processes

MDPI

Article

Development and Quality Characterization of Seasoned Grilled Conger Eel (*Conger myriaster*) Fillets for Home Meal Replacement Applications

Maya Malikhaturohmah [1,†], Seok Jeong Lee [2,†], Hye-Ryeon An [1], Dong Myeong Kang [1], Antony Rinthiya Mariadavid [1], Jae Hak Sohn [3,4], Khawaja Muhammad Imran Bashir [1,*] and Jae-Suk Choi [1,*]

[1] Department of Seafood Science and Technology, The Institute of Marine Industry, Gyeongsang National University, Tongyeong 53064, Republic of Korea; mayamalikha@gnu.ac.kr (M.M.); grace@gnu.ac.kr (H.-R.A.); dongmyeong@gnu.ac.kr (D.M.K.); antonyrinthiya@gnu.ac.kr (A.R.M.)
[2] Woojin Moolsan Co., Ltd., Tongyeong 53000, Republic of Korea; woojinri@naver.com
[3] Department of Food Science and Culinary Arts, College of Health and Welfare, Silla University, Busan 46958, Republic of Korea; jhsohn@silla.ac.kr
[4] Seafood Research Center, Industry-Academic Cooperation Foundation, Silla University, Busan 49277, Republic of Korea
* Correspondence: imranbashir@gnu.ac.kr (K.M.I.B.); jsc1008@gnu.ac.kr (J.-S.C.); Tel.: +82-55-772-9140 (K.M.I.B.); +82-55-772-9142 (J.-S.C.)
† These authors contributed equally to this work.

Abstract

Home meal replacement (HMR) products have become increasingly popular because of their convenience and ability to provide nutritionally balanced meals. This study developed seasoned grilled conger eel (*Conger myriaster*) fillets for HMR applications and evaluated their nutritional quality, safety, and storage stability during frozen storage. The seasoned grilled conger eel fillets were prepared by boiling at 100 ± 10 °C, oven grilling under optimized conditions (200 °C for 10 min), and freezing at −25 °C. Nutritional composition, fatty acid and amino acid profiles, physicochemical properties, microbiological quality, safety, and sensory characteristics were evaluated. The seasoned grilled conger eel fillets contained 17.7 g 100 g^{-1} crude protein and were rich in glutamic acid (2670.0 mg 100 g^{-1}), lysine (1700.0 mg 100 g^{-1}), and aspartic acid (1656.6 mg 100 g^{-1}). The lipid profile showed monounsaturated (2663.7 mg 100 g^{-1}), saturated (1584.1 mg 100 g^{-1}), and polyunsaturated fatty acids (1553.9 mg 100 g^{-1}). Heavy metals and radionuclides were not detected in the raw conger eel fillets. During 180 days of storage at −23, −18, and −13 °C, thiobarbituric acid reactive substances, total bacterial count, and total volatile basic nitrogen increased gradually but remained within acceptable limits, reaching 0.41 mg MDA kg^{-1}, 1.92–2.11 log CFU g^{-1}, and 7.58–7.82 mg 100 g^{-1}, respectively. Samples stored at −23 °C generally retained quality and sensory attributes better than those stored at higher temperatures (−13 and −18 °C). The model-based shelf-life of the seasoned grilled conger eel fillets was estimated at 25 months at −18 °C. Overall, the findings demonstrate the nutritional characteristics and frozen storage quality of seasoned grilled conger eel fillets, supporting their potential use as a seafood component in HMR applications.

Keywords: frozen storage stability; home meal replacement (HMR); lipid oxidation; sensory quality; shelf-life assessment

Check for updates

Academic Editor: Dariusz Dziki

Received: 12 September 2026
Revised: 18 October 2026
Accepted: 26 October 2026
Published: 29 October 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Rapid urbanization, changing dietary habits, and increasingly time-constrained consumer lifestyles have driven growing demand for convenient, ready-to-eat food products. [1]. As a result, home meal replacement (HMR) products have emerged as an important sector within the food industry because they provide convenience while maintaining nutritional and sensory quality [2]. Seafood products are well suited for HMR development because they supply vitamins and minerals alongside protein, amino acids, and fatty acids (such as omega-3) [3–5]. To obtain these nutritional benefits, a weekly seafood intake of approximately 225 g is generally recommended for adults, whereas higher intakes ranging from 225 to 340 g are suggested for individuals during pregnancy or lactation and children [6]. Beyond their nutritional value, value-added seafood products have been considered an effective strategy for improving the utilization of marine resources while simultaneously meeting evolving consumer preferences for convenient and functional food products [7]. Therefore, the development of nutritionally valuable seafood products that can be conveniently prepared, stored, and consumed is of practical importance for expanding seafood-based HMR applications.

Conger eel (*Conger myriaster*) is widely consumed in East Asian countries, particularly in South Korea and Japan, due to its nutritional properties, soft texture, and distinctive flavor [8,9]. It contains considerable amounts of protein and lipids, including physiologically beneficial fatty acids, which contribute to its nutritional importance [9]. However, similar to many marine fish species, conger eel is highly perishable because of its biochemical composition and relatively high lipid content [10]. Lipid oxidation, protein degradation, and microbial activity can rapidly reduce product quality during processing, storage, and distribution, leading to undesirable changes in flavor, odor, texture, and nutritional value [11]. For HMR applications, controlling these deterioration processes is essential to maintaining product quality during storage and distribution [3]. Consequently, appropriate processing conditions and preservation strategies are necessary to develop seasoned grilled conger eel fillets with desirable quality characteristics and storage stability. Despite the established consumption of conger eel, its conversion into a standardized, ready-to-cook or ready-to-eat HMR format requires simultaneous consideration of processing conditions, nutritional characteristics, food safety, and quality retention during storage under frozen conditions.

Grilling is a widely employed thermal processing technique in the preparation of meat [12] and fish products [13], and it is commonly applied to eel products [9] because it enhances flavor, texture, and overall sensory acceptability through the development of roasted aromas, characteristic flavors, and surface browning [14]. Grilling at elevated temperatures facilitates Maillard browning and lipid oxidation; both play a critical role in developing desirable color and flavor characteristics [15]. Grilled eel is one of the most common forms of eel consumption and is highly preferred by consumers because of its characteristic aroma and complex flavor profile [16]. Nevertheless, thermal processing at high temperatures may also alter nutritional composition by affecting amino acid stability and fatty acid profiles, particularly through degradation or oxidation of heat-sensitive compounds [17]. In HMR products, pre-cooking and the application of sauces during grilling may also influence the nutritional composition. Therefore, characterizing the nutritional composition of seasoned grilled conger eel fillets is important for evaluating the nutritional characteristics and suitability of HMR products. In this context, optimization of the grilling process based on sensory acceptability can help establish appropriate processing conditions that provide desirable sensory characteristics and consistent product quality for HMR development.

Frozen storage is a widely adopted preservation approach that effectively extends the shelf life of seafood [18], including seafood-based HMR products. Freezing suppresses microbial growth, biochemical reactions, and enzymatic processes, thereby delaying quality deterioration during storage [10,18]. However, prolonged frozen storage may still induce undesirable quality changes, including protein denaturation, texture softening, drip loss after thawing, and lipid oxidation [19,20]. These changes can negatively affect both sensory quality and nutritional value [20]. Although studies have investigated quality changes in raw conger eel during storage [21], relatively limited information is available regarding the quality characteristics of seasoned grilled conger eel fillets during prolonged frozen storage, particularly for HMR applications. Furthermore, comprehensive evaluations integrating physicochemical indicators such as thiobarbituric acid reactive substances (TBARS), total volatile basic nitrogen (TVBN), and pH together with sensory quality changes during storage remain insufficiently explored for grilled conger eel products. Despite the established use of freezing and conventional quality indicators in seafood preservation, limited information is available on storage stability and quality characteristics of seasoned grilled *C. myriaster* developed specifically for HMR applications. Comprehensive evaluation of nutritional, microbiological, physicochemical, and sensory characteristics at different frozen storage temperatures is therefore important for assessing the quality retention and storage stability of this product and its suitability for HMR applications.

In addition to quality evaluation, food safety is a critical consideration in the development of seafood-based HMR products [22]. Marine organisms may accumulate hazardous substances such as radioactive contaminants and heavy metals from the surrounding environment, which may pose potential risks to human health [23]. Moreover, microbiological contamination remains an important indicator of product safety and hygienic quality during processing and storage [24,25]. Microbiological parameters, including total coliform group (TCG) and total bacterial count (TBC), are commonly used to evaluate microbial safety and hygienic conditions in processed seafood products [9,24]. Therefore, chemical contaminant screening of raw eel materials and microbiological assessment of processed eel fillets can provide complementary information relevant to the development of seafood products for HMR applications. Accordingly, combining contaminant screening of the raw material with microbiological, physicochemical, and sensory monitoring during frozen storage provides a more comprehensive assessment of the practical suitability of the developed product.

Accordingly, the present study aimed to develop seasoned grilled conger eel (*C. myriaster*) fillets for HMR applications by optimizing grilling conditions and evaluating quality characteristics of the finished product. The optimal grilling time and temperature were estimated through response surface methodology (RSM), using overall sensory acceptability as the response variable. Comparative analyses of raw conger eel fillets and frozen seasoned grilled conger eel fillets were conducted to assess differences in their nutritional characteristics and the measured concentrations of fatty acids, free amino acids, and amino acids. The raw conger eel fillets were assessed for heavy metals and radionuclides, while the seasoned grilled conger eel fillets were evaluated for changes in physicochemical properties, microbiological quality, and sensory attributes over a 180-day period at −23, −18, and −13 °C. By integrating process optimization, nutritional characterization, contaminant screening, and multidimensional quality assessment during frozen storage, this study aimed to characterize the developed seasoned grilled *C. myriaster* fillets for potential use as a seafood component in HMR applications. The findings provide practical information on processing conditions, nutritional characteristics, food safety-related parameters, and storage stability that can contribute to the further development of value-added eel-based foods for HMR applications.

2. Materials and Methods

2.1. Raw Materials and Reagents

Fresh conger eel (*Conger myriaster*) was obtained from Woojin Moolsan Co., Ltd., Tongyeong, Republic of Korea. The head, tail, viscera, blood, and excess fat were removed during the preparation of eel fillets. Raw and pre-cooked butterfly-cut conger eel fillets were supplied by Woojin Moolsan as separate sample groups. All sauce ingredients and seasonings were prepared in-house. All analytical- and HPLC-grade reagents were purchased from Sigma-Aldrich, St. Louis, MO, USA.

2.2. Production Process of Seasoned Grilled Conger Eel Fillets

Fresh conger eel fillets were pre-cooked in a primary sauce consisting of soy sauce, white sugar, water, and mirin at 100 ± 10 °C for 40 ± 5 min. The pre-cooked fillets weighed 120 ± 10 g each before grilling. Following pre-cooking, the fillets underwent oven grilling for 10 min at 200 °C, with repeated applications of a secondary sauce composed of soy sauce, white sugar, spirits, and mirin. The sauce was applied twice to the skin side prior to grilling. After flipping the fillets, the sauce was applied three additional times to the flesh side prior to further grilling. The product formulation consisted of 98.5% conger eel, 0.5% white sugar, 0.5% soy sauce, 0.2% spirits, and 0.3% mirin (*w*/*w*). No additional oil was used during pre-cooking or grilling. Following grilling, the fillets were transferred to a blast chiller (0–3 °C) for 30–35 min. They were subsequently transferred to a freezer (−25 °C) and held for 12–14 h. The frozen products were partially thawed to facilitate slicing and portioning, vacuum-packaged in polyethylene (PE) film using a double-chamber vacuum packaging machine (Dongbang Automatic Packaging Machinery, Bucheon, Republic of Korea), and subsequently refrozen at −25 °C. The packaged products then underwent metal detection, followed by final packaging and storage at −18 °C. The overall product preparation process is presented in Figure S1.

2.3. Grilling Conditions Optimization by Response Surface Methodology

The optimal grilling conditions for seasoned grilled conger eel fillets were estimated through response surface methodology (RSM). Grilling temperature (180–220 °C) and processing time (8–12 min) were selected as independent variables. Their corresponding actual and coded levels are provided in Table S1. The experimental design in this study comprised 11 experimental runs, as outlined in Table S2. Overall acceptability obtained from the sensory evaluation was used as the response variable (Y1) for RSM optimization (Tables S2 and S3). Minitab 14 (Minitab Inc., State College, PA, USA) was utilized for experimental design and regression analysis, while Maple 7 (Waterloo Maple Inc., Waterloo, ON, Canada) was employed to visualize the response surfaces in three dimensions.

2.4. Quality Analysis of Seasoned Grilled Conger Eel Fillets

2.4.1. Nutritional Composition Analysis

The nutritional constituents were evaluated by comparing nutritional parameters. These parameters included energy, carbohydrates, sugars, crude protein, saturated fat, crude fat, vitamin D, cholesterol, calcium, potassium, sodium, and iron. Nutritional values were reported per 100 g of sample on a wet-weight basis. The nutritional composition was evaluated following the methods published by the Association of Official Analytical Chemists (AOAC) [26].

2.4.2. Analysis of Amino Acid Composition

Amino acid composition of raw and seasoned grilled conger eel fillets was analyzed according to AOAC official methods [26]. For hydrolysis, samples were treated with 15 mL of 6 N HCl under adjusted pressure for 24 h at 110 °C in an oven (VS-1202D3; Vision Scientific Co., Ltd., Bucheon, Republic of Korea). Following filtration, an EYELA N-1000 rotary evaporator (Riakikai Co., Ltd., Tokyo, Japan) was used to concentrate the hydrolysates under vacuum at 55 °C to remove residual HCl and moisture. Following dilution of the residues with sodium citrate buffer (pH 2.2), the resulting solution was passed through a 0.45 µm filter. Amino acid composition was then analyzed with a Biochrom 20 automatic amino acid analyzer (Pharmacia Biotech Ltd., Cambridge, UK) and reported as mg 100 g^{-1} of sample (wet weight).

2.4.3. Analysis of Fatty Acid Composition

Fatty acids in the raw and seasoned grilled conger eel fillets were analyzed according to AOAC official methods [26] by GC-2010 Plus gas chromatography (Shimadzu Corp., Kyoto, Japan) with a flame ionization detector (FID). Lipid extraction was carried out with a chloroform–methanol solvent method reported by Bligh and Dyer [27], followed by conversion to fatty acid methyl esters (FAMEs) through methylation [28]. For FAME separation, the gas chromatograph was fitted with an SP-2560 capillary column (Supelco, Bellefonte, PA, USA) with length (100 m), film thickness (0.25 µm), and internal diameter (0.25 mm), and the oven temperature was set at 240 °C. Fatty acid identities were established through chromatographic retention-time matching against reference FAME mixtures, and expressed as mg 100 g^{-1} of sample (wet-weight).

2.4.4. Physicochemical Properties and Sensory Evaluation

pH Measurement

Following the Korean Ministry of Food and Drug Safety (MFDS) protocol [29], pH measurements of the seasoned grilled conger eel fillets were taken using a Starter 2100 glass-electrode pH meter (Ohaus, Seoul, Republic of Korea). Samples (5 g) were homogenized with distilled water and filtered prior to pH measurement.

Total Volatile Basic Nitrogen (TVBN)

The Conway microdiffusion technique was applied for quantifying TVBN content in accordance with MFDS guidelines [30]. Two portions of homogenized sample (10 g each) were processed separately by adding 50 mL of distilled water. Both mixtures underwent extraction for 30 min before filtration. Sample extracts were transferred into Conway diffusion chambers and maintained at 25 °C for 60 min to facilitate diffusion of volatile nitrogen compounds. The volatile nitrogen compounds were absorbed in (0.01 N) H_2SO_4, and the remaining acid was titrated with (0.01 N) NaOH for quantification. TVBN values were reported in mg 100 g^{-1} of sample.

Thiobarbituric Acid Reactive Substances (TBARS)

The TBARS content of the seasoned grilled conger eel fillets was analyzed following Mohibbullah et al. [31]. The sample (5 g) was treated with 12.5 mL of a 20% trichloroacetic acid (TCA) solution in 2 M phosphoric acid. Homogenization was performed for 1 min at 1000 rpm with a homogenizer (SHG-15D; SciLab Co., Ltd., Seoul, Republic of Korea). Volume was adjusted to 25 mL with distilled water, and centrifuged at 4 °C and 1600× g (Labogene 416; Gyrozen Co., Ltd., Gimpo, Republic of Korea) for 15 min. The supernatant subsequently underwent filtration through 70 mm filter paper (Toyo Roshi Kaisha Ltd., Tokyo, Japan). For the thiobarbituric acid (TBA) reaction, equal volumes (2 mL each)

of the filtrate and 0.005 M TBA solution were mixed and heated at 95 °C in a water bath (JSWB-22TL; JS Research Inc., Gongju, Republic of Korea) for 30 min. The absorbance was measured using a SPECTROstar Nano microplate reader (BMG Labtech, Ortenberg, Germany) at 530 nm after cooling to room temperature, and TBARS levels were reported as mg MDA kg^{-1} of sample.

Sensory Evaluation

Appearance, odor, taste, texture, and overall acceptability of seasoned grilled conger eel fillets were evaluated by 21 trained panelists from the Industry-Academic Cooperation Foundation of Silla University, Busan, Republic of Korea. A 9-point hedonic scale was used for assessment, with ratings extending from 1 ("extremely disliked") to 9 ("extremely liked") [32]. Assessments were performed on storage days 0, 30, 60, 90, 120, 150, and 180. Scores provided by each panelist were documented individually ($n = 21$). The study protocol was approved by the Institutional Review Board of Silla University (Approval No. 1041449-202604-HR-009).

2.5. Safety Evaluation Analysis of Seasoned Grilled Conger Eel Fillets

2.5.1. Heavy Metals Analysis

The heavy metals (arsenic, cadmium, mercury, and lead) concentrations in raw conger eel fillets were determined according to AOAC official methods [26]. Samples were digested using a MARS6 microwave (CEM Corporation, Matthews, NC, USA) at 450 °C until complete decomposition was achieved. Following digestion, 5 N nitric acid was used to dissolve the samples, and the final volume was adjusted to 20 mL. The concentrations of cadmium, arsenic, and lead were measured using inductively coupled plasma analysis (Optima 5300 DV; PerkinElmer, Waltham, MA, USA), while mercury was analyzed separately with a MA-2 mercury analyzer (Nippon Instruments Corporation, Tokyo, Japan). Heavy metal concentrations were reported as mg kg^{-1} of sample.

2.5.2. Radioactivity Evaluation

The radioactivity of raw conger eel fillets was assessed for iodine-131, cesium-134, and cesium-137 by ORTEC GEM-60195-P high-purity Germanium gamma-ray spectrometry (Ortec, Oak Ridge, TN, USA), following MFDS guidelines [33]. For measurement, the raw fillets were enclosed in stainless steel casts and subjected to counting periods exceeding 10,000 s. The radioactivity concentrations were estimated depending on counting efficiency, counting duration, sample mass, emission ratio, and peak area. The measurements were carried out at Pusan National University's Radiation Analysis Center in Busan, Republic of Korea. Radionuclide activity concentrations were expressed in Bq kg^{-1}.

2.5.3. Microbiological Analysis

Microbiological analysis of seasoned grilled conger eel fillets was conducted to determine TBC and TCG, following the official AOAC procedures [26]. Samples (10 g) were collected aseptically, homogenized in 90 mL of sterile saline, and ten-fold serial diluted. The solution was inoculated onto dry rehydratable film media (Coliform/*Escherichia coli* Count Plates and Aerobic Count Plates; 3M Co., Ltd., Saint Paul, MN, USA). The inoculated plates were incubated at 35–37 °C for 24–48 h and bacterial colonies were counted following the official AOAC procedures [26] and Schumacher et al. [34].

2.6. Storage Stability Evaluation of Seasoned Grilled Conger Eel Fillets

The stability of seasoned grilled conger eel fillets was evaluated over 180 days at three frozen-storage temperatures (−23, −18, and −13 °C), with measurements performed on days 0, 30, 60, 90, 120, 150, and 180. Microbiological quality was assessed using TBC and TCG, whereas physicochemical quality was evaluated by measuring pH, TVBN, and TBARS. Sensory attributes were evaluated throughout storage. Before sensory assessment, seasoned grilled conger eel fillets were thawed for 2 min in a microwave (LG Electronics Co., Ltd., Seoul, Republic of Korea). Shelf-life predictions were generated with the Visual Shelf-Life Simulator for Foods (VSLSF) according to MFDS guidance [35]. Changes in TBC, TVBN, and overall sensory acceptability were analyzed by fitting zero-order and first-order kinetic models. Storage-time regression parameters were determined at each temperature, and their temperature dependence was assessed by Arrhenius regression to obtain model-based shelf-life estimates at the intended frozen-storage temperature of −18 °C. To account for possible temperature variations during distribution and consumer storage, the selected shelf-life estimate was multiplied by a safety factor (0.80).

2.7. Statistical Analysis

Three distinct fillets from each group were analyzed individually ($n = 3$ per group), with each fillet representing a sampling unit. The pre-cooked fillets were subsequently grilled, and no individual-fish-level pairing between raw and grilled samples was documented. Nutritional, amino acid, free amino acid, and fatty acid composition were compared between raw conger eel fillets and seasoned grilled conger eel fillets using an independent-samples *t*-test. Sensory data ($n = 21$) were analyzed by two-way repeated-measures analysis of variance (ANOVA) to assess the effects of storage temperature, storage period, and their interaction, followed by Bonferroni-adjusted pairwise comparisons. The pH, TVBN, TBARS, and TBC data ($n = 3$) were subjected to two-way ANOVA to analyze the impact of storage temperature, storage period, and their interaction. Experimental data are expressed as means ± standard deviation (SD). Statistical analysis was done using SPSS software version 27.0 (IBM Corp., Armonk, NY, USA). Tukey's post hoc test was used for pairwise comparisons when statistically significant main effects were observed, with statistical significance determined at $p < 0.05$.

3. Results

3.1. Grilling Conditions for Seasoned Grilled Conger Eel Fillets

As illustrated by the three-dimensional (3D) response surface plot, overall sensory acceptability improved as the grilling temperature and duration approached their optimal levels but subsequently decreased when the processing conditions became more intensive (Figure 1). The response surface exhibited greater curvature along the temperature axis than along the processing time axis, suggesting that grilling temperature had a stronger influence on overall acceptability. A second-order polynomial model incorporating the quadratic, linear, and interaction effects of grilling time and temperature was fitted to the overall acceptability data (Table S3). The coefficient of determination (R^2), predicted R^2, and adjusted R^2 were 95.69%, 75.59%, and 91.38%, respectively. As shown in Table S4, the ANOVA results indicated that the fitted regression model was significant ($p = 0.002$). Both the linear ($p < 0.001$) and quadratic ($p = 0.001$) effects of grilling temperature on overall acceptability were statistically significant. In contrast, neither the linear ($p = 0.166$) nor quadratic ($p = 0.767$) effect of grilling time, nor the interaction between time and temperature ($p = 0.402$), reached statistical significance. The model predicted the optimal grilling condition to be 201.4 °C for 10.5 min, corresponding to an estimated overall acceptability score of 8.39 (Table S5). The experimental validation result showed an

overall acceptability score of 8.47 ± 0.48 under the predicted optimal condition (Table S5). However, considering industrial applicability and process convenience, the condition was adjusted to 200 °C for 10 min and selected as the final wet-lab processing condition. This adjusted condition remained within the optimal range predicted by the model. The most desirable appearance was observed in the eel fillet grilled at 200 °C for 10 min, consistent with the optimal condition predicted by the model.

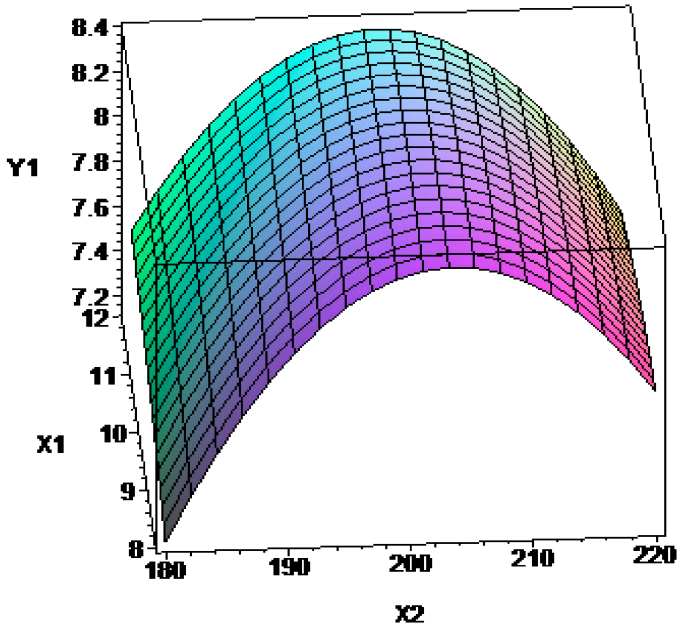

Figure 1. Three-dimensional (3D) visualization of the response surface showing the influence of temperature and processing time on the sensory overall acceptability of seasoned grilled conger eel fillets. Y_1: Sensory overall acceptability (score); X_1: Time (min); X_2: Temperature (°C).

3.2. Nutritional Characterization of Seasoned Grilled Conger Eel Fillets

3.2.1. Nutritional and Mineral Composition

The nutritional properties of raw and seasoned grilled conger eel fillets, expressed per 100 g of sample, are presented in Table 1. Compared with raw conger eel fillets, seasoned grilled conger eel fillets exhibited higher values for energy (156.6 vs. 88.4 kcal 100 g^{-1}), crude protein (17.7 vs. 16.7 g 100 g^{-1}), crude fat (7.4 vs. 2.4 g 100 g^{-1}), saturated fat (2.0 vs. 0.7 g 100 g^{-1}), cholesterol (168.5 vs. 111.6 mg 100 g^{-1}), sodium (220.5 vs. 88.5 mg 100 g^{-1}), calcium (88.5 vs. 62.2 mg 100 g^{-1}), vitamin D (0.90 vs. 0.60 µg 100 g^{-1}), and carbohydrates and sugars (4.8 and 0.0 g 100 g^{-1} for each), with each pair representing the seasoned grilled conger eel fillets and raw conger eel fillets, respectively. In contrast, potassium concentrations were lower (190.9 vs. 304.7 mg 100 g^{-1}), whereas iron concentrations remained unchanged at 0.20 mg 100 g^{-1}. The corresponding percentages of recommended daily intake based on FDA [36] and MFDS [37] standards are also included. Statistical analysis showed significant differences between raw conger eel fillets and seasoned grilled conger eel fillets in energy, carbohydrate, sugars, crude protein, crude fat, saturated fat, cholesterol, sodium, calcium, and potassium contents ($p < 0.05$). In contrast, neither iron nor vitamin D content differed significantly ($p > 0.05$).

Table 1. Nutritional composition of raw and seasoned grilled conger eel fillets.

Items	Unit	Raw Conger Eel Fillet			Grilled Conger Eel Fillet			DRV	
		Amount	% of FDA RV	% of MFDS RV	Amount	% of FDA RV	% of MFDS RV	FDA [1]	MFDS [2]
Energy	kcal	88.4 ± 1.8 [b]	–	–	156.6 ± 3.4 [a]	–	–	–	–
Carbohydrate	g	0.0 [b]	0.0	0.0	4.8 ± 0.10 [a]	1.7	1.5	>275	>324
Sugars	g	0.0 [b]	0.0	0.0	4.8 ± 0.10 [a]	9.6	4.8	<50	<100
Crude Protein	g	16.7 ± 0.29 [b]	33.4	30.4	17.7 ± 0.31 [a]	35.4	32.2	>50	>55
Crude Fat	g	2.4 ± 0.06 [b]	3.1	4.4	7.4 ± 0.15 [a]	9.5	13.7	<78	<54
Saturated Fat	g	0.7 ± 0.02 [b]	3.5	4.7	2.0 ± 0.05 [a]	10.0	13.3	<20	<15
Trans Fat	g	–	–	–	–	–	–	<2	–
Dietary Fiber	g	–	–	–	–	–	–	>28	>25
Cholesterol	g	111.6 ± 4.1 [b]	37.2	37.2	168.5 ± 5.9 [a]	56.2	56.2	<300	<300
Sodium	mg	88.5 ± 3.4 [b]	3.8	4.4	220.5 ± 7.4 [a]	9.6	11.0	<2300	<2000
Calcium	mg	62.2 ± 2.5 [b]	4.8	8.9	88.5 ± 3.4 [a]	6.8	12.6	>1300	>700
Potassium	mg	304.7 ± 9.7 [a]	6.5	8.7	190.9 ± 6.5 [b]	4.1	5.5	>4700	>3500
Iron	mg	0.20 ± 0.02 [a]	1.1	1.7	0.20 ± 0.02 [a]	1.1	1.7	>18	>12
Vitamin D	µg	0.60 ± 0.14 [a]	3.0	6.0	0.90 ± 0.19 [a]	4.5	9.0	>20	>10

[1] According to the US-FDA [36]; [2] According to article 6 of the advertising and labeling of food [37]; MFDS: Ministry of Food and Drug Safety; FDA: Food and Drug Administration; RV: Recommended value. DRV: Daily recommended value. Values are presented as means ± SD ($n = 3$). Lowercase superscript letters (a–b) within the same row show significant differences between raw and seasoned grilled conger eel fillets ($p < 0.05$). A dash (–) indicates not detected. Nutritional values are expressed per 100 g of sample on a wet-weight basis.

3.2.2. Amino Acid Composition

Amino acid composition of raw and seasoned grilled conger eel fillets is presented in Table 2. Overall, seasoned grilled conger eel fillets exhibited higher concentrations of most amino acids compared with raw conger eel fillets on a per-100-g wet-weight basis. Compared with raw conger eel fillets, seasoned grilled conger eel fillets showed higher concentrations of sulfur-containing amino acids (SAAs; cystine and methionine: 522.2 vs. 453.5 mg 100 g^{-1}) and aromatic amino acids (AAAs; tyrosine and phenylalanine: 1205.2 vs. 970.4 mg 100 g^{-1}). Total non-essential amino acids (NAAs; 9158.5 vs. 7378.5 mg 100 g^{-1}), and essential amino acids (EAAs; 7566.2 vs. 5502.0 mg 100 g^{-1}) were also higher, along with the EAA/NAA ratio (0.83 vs. 0.75). The corresponding recommended daily intake values for amino acids in human nutrition are also provided, following the recommenda tions jointly published by the World Health Organization [38]. Statistical analysis showed significant differences between raw conger eel fillets and seasoned grilled conger eel fillets in the concentrations of most amino acids, including SAA, AAA, EAA, and NAA ($p < 0.05$). However, no significant variations were noted for proline or glycine between raw conger eel fillets and seasoned grilled conger eel fillets ($p > 0.05$).

Table 2. Amino acid composition of raw and seasoned grilled conger eel fillets.

Amino Acid	Raw Conger Eel Fillet (mg 100 g^{-1})	Grilled Conger Eel Fillet (mg 100 g^{-1})	Recommended Daily Requirement [1] (g 70 kg^{-1} BW)
Histidine	244.8 ± 5.4 ^{b}	501.1 ± 10.0 ^{a}	1.05
Isoleucine	573.0 ± 10.9 ^{b}	761.8 ± 13.7 ^{a}	2.10
Leucine	968.9 ± 15.5 ^{b}	1292.3 ± 19.4 ^{a}	4.13
Lysine	1157.3 ± 16.2 ^{b}	1700.0 ± 22.1 ^{a}	3.15
Threonine	529.3 ± 10.1 ^{b}	782.6 ± 14.1 ^{a}	1.61
Valine	604.8 ± 10.9 ^{b}	801.0 ± 13.6 ^{a}	2.73
Cystine	133.5 ± 3.2 ^{b}	153.0 ± 3.5 ^{a}	
Methionine	320.0 ± 7.0 ^{b}	369.2 ± 7.8 ^{a}	
SAA	453.5 ± 7.7 ^{b}	522.2 ± 8.5 ^{a}	1.54
Tyrosine	414.2 ± 8.7 ^{b}	562.1 ± 11.2 ^{a}	
Phenylalanine	556.2 ± 10.6 ^{b}	643.1 ± 11.6 ^{a}	
AAA	970.4 ± 13.7 ^{b}	1205.2 ± 16.1 ^{a}	2.66
∑EAA	5502.0 ± 33.4 ^{b}	7566.2 ± 43.2 ^{a}	18.97
Aspartic acid	1187.0 ± 17.8 ^{b}	1656.6 ± 23.2 ^{a}	
Serine	476.2 ± 9.5 ^{b}	709.8 ± 13.5 ^{a}	
Glutamic acid	2158.8 ± 25.9 ^{b}	2670.0 ± 32.0 ^{a}	
Proline	700.2 ± 11.9 ^{a}	714.9 ± 12.2 ^{a}	
Glycine	1161.1 ± 17.4 ^{a}	1174.0 ± 17.6 ^{a}	
Alanine	935.7 ± 15.0 ^{b}	1095.1 ± 16.4 ^{a}	
Arginine	759.5 ± 13.7 ^{b}	1138.1 ± 18.2 ^{a}	
∑NAA	7378.5 ± 44.0 ^{b}	9158.5 ± 52.9 ^{a}	
EAA/NAA	0.75 ± 0.01 ^{b}	0.83 ± 0.01 ^{a}	

[1] Ref. [38]; AAA: Aromatic amino acids; SAA: Sulfur amino acids; NAA: Non-essential amino acids; EAA: Essential amino acids; BW: Body weight. Values are presented as means ± SD ($n = 3$). Lowercase superscript letters (a–b) within the same row indicate significant differences between raw and seasoned grilled conger eel fillets ($p < 0.05$). Amino acid concentrations are expressed per 100 g of sample on a wet-weight basis.

3.2.3. Free Amino Acid Composition

Free amino acid composition of raw and seasoned grilled conger eel fillets is presented in Table 3. The observed trend differed from that of total amino acids, with most free amino acids detected in both tested groups showing lower concentrations in the seasoned grilled conger eel fillets. Marked reductions were observed in ammonium chloride (971.4 to 22.1 mg 100 g^{-1}), L-alanine (311.9 to 9.2 mg 100 g^{-1}), and L-lysine (239.1 to 17.1 mg 100 g^{-1}). Other compounds showing decreased levels included taurine, glutamic acid, γ-amino-n-butyric acid, β-alanine, δ-hydroxylysine, L-phenylalanine, L-leucine, L-methionine, L-valine, L-cystine, L-tyrosine, L-ornithine, and L-isoleucine. Among free amino acids detected in both sample groups, L-histidine was higher in the seasoned grilled conger eel fillets (6.6 mg 100 g^{-1}) than in the raw conger eel fillets (3.2 mg 100 g^{-1}). Several compounds, including L-carnosine, L-citrulline, L-homocystine, L-proline, L-serine, L-threonine, glycine, and cystathionine, were detected only in the seasoned grilled conger eel fillets. In contrast, O-phospho-L-serine, L-sarcosine, DL-β-aminoisobutyric acid, 1-methyl-L-histidine, and L-arginine were detected only in the raw conger eel fillets. Among the free amino acids

detected, all showed significant differences between raw conger eel fillets and seasoned grilled conger eel fillets ($p < 0.05$).

Table 3. Free amino acid composition of raw and seasoned grilled conger eel fillets.

Free Amino Acid	Raw Conger Eel Fillet (mg 100 g^{-1})	Grilled Conger Eel Fillet (mg 100 g^{-1})
O-Phospho-L-serine	0.6 ± 0.05	–
Taurine	126.9 ± 3.4 [a]	75.9 ± 3.4 [b]
O-Phosphoethanolamine	–	–
Urea	–	–
L-Aspartic acid	–	–
Hydroxy-L-proline	–	–
L-Threonine	–	2.5 ± 0.15
L-Serine	–	1.0 ± 0.05
L-Asparagine	–	–
L-Glutamic acid	9.2 ± 0.63 [a]	5.1 ± 0.24 [b]
L-Sarcosine	4.6 ± 0.34	–
L-α-Aminoadipic acid	–	–
L-Proline	–	6.3 ± 0.35
Glycine	–	12.6 ± 0.66
L-Alanine	311.9 ± 7.7 [a]	9.2 ± 0.59 [b]
L-Citrulline	–	1.2 ± 0.07
L-α-Aminoiso-n-butyric acid	20.4 ± 0.78 [a]	0.3 ± 0.02 [b]
L-Valine	99.4 ± 4.9 [a]	4.0 ± 0.21 [b]
L-Cystine	3.3 ± 0.22 [a]	0.2 ± 0.02 [b]
L-Methionine	24.0 ± 1.3 [a]	1.4 ± 0.07 [b]
Cystathionine	–	2.8 ± 0.20
L-Isoleucine	44.0 ± 1.8 [a]	1.9 ± 0.11 [b]
L-Leucine	54.9 ± 2.6 [a]	5.7 ± 0.36 [b]
L-Tyrosine	1.9 ± 0.12 [a]	0.4 ± 0.03 [b]
β-Alanine	59.7 ± 2.7 [a]	4.9 ± 0.25 [b]
L-Phenylalanine	4.9 ± 0.33 [a]	1.7 ± 0.08 [b]
DL-β-Aminoisobutyric acid	1.7 ± 0.12	–
L-Homocystine	–	0.2 ± 0.02
γ-Amino-n-butyric acid	7.0 ± 0.39 [a]	1.0 ± 0.06 [b]
Ethanolamine	–	–
Ammonium chloride	971.4 ± 15.3 [a]	22.1 ± 1.1 [b]
δ-Hydroxylysine	161.4 ± 5.5 [a]	1.9 ± 0.12 [b]
L-Ornithine	55.1 ± 2.1 [a]	4.2 ± 0.22 [b]
L-Lysine	239.1 ± 6.7 [a]	17.1 ± 0.84 [b]
1-Methyl-L-histidine	4.8 ± 0.33	–
L-Histidine	3.2 ± 0.15 [b]	6.6 ± 0.05 [a]
L-Tryptophan	–	–
3-Methyl-L-histidine	–	–
L-Anserine	–	–
L-Carnosine	–	51.5 ± 2.8
L-Arginine	6.1 ± 0.45	–

Values are presented as means ± SD ($n = 3$). Lowercase superscript letters (a–b) within the same row show significant differences between raw and seasoned grilled conger eel fillets ($p < 0.05$). A dash (–) indicates not detected. Free amino acid concentrations are presented per 100 g of sample on a wet-weight basis.

3.2.4. Fatty Acid Composition

Fatty acid composition of raw and seasoned grilled conger eel fillets is presented in Table 4. Overall, seasoned grilled conger eel fillets exhibited higher concentrations of most fatty acids compared with raw conger eel fillets on a per-100-g wet-weight basis, whereas gamma-linolenic acid showed a lower concentration (8.3 and 6.4 mg 100 g^{-1}, respectively). Neither myristoleic acid nor heneicosanoic acid was detected in raw conger eel fillets. However, their respective concentrations in seasoned grilled conger eel fillets were 7.3 and 3.2 mg 100 g^{-1}. Among saturated fatty acids (SFAs), palmitic acid predominated in both fillet groups, with concentrations of 403.3 mg/100 g in raw conger eel fillets and 1227.4 mg 100 g^{-1} in seasoned grilled conger eel fillets. Total SFA concentrations were 571.1 and 1584.1 mg 100 g^{-1}, respectively. Among monounsaturated fatty acids (MUFAs), oleic acid was the main component in both fillet groups, with concentrations of 610.6 mg 100 g^{-1} in raw conger eel fillets and 2042.2 mg 100 g^{-1} in seasoned grilled conger eel fillets. Total MUFA concentrations were 816.0 and 2663.7 mg 100 g^{-1}, respectively. Among the polyunsaturated fatty acids (PUFAs), docosahexaenoic acid (DHA) was present at the highest concentration in both sample groups, measuring 398.2 mg 100 g^{-1} in raw conger eel fillets and 929.1 mg 100 g^{-1} in seasoned grilled conger eel fillets. For eicosapentaenoic acid (EPA), the measured concentrations were 121.8 mg 100 g^{-1} in raw conger eel fillets and 284.2 mg 100 g^{-1} in seasoned grilled conger eel fillets. Total n-3 PUFA concentrations were 535.1 and 1277.7 mg 100 g^{-1}, respectively. In the n-6 PUFA group, linoleic acid was the dominant fatty acid, with concentrations of 33.3 and 81.1 mg 100 g^{-1} in raw conger eel fillets and seasoned grilled conger eel fillets, respectively. Total n-6 PUFA concentrations were 85.1 and 276.2 mg 100 g^{-1}, while total PUFA concentrations were 620.2 and 1553.9 mg 100 g^{-1}, respectively. Statistical analysis showed significant differences between raw conger eel fillets and seasoned grilled conger eel fillets for all fatty acids detected in both sample groups ($p < 0.05$). Fatty acids detected in only one sample group were not subjected to statistical comparison.

3.3. Storage Stability of Seasoned Grilled Conger Eel Fillets

3.3.1. Sensory Properties During Storage

Sensory scores for seasoned grilled conger eel fillets generally declined, with some fluctuations, throughout the 180-day evaluation at all three tested temperatures (Table 5). The seasoned grilled conger eel fillets showed the most pronounced decline in sensory quality, particularly in taste and texture, both of which reached scores of 7.13 on day 180 at −13 °C. The seasoned grilled conger eel fillets stored at −18 °C also showed reductions in sensory scores, with odor and texture decreasing to 7.05 and 7.22, respectively. In contrast, the seasoned grilled conger eel fillets stored at −23 °C generally showed higher scores for several sensory attributes toward the end of storage, although most attributes decreased below 8.0 by day 180. Taste showed the lowest score at this temperature, reaching 7.23. On day 180, the overall acceptability scores were 7.34 for samples stored at −13 °C, 7.47 at −18 °C, and 7.51 at −23 °C. Statistical analysis showed that storage period significantly affected all sensory attributes ($p < 0.05$). Storage temperature significantly affected appearance and texture ($p < 0.05$), whereas taste and overall acceptability were significantly affected by storage period alone ($p < 0.05$). A significant temperature × storage period interaction was noted for odor ($p < 0.05$), with Bonferroni-adjusted pairwise comparisons indicating significant differences among storage temperatures at day 120 ($p < 0.05$). No significant temperature × storage period interactions were observed for overall acceptability, texture, taste, or appearance ($p > 0.05$).

Table 4. Fatty acid composition of raw and seasoned grilled conger eel fillets.

Fatty Acid	Shorthand	Raw Conger Eel Fillet (mg 100 g^{-1})	Grilled Conger Eel Fillet (mg/100 g^{-1})
Butyric acid	C4:0	–	–
Caproic acid	C6:0	–	–
Caprylic acid	C8:0	–	–
Capric acid	C10:0	–	–
Undecanoic acid	C11:0	–	–
Lauric acid	C12:0	–	–
Tridecanoic acid	C13:0	–	–
Palmitic acid	C16:0	403.3 ± 8.9 ^{b}	1227.4 ± 22.1 ^{a}
Pentadecanoic acid	C15:0	9.5 ± 0.62 ^{b}	27.4 ± 1.32 ^{a}
Margaric acid	C17:0	11.1 ± 0.67 ^{b}	24.8 ± 1.24 ^{a}
Stearic acid	C18:0	98.3 ± 3.7 ^{b}	214.4 ± 5.4 ^{a}
Arachidic acid	C20:0	7.7 ± 0.52 ^{b}	16.6 ± 0.91 ^{a}
Heneicosanoic acid	C21:0	–	3.2 ± 0.27
Behenic acid	C22:0	1.8 ± 0.16 ^{b}	4.7 ± 0.35 ^{a}
Tricosanoic acid	C23:0	37.0 ± 1.7 ^{b}	61.2 ± 2.4 ^{a}
Lignoceric acid	C24:0	2.4 ± 0.20 ^{b}	4.4 ± 0.35 ^{a}
∑SFA		571.1 ± 9.8 ^{b}	1584.1 ± 23.0 ^{a}
Myristoleic acid	C14:1	–	7.3 ± 0.47
Pentadecenoic acid	C15:1	–	–
Palmitoleic acid	C16:1	139.3 ± 4.2 ^{b}	414.3 ± 9.1 ^{a}
Margaroleic acid	C17:1	11.2 ± 0.65 ^{b}	30.1 ± 1.38 ^{a}
Oleic acid	C18:1	610.6 ± 11.6 ^{b}	2042.2 ± 32.7 ^{a}
Trans oleic acid	C18:1	8.5 ± 0.53 ^{b}	12.3 ± 0.74 ^{a}
Eicosenic acid	C20:1	36.7 ± 1.7 ^{b}	131.0 ± 3.8 ^{a}
Docosenoic acid	C22:1	9.7 ± 0.62 ^{b}	26.5 ± 1.30 ^{a}
∑MUFA		816.0 ± 12.5 ^{b}	2663.7 ± 34.2 ^{a}
Trans linoleic acid	C18:2 (n-6)	4.4 ± 0.34 ^{b}	11.7 ± 0.71 ^{a}
Linoleic acid	C18:2 (n-6)	33.3 ± 1.7 ^{b}	81.1 ± 3.2 ^{a}
Eicosadienoic acid	C20:2 (n-6)	16.2 ± 0.89 ^{b}	57.2 ± 2.5 ^{a}
Gamma-linolenic acid	C18:3 (n-6)	8.3 ± 0.55 ^{a}	6.4 ± 0.45 ^{b}
Eicosatrienoic acid	C20:3 (n-6)	3.2 ± 0.27 ^{b}	52.8 ± 2.4 ^{a}
Arachidonic acid	C20:4 (n-6)	–	–
Docosadienoic acid	C22:2 (n-6)	19.7 ± 1.0 ^{b}	67.0 ± 2.5 ^{a}
∑n-6		85.1 ± 2.3 ^{b}	276.2 ± 5.4 ^{a}
Alpha-linolenic acid	C18:3 (n-3)	10.5 ± 0.63 ^{b}	50.5 ± 2.2 ^{a}
Eicosatrienoic acid	C20:3 (n-3)	4.6 ± 0.35 ^{b}	13.9 ± 0.81 ^{a}
Eicosapentaenoic acid	C20:5 (n-3)	121.8 ± 3.8 ^{b}	284.2 ± 6.8 ^{a}
Docosahexaenoic acid	C22:6 (n-3)	398.2 ± 9.2 ^{b}	929.1 ± 17.7 ^{a}
∑n-3		535.1 ± 9.9 ^{b}	1277.7 ± 19.1 ^{a}
∑PUFA		620.2 ± 10.2 ^{b}	1553.9 ± 19.8 ^{a}
Total fatty acid (mg/100 g)		2007.3 ± 18.9 ^{b}	5801.7 ± 45.7 ^{a}

Values are presented as means ± SD ($n = 3$). MUFA: Monounsaturated fatty acid; SFA: Saturated fatty acid; PUFA: Polyunsaturated fatty acid. Lowercase superscript letters (a–b) within the same row show significant differences between raw and seasoned grilled conger eel fillets ($p < 0.05$). Dash (–) indicates not detected. Fatty acid concentrations are expressed per 100 g of sample on a wet-weight basis.

Table 5. Sensory properties of seasoned grilled conger eel fillets stored at different temperatures.

Temperature	Day	Appearance	Taste	Odor	Texture	Overall Acceptability
−13 °C	0	8.50 ± 0.64 ^{abB}	8.50 ± 0.58 ^{a}	8.40 ± 0.45 ^{aA}	8.50 ± 0.53 ^{aB}	8.47 ± 0.48 ^{a}
	30	8.50 ± 0.47 ^{aB}	8.40 ± 0.73 ^{ab}	8.17 ± 0.69 ^{abA}	8.17 ± 0.68 ^{abB}	8.31 ± 0.82 ^{a}
	60	8.17 ± 0.81 ^{abB}	8.17 ± 0.46 ^{ab}	8.00 ± 0.81 ^{abA}	8.07 ± 0.45 ^{aB}	8.10 ± 0.59 ^{a}
	90	7.98 ± 0.60 ^{bB}	7.65 ± 0.82 ^{bc}	8.07 ± 0.57 ^{aA}	7.90 ± 0.79 ^{abB}	7.90 ± 0.71 ^{ab}
	120	7.48 ± 0.74 ^{abB}	7.57 ± 0.65 ^{cd}	8.40 ± 0.74 ^{aA}	7.48 ± 0.61 ^{bcB}	7.73 ± 0.54 ^{b}
	150	8.30 ± 0.42 ^{abB}	7.22 ± 0.54 ^{e}	7.33 ± 0.50 ^{cA}	7.13 ± 0.86 ^{cB}	7.50 ± 0.87 ^{bc}
	180	7.80 ± 0.87 ^{bB}	7.13 ± 0.89 ^{de}	7.30 ± 0.86 ^{bcA}	7.13 ± 0.57 ^{cB}	7.34 ± 0.64 ^{c}
−18 °C	0	8.50 ± 0.64 ^{abAB}	8.50 ± 0.58 ^{a}	8.40 ± 0.45 ^{abA}	8.50 ± 0.53 ^{aAB}	8.47 ± 0.48 ^{a}
	30	8.50 ± 0.69 ^{aAB}	8.50 ± 0.77 ^{ab}	8.50 ± 0.78 ^{abA}	7.92 ± 0.46 ^{abAB}	8.35 ± 0.76 ^{a}
	60	8.17 ± 0.78 ^{abAB}	8.17 ± 0.49 ^{ab}	8.40 ± 0.54 ^{aA}	8.17 ± 0.82 ^{aAB}	8.22 ± 0.61 ^{a}
	90	8.08 ± 0.51 ^{bAB}	7.95 ± 0.84 ^{bc}	8.03 ± 0.90 ^{abcA}	8.07 ± 0.65 ^{abAB}	8.03 ± 0.88 ^{ab}
	120	8.40 ± 0.90 ^{abAB}	7.57 ± 0.57 ^{cd}	7.73 ± 0.67 ^{bcB}	7.65 ± 0.50 ^{bcAB}	7.84 ± 0.53 ^{b}
	150	8.30 ± 0.65 ^{abAB}	7.13 ± 0.72 ^{e}	7.63 ± 0.48 ^{cdA}	7.40 ± 0.88 ^{cAB}	7.62 ± 0.69 ^{bc}
	180	7.97 ± 0.44 ^{bAB}	7.63 ± 0.44 ^{de}	7.05 ± 0.72 ^{dA}	7.22 ± 0.60 ^{cAB}	7.47 ± 0.44 ^{c}
−23 °C	0	8.50 ± 0.64 ^{abA}	8.50 ± 0.58 ^{a}	8.40 ± 0.45 ^{abA}	8.50 ± 0.53 ^{aA}	8.47 ± 0.48 ^{a}
	30	8.33 ± 0.58 ^{aA}	8.33 ± 0.79 ^{ab}	8.37 ± 0.85 ^{abcdA}	8.43 ± 0.43 ^{abA}	8.37 ± 0.57 ^{a}
	60	8.33 ± 0.84 ^{abA}	8.00 ± 0.52 ^{ab}	8.33 ± 0.52 ^{acA}	8.40 ± 0.77 ^{aA}	8.27 ± 0.73 ^{a}
	90	8.07 ± 0.49 ^{bA}	8.15 ± 0.87 ^{bc}	8.17 ± 0.75 ^{abcdA}	8.15 ± 0.62 ^{abA}	8.13 ± 0.85 ^{ab}
	120	8.40 ± 0.76 ^{abA}	7.90 ± 0.61 ^{cd}	7.82 ± 0.64 ^{cdeB}	7.73 ± 0.85 ^{bcA}	7.96 ± 0.60 ^{b}
	150	8.30 ± 0.62 ^{abA}	7.28 ± 0.76 ^{e}	7.63 ± 0.87 ^{bdeA}	7.52 ± 0.56 ^{cA}	7.68 ± 0.67 ^{bc}
	180	8.13 ± 0.86 ^{bA}	7.23 ± 0.48 ^{de}	7.38 ± 0.56 ^{eA}	7.30 ± 0.71 ^{cA}	7.51 ± 0.51 ^{c}

Values are presented as means ± SD ($n = 21$). Lowercase (a–e) and uppercase (A–B) superscript letters show significant variations according to Bonferroni-adjusted pairwise comparisons ($p < 0.05$). For appearance and texture, lowercase and uppercase letters show significant variations among storage periods and storage temperatures, respectively. For taste and overall acceptability, lowercase letters show significant variations among storage periods. For odor, Lowercase and uppercase letters show significant variations among storage periods and storage temperatures, respectively, reflecting a significant temperature × storage period interaction.

3.3.2. Variations in pH During Storage

The pH of seasoned grilled conger eel fillets during storage remained relatively stable, with only slight variations observed among storage temperatures (Figure 2). The seasoned grilled conger eel fillets stored at −13 °C and −18 °C exhibited minor fluctuations within the range of 6.83–6.88. A slight increase during the early storage period was observed, followed by small decreases, with values increasing again toward the end of storage. The seasoned grilled conger eel fillets stored at −23 °C showed minimal variation in pH, which remained between 6.82 and 6.88 throughout storage. Statistical analysis revealed a notable impact of storage period and a significant temperature × storage period interaction ($p < 0.05$), whereas no significant impact of temperature was observed ($p > 0.05$).

3.3.3. Variations in TVBN Values

The TVBN content of seasoned grilled conger eel fillets increased progressively during storage, with similar trends observed across all storage temperatures (Figure 3). The seasoned grilled conger eel fillets stored at −13 °C and −18 °C showed continuous increases, reaching 7.82 mg 100 g^{-1} at day 180. The seasoned grilled conger eel fillets stored at −23 °C exhibited a similar trend but showed a slightly lower final value of 7.58 mg 100 g^{-1}. Statistical analysis indicated a significant effect of storage period on

TVBN values ($p < 0.05$), whereas neither the main effect of storage temperature nor its interaction with storage period reached statistical significance ($p > 0.05$).

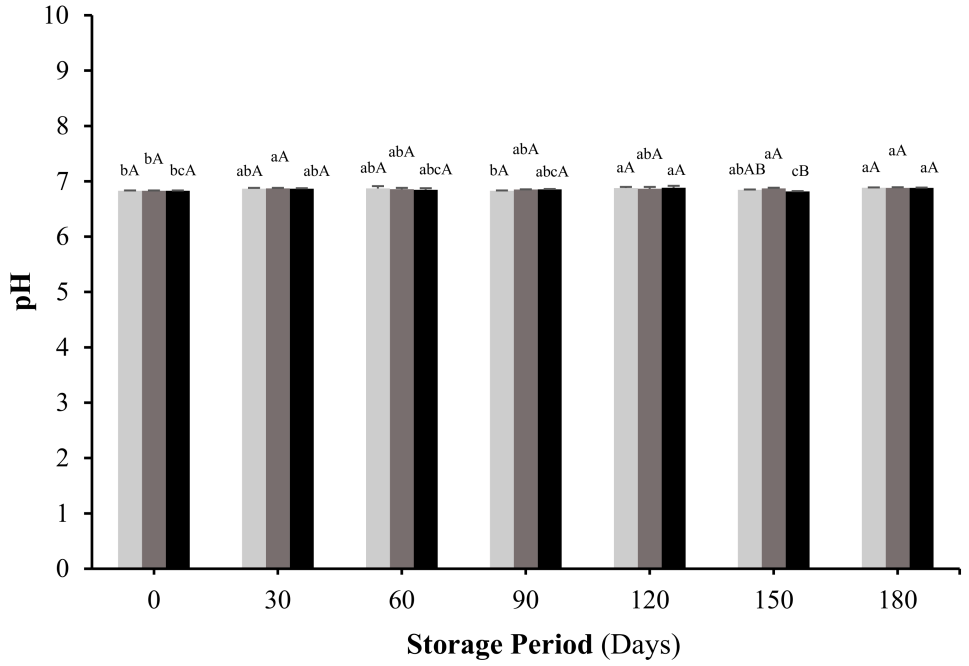

Figure 2. Changes in pH of seasoned grilled conger eel fillets during frozen storage at −13 °C (▒), −18 °C (■), and −23 °C (■) over 180 days. Values are presented as means ± SD ($n = 3$). Lowercase (a–c) and uppercase (A–B) superscript letters show significant variations among storage periods and temperatures, respectively ($p < 0.05$), with a significant temperature × storage period interaction ($p < 0.05$).

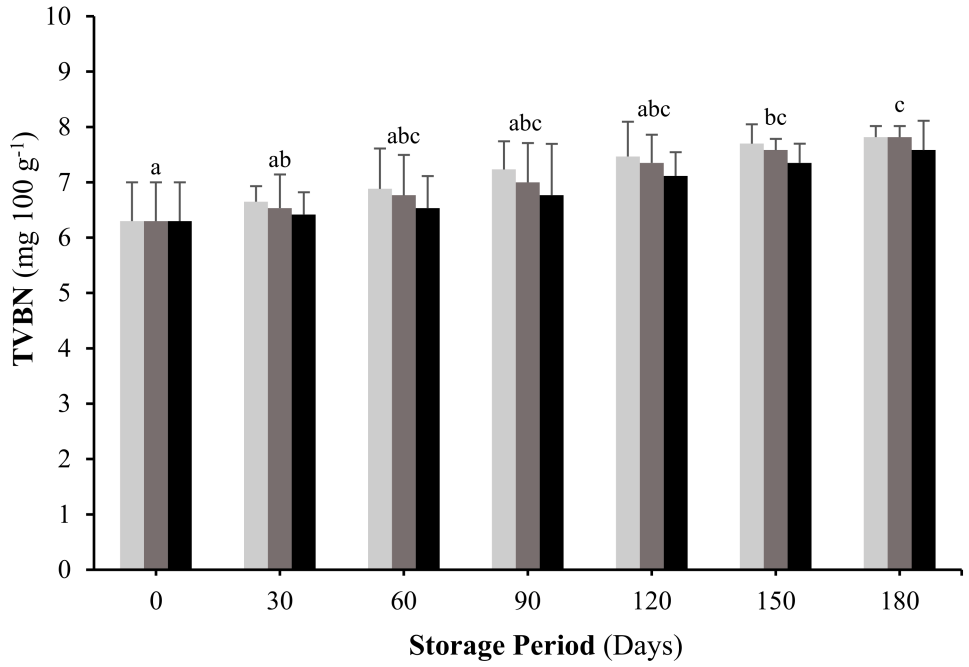

Figure 3. Changes in TVBN values of seasoned grilled conger eel fillets during frozen storage at −13 °C (▒), −18 °C (■), and −23 °C (■) over 180 days. Values are presented as means ± SD ($n = 3$). Lowercase superscript letters (a–c) show significant variations among storage periods ($p < 0.05$) based on marginal means across storage temperatures, while no significant effects of storage temperature or temperature × storage period interaction were observed ($p > 0.05$).

3.3.4. Variations in TBARS Values

The TBARS values of seasoned grilled conger eel fillets showed a continuous increase during storage, with similar patterns observed across storage conditions (Figure 4). The seasoned grilled conger eel fillets stored at −13 °C and −18 °C showed numerically higher TBARS values at some storage periods compared with samples stored at −23 °C. At day 150, the seasoned grilled conger eel fillets showed TBARS values of 0.40 mg MDA kg^{-1} at −13 °C and 0.38 mg MDA kg^{-1} at −18 °C, both numerically higher than the 0.37 mg MDA kg^{-1} at −23 °C. Nevertheless, all seasoned grilled conger eel fillets reached a final value of approximately 0.41 mg MDA kg^{-1} by day 180. The impact of temperature and its interaction with storage period were not statistically significant ($p > 0.05$), whereas the impact of storage period was significant ($p < 0.05$).

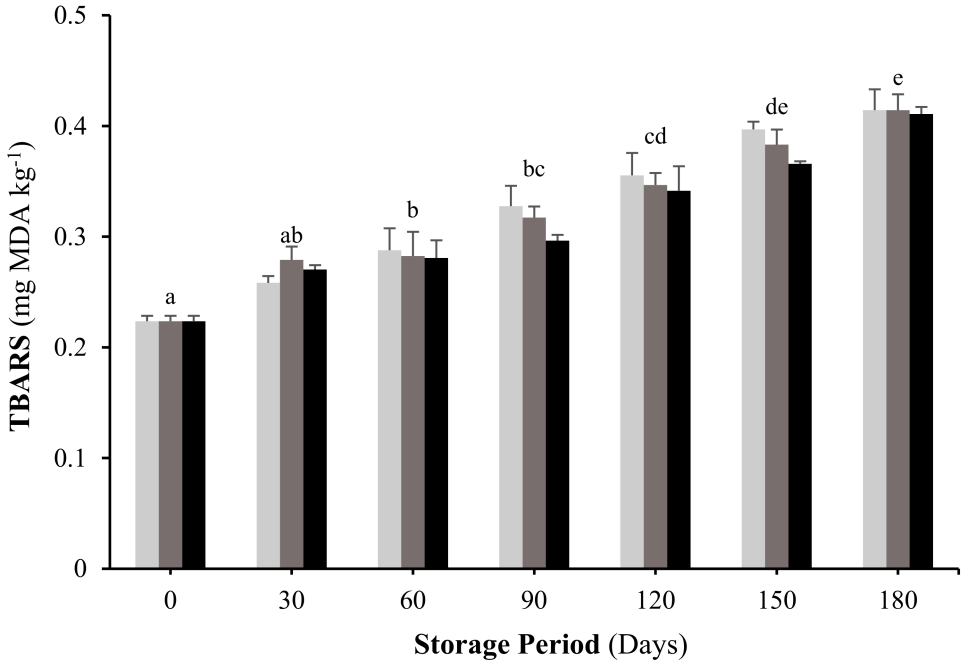

Figure 4. Changes in TBARS values of seasoned grilled conger eel fillets during frozen storage at −13 °C (□), −18 °C (■), and −23 °C (■) over 180 days. Values are presented as means ± SD ($n = 3$). Lowercase superscript letters (a–e) show significant variations among storage periods ($p < 0.05$) based on marginal means across storage temperatures, while no significant effects of storage temperature or temperature × storage period interaction were observed ($p > 0.05$).

3.4. Safety Evaluation of Seasoned Grilled Conger Eel Fillets

3.4.1. Microbial Quality During Storage

The total bacterial count (TBC) of seasoned grilled conger eel fillets increased gradually during frozen storage at all temperatures (Table 6). At day 0, the initial TBC was 1.66 log CFU g^{-1}. After 180 days, TBC reached 2.11, 2.07, and 1.92 log CFU g^{-1} at −23, −18, and −13 °C, respectively. Storage period significantly affected TBC ($p < 0.05$), whereas the effects of temperature ($p = 0.066$) and the temperature × storage interaction ($p = 0.957$) were not significant. The tested samples contained no total coliform or *E. coli* throughout the storage period.

Table 6. Changes in the microbiological properties of seasoned grilled conger eel fillets stored at different storage temperatures.

Temperature	Day	Total Bacterial Count (log CFU g^{-1})	*Escherichia coli* (CFU g^{-1})	Total Coliform Group (CFU g^{-1})
−13 °C	0	1.66 ± 0.10 ^{a}	–	–
	30	1.68 ± 0.07 ^{ab}	–	–
	60	1.76 ± 0.08 ^{abc}	–	–
	90	1.89 ± 0.07 ^{bcd}	–	–
	120	1.93 ± 0.03 ^{cd}	–	–
	150	1.95 ± 0.06 ^{de}	–	–
	180	2.11 ± 0.05 ^{e}	–	–
−18 °C	0	1.66 ± 0.10 ^{a}	–	–
	30	1.68 ± 0.03 ^{ab}	–	–
	60	1.74 ± 0.04 ^{abc}	–	–
	90	1.81 ± 0.14 ^{bcd}	–	–
	120	1.86 ± 0.08 ^{cd}	–	–
	150	1.90 ± 0.03 ^{de}	–	–
	180	2.07 ± 0.07 ^{e}	–	–
−23 °C	0	1.66 ± 0.10 ^{a}	–	–
	30	1.67 ± 0.03 ^{ab}	–	–
	60	1.72 ± 0.08 ^{abc}	–	–
	90	1.78 ± 0.13 ^{bcd}	–	–
	120	1.81 ± 0.14 ^{cd}	–	–
	150	1.89 ± 0.26 ^{de}	–	–
	180	1.92 ± 0.08 ^{e}	–	–

Values are presented as means ± SD ($n = 3$). Lowercase superscript letters (a–e) within the same column show significant differences among storage periods ($p < 0.05$). No significant impact of storage temperature ($p = 0.066$) and interaction between storage temperature and storage period ($p = 0.957$) was observed. A dash (–) indicates not detected.

3.4.2. Heavy Metals and Radioactivity

The radionuclide and heavy metal analysis results are presented in Table 7. Inorganic arsenic, mercury, lead, and cadmium were not detected in the analyzed raw conger eel fillet samples. The corresponding MFDS reference limits for cadmium, lead, and mercury in fish are provided in Table 7 [39]. Similarly, cesium-134, cesium-137, and iodine-131 were not detected in the analyzed samples. These results represent contaminant screening of the raw conger eel fillets used as the raw material in this study and should not be interpreted as directly demonstrating the contaminant status or regulatory compliance of the finished seasoned grilled conger eel fillets.

Table 7. Heavy metals and radioactivity screening results of raw conger eel fillets.

Category	Parameter	Unit	Results	MFDS Standard	International Standard
Heavy metals	Arsenic (Inorganic)	mg kg^{-1}	N.D.	N.E. [1]	0.10 [2]
	Cadmium		N.D.	0.2 [1]	0.05 [3]
	Lead		N.D.	0.5 [1]	0.30 [3]
	Mercury		N.D.	0.5 [1]	0.50 [3]
Radioactivity	$Cesium^{134}$	Bq kg^{-1}	N.D.	100 [4]	1200 [5]
	$Cesium^{137}$		N.D.		
	$Iodine^{131}$		N.D.	100 [4]	170 [5]

[1] According to the Korean Food Code for heavy metal limits in fish by the MFDS [39]; [2] According to EU maximum level for inorganic arsenic [40]; [3] According to EU maximum levels for cadmium, lead, and mercury [41]; [4] According to the radioactivity standards established by the MFDS [42]; [5] According to US FDA Derived Intervention Levels (DILs) for radionuclides in food [43]. N.D. indicates not detected. N.E. indicates not established.

3.5. Shelf-Life Estimation of Seasoned Grilled Conger Eel Fillets

Shelf-life estimates for seasoned grilled conger eel fillets were derived from microbiological, chemical, and sensory quality indicators (Table 8). The VSLSF-based shelf-life estimates varied according to the quality indicator and kinetic model. For TBC, the zero-order and first-order models predicted shelf lives of 54.75 and 32.99 months, respectively, at −18 °C. The corresponding predictions were 54.72 and 32.32 months for TVBN and 28.54 and 35.93 months for overall sensory acceptability, respectively. The Arrhenius regression models yielded coefficients of determination (R^2) ranging from 0.7198 to 0.9896, reflecting differences in temperature-dependent model fit among the indicators and kinetic orders. The first-order TVBN prediction (32.32 months) was selected for determining the assigned shelf-life. Applying a safety factor of 0.80 resulted in an adjusted estimate of 25.86 months, which was conservatively set at 25 months.

Table 8. VSLSF-predicted shelf-life of seasoned grilled conger eel fillets.

Quality Indicator	Reaction Order	Time-Regression Slope at −18 °C	Arrhenius Slope (K)	Arrhenius Intercept	Arrhenius R^2	Predicted Shelf-Life (Months)
Total bacterial count	0-order	0.0021	−2879.14	5.08	0.9667	54.75
	1st-order	0.0011	−2614.20	3.44	0.9713	32.99
Total volatile basic nitrogen	0-order	0.0086	−903.73	−1.26	0.7597	54.72
	1st -order	0.0012	−733.83	−3.87	0.7198	32.32
Sensory evaluation score	0-order	−0.0045	−1396.20	0.09	0.9896	28.54
	1st -order	−0.0005	−1475.72	−1.74	0.9880	35.93

Zero-order and first-order indicate kinetic reaction orders. R^2: the coefficient of determination for the Arrhenius regression.

4. Discussion

The nutritional composition of conger eel fillets showed notable differences following processing into seasoned grilled products, which may reflect the combined influences of thermal processing, moisture reduction, and seasoning incorporation. Similar changes in fish composition associated with processing have been documented in studies on mullet [44] and Pacific cod [45], highlighting the importance of considering processing conditions when interpreting nutritional differences. Several nutritional components, including crude protein, crude fat, cholesterol, sodium, and calcium, showed higher concentrations in the seasoned grilled conger eel fillets, whereas potassium concentration was lower. Moisture reduction during thermal processing may contribute to differences in nutrient concentrations expressed per unit weight [46–48]. However, because moisture content and cooking yield were not determined, the extent to which water loss contributed to the observed differences could not be quantified. The presence of carbohydrates and sugars in the seasoned grilled conger eel fillets is consistent with the addition of sugar-containing seasonings during pre-cooking and grilling. Similar increases in carbohydrate and sugar contents were reported by Tirtawijaya et al. [49]. The higher sodium concentration may also be partly associated with the use of soy sauce, whereas the lower potassium concentration may reflect the transfer of water-soluble minerals from the fillets into the boiling liquid [50]. Because mineral elements are not destroyed by conventional thermal processing, differences in their concentrations may reflect changes in sample mass, leaching into the cooking medium, and contributions from added seasonings [46,48,50]. In particular, the higher calcium concentration could not be attributed to a specific mechanism without measurements of moisture content, cooking yield, and seasoning retention. Nevertheless, the contributions of seasoning ingredients and processing-related nutrient losses could not be quantified because sauce retention and nutrient mass balance were not determined. No additional oil was used during processing; therefore, the higher crude fat concentration cannot be attributed to added oil absorption.

Accordingly, these differences should be regarded as changes in nutrient concentrations between raw and seasoned grilled conger eel fillets rather than evidence of an absolute increase in nutrient content during processing.

The amino acid profiles of raw conger eel fillets and seasoned grilled conger eel fillets differed on a per-100-g wet-weight basis. AAA, EAA, NAA, and SAA showed higher reported concentrations in the seasoned grilled conger eel fillets. Comparable findings have also been documented in studies of grilled mullet [44] and Pacific cod [45]. Although moisture reduction during thermal processing may contribute to differences in amino acid concentrations expressed per unit weight [47], its contribution could not be quantified because moisture content and cooking yield were not determined. Furthermore, the addition of seasonings during pre-cooking and grilling may influence the amino acid composition of the finished product, although their individual contributions were not evaluated. Thermal processing may also alter muscle protein structure, potentially affecting protein extractability as well as amino acid concentrations measured after hydrolysis [51,52]. However, the higher essential amino acid concentrations and EAA/NAA ratio observed in the seasoned grilled conger eel fillets should not be taken to indicate enhanced biological protein quality or increased absolute amino acid retention. Moreover, the difference in EAA/NAA ratio cannot be explained by a uniform moisture-concentration effect alone, because both amino acid groups would be affected proportionally. In contrast to total amino acids, most free amino acids detected in both sample groups showed lower concentrations in the seasoned grilled conger eel fillets, consistent with findings reported by Lee et al. [45]. These differences may be associated with multiple factors, including the release of water-soluble free amino acids throughout boiling, thermal degradation during grilling, and participation in Maillard reactions and Strecker degradation pathways [53,54]. These reactions are known to contribute to flavor development in thermally processed foods [55]. The detection of certain free amino acids only in one sample group may reflect processing-related transformations or differences in analytical detection rather than confirming their formation or degradation during processing [56,57]. Because the intermediate pre-cooked fillets were not analyzed for amino acid composition, the individual contributions of boiling, grilling, and seasoning to the observed differences could not be determined.

The fatty acid composition of seasoned grilled conger eel fillets differed from that of raw conger eel fillets on a per-100-g wet-weight basis, with generally higher concentrations of SFAs, MUFAs, and PUFAs in the finished product. This finding aligns with Lee et al. [45], who documented increased fatty acid content in grilled Pacific cod. Moisture reduction during thermal processing may contribute to higher lipid concentrations per unit sample weight [58]. However, because moisture content, cooking yield, and lipid mass balance were not determined, the contribution of this concentration effect could not be quantified. Major fatty acids, including DHA, EPA, oleic acid, and palmitic acid, showed higher concentrations in the seasoned grilled conger eel fillets. In particular, DHA and EPA concentrations ranged from 398.2 to 929.1 mg 100 g^{-1} and from 121.8 to 284.2 mg 100 g^{-1}, respectively. As no additional oil was used during pre-cooking or grilling, the observed differences cannot be ascribed to oil absorption during processing. Nevertheless, the contribution of seasoning ingredients to the fatty acid profile was not evaluated separately. The higher concentrations of DHA and EPA in the finished product do not establish an absolute increase in their quantities or their formation during processing. Furthermore, without measurements of initial and final fillet weights, moisture contents, and retained seasoning amounts, a mass-balance calculation could not be performed to determine the absolute retention of DHA and EPA during processing. However, gamma-linolenic acid showed a lower concentration in the seasoned grilled conger eel fillets, which may reflect oxidative degradation of heat-sensitive PUFAs during thermal treatment [59]. PUFAs, particularly EPA and DHA, have a strong

tendency to oxidize when exposed to heat and oxygen [59,60]. The detection of certain fatty acids only after processing may also reflect altered lipid extractability associated with thermal disruption of tissue structures [61] or differences in analytical detectability. Overall, these findings indicate differences in fatty acid concentrations between raw conger eel fillets and the finished seasoned grilled conger eel fillets, while the individual contributions of pre-cooking, grilling, and seasoning remain undetermined.

The sensory quality of seasoned grilled conger eel fillets generally declined during 180 days of frozen storage, although fluctuations were observed among sensory attributes and storage conditions. A similar trend has been reported for grilled Pacific cod, where sensory quality decreased during frozen storage [45]. At day 180, overall acceptability of the sample was numerically slightly higher at −23 °C (7.51) than at −18 °C (7.47) and −13 °C (7.34), although these differences were small. Samples stored at lower temperatures retained comparatively higher sensory scores over the storage period, whereas samples stored at −13 °C exhibited more rapid declines in sensory attributes. These changes are likely associated with biochemical and structural deterioration occurring during frozen storage [62]. Lipid oxidation produces compounds formed during secondary lipid oxidation, such as ketones and aldehydes, that cause off-flavors and rancid odors [63]. Simultaneously, protein degradation forms volatile nitrogenous compounds that contribute to unpleasant fishy odors and reduced sensory acceptability [21]. These changes corresponded with the progressive increases observed in TBARS and TVBN values during storage. The increase in TBARS values reflects ongoing lipid oxidation [63], while elevated TVBN values indicate protein degradation and accumulation of volatile basic compounds [21]. Structural damage caused by ice crystal formation under frozen storage conditions may have further contributed to texture deterioration. Ice crystal formation may decrease the water-holding capacity of the muscle tissue, disrupt muscle fibers, and negatively affect texture and overall product acceptability [64]. The slightly higher sensory scores observed at −23 °C may suggest better retention of certain sensory attributes, possibly because lower storage temperatures slowed these deterioration processes and helped preserve product quality [65]. This result is consistent with the findings of Yin et al. [62], who observed that higher storage temperatures (−10 °C) accelerated protein oxidation and texture softening in frozen tilapia fillets compared to lower temperatures (−20 °C).

The pH value is commonly used to assess quality deterioration and estimate shelf-life in the fish marketing sector [66]. In the present study, pH values remained relatively stable throughout storage at all temperatures, ranging from 6.82 to 6.88, indicating limited changes in acid–base balance under frozen conditions. This observation is consistent with previous studies on ready-to-eat conger eel products containing ginseng and pine mushroom, which also reported pH values that were relatively stable during storage for 60 days at −20 °C [67]. Such stability is likely attributable to reduced microbial and enzymatic activities during frozen storage [65]. Nevertheless, minor fluctuations in pH may be associated with limited biochemical reactions and the gradual accumulation of basic nitrogenous compounds over time [62,65]. Although pH is considered an important indicator of freshness [68,69], its relatively stable values alone cannot confirm the overall quality or safety of this cooked and frozen product. Therefore, pH should be interpreted alongside other quality parameters, including TVBN, TBARS, microbiological measurements, and sensory attributes.

In contrast, TVBN values increased progressively throughout storage at all temperatures, reflecting the accumulation of volatile nitrogen compounds produced during protein degradation [63]. Slightly lower values were observed numerically at −23 °C, although neither storage temperature nor the temperature × storage period interaction had a noticeable impact ($p > 0.05$). These compounds are associated with undesirable flavors and fishy odors and contribute to sensory deterioration during storage [70]. Thermal processing may

have influenced the initial TVBN levels [71], while frozen storage facilitated the gradual accumulation of these compounds over time [70]. Similar trends have been reported for grilled Pacific cod [45] and roasted grass carp [71], where TVBN values increased during frozen storage. According to Commission Regulations (EC) [72], fish is generally considered fresh when TVBN values are below 25 mg 100 g^{-1}, while the upper acceptable limit for human consumption typically ranges from 30 to 35 mg 100 g^{-1}, with variations across species and specific categories. In the present study, TVBN values ranged from 6.30 to 7.82 mg 100 g^{-1} during 180 days of storage at all three temperatures. These results indicate relatively limited accumulation of volatile basic nitrogen during frozen storage, with values remaining below the reference limits discussed above.

Similarly, TBARS values increased throughout storage, with numerically lower values observed at −23 °C at some storage periods, although neither storage temperature nor the temperature × storage period interaction had a marked impact ($p > 0.05$). Comparable trends have been reported for grilled Pacific cod [45] and roasted grass carp [71], where TBARS values increased during frozen storage. The TBARS assay is widely used to evaluate lipid oxidation in fish and meat by measuring secondary oxidation products, particularly malondialdehyde (MDA), which serves as a reliable indicator of oxidative deterioration [73]. The increase in TBARS levels indicates that lipid oxidation progressed throughout the storage period [63]. This process forms volatile compounds, especially aldehydes and ketones, that cause off-flavors and rancid odors [74]. These compounds are readily detected by the human olfactory system, and therefore lipid oxidation is closely associated with the decline in sensory quality during storage [75]. In general, TBARS values under 3 mg MDA kg^{-1}, and not exceeding 5 mg MDA kg^{-1}, are considered indicative of acceptable fish quality [76]. In the present study, TBARS values ranged from 0.22 to 0.41 mg MDA kg^{-1} during 180 days of storage at all three temperatures, indicating relatively low levels of lipid oxidation under the tested storage conditions, with values remaining below the reference levels reported for fish quality. Overall, the relatively stable pH, gradual increases in TVBN and TBARS values, and sensory scores remaining above 7 at day 180 indicate that seasoned grilled conger eel fillets maintained generally favorable physicochemical and sensory characteristics throughout 180 days of storage at all three tested temperatures.

From a safety perspective, the assessment of heavy metals and radionuclides is important because certain contaminants may accumulate in aquatic organisms and pose potential health risks [77]. In the present study, inorganic arsenic, cadmium, lead, and mercury were not detected in the raw conger eel fillet samples. The MFDS reference limits for fish are 0.2 mg kg^{-1} for cadmium and 0.5 mg kg^{-1} for both lead and mercury [39]. However, the non-detection of these contaminants in the raw material does not conclusively establish compliance with all applicable regulatory limits, particularly where analytical sensitivity and regulatory limits cannot be directly compared. Furthermore, heavy metal and radionuclide analyses were conducted on raw conger eel fillets rather than on the finished seasoned grilled conger eel products. Potential contributions from seasoning ingredients, processing water, and food-contact materials were therefore not directly evaluated. Accordingly, these results provide preliminary information on the contaminant status of the raw material, rather than a comprehensive safety assessment of the finished product. Further evaluation of the finished product would be necessary to directly assess its contaminant status and regulatory compliance.

Microbiological evaluation, including TBC, *E. coli*, and TCG, is also critical for assessing food safety and hygienic quality [24,25]. The results showed a gradual increase in TBC during storage; however, microbial levels remained low throughout the storage period. Samples stored at lower temperatures exhibited numerically slower increases in microbial counts, although neither storage temperature nor the temperature × storage period

interaction had a significant impact ($p > 0.05$). This numerical trend may be consistent with reduced microbial activity at lower frozen-storage temperatures [65]. Importantly, microbiological testing of seasoned grilled conger eel fillets yielded no detectable total coliforms or *E. coli*, suggesting that hygienic handling and processing conditions were well maintained throughout production [78]. In water and food-processing environments, coliforms serve as widely recognized indicators of hygienic conditions, while *E. coli* indicates potential fecal contamination or unsanitary processing conditions [79]. Similar findings have been reported for grilled Pacific cod [45], where limited microbial growth and no detection of *E. coli* or coliforms were observed during frozen storage. According to MFDS guidelines [80], the maximum allowable limit for TBC in frozen foods intended for consumption after heating is 6.7 log CFU g^{-1}. The observed TBC values ranged from 1.66 to 2.11 log CFU g^{-1} at all three tested temperatures during storage, indicating that total bacterial counts remained low throughout the storage period and were below the referenced microbiological limit. The combined effects of boiling, grilling, vacuum packaging, and frozen storage likely contributed to microbial reduction and the inhibition of microbial growth during storage [81–84]. Although these parameters provide useful information on general microbial quality, the absence of pathogen-specific analyses for *Staphylococcus aureus*, *Salmonella* spp., and *Listeria monocytogenes* represents a limitation of this study. Further investigation of these pathogens is recommended for a more comprehensive safety assessment of the finished product.

The model-based shelf-life estimates varied across quality indicators and reaction orders. The zero-order sensory model predicted a shorter shelf-life (28.54 months) than the first-order TVBN model (32.32 months), whereas the first-order sensory model predicted 35.93 months. These differences indicate that shelf-life estimates depend on the quality indicator and kinetic model selected. The first-order TVBN estimate of 32.32 months was used to determine the final shelf life. Applying a safety factor of 0.80 resulted in 25.86 months, which was conservatively rounded down to 25 months. As the experimental observations covered only 180 days, this 25-month value should be interpreted as a model-based prediction rather than a directly validated storage duration. Further long-term storage studies are required to confirm the estimate under practical frozen-distribution conditions.

5. Conclusions

This study developed seasoned grilled conger eel (*C. myriaster*) fillets for HMR applications and evaluated their nutritional characteristics, safety-related parameters, and quality stability during frozen storage. The optimized thermal processing produced a product containing beneficial omega-3 fatty acids, particularly EPA and DHA, substantial protein, and essential amino acids. Although the higher measured concentrations of some nutrients in the finished product may have been influenced by moisture reduction and seasoning incorporation, these contributions could not be quantitatively separated. Screening of the raw materials showed no detectable inorganic arsenic, cadmium, lead, mercury, or radionuclides, providing preliminary information on contaminant status rather than confirming the safety of the finished product. During 180 days of frozen storage at all three temperatures, pH remained relatively stable, while TVBN, TBARS, and TBC increased gradually. *E. coli* and TCG were not detected throughout storage. Sensory quality gradually decreased with storage time, although overall acceptability remained relatively favorable on day 180, with scores of 7.51 for samples stored at −23 °C, 7.47 at −18 °C, and 7.34 at −13 °C. The slightly higher sensory scores at −23 °C were not consistently accompanied by corresponding differences in physicochemical or microbiological indicators. The model-based shelf-life prediction estimated a storage life of 25 months at −18 °C, although this estimate requires validation through longer-term storage studies. Overall, seasoned grilled conger eel fillets

demonstrated favorable nutritional characteristics and generally acceptable quality during the tested frozen-storage period, supporting their potential as a seafood component for HMR applications. The findings provide practical information to further optimize, validate, and commercialize value-added eel-based foods for HMR applications.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/pr14213463/s1. Figure S1: Flowchart of the seasoned grilled conger eel fillets production process; Table S1: Coded and actual levels of independent variables for RSM optimization; Table S2: Experimental design for RSM optimization of seasoned grilled conger eel fillets; Table S3: Response surface regression model for predicting the overall acceptability of seasoned grilled conger eel fillets; Table S4: ANOVA of the response surface model used to optimize grilling conditions for seasoned grilled conger eel fillets; Table S5: Optimal processing conditions of seasoned grilled conger eel fillets determined by response surface methodology.

Author Contributions: Conceptualization, K.M.I.B. and J.-S.C.; methodology, M.M., S.J.L. and K.M.I.B.; software, M.M. and K.M.I.B.; validation, J.H.S., K.M.I.B. and J.-S.C.; formal analysis, M.M., S.J.L., H.-R.A., D.M.K. and A.R.M.; investigation, J.H.S., K.M.I.B. and J.-S.C.; resources, J.-S.C.; data curation, M.M., S.J.L., H.-R.A., D.M.K. and A.R.M.; writing—original draft preparation, M.M., S.J.L. and K.M.I.B.; writing—review and editing, J.H.S., K.M.I.B. and J.-S.C.; visualization, J.H.S., K.M.I.B. and J.-S.C.; supervision, K.M.I.B. and J.-S.C.; project administration, J.-S.C.; funding acquisition, J.-S.C. All authors have read and agreed to the published version of the manuscript.

Funding: The Korea Fisheries Infrastructure Public Agency (FIPA) provided financial support for this study through funds from the Ministry of Oceans and Fisheries (Grant No. 202408480003), in support of the Blue-Food Technology Department at Gyeongsang National University.

Data Availability Statement: The data reporting the findings of this study are contained in this article and the Supplementary Files. Additional information can be directed to the corresponding authors.

Conflicts of Interest: Author Seok Jeong Lee was employed by the company Woojin Moolsan. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest. The authors declare that this study received funding from the Ministry of Oceans and Fisheries of Korea. The funding organization did not participate in designing the study, collecting, analyzing, or interpreting the data, writing the manuscript, or deciding to submit it for publication.

Abbreviations

Abbreviations used in this manuscript are listed below:

AAA	Aromatic amino acids
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
BW	Body weight
CCP	Critical control point
CFU	Colony-forming units
DHA	Docosahexaenoic acid
EAA	Essential amino acids
EPA	Eicosapentaenoic acid
FAO	Food and Agriculture Organization
FAME	Fatty acid methyl esters
FDA	Food and Drug Administration
FID	Flame ionization detector
FIPA	Korea Fisheries Infrastructure Public Agency
HMR	Home meal replacement
HPLC	High-performance liquid chromatography
MDA	Malondialdehyde
MFDS	Ministry of Food and Drug Safety

MUFA	Monounsaturated fatty acids
NAA	Non-essential amino acids
PE	Polyethylene
PUFA	Polyunsaturated fatty acids
RSM	Response surface methodology
RV	Recommended value
SAA	Sulfur-containing amino acids
SD	Standard deviation
SFA	Saturated fatty acids
TBA	Thiobarbituric acid
TBARS	Thiobarbituric acid reactive substances
TBC	Total bacterial count
TCA	Trichloroacetic acid
TCG	Total coliform group
TVBN	Total volatile basic nitrogen
UNU	United Nations University
VSLSF	Visual Shelf-Life Simulator for Foods
WHO	World Health Organization

References

1. TBRC Business Research Pvt Ltd. Packaged Food Market 2026 Changing Consumer Lifestyles Driving Convenient Food Solutions. Available online: https://www.einpresswire.com/article/900008427/packaged-food-market-2026-changing-consumer-lifestyles-driving-convenient-food-solutions (accessed on 17 April 2026).
2. Ji, Y.; Han, J. Sustainable home meal replacement (HMR) consumption in Korea: Exploring service strategies using a modified importance–performance analysis. *Foods* **2022**, *11*, 889. [CrossRef] [PubMed]
3. Tirtawijaya, G.; Kim, S.R.; Cho, W.H.; Sohn, J.H.; Kim, J.-S.; Choi, J.-S. Development of a home meal replacement product containing braised mackerel (*Scomber japonicus*) with radish (*Raphanus sativus*). *Foods* **2021**, *10*, 1135. [CrossRef] [PubMed]
4. Hosomi, R.; Yoshida, M.; Fukunaga, K. Seafood consumption and components for health. *Glob. J. Health Sci.* **2012**, *4*, 72–86. [CrossRef] [PubMed]
5. Özoğul, Y.; Özoğul, F. Nutritional benefits and health risks of seafood consumption. *Agric. Food Technol.* **2025**, *3*, 103–118. [CrossRef]
6. Jawale, R.S. Nutritional and health benefits of seafood for human: A review. *Eur. J. Nutr. Food Saf.* **2025**, *17*, 74–83. [CrossRef]
7. Persistence Market Research Pvt. Ltd. Seafood Market to Reach US$611.3 Billion by 2033, Amid Rising Nutrition Demand and Aquaculture Innovation. Available online: https://www.prnewswire.co.uk/news-releases/seafood-market-to-reach-us611-3-billion-by-2033–amid-rising-nutrition-demand-and-aquaculture-innovation—persistence-market-research-302689408.html (accessed on 17 April 2026).
8. Shiraishi, H.; Han, Y.-S.; Kaifu, K. Eel consumption in Japan: Insights from genetic species identification and trade data. *Fish. Sci.* **2025**, *91*, 1053–1062. [CrossRef]
9. Choi, J.D.; Kang, S.I.; Kim, Y.J.; Lee, S.G.; Heu, M.S.; Kim, J.S. Sanitary quality characterization of commercial semi-dried conger eel (*Conger myriaster*) and guideline for controlling quality. *Korean J. Fish. Aquat. Sci.* **2015**, *48*, 417–425. [CrossRef]
10. Tavares, J.; Martins, A.; Fidalgo, L.G.; Lima, V.; Amaral, R.A.; Pinto, C.A.; Silva, A.M.; Saraiva, J.A. Fresh fish degradation and advances in preservation using physical emerging technologies. *Foods* **2021**, *10*, 780. [CrossRef] [PubMed]
11. Suárez-Medina, M.D.; Sáez-Casado, M.I.; Martínez-Moya, T.; Rincón-Cervera, M.Á. The effect of low temperature storage on the lipid quality of fish, either alone or combined with alternative preservation technologies. *Foods* **2024**, *13*, 1097. [CrossRef] [PubMed]
12. Hossain, M.J.; Alam, A.N.; Kim, S.-H.; Kim, C.-J.; Joo, S.-T.; Hwang, Y.-H. Techniques and emerging trends in flavor and taste development in meat. *Food Sci. Anim. Resour.* **2025**, *45*, 266–281. [CrossRef] [PubMed]
13. Bhat, Z.F.; Morton, J.D.; Bekhit, A.E.-D.A.; Kumar, S.; Bhat, H.F. Thermal processing implications on the digestibility of meat, fish and seafood proteins. *Compr. Rev. Food Sci. Food Saf.* **2021**, *20*, 4511–4548. [CrossRef] [PubMed]
14. El-Lahamy, A.A.; Khalil, K.I.; El-Sherif, S.A.; Ibrahim, H.R.; Mahmud, A.A. Changes in fish during cooking methods (frying and grilling): A review. *J. Public Health Nutr.* **2019**, *2*, 1–4.

15. Zhong, R.; Lu, X.; Zhong, J.; Chen, L.; Cheng, W.; Liang, P. Influence of Maillard reaction in volatile flavor compounds of blue round scad (*Decapterus maruadsi*) enzymatic hydrolysate. *J. Aquat. Food Prod. Technol.* **2021**, *30*, 615–629. [CrossRef]
16. Huang, X.-H.; Luo, Y.; Zhu, X.-H.; Ayed, C.; Fu, B.-S.; Dong, X.-P.; Fisk, I.; Qin, L. Dynamic release and perception of key odorants in grilled eel during chewing. *Food Chem.* **2022**, *378*, 132073. [CrossRef] [PubMed]
17. Mehta, B.M. Nutritional and toxicological aspects of the chemical changes of food components and nutrients during heating and cooking. In *Handbook of Food Chemistry*; Cheung, P.C.K., Mehta, B.M., Eds.; Springer: Berlin/Heidelberg, Germany, 2015; pp. 897–936. [CrossRef]
18. Sharanagat, V.S.; Kansal, V.; Singh, L. Fish freezing: Principles, methods, and scope. In *Technological Processes for Marine Foods, from Water to Fork*; Goyal, M.R., Suleria, H.A.R., Kirubanandan, S., Eds.; Apple Academic Press: Palm Bay, FL, USA, 2020; pp. 97–146.
19. Zhu, Y.; Zhu, J.; Shi, X.; Fan, M. Effects of freezing, frozen storage and thawing on the water status, quality, nutrition and digestibility of meat: A review. *Food Sci. Nutr.* **2025**, *13*, e70774. [CrossRef] [PubMed]
20. Sampels, S. Fish preservation. *J. Food Process. Preserv.* **2015**, *39*, 1206–1215. [CrossRef]
21. Chen, H.; Ge, Y.; Yang, T.; Wang, S.; Liu, N.; Sun, Y.; Zhou, D.; Xi, R.; Sun, G. Quality changes of whitespotted conger (*Conger myriaster*) based on physicochemical changes and label-free proteomics analysis during frozen storage. *Curr. Res. Food Sci.* **2024**, *8*, 100779. [CrossRef] [PubMed]
22. Bašić, J.; Dragaš Milovanović, D.; Pecarski, D.; Milanović, I.; Nikić, S.; Ivanović, M.; Krsmanović, S. Food quality and safety standards: A key factor in public health protection. *J. Hyg. Eng. Des.* **2025**, *51*, 42–49.
23. Akter, S.; Rahman, M.A.; Awal, M.R.; Sarker, F.; Ashrafudoulla, M.; Moniruzzaman, M. Seafood safety under the microscope: An integrated bibliometric and scientific perspective on hazards and emerging risks in aquatic foods. *Reg. Stud. Mar. Sci.* **2026**, *96*, 104897. [CrossRef]
24. Issa-Zacharia, A.; Msangi, R.S.; Mboya, G.R. Revisiting chemical and microbiological quality and safety of fish and fish products. *Int. J. Microbiol. Biotechnol.* **2025**, *10*, 73–90. [CrossRef]
25. Samarajeewa, U. Safety, processing, and utilization of fishery products. *Fishes* **2024**, *9*, 146. [CrossRef]
26. AOAC International. *Official Methods of Analysis of AOAC International*, 21st ed.; AOAC International: Rockville, MD, USA, 2019.
27. Bligh, E.G.; Dyer, W.J. A rapid method of total lipid extraction and purification. *Can. J. Biochem. Physiol.* **1959**, *37*, 911–917. [CrossRef] [PubMed]
28. Ambrozova, J.V.; Misurcova, L.; Vicha, R.; Machu, L.; Samek, D.; Baron, M.; Mlcek, J.; Sochor, J.; Jurikova, T. Influence of extractive solvents on lipid and fatty acids content of edible freshwater algal and seaweed products, the green microalga *Chlorella kessleri* and the cyanobacterium *Spirulina platensis*. *Molecules* **2014**, *19*, 2344–2360. [CrossRef] [PubMed]
29. MFDS—Ministry of Food and Drug Safety. *4th General Analysis Method*; Food Additives Code; Ministry of Food and Drug Safety: Cheongju, Republic of Korea, 2020. Available online: https://various.foodsafetykorea.go.kr/fsd/?idx=878#/ext/Document/FC?searchNm=pH&itemCode=FC0A263004005A269 (accessed on 1 April 2026).
30. MFDS—Ministry of Food and Drug Safety. *8th General Analysis Method: Food Code*; Ministry of Food and Drug Safety: Cheongju, Republic of Korea, 2020. Available online: https://various.foodsafetykorea.go.kr/fsd/#/ext/Document/FC?searchNm=%ED%9C%98%EB%B0%9C%EC%84%B1&itemCode=FC0A003001002A017 (accessed on 1 April 2026).
31. Mohibbullah, M.; Won, N.E.; Jeon, J.-H.; An, J.H.; Park, Y.; Kim, H.; Bashir, K.M.I.; Park, S.-M.; Kim, Y.-S.; Yoon, S.-J.; et al. Effect of superheated steam roasting with hot smoking treatment on improving physicochemical properties of the adductor muscle of pen shell (*Atrina pectinate*). *Food Sci. Nutr.* **2018**, *6*, 1317–1327. [CrossRef] [PubMed]
32. Everitt, M. Consumer-targeted sensory quality. In *Global Issues in Food Science and Technology*; Barbosa-Cánovas, G., Mortimer, A., Lineback, D., Spiess, W., Buckle, K., Colonna, P., Eds.; Academic Press: San Diego, CA, USA, 2009; pp. 117–128. [CrossRef]
33. MFDS—Ministry of Food and Drug Safety. *Food Code*; Ministry of Food and Drug Safety: Cheongju, Republic of Korea, 2022. Available online: https://various.foodsafetykorea.go.kr/fsd/?idx=11142#/ext/Document/FC?searchNm=%EB%B0%A9%EC%82%AC%EB%8A%A5&itemCode=FC0A070002003A725 (accessed on 1 April 2026).
34. Schumacher, A.J.; Lingle, C.K.; Silbernagel, K.M.; Thompson-Strehlow, L. Validation of the 3M™ Petrifilm™ Coliform Count Plate for enumeration of coliforms in bottled water: AOAC Performance Tested Method SM 082101. *J. AOAC Int.* **2022**, *105*, 866–875. [CrossRef] [PubMed]
35. MFDS—Ministry of Food and Drug Safety. *Guidelines for Shelf-Life Setting Experiments for Foods, Livestock Products, and Health Functional Foods*; Ministry of Food and Drug Safety: Cheongju, Republic of Korea, 2023. Available online: https://www.mfds.go.kr/brd/m_1060/view.do?seq=15279 (accessed on 1 April 2026).
36. U.S. Food and Drug Administration. Food Labeling: Revision of the Nutrition and Supplement Facts Labels. *Fed. Regist.* **2016**, *81*, 33742. Available online: https://www.govinfo.gov/content/pkg/FR-2016-05-27/pdf/2016-11867.pdf (accessed on 20 April 2026).
37. MFDS—Ministry of Food and Drug Safety. *Standard for Food Labeling*; Ministry of Food and Drug Safety: Cheongju, Republic of Korea, 2020. Available online: https://various.foodsafetykorea.go.kr/fsd/#/ (accessed on 21 April 2026).

38. World Health Organization. *Protein and Amino Acid Requirements in Human Nutrition: Report of a Joint WHO/FAO/UNU Expert Consultation*; WHO Technical Report Series 935; World Health Organization: Geneva, Switzerland, 2007. Available online: https://iris.who.int/items/78c03092-bcc2-40f5-90d1-60641ecdf6ea (accessed on 23 April 2026).
39. MFDS—Ministry of Food and Drug Safety. *Korean Food Code: Standards and Specifications for Foods*; MFDS Notification No. 2026-55; Ministry of Food and Drug Safety: Cheongju, Republic of Korea, 2026. Available online: https://www.mfds.go.kr/brd/m_211/view.do?seq=14983 (accessed on 11 October 2026).
40. European Commission. Commission Regulation (EU) 2025/1891 of 17 September 2025 Amending Regulation (EU) 2023/915 as Regards Maximum Levels of Inorganic Arsenic in Fish and Other Seafood. *Off. J. Eur. Union* **2025**, L2025/1891. Available online: https://eur-lex.europa.eu/eli/reg/2025/1891/oj/eng (accessed on 15 October 2026).
41. European Commission. Commission Regulation (EU) 2023/915 of 25 April 2023 on Maximum Levels for Certain Contaminants in Food and Repealing Regulation (EC) No 1881/2006. *Off. J. Eur. Union* **2023**, *L119*, 103–157. Available online: https://eur-lex.europa.eu/eli/reg/2023/915/oj/eng (accessed on 15 October 2026).
42. MFDS—Ministry of Food and Drug Safety. *Korean Food Code: General Standards and Specifications for Foods, Section 5 (10), Radioactivity Standards*; Ministry of Food and Drug Safety: Cheongju, Republic of Korea, 1988. Available online: https://www.foodsafetykorea.go.kr/popup/safefoodlife/food/foodRvlv/foodRvlvDetail.do?rvlv_no=12 (accessed on 15 October 2026).
43. U.S. Food and Drug Administration. *Supporting Document for Guidance Levels for Radionuclides in Domestic and Imported Foods*; U.S. Food and Drug Administration: Silver Spring, MD, USA, 2004. Available online: https://www.fda.gov/food/process-contaminants-food/supporting-document-guidance-levels-radionuclides-domestic-and-imported-foods (accessed on 15 October 2026).
44. El Lahamy, A.A.; Khalil, K.I.; El Sherif, S.A.; Abdelazim, S.A.A.; Mahmud, A.A. Effect of frozen storage and cooking method on amino acid composition of mullet fish (*Mugil cephalus*). *MOJ Food Process. Technol.* **2018**, *6*, 458–463. [CrossRef]
45. Lee, M.-J.; Son, A.H.; Bashir, K.M.I.; An, H.-R.; Kang, D.-M.; Mansoor, S.; Choi, J.-S.; Sohn, J.H. Development and quality characteristics of grilled Pacific cod (*Gadus macrocephalus*) fillet home meal replacement (HMR). *Processes* **2026**, *14*, 669. [CrossRef]
46. Marimuthu, K.; Thilaga, M.; Kathiresan, S.; Xavier, R.; Mas, R.H.M.H. Effect of different cooking methods on proximate and mineral composition of striped snakehead fish (*Channa striatus*). *J. Food Sci. Technol.* **2012**, *49*, 373–377. [CrossRef] [PubMed]
47. Chew, S.C.; How, Y.H.; Chang, L.S.; Tan, C.H.; Chuo, K.M.J.; Wong, S.Y.W.; Degraeve, P.; Nyam, K.L. The impact of cooking methods on the physical, sensory, and nutritional quality of fish. *Int. J. Gastron. Food Sci.* **2024**, *38*, 101061. [CrossRef]
48. Tenyang, N.; Mawamba, L.A.; Ponka, R.; Mamat, A.; Tiencheu, B.; Womeni, H.M. Effect of cooking and smoking methods on proximate composition, lipid oxidation and mineral contents of *Polypterus bichir* bichir fish. *Heliyon* **2022**, *8*, e10921. [CrossRef] [PubMed]
49. Tirtawijaya, G.; Lee, M.-J.; Negara, B.F.S.P.; Cho, W.-H.; Sohn, J.-H.; Kim, J.-S.; Choi, J.-S. Effects of vacuum frying on the preparation of ready-to-heat batter-fried and sauced chub mackerel (*Scomber japonicus*). *Foods* **2021**, *10*, 1962. [CrossRef] [PubMed]
50. Batista, R.A.B.; Japur, C.C.; Prestes, I.V.; Fortunato Silva, J.; Cavanha, M.; das Graças Pena, G. Potassium reduction in food by preparation technique for the dietetic management of patients with chronic kidney disease: A review. *J. Hum. Nutr. Diet.* **2021**, *34*, 736–746. [CrossRef] [PubMed]
51. Strzelczak, A.; Balejko, J.; Szymczak, M.; Witczak, A. Effect of protein denaturation temperature on rheological properties of Baltic herring (*Clupea harengus membras*) muscle tissue. *Foods* **2021**, *10*, 829. [CrossRef] [PubMed]
52. Suwannarong, S.; Boonarsa, P.; Ratseewo, J.; Siriamornpun, S. Impact of thermal processing on amino acid composition, physicochemical properties, and bioactive compounds of watermeal (*Wolffia globosa*) extract. *Appl. Food Res.* **2026**, *6*, 101875. [CrossRef]
53. Zhou, F.; Wang, X.-C. Effect of heat extraction on water-soluble taste substances in processing products of chilled large yellow croaker (*Pseudosciaena crocea*). *Food Sci. Nutr.* **2019**, *7*, 3863–3872. [CrossRef] [PubMed]
54. El Hosry, L.; Elias, V.; Chamoun, V.; Halawi, M.; Cayot, P.; Nehme, A.; Bou-Maroun, E. Maillard reaction: Mechanism, influencing parameters, advantages, disadvantages, and food industrial applications: A review. *Foods* **2025**, *14*, 1881. [CrossRef] [PubMed]
55. Selli, S.; Sevindik, O.; Guclu, G.; Zhao, J. Flavour of fish and fish proteins. In *Flavour and Consumer Perception of Food Proteins*; Zhao, J., Ed.; Royal Society of Chemistry: Cambridge, UK, 2023; pp. 119–149. [CrossRef]
56. Li, R.; Sun, Z.; Zhao, Y.; Li, L.; Yang, X.; Chen, S.; Wei, Y.; Li, C.; Wang, Y. Effect of different thermal processing methods on water-soluble taste substances of tilapia fillets. *J. Food Compos. Anal.* **2022**, *106*, 104298. [CrossRef]
57. Zhu, R.-G.; Xiao, H.-Y.; Zhou, Z.; Yin, M.; Xiao, H.; Hu, C.; Wei, G.; Liu, C. Thermal degradation of 18 amino acids during pyrolytic processes. *Sci. Rep.* **2024**, *14*, 29192. [CrossRef] [PubMed]
58. Tan, K.; Huang, L.; Tan, K.; Lim, L.; Peng, Y.; Cheong, K.-L. Effects of culinary treatments on the lipid nutritional quality of fish and shellfish. *Food Chem. X* **2023**, *19*, 100856. [CrossRef] [PubMed]
59. Tan, C.; Li, X.; Yu, Y.; Nie, S.; Wen, Q.; Tu, Z.; Zhang, L. Effects of five thermal processing methods on the physicochemical properties and flavor characteristics of grass carp meat. *LWT* **2024**, *206*, 116599. [CrossRef]

60. Saini, R.K.; Prasad, P.; Sreedhar, R.V.; Naidu, K.A.; Shang, X.; Keum, Y.-S. Omega-3 polyunsaturated fatty acids (PUFAs): Emerging plant and microbial sources, oxidative stability, bioavailability, and health benefits—A review. *Antioxidants* **2021**, *10*, 1627. [CrossRef] [PubMed]
61. Bastías, J.M.; Balladares, P.; Acuña, S.; Quevedo, R.; Muñoz, O. Determining the effect of different cooking methods on the nutritional composition of salmon (*Salmo salar*) and Chilean jack mackerel (*Trachurus murphyi*) fillets. *PLoS ONE* **2017**, *12*, e0180993. [CrossRef] [PubMed]
62. Yin, M.; Dai, K.; Qiu, Z.; Shi, Y.; Shi, J.; Matsuoka, R.; Jiang, Q.; Fang, Z.; Shi, W.; Wang, X. Effect of temperature fluctuations during frozen storage on ice crystal distribution and quality of tilapia (*Oreochromis mossambicus*). *Food Chem.* **2025**, *463*, 141104. [CrossRef] [PubMed]
63. Hematyar, N.; Rustad, T.; Sampels, S.; Kastrup Dalsgaard, T. Relationship between lipid and protein oxidation in fish. *Aquac. Res.* **2019**, *50*, 1393–1403. [CrossRef]
64. Tan, M.; Mei, J.; Xie, J. The formation and control of ice crystal and its impact on the quality of frozen aquatic products: A review. *Crystals* **2021**, *11*, 68. [CrossRef]
65. Duarte, A.M.; Silva, F.; Pinto, F.R.; Barroso, S.; Gil, M.M. Quality assessment of chilled and frozen fish—Mini review. *Foods* **2020**, *9*, 1739. [CrossRef] [PubMed]
66. Abbas, K.A.; Mohamed, A.; Bakar, J.; Ebrahimian, M. A review on correlations between fish freshness and pH during cold storage. *Am. J. Biochem. Biotechnol.* **2008**, *4*, 416–421. [CrossRef]
67. Kim, H.-Y.; Lim, Y.I. Studies on quality changes of ready-prepared conger eel products adding ginseng and pine mushroom during storage and sterilization. *Korean J. Food Cook. Sci.* **2003**, *19*, 396–402.
68. Chan, S.T.; Yao, M.W.Y.; Wong, Y.C.; Wong, T.; Mok, C.S.; Sin, D.W.M. Evaluation of chemical indicators for monitoring freshness of food and determination of volatile amines in fish by headspace solid-phase microextraction and gas chromatography–mass spectrometry. *Eur. Food Res. Technol.* **2006**, *224*, 67–74. [CrossRef]
69. Kim, D.-Y.; Park, S.-W.; Shin, H.-S. Fish freshness indicator for sensing fish quality during storage. *Foods* **2023**, *12*, 1801. [CrossRef] [PubMed]
70. Abdelnaby, T.; Feng, T.; Zhang, T.; Jiang, X.; Wang, Y.; Li, Z.; Xue, C. Impact of frozen storage on physicochemical parameters and quality changes in cooked crayfish. *Heliyon* **2024**, *10*, e31649. [CrossRef] [PubMed]
71. Zhang, L.; Yu, Y.; Tan, C.; Nie, S.; Wen, Q.; Tu, Z. Exploration of changes in sensory, physicochemical properties and microbial metabolic activities of grass carp meat during refrigerated storage. *Food Chem. X* **2024**, *23*, 101662. [CrossRef] [PubMed]
72. European Commission. Commission Regulation (EC) No 2074/2005 laying down implementing measures for certain products under Regulation (EC) No 853/2004 of the European Parliament and of the Council. *Off. J. Eur. Union* **2005**, *L338*, 27–59. Available online: https://eur-lex.europa.eu/eli/reg/2005/2074/oj/eng (accessed on 27 April 2026).
73. Irwin, J.W.; Hedges, N. Measuring lipid oxidation. In *Understanding and Measuring the Shelf-Life of Food*; Steele, R., Ed.; Woodhead Publishing: Cambridge, UK, 2004; pp. 289–316. [CrossRef]
74. Abeyrathne, E.D.N.S.; Nam, K.; Ahn, D.U. Analytical methods for lipid oxidation and antioxidant capacity in food systems. *Antioxidants* **2021**, *10*, 1587. [CrossRef] [PubMed]
75. Hu, L.; Ren, S.; Shen, Q.; Chen, J.; Ye, X.; Ling, J. Proteomic study of the effect of different cooking methods on protein oxidation in fish fillets. *RSC Adv.* **2017**, *7*, 27496–27505. [CrossRef]
76. Gokoglu, N.; Ucak, I. Effect of freshness grade of anchovy (*Engraulis encrasicolus*) on the quality of marinated product stored at 4 °C. *Acta Aquat.* **2020**, *7*, 54–59. [CrossRef]
77. Kim, D.-Y.; Jeon, H.; Shin, H.-S. Risk assessment and determination of arsenic and heavy metals in fishery products in Korea. *Foods* **2023**, *12*, 3750. [CrossRef] [PubMed]
78. International Commission on Microbiological Specifications for Foods. *Microorganisms in Foods 8: Use of Data for Assessing Process Control and Product Acceptance*; Springer: New York, NY, USA, 2011. [CrossRef]
79. U.S. Food and Drug Administration. *Bacteriological Analytical Manual, Chapter 4: Enumeration of Escherichia coli and the Coliform Bacteria*; U.S. Food and Drug Administration: Silver Spring, MD, USA, 2020. Available online: https://www.fda.gov/food/laboratory-methods-food/bam-chapter-4-enumeration-escherichia-coli-and-coliform-bacteria (accessed on 28 April 2026).
80. MFDS—Ministry of Food and Drug Safety. *Food Code (Notice No. 2021-54)*; Ministry of Food and Drug Safety: Cheongju, Republic of Korea, 2021. Available online: https://www.mfds.go.kr/eng/brd/m_15/view.do?seq=72437 (accessed on 29 April 2026).
81. Rosa, G.; Miller, L.; Clasen, T. Microbiological effectiveness of disinfecting water by boiling in rural Guatemala. *Am. J. Trop. Med. Hyg.* **2010**, *82*, 473–477. [CrossRef] [PubMed]
82. Park, J.-H.; Cha, Y.-J.; Kim, S.-J.; Lee, E.-J. Shelf life prediction of vacuum-packaged grilled mackerel. *Prev. Nutr. Food Sci.* **2023**, *28*, 200–208. [CrossRef] [PubMed]

83. Muthee, M.W.; Khamis, F.M.; Cheseto, X.; Tanga, C.M.; Subramanian, S.; Egonyu, J.P. Effect of cooking methods on nutritional value and microbial safety of edible rhinoceros beetle grubs (*Oryctes* sp.). *Heliyon* **2024**, *10*, e25331. [CrossRef] [PubMed]
84. Odike, O. Investigation of bacterial spoilage of cooked food stored in freezer during thawing. *Int. J. Microbiol. Appl. Sci.* **2024**, *3*, 180–190.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.