fibre structure, and after 6 months, macroscopic damage, including cracks and a loss of juiciness. These changes were accompanied by a decrease in the proportion of moisture in the tissues and an increase in the stiffness of the meat, which is associated with the degradation of protein structures and ice crystallisation.

Lipid oxidation progressively increased over the storage period, with the rate of TBARS accumulation varying depending on the type of packaging. In conventional packaging, TBARS levels nearly tripled after 6 months. In contrast, the increase did not exceed 40% of the initial values in vacuum packaging and modified atmosphere packaging (50% CO_2, 40% N_2, 10% O_2). Measurements were conducted after 1, 3, and 6 months of frozen storage at -18°C, and each point in Figures 2-4 represents the mean of three

replicates. A similar trend was recorded by Siddiqui et al. [31], who noted a significant deterioration in organoleptic characteristics and an increase in bacterial load during storage of freshwater shrimp at low temperature. A characteristic "fishy" or "fatty acid" flavour, which correlates with TBARS values exceeding 5.0 mg MDA/kg, indicates the onset of oxidative spoilage.

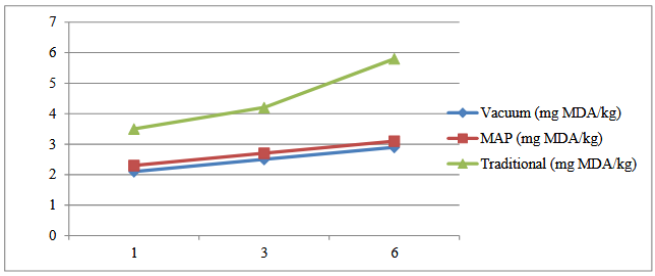


Figure 2. Dynamics of lipid oxidation (TBARS) in carp fillets during frozen storage at -18°C under different packaging conditions. Note: X-axis – storage duration (in months); Y-axis –TBARS (mg MDA/kg); MAP – modified atmosphere packaging. Source: compiled by the authors.

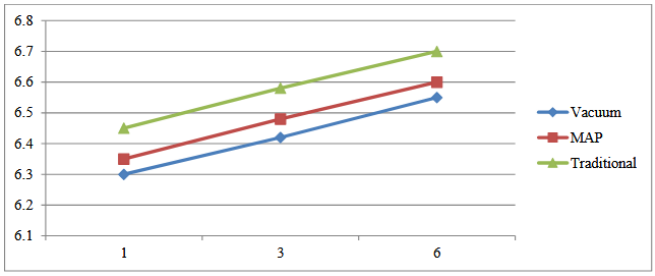


Figure 3. Changes in pH of carp fillets during frozen storage at -18°C under different packaging conditions. Note: X-axis – storage duration (in months); Y-axis – pH. Source: compiled by the authors.

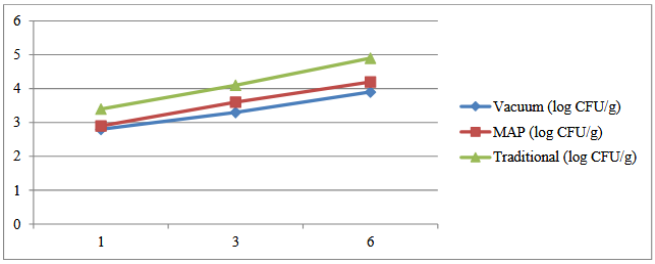


Figure 4. Dynamics of total viable counts (TVC) in carp fillets during frozen storage at -18°C under different packaging conditions. Note: X-axis – storage duration (in months); Y-axis – TVC (log CFU/g). Source: compiled by the authors.

Figure 2 illustrates how lipid oxidation (TBARS) rose gradually over time, with samples in conventional packing showing the highest oxidation levels. The oxidation process was successfully halted by vacuum and MAP packaging. The fillets' pH steadily dropped in Figure 3, with samples kept in conventional packaging experiencing a more noticeable decline, suggesting that the fillets' acidity increased with time. After six months, traditional packaging once again displays the largest microbial load, as seen in Figure 4, which shows the rise of TVC. On the other hand, MAP and vacuum packing showed superior control over microbial development, preserving lower TVC over the course of storage. To complement the visual representation, detailed numerical data for each parameter (TBARS, pH, TVC) by packaging type and storage duration are presented in Table 2.

Table 2. Changes in lipid oxidation (TBARS), pH, and microbial load (TVC) in frozen carp fillets at -18°C depending on packaging type and storage duration.

Storage time	Packaging type	TBARS (mg DA/kg)	pH	TVC (log FU/g)
1 month	Vacuum	2.1±0.2	6.30±0.05	2.8±0.2
	MAP	2.3±0.3	6.35±0.06	2.9±0.2
	Traditional	3.5±0.4	6.45±0.08	3.4±0.3
3 months	Vacuum	2.5±0.2	6.42±0.04	3.3±0.2
	MAP	2.7±0.2	6.48±0.05	3.6±0.2
	Traditional	4.2±0.3	6.58±0.07	4.1±0.3
6 months	Vacuum	2.9±0.3	6.55±0.06	3.9±0.2
	MAP	3.1±0.2	6.60±0.07	4.2±0.2
	Traditional	5.8±0.4	6.70±0.09	4.9±0.3

Note: TBARS – thiobarbituric acid reactive substances; pH – acidity of muscle tissue; TVC – total viable count of microorganisms. Values are expressed as mean ± standard deviation (n=3). MAP – modified atmosphere packaging (50% CO_2, 40% N_2, 10% O_2). Source: compiled by the authors.

The curve has a pronounced linearly increasing character, which indicates a gradual accumulation of secondary lipid oxidation products (malondialdehyde) under conditions of long-term storage at 18°C. Such dynamics are typical for the processes of auto-oxidation of unsaturated fatty acids, which occur even at low temperatures in the presence of residual oxygen. After the third month, the growth rate of TBARS significantly accelerates, which may be due to the exhaustion of the antioxidant potential of tissues and the intensification of radical reactions. Similar observations were recorded by Wei et al. [32], who proved that even under conditions of high hydrostatic pressure, an increase in microbiological risks, deterioration of sensory properties and transformation of the microbial composition of meat occurred during storage of Escolar fillets.

These changes were explained by the spoilage mechanisms described by Green [33], including enzymatic reactions, lipid oxidation and the activity of

specific microflora. Similar dynamics were observed by Elbarbary et al. **[34]**, who found that even with the use of functional additives (e.g., *Moringa oleifera*), long-term storage was accompanied by a gradual degradation of the taste and texture properties of fish products. This is also consistent with the results of Al-Kuraieef **[35]**, who showed that even under gamma irradiation, the preservation of texture, colour, and taste decreased over time, despite the effective inhibition of microflora. Exceeding the level of 5.0 mg MDA/kg at the end of storage indicates a critical decrease in the organoleptic quality of the product and the need to reduce the freezing time or use inhibitory technologies.

The microbiological condition of the frozen samples remained within acceptable limits, but after 6 months, an increase in the total number of mesophilic microbiota was recorded. Psychrotrophic bacteria of the genus *Pseudomonas* showed the greatest resistance, the activity of which led to a gradual increase in the pH of meat, which further reduced the quality of the product.

The quality of smoked fish significantly depended on the storage temperature, duration, and tightness of the packaging. Carp fillets processed by both hot (4, 6, and 8 hours) and cold smoking (8, 12, and 14 hours) were stored at +4°C and at room temperature (20-25°C) and tested at regular 15-day intervals over a period of 90 days. During storage at +4°C, microbiological indicators (including total viable counts, moulds, and *Listeria innocua*) remained within acceptable limits for the first 30 days in all packaging types. However, by day 45, the appearance of microscopic moulds and bacterial contamination (*Listeria innocua*) was observed in samples stored in conventional, less hermetic packaging. These changes were more pronounced in cold-smoked products, indicating a lower bactericidal effect of cold smoking compared to hot smoking. At room temperature (20-25°C), microbiological instability appeared as early as day 10 across all smoking durations and packaging types. *Escherichia coli* was detected in multiple samples, confirming that storing smoked products outside the cold chain is unacceptable. Sensory degradation during storage included a noticeable decline in smoke aroma intensity, attributed to the gradual loss of volatile phenolic compounds. Furthermore, samples stored in conventional or less airtight packaging showed a progressive reduction in sodium content, likely due to salt diffusion into the packaging environment, which negatively affected taste. In contrast, vacuum packaging significantly slowed down these adverse processes, with a reduction in flavour loss of nearly 50% compared to other packaging types. These results are in line with the findings of Aref et al. **[36]**, who demonstrated that food films based on chitosan, nanochitosan, and essential oils can partially delay oxidative and microbiological spoilage of fish meat during cold storage.

Dried fish showed the highest microbiological stability due to low water activity but underwent gradual degradation of the fat fraction. Over the course of 12 months, the peroxide number increased almost threefold, causing the flavour to change from a characteristic one to a bitter one with notes of ageing. This was especially noticeable in samples without hermetic packaging and with poor oxidation protection. When the moisture content was reduced to 18-20%, the meat lost its elasticity and became brittle, with a characteristic tough texture. The same dependence was found by Ramadhan et al. **[37]**, who found that the degree of oxidation of proteins and fats in fish muscles directly depended on the packaging method and the period of cold storage in silver carp fillets. Similar effects of long-term storage were reported by Lithi et al. **[38]**, who, in their study of tilapia fish burgers, found a deterioration in texture characteristics and an increase in residual moisture due to oxidative changes during deep freezing.

In samples where the residual moisture content exceeded 25% due to uneven drying, the growth of moulds, in particular *Aspergillus flavus*, was recorded. The reduction in oxidation intensity and stabilisation of sensory indicators were most clearly observed in samples stored in vacuum packaging or in a MAP, which limited contact with oxygen. The duration of storage is a critical factor that determines the preservation of freshwater fish meat quality after processing **[39, 40]**. Extended data on the effect of time and temperature on the sensory quality of products are provided by Valentim et al. **[41]**, where the effect of the cooking method on texture and fatty acid profile was determined. Frozen samples retained an acceptable level of quality for up to 3 months, after which intense oxidation and texture deterioration began. Smoked products were sensitive to environmental conditions, especially temperature, and required protective packaging to minimise sensory and microbiological losses. Dried fish remained stable during long-term storage but required optimised drying conditions and the use of antioxidants to prevent lipid deterioration. Incorporating the features, the choice of processing method and appropriate packaging should be based on the target shelf life and logistical characteristics of the product.

Packaging is a key element in the storage system of fish products, as it directly affects the rate of lipid

oxidation, microflora development and preservation of sensory properties **[42, 43]**. The study evaluated the impact of three packaging options: vacuum, MAP and traditional (polyethylene, paper) on the quality of fish processed by freezing, smoking and drying.

In samples of frozen fish stored in vacuum packaging at -18°C for 6 months, the level of malondialdehyde (TBARS) was 2.9±0.3 mg/kg, which was 35-40% lower than in control samples in polyethylene (4.8±0.4 mg/kg; $p<0.01$). This indicated an effective inhibition of lipid oxidation due to the absence of oxygen, which catalyses auto-oxidation processes. Textural properties were maintained at a stable level, in particular, the loss of tissue juice did not exceed 12%. In smoked fish, vacuum packaging retained up to 90% of the initial intensity of the smoke flavour after 3 months of storage. The sensory evaluation of the aroma remained high at 4.2±0.3 points.

For dried fish, packaging in MAP with 50% CO_2, 40% N_2 and 10% O_2 was effective. This combination contributed to the inhibition of aerobic microflora. After 9 months of storage, the total number of bacteria did not exceed 2.1±0.2 lg CFU/g, while in traditional packaging this figure reached 4.0±0.3 lg CFU/g. This confirmed the ability of CO_2 to inhibit the metabolic activity of spoilage bacteria of the genus *Pseudomonas* and *Bacillus*. These results correlated with the findings of Kunová et al. **[44]**, who indicated the effectiveness of natural preservatives and modified atmosphere packaging in reducing bacterial contamination.

MAP also effectively slowed down the auto-oxidation of fats: the peroxide number after 12 months of storage did not exceed 14.5±0.6 mEq/kg. For comparison, in samples with traditional packaging, this figure reached 25.3±1.1 mEq/kg. The growth of facultative anaerobic bacteria (*Clostridium spp.*) was recorded, which required preliminary dehydration before packaging. Polyethylene and paper materials did not provide sufficient protection against external factors. In frozen fish packed in polyethylene, the level of TBARS after 3 months was 4.2±0.3 mg/kg, which indicated accelerated lipid oxidation. In addition, protein oxidation was intensified: the content of free amino groups increased from 12.4 to 18.7 μmol/g, which correlated with the appearance of a persistent "fishy" odour.

In the smoked samples, paper packaging caused a significant loss of volatile compounds as the fibrous structure of the paper absorbed the aromatic components. After 30 days, the sensory assessment of aroma decreased from 4.0 to 2.5 points. The dried fish in polyethylene showed increased water activity (Aw up to 0.82), which contributed to the growth of moulds (*Aspergillus*, *Penicillium*) up to 2.5 lg CFU/g within 6 months. To ensure comprehensive coverage of changes in carp meat quality, the study monitored sensory, physicochemical, and microbiological parameters at three storage intervals: 1, 3, and 6 months. However, all significant trends observed between 1 and 3 months are consistent with the patterns described. In addition, for smoked products, the presentation of data focuses on one representative duration for each smoking method (hot smoking – 6 hours; cold smoking – 12 hours), which showed the most balanced sensory properties based on preliminary screening. This decision was made to avoid unnecessary redundancy and to allow for a clearer interpretation of the storage dynamics under controlled conditions. The choice is explicitly aligned with Option 2 proposed by the reviewer: selecting key combinations and presenting complete longitudinal data for them. Regarding the reference to 45 days of storage, we clarify that this interval was used in microbiological and sensory stability testing for smoked samples, which were evaluated at 15-day intervals up to 90 days (i.e., 15, 30, 45, 60, 75, 90 days). This short-term monitoring corresponds to real-world shelf-life expectations for smoked fish and does not contradict the general 1-3-6-month storage framework applied to frozen and dried products. The inclusion of a 6-month period for smoked products was performed exclusively for experimental purposes to observe longterm degradation trends, even beyond commercially relevant storage durations. As noted in the text and figure legends, results beyond 60 days for smoked fish should be interpreted with caution and are not intended to recommend extended shelf-life practices (Table 3).

Table 3. Comparative effectiveness of packaging types for different fish processing methods after 6 months of storage.

Processing method	Variant	Type of packaging	TBARS (mg/kg)	Odour loss (%)	Microbial load (log CFU/g)	Sensory score (5-point scale)
Freezing	–	Vacuum	2.9±0.3	10	3.0±0.3	4.0±0.2
		MAP	3.1±0.2	15	3.1±0.2	3.9±0.2
		Traditional	4.2±0.3	50	4.0±0.3	2.5±0.3
Hot smoking (6 h)	smoked 6 h	Vacuum	–	12	2.9±0.2	4.2±0.3
		MAP	–	15	2.1±0.2	3.8±0.2
		Traditional	–	60	4.2±0.3	2.5±0.4
Cold smoking (12 h)	smoked 12 h	Vacuum	–	20	3.4±0.3	3.6±0.3
		MAP	–	25	3.0±0.3	3.2±0.3
		Traditional	–	65	4.5±0.4	2.2±0.4
Drying	Traditional	Vacuum	–	–	2.2±0.2	3.6±0.3
		MAP	14.5±0.6	–	2.1±0.2	3.5±0.2
		Traditional	25.3±1.1	–	2.5±0.2	2.4±0.3
	Optimised	Vacuum	–	–	2.0±0.2	3.8±0.2
		MAP	13.9±0.5	–	2.1±0.2	3.6±0.2
		Traditional	24.6±1.0	–	2.6±0.3	2.6±0.3

Note: TBARS values are expressed in mg of malondialdehyde per kg of product. Odour loss (%) is based on comparison with the fresh control group. Microbial load reflects total viable count (TVC). Sensory score is the average of 10 certified panelists on a 5-point hedonic scale. Measurements were taken after 6 months of storage at +4°C for freezing and smoked samples, and at +20°C for dried samples under controlled humidity. A 6-month storage period is presented here for comparative purposes, although typical market shelf life for smoked fish is ≤45-60 days. Therefore, sensory and microbiological changes beyond this period should be interpreted cautiously Source: compiled by the authors.

The analysis confirmed the high efficiency of vacuum packaging and modified gas atmosphere for stabilising the organoleptic, physicochemical and microbiological properties of carp meat. Similar results were presented by Vijayakumar et al. **[45]**, who determined that modern barrier packaging materials can significantly reduce the loss of sensory properties of fish products, ensuring their stability during storage. This correlated with the results of Kazam et al. **[46]**, proving the effectiveness of neem oil-based nanoemulsions as a natural barrier to preserve the sensory characteristics of Oreochromis niloticus fillets, particularly when stored in hermetic conditions. Vacuum packaging minimised lipid oxidation, ensured flavour stability and reduced tissue juice loss. MAP proved to be particularly effective for dried products due to its ability to inhibit microbial growth and inhibit the auto-oxidation of fats. In contrast, traditional materials did not provide an adequate barrier to oxygen and moisture, leading to sensory and microbiological degradation of the product. This correlated with the results of a study by Salman et al. **[47]**, noting that even when recycled materials were used (e.g., silver carp fishcakes), shelf life had a critical impact on the taste, smell and microbiological stability of the product. Therefore, the choice of packaging should be based on the type of processing, shelf life, and stability of the fat and protein fractions of the product.

Based on the results, the data were statistically processed to quantify the impact of processing methods, packaging types and storage time on the quality of carp meat.

ANOVA showed statistically significant differences between the three main processing methods (freezing, smoking, drying) for all organoleptic criteria ($p<0.05$). In particular, the level of lipid oxidation (TBARS) showed a significant difference between the groups ($F=45.6$; $p<0.001$). The lowest values were typical for smoked samples, and the highest for dried ones. Tukey's test confirmed that the largest statistical gap was observed between frozen and dried samples (difference in mean=5.3 mg/kg; 95% confidence interval: 4.8-5.8).

Correlation analysis showed strong correlations between storage time and degradation changes in fish products. For example, in frozen samples, TBARS levels had a high positive correlation with storage time ($r=0.85$; $p<0.01$), indicating a steady increase in oxidation products over time. At the same time, the intensity of natural aroma decreased with increasing storage time ($r=-0.72$; $p<0.05$), which correlated with the loss of volatile components.

For smoked samples, a decrease in flavour intensity was observed after 30-45 days of storage at 4°C, which is possibly determined by the migration of dissolved components into the packaging environment or structural changes in protein fibres. In the samples stored at room temperature, a high positive correlation between storage time and *Listeria* spp. Contamination was observed ($r=0.91$; $p<0.001$), indicating that such conditions are unsuitable for long-term storage. In the dried samples, a strong positive correlation was observed between storage time and peroxide number ($r=0.94$; $p<0.01$), indicating the accumulation of primary fat oxidation products.

Similar trends were recorded in a study by Elbarabary et al. **[34]** on the effect of combined processing and packaging methods on the quality of tilapia fillets during storage. The study determined that a combination of vacuum packaging and hot smoking can significantly reduce lipid oxidation and stabilise organoleptic characteristics for up to 60 days. At the same time, traditional packaging methods, even when stored at low temperatures, did not provide adequate protection against microbial contamination and texture degradation. Comparison with the current results demonstrates the consistency of the conclusions regarding the effectiveness of barrier packaging and technologies with a pronounced antimicrobial and antioxidant effect. Thus, the results of the study confirm that optimal preservation of carp meat quality is achieved by combining an effective method of heat treatment (in particular, hot smoking or dehydration in a controlled environment) with a barrier type of packaging (vacuum or MAP). This approach ensures a reduction in oxidation intensity, stability of sensory characteristics and slowing down of microbiological processes even during longterm storage.

Limitations

One of the study's limitations is that it concentrated solely on carp, which might not be applicable to other fish species with various traits. The lengthy storage periods (six months for smoking, for example) exceed the usual commercial shelf life, which may restrict their usefulness. Furthermore, the study's geographic reach was limited, and more investigation is required to take seasonal and regional differences in fish quality into account. Studies using natural antioxidants, innovative packaging materials, and calculating the economic efficiency of selected technological solutions are promising.

Conclusion

The study determined that the combination of processing method and type of packaging significantly affects the organoleptic and physicochemical quality indicators of carp meat during storage. The highest total score was given to carp fillets processed by hot smoking and stored in vacuum packaging with 4.8 points in the first month of storage and 4.5 points in the sixth month. The least favourable results were recorded for the samples after freezing and storage in traditional packaging: 4.0 and 2.5 for the first and sixth months of storage. In vacuum-packed fillets, regardless of the type of processing, the total number of microorganisms did not exceed 4.5 log CFU/g even after 6 months of storage, while in traditional packaging this figure reached 6.7 log CFU/g. Packaging in a modified gas atmosphere (50% CO_2, 40% N_2, 10% O_2) showed intermediate efficiency, reducing the rate of lipid oxidation by an average of 30% compared to traditional packaging. The correlation analysis revealed a close relationship between the duration of storage and the increase in malondialdehyde levels ($r=0.89$, $p<0.01$). The practical significance of the study is determined by the possibility of adapting the results to the conditions of industrial production to ensure the long-term stability of the quality of fish products.

CRediT

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References

1. The State of World Fisheries and Aquaculture 2024: Blue Transformation in Action; 2024. Available at: https://doi.org/10.4060/cd0683en.
2. OECD-FAO Agricultural Outlook 2024-2033; 2024. Available at: https://www.oecd.org/en/publications/oecd-fao-agricultural-outlook-2024-2033_4c5d2cfben.html.
3. Dossybayev K, Amandykova M, Orakbayeva A, et al. Genome-Wide Association Studies Revealed Several Candidate Genes of Meat Productivity in Saryarka Fat-Tailed Coarse-Wool Sheep Breed. Gen. 2024;15(12):1549.
4. Adamkulova Ch, Akylbekova N, Omurova S, Mambetova A, Mambetkazieva N. Digital farming platforms as a tool for strengthening cooperation between Kyrgyzstan and China: Potential and prospects. Ekon APK. 2025;32(2):63-75.

5. Yaroshevych T, Pakholiuk V. Ukrainian fish and seafood market: Challenges and prospects. Comm Bull. 2020;13(1):40-51.
6. The EU Fish Market: 2023 Edition; 2023. Available at: https://eumofa.eu/documents/20124/35668/EFM2023_EN.pdf/95612366-79d2-a4d1-218b8089c8e7508c?t=1699541180521.
7. Fotina T, Yarmoshenko Yu, Dudnyk Ye, Kovalenko L, Negreba Y. Results of iodine-based treatment application in carp aquaculture within closed water systems. Sci Horiz. 2024;27(9): 20-31.
8. Liasota V, Bukalova N, Bohatko N, et al. The risk-based control of the safety and quality of freshwater fish for sale in the agri-food market. Potr Slovak J Food Sci. 2023;17:200-216.
9. Duarte AM, Silva F, Pinto FR, Barroso S, Gil MM. Quality assessment of chilled and frozen fish – Mini review. Foods. 2020;9(12):1739.
10. Walayat N, Tang W, Wang X, et al. Quality evaluation of frozen and chilled fish: A review. eFood. 2023;4(1):1-8.
11. Bernardo YAA, Rosario DKA, Delgado IF, Conte-Junior CA. Fish quality index method: Principles, weaknesses, validation, and alternatives – A review. Compr Rev Food Sc Food Saf. 2020;19(5):2657-2676.
12. Xie X, Zhai X, Chen M, et al. Effects of frozen storage on texture, chemical quality indices and sensory properties of crisp Nile tilapia fillets. Aquacult Fish. 2023;8(6):626-633.
13. ISO 8586:2023: Sensory analysis – Selection and training of sensory assessors; 2023. Available at: https://www.iso.org/standard/76667.html.
14. ISO 11136:2014: Sensory analysis – Methodology – General guidance for conducting hedonic tests with consumers in a controlled area; 2014. Available at: https://www.iso.org/standard/50125.html.
15. ISO 4121:2003: Sensory analysis – Guidelines for the use of quantitative response scales; 2003. Available at: https://www.iso.org/standard/33817.html.
16. ISO 13299:2016: Sensory analysis – Methodology – General guidance for establishing a sensory profile; 2016. Available at: https://www.iso.org/standard/58042.html.
17. ISO 3960:2017: Animal and vegetable fats and oils – Determination of peroxide value – Iodometric (visual) endpoint determination; 2017. Available at: https://www.iso.org/standard/71268.html.
18. ISO 4833-1:2013: Microbiology of the food chain – Horizontal method for the enumeration of microorganisms. Part 1: Colony count at 30°C by the pour plate technique; 2013. Available at: https://www.iso.org/standard/53728.html.
19. Yevlash VV, Gazzavi-Rohozina LV, Pilyugina IS, Senogogova LI. Food raw materials and product safety. Kharkiv: World of Books; 2021.
20. Ekelemu JK, Nwabueze AA, Irabor AE, Otuye NJ. Spicing: A means of improving organoleptic quality and shelf life of smoked catfish. Sci Afr. 2021;13:e00930.
21. Oli AU, Okeke PA, Oli CC, Ibe FN, Okogwu JD. Comparative study of the proximate composition and sensory evaluation of fresh and smoke-dried fish species from Omambala River, Anambra State, Nigeria. Newport Int J Biol Appl Sci. 2024;5(2):44-50.
22. Aktaruzzaman M, Hani U, Sayeed MA, et al. Quality assessment and shelf-life of processed tilapia (Oreochromis niloticus) fish sticks: Laboratory based study. Arch Agr Environ Sci. 2022;7(4):514-520.
23. Tavares J, Martins A, Fidalgo LG, et al. Fresh fish degradation and advances in preservation using physical emerging technologies. Foods. 2021;10(4):780.
24. Omoruyi K, Omosoh C. Nutritional value and organoleptic assessment of burgers made with some commercially important fish species. J Agr Environ. 2024;20(2):283-295.
25. Sansyzbayeva B, Adylkanova S, Sadykulov T, Kırıkçı K. Determination of CAST/MspI Gene Polymorphism and its Effects on 180-Day Weight in Meat Production Line of Kazakh Saryarka Lambs. Pak J Zoo. 2024;56(6):2977-2980.
26. Uazhanova R, Moldakhmetova Z, Tungyshbayeva U, et al. Ensuring quality and safety in the production and storage of poultry meat. Casp J Envir Sci. 2024;22(5):1271-1277.
27. Tian Y, Xiong Z, Yuan L, et al. Evaluate the freshness and shelf life of refrigerated salted perch (Perca fluviatilis) focusing on the flavor change. Food Control. 2025;176:111394.
28. Yu D, Wu L, Regenstein JM, et al. Recent advances in quality retention of non-frozen fish and fishery products: A review. Crit Rev Food Sci Nutr. 2020;60(10):1747-1759.
29. Uazhanova RU, Kazhymurat AT, Tungyshbayeva UO, Saez AC. Development and implementation of haccp plan based on fmea in collagen hydrolizate industry. J Hyg Eng Des. 2019;28:13-21.
30. Adamkulova Ch, Zhakshylykova K, Asanov R,

Akylbekova N, Mambetkazieva N. Dairy industry as a driver of economic growth. Sci Horiz. 2025;28(4):70-83.

31. Siddiqui N, Chowdhury MR, Hasan J, et al. Organoleptic, biochemical and microbiological changes of freshwater prawn (Macrobrachium rosenbergii) in different storage conditions. Bangladesh Res Publ J. 2011;5(3):234-244.
32. Wei P, Lee Y, Kang C, Tsai Y, Arakawa O. High-hydrostatic pressure on Escolar meats: Impact on the microbial, chemical, and organoleptic qualities and bacterial community by using highthroughput sequencing. LWT. 2024;215:117196.
33. Green DP. Sensory evaluation of fish freshness and eating qualities. In: C Alasalvar, F Shahidi, K Miyashita, U Wanasundara, eds. Handbook of Seafood Quality, Safety and Health Applications. Hoboken: Blackwell Publishing Ltd.; 2010:29-38.
34. Elbarabary BK, Maky HH, Gomaa R, Hassan MA. Evaluation of the quality of fish burger formulated with Moringa oleifera leaves during frozen storage. Egypt J Aquatic Biol Fish. 2024;28(3):473-490.
35. Al-Kuraieef AN. Microbiological, chemical and organoleptic evaluation of fresh fish and its products irradiated by gamma rays. Potr Slovak J Food Sci. 2021;15:95-100.
36. Aref S, Habiba R, Morsy N, Abdel-Daim M, Zayet F. Improvement of the shelf life of grey mullet (Mugil cephalus) fish steaks using edible coatings containing chitosan, nanochitosan, and clove oil during refrigerated storage. Food Prod Process Nutr. 2022;4:27.
37. Ramadhan AH, Dawei Y, Hlaing KSS, et al. Effects of packaging and storage time on lipid and protein oxidation and modifications in texture characteristics of refrigerated grass carp (Ctenopharyngodon idellus) fish muscles. Int J Food Sci Technol. 2025;60(2):1-11.
38. Lithi U, Faridullah M, Uddin M, Mehbub M, Zafar M. Quality evaluation of fish burger from tilapia (Oreochromis mossambicus) during frozen storage (-18°c). J Bangladesh Agr Univ. 2020;18(2):524-528.
39. Aljizani N, Shafi M. Using various fish processing techniques to maintain flesh quality and shelf life: An updated review. J King Abdulaziz Univ Meteorol Environ Arid Land Agr. 2024;33(1):29-46.
40. Verkhivker Ya, Myroshnichenko O. Modern types of polymer containers for canned food. Comm Bull. 2021;14(1):6-17.
41. Valentim J, Afonso C, Gomes R, et al. Influence of cooking methods and storage time on colour, texture, and fatty acid profile of a novel fish burger for the prevention of cognitive decline. Heliyon. 2024;10(5):e27171.
42. Madani M, Shevchenko R, Garkovich O. Bioconversion of the fat-containing phase of effluents of fish processing enterprises into a feed additive. Ukrainian Black Sea Reg Agrar Sci. 2021;25(3):54-65.
43. Pashova S, Radev R, Dimitrov G. Physical properties of edible films with different composition. Qual Acc Succ. 2019;20(171):152-156.
44. Kunová S, Sendra E, Haščík P, et al. Influence of essential oils on the microbiological quality of fish meat during storage. Animals. 2021;11(11):3145.
45. Vijayakumar R, Sharadbhai BR, Elavarasan K, et al. Physical and sensory quality of processed and packaged fish products. In: AK Shukla, CN Ravishankar, eds. Quality Analysis and Packaging of Seafood Products. Amsterdam: Academic Press; 2025:335-355.
46. Kazam J, Iqbal KJ, Shafi A, Majeed U, Lackner M. Neem oil (Azadirachta indica L.) response surface methodology (RSM)-optimized nanoemulsions for sensory quality preservation of Oreochromis niloticus fillets. Biology. 2025;14(4):400.
47. Salman ASM, Hussain A, Sultana S, et al. Effect of storage conditions on the quality attributes of value-added cutlets produced from low-cost silver carp (Hypophthalmichthys molitrix). J Aquat Food Prod Technol. 2022;31(5):430-444.

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