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RESEARCH ARTICLE

Quality Characteristics of Tuna Trim Surimi Patties with Added Carrageenan: Proximate, Sensory, and Physical Analyses

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Abstract. Tuna trim is a fishery by-product with potential for processing into surimi-based value-added products. This study evaluated the effects of κ-carrageenan concentrations (0.5%, 1.0%, and 1.5% w/w; two replications per treatment) on the proximate composition, sensory characteristics, and physical quality of tuna trim surimi patties. Proximate parameters, including moisture, ash, protein, fat, and crude fiber, were analyzed according to AOAC methods. Sensory evaluation was conducted using a 5-point hedonic scale for texture, taste, color, and flavor, while physical quality was assessed using folding and biting tests. Descriptive statistics were calculated for all parameters, and differences among treatments were analyzed using the Kruskal–Wallis test ($\alpha = 0.05$) because the small number of replications did not meet the normality assumption required for parametric ANOVA. The results showed that carrageenan addition did not significantly affect any proximate or sensory parameter ($p > 0.05$). Moisture content ranged from 60.66–63.89%, ash from 1.88–1.94%, protein from 12.27–13.05%, fat from 0.145–0.207%, and crude fiber from 5.97–6.40%. Although the sensory differences were not statistically significant, the 1.0% κ-carrageenan treatment yielded the highest mean sensory scores and the best physical quality, achieving Grade A in the folding test and a chewy texture in the biting test. In contrast, patties containing 0.5% and 1.5% κ-carrageenan tended to break during physical testing. Therefore, 1.0% κ-carrageenan represents the most promising formulation for further development of tuna trim surimi patties.

Keywords: carrageenan, gel texture, patty, proximate analysis, sensory evaluation, tuna trim, physical quality.

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INTRODUCTION

The tuna processing industry generates various by-products, including heads, skin, bones, trimmings, and meat portions that do not meet loin-grade specifications. Globally, these by-products are generated in substantial quantities because a considerable proportion of the tuna biomass is discarded during canning and filleting processes (Garofalo *et al.*, 2023). Nevertheless, these materials retain considerable nutritional value and utilization potential when further processed into value-added food or feed products (Baek & Cho, 2024). One promising approach is to process tuna trimmings into surimi and subsequently formulate them into processed products such as patties (Yin & Park, 2023). The conversion of fishery by-products into value-added food products is also consistent with efforts to improve raw material utilization efficiency and reduce waste in the fish processing industry (Yin & Park, 2023).

A patty is a type of processed product made from minced meat that is formed into a flattened shape and cooked, and it is commonly used as a component of burgers, nuggets, and other ready-to-cook animal protein-based products (Xie *et al.*, 2024). This product form was selected as a model for processing tuna trim surimi because its preparation is relatively simple and does not require specialized molding equipment, as used for emulsion-based products such as meatballs or sausages. It also allows direct evaluation of the gel properties formed through physical tests such as the folding test and biting test (Park, 2005). In addition, surimi-based patties offer modifiable textural properties through the incorporation of hydrocolloids, relatively high protein content, and formulation flexibility for the development of value-added ready-to-eat products (Shaviklo & Johannsson, 2006; Yin & Park, 2023). These characteristics make patties a representative product form for comprehensively evaluating the effects of carrageenan addition on the quality of tuna trim surimi.

Surimi is a concentrate of myofibrillar proteins obtained through washing minced fish muscle to remove sarcoplasmic proteins, blood, fat, and pigments, thereby producing a raw material with good gel-forming ability (Park, 2005). In the development of surimi-based products, hydrocolloids are frequently incorporated to improve water-binding capacity, emulsion stability, structural cohesiveness, and product texture (Monto *et al.*, 2022; Xie *et al.*, 2024). One widely used hydrocolloid is κ-carrageenan, which has been reported to improve gel network strength, enhance water-holding capacity, and improve the texture of surimi products through interactions with myofibrillar proteins (Chen *et al.*, 2024; Lan *et al.*, 2023; Zhao *et al.*, 2024). The addition of κ-carrageenan has also been shown to improve gel quality in various surimi products, including crayfish surimi (Wei *et al.*, 2024) and Antarctic krill surimi (Chen *et al.*, 2024). However, excessive carrageenan addition may result in undesirable changes in gel structure, including increased brittleness or fragmentation (Lan *et al.*, 2023; Yang *et al.*, 2025).

Nevertheless, most studies investigating the effects of carrageenan on surimi gel quality have focused on whole-fish raw materials or non-tuna species, such as crayfish surimi (Wei *et al.*, 2024), Antarctic krill surimi (Chen *et al.*, 2024), and various freshwater and marine fish species (Xie *et al.*, 2024). Studies specifically using tuna trimmings as a raw material for surimi remain limited. Furthermore, previous studies have generally focused on chemical characteristics or instrumental texture, while relatively few have simultaneously integrated proximate, sensory, and physical evaluations, including folding and biting tests, within a single study of carrageenan formulation for tuna trim surimi patties. This research gap highlights the need for further investigation into the effects of carrageenan addition on the quality of tuna trim surimi patties using a comprehensive evaluation approach. Therefore, this study was conducted to evaluate the quality characteristics of tuna trim surimi patties formulated with different carrageenan concentrations and to identify the most promising formulation for the development of value-added fishery products. The novelty of this study lies in the utilization of tuna trimmings, a by-product of the tuna processing industry that remains underutilized, as a raw material for surimi, combined with a comprehensive quality evaluation integrating proximate, sensory, and physical analyses. This approach provides additional scientific information on carrageenan formulation for the development of value-added patties from tuna processing by-products.

METHODS

This study was conducted as a laboratory-based experimental study to evaluate the effect of κ-carrageenan addition on the quality characteristics of patties formulated from tuna trim surimi. The study was conducted at the Fishery Product Processing Workshop and the Chemistry Laboratory, Department of Aquaculture, Politeknik Pertanian Negeri Pangkajene Kepulauan. The additional ingredients included commercial food-grade κ-carrageenan, table salt (NaCl), and other auxiliary ingredients according to the standard surimi formulation. The main equipment included a food processor/chopper, patty molds, a steamer, an analytical balance, and equipment for proximate analysis, including an oven, muffle furnace, Kjeldahl distillation unit, and Soxhlet extractor. A single-factor treatment design was used with three carrageenan concentrations, namely 0.5%, 1.0%, and 1.5% (w/w based on the total surimi mixture), with two replications for each treatment, resulting in six experimental units. The number of replications was selected because this study was exploratory and preliminary in nature; therefore, the statistical results should be interpreted as preliminary indications and confirmed in further studies with a larger number of replications to increase statistical power.

The study consisted of two main stages. Stage 1, preparation of tuna trim surimi, and Stage 2, preparation and cooking of surimi patties with carrageenan addition, as described below.

1. Preparation of Tuna Trim Surimi

Surimi was prepared through a series of processing steps, including three washing (*leaching*) cycles using cold water at a meat-to-water ratio of 1:3 and a temperature of 5–10 °C to remove sarcoplasmic proteins, fat, and pigments, followed by pressing (*dewatering*) to reduce the moisture content. The resulting surimi was then supplemented with cryoprotectants consisting of 2% powdered sugar and 0.2% sodium tripolyphosphate (STPP), producing tuna trim surimi as the raw material for Stage 2.

2. Preparation of Surimi Patties

The patties were prepared by adding carrageenan according to the treatment levels (0.5%, 1.0%, and 1.5%), together with 1.5% salt and 20% crushed ice. The surimi mixture was then formed into patties approximately 1 cm thick and steamed at 90 °C for 20 min (Park, 2005; Yin & Park, 2023). The preparation of the surimi and patties followed a modified procedure based on the standard method described by Shaviklo and Johannsson (2006).

Quality Evaluation

The quality of the tuna trim surimi patties was evaluated through three main analyses: (1) proximate analysis, (2) sensory evaluation, including hedonic scoring, and (3) physical texture assessment.

Proximate analysis included moisture content using the oven-drying method (AOAC 925.10), ash content using the dry ashing method (AOAC 920.153), protein content using the Kjeldahl method (AOAC 928.08), fat content using the Soxhlet method (AOAC 991.36), and crude fiber content using the acid–base hydrolysis method (AOAC 962.09), following AOAC (2016). Sensory evaluation was conducted using a hedonic scoring method, while physical texture was assessed using folding and biting tests.

The hedonic test was conducted by 20 semi-trained panelists to evaluate texture, taste, color, and flavor using a 5-point hedonic scale: 1 = strongly dislike, 2 = dislike, 3 = neither like nor dislike, 4 = like, and 5 = strongly like. Texture evaluation included the folding test, with the following categories: A, no cracking when folded four times; B, no cracking when folded twice; C, gradual cracking when folded twice; and D, immediate breakage upon folding. The biting test was used to describe product elasticity through organoleptic assessment. Both tests followed surimi evaluation methods described by Shaviklo and Johannsson (2006) and Park (2005).

The experimental data were analyzed using the Kruskal–Wallis test at α = 0.05. This non-parametric test was selected because the small number of replications (n = 2 per treatment) limited the meaningful assessment of normality assumptions and increased the risk of violating the assumptions required for ANOVA. The Kruskal–Wallis test was therefore used as a more conservative alternative to one-way ANOVA for comparing three independent treatment groups (Kruskal & Wallis, 1952).

Data Analysis

Proximate and sensory data were presented as mean ± standard deviation (SD) for each treatment level (Table 1). Before the comparison test was conducted, data were assessed for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test. Because the number of replications per treatment was relatively small (n = 2), some data did not meet the normality assumption. Therefore, the analysis was continued using the non-parametric Kruskal–Wallis test at $\alpha = 0.05$ as an alternative to one-way ANOVA for comparing the three independent treatment groups (Kruskal & Wallis, 1952). All statistical analyses were performed using SPSS version 29.

RESULTS AND DISCUSSION

Proximate and Sensory Characteristics of Tuna Trim Surimi Patties

The effects of carrageenan addition at different concentrations on the proximate and sensory characteristics of tuna trim surimi patties were evaluated using the Kruskal–Wallis test. This non-parametric statistical test is used to compare three or more independent treatment groups (Kruskal & Wallis, 1952). Statistical significance was determined based on the *p*-value, with differences among treatments considered statistically significant when $p \leq 0.05$. The complete results of the descriptive statistics are presented in Table 1.

Table 1. Descriptive Statistics (Mean ± SD) of Proximate and Sensory Parameters of Tuna Trim Surimi Patties by Carrageenan Concentration

Parameter	0.5%	1.0%	1.5%
Moisture Content (%)	60,66 ± 0,34	63,45 ± 0,08	63,89 ± 0,01
Ash Content (%)	1,94 ± 0,06	1,88 ± 0,04	1,89 ± 0,02
Protein Content (%)	12,46 ± 0,08	12,27 ± 0,04	13,05 ± 0,01
Fat Content (%)	0,145 ± 0,001	0,198 ± 0,001	0,207 ± 0,004
Crude Fiber (%)	6,40 ± 0,02	5,97 ± 0,01	6,19 ± 0,01
Texture	4,00 ± 0,00	5,00 ± 0,00	3,00 ± 0,00
Taste	4,00 ± 0,00	5,00 ± 0,00	3,50 ± 0,71
Color	4,00 ± 0,00	5,00 ± 0,00	3,00 ± 0,00
Flavour	4,00 ± 0,00	5,00 ± 0,00	3,00 ± 0,00

Note: values are presented as mean ± SD (n = 2 replicates per treatment).

It should be noted that identical H and *p*-values (4.571 and 0.102, respectively) were obtained for four different proximate parameters, namely moisture, protein, fat, and crude fiber (Table 2). Based on the raw data (Table 1), this finding was confirmed not to result from data-entry errors but rather from the mathematical properties of the Kruskal–Wallis test, which calculates the H statistic based on data ranks rather than absolute values. For these four parameters, the rank order of the six experimental units (two replications × three treatment levels) happened to be identical despite differences in their absolute values. Consequently, the sum of ranks for each treatment group produced the same rank configuration, resulting in an identical H statistic (H = 4.571) across the four parameters (Demedts, 2022). Therefore, the identical H and *p*-values reported in Table 2 represent a statistically valid finding rather than an indication of a data error.

Table 2. Kruskal-Wallis Test Results for Quality Characteristics of Tuna Trim Surimi Patties

Parameter	H-value	p-value	Interpretation
Moisture Content (%)	4,571	0,102	Not significantly different
Ash Content (%)	2,258	0,323	Not significantly different
Protein Content (%)	4,571	0,102	Not significantly different
Fat Content (%)	4,571	0,102	Not significantly different
Crude Fiber (%)	4,571	0,102	Not significantly different
Texture	5,000	0,082	Not significantly different
Taste	4,333	0,115	Not significantly different
Color	5,000	0,082	Not significantly different
Flavour	5,000	0,082	Not significantly different

Note: ns = not significantly different ($p > 0.05$)

1. Proximate Characteristics

A comparison of the mean values of the five proximate parameters—moisture, ash, protein, fat, and crude fiber—at carrageenan concentrations of 0.5%, 1.0%, and 1.5% is presented in Table 1. The following discussion describes the comparative patterns among the carrageenan concentrations for each parameter, along with a scientific interpretation of the Kruskal–Wallis test results presented in Table 2.

1.1 Moisture Content

The statistical analysis showed that the addition of carrageenan at different concentrations did not significantly affect the moisture content of tuna trim surimi patties ($H = 4.571$; $p = 0.102$; $p > 0.05$). The absence of a significant effect may be attributed to the ability of carrageenan to form a gel matrix that had not reached a critical level of water binding sufficient to produce statistically distinguishable differences among the concentrations tested. Carrageenan is a hydrophilic sulfated polysaccharide with a strong capacity to bind water; however, within the concentration range used in this study, differences in water-binding capacity among treatments may not have been sufficiently large to be statistically detectable. This finding is consistent with Lalopua and Onsu (2021), who reported that carrageenan addition at concentrations of 1.0–2.0% did not significantly affect the moisture content of kamaboko prepared from tuna trim surimi. Descriptively, moisture content increased with increasing carrageenan concentration, from 60.66 ± 0.34% at 0.5% to 63.45 ± 0.08% at 1.0% and 63.89 ± 0.01% at 1.5% (Table 1). This trend is consistent with the hydrophilic and water-binding properties of carrageenan within the gel matrix, although the magnitude of the increase was insufficient to produce a statistically significant difference.

1.2 Ash Content

The ash content of the tuna trim surimi patties was not significantly affected by the addition of carrageenan at different concentrations ($H = 2.258$; $p = 0.323$; $p > 0.05$). The relatively low H value (2.258) indicates limited variation among the treatment groups. Carrageenan generally contains certain mineral components, particularly sodium, potassium, and calcium, which may be associated with sulfate groups along its polysaccharide chains. However, the mineral contribution from the added carrageenan appears to have been insufficient to significantly alter the total ash content of the product, particularly because the primary raw material, tuna trim, had relatively consistent mineral content. Descriptively, ash content remained relatively stable across carrageenan concentrations, with values of 1.94 ± 0.06% (0.5%), 1.88 ± 0.04% (1.0%), and 1.89 ± 0.02% (1.5%) (Table 1), without a consistent increasing or decreasing trend. This observation is consistent with the non-significant Kruskal–Wallis test result.

1.3 Protein Content

The addition of carrageenan at different concentrations did not significantly affect the protein content of the surimi patties ($H = 4.571$; $p = 0.102$; $p > 0.05$). This result can be explained by the fact that carrageenan is a polysaccharide and does not contain protein; therefore, its addition would not directly contribute to an increase in the protein content of the product. The protein content of surimi patties is more strongly influenced by the myofibrillar protein content of the fish raw material, particularly actomyosin, which is a major component involved in surimi gel formation. The mean protein content exhibited a non-linear pattern across the treatments, decreasing from 12.46 ± 0.08% at 0.5% to 12.27 ± 0.04% at 1.0%, and then increasing to 13.05 ± 0.01% at 1.5% (Table 1). This pattern may reflect natural variation in the protein composition of tuna trim among surimi production batches rather than a direct effect of carrageenan addition (Park, 2005).

1.4 Fat Content

The statistical analysis showed that fat content did not differ significantly among treatments (H = 4.571; p = 0.102; $p > 0.05$). As a hydrocolloid, carrageenan does not contain fat; therefore, its addition would not be expected to directly alter the lipid profile of the final product. The relatively stable fat content among treatments also suggests that carrageenan did not substantially interact with lipid components within the surimi gel matrix at the concentrations tested. Nevertheless, descriptively, the mean fat content increased with increasing carrageenan concentration, from 0.145 ± 0.001% at 0.5% to 0.198 ± 0.001% at 1.0% and 0.207 ± 0.004% at 1.5% (Table 1). This numerical increase was relatively small and remained within a narrow range, which may explain why it was not statistically significant according to the Kruskal–Wallis test, particularly given the limited number of replications.

1.5 Crude Fiber Content

Although carrageenan is chemically classified as a dietary fiber, the analysis showed that the crude fiber content of the surimi patties did not differ significantly among carrageenan concentrations (H = 4.571; p = 0.102; $p > 0.05$). This finding may be attributed to the limitations of the conventional crude fiber analysis (Weende method), which extracts only a portion of the polysaccharide fraction and therefore does not fully represent the total carrageenan incorporated into the product. In addition, the concentration range of carrageenan used in this study may have been insufficient to produce differences detectable by this analytical method. The mean crude fiber content decreased slightly from 6.40 ± 0.02% at 0.5% to 5.97 ± 0.01% at 1.0%, before increasing again to 6.19 ± 0.01% at 1.5% (Table 1). Thus, the observed pattern did not indicate a linear relationship between carrageenan concentration and crude fiber content.

2. Sensory Characteristics

2.1 Hedonic Scoring Method

Sensory evaluation was conducted by trained panelists using a hedonic scoring method to assess four quality attributes: texture, taste, color, and flavor. The Kruskal–Wallis test showed no significant differences among treatments for any of the sensory attributes, as described below.

The texture attribute of the tuna trim surimi patties was not significantly affected by differences in carrageenan concentration (H = 5.000; p = 0.082; $p > 0.05$). Although the p-value was close to the significance threshold (0.05), the observed differences were not statistically sufficient to be considered significant. Descriptively, there was a tendency for the texture score to increase with increasing carrageenan concentration, which may be associated with the ability of carrageenan to form a more cohesive gel network. Carrageenan acts as a binding agent that can enhance the chewiness and elasticity of fish gel products through ionic interactions with myofibrillar proteins. The mean texture score increased from 4.00 ± 0.00 (liked) at 0.5% carrageenan to 5.00 ± 0.00 (liked very much) at 1.0%, but decreased to 3.00 ± 0.00 (neutral) at 1.5% (Table 1). This non-linear pattern is consistent with the physical test results, which showed that the 1.5% carrageenan treatment tended to produce a more brittle texture, making it less preferred by the panelists than the 1.0% treatment (Imeson, 2010).

The addition of carrageenan did not significantly affect the taste attribute of the surimi patties (H = 4.333; $p = 0.115$; $p > 0.05$). Carrageenan is a hydrocolloid that is essentially neutral in taste; therefore, its addition would not be expected to make a significant contribution to the taste of the product. The consistency of the panelists' taste evaluations indicates that the taste profile of the surimi patties was predominantly influenced by the fish raw material and seasonings rather than by carrageenan. The mean taste scores were 4.00 ± 0.00 (0.5%), 5.00 ± 0.00 (1.0%), and 3.50 ± 0.71 (1.5%) (Table 1). All treatments remained within the neutral-to-liked range, with no indication of undesirable off-taste, despite a slight decrease in the score at the highest carrageenan concentration.

The color attribute of the surimi patties did not differ significantly among treatments (H = 5.000; $p = 0.082$; $p > 0.05$). Carrageenan generally has a white to pale cream color in powder form and, at low concentrations, does not contribute appreciable pigmentation to the final product. The color of surimi patties is more strongly influenced by the characteristics of the surimi raw material, including myoglobin pigments, as well as the heating process during processing. The mean color preference scores followed a pattern similar to that observed for texture, namely 4.00 ± 0.00 (0.5%), 5.00 ± 0.00 (1.0%), and 3.00 ± 0.00 (1.5%) (Table 1). Visually, patties from all treatments exhibited relatively uniform white to yellowish-white coloration. Therefore, the lower score at 1.5% was more likely associated with the panelists' perception of the less desirable texture rather than with an actual change in color.

In sensory evaluation, flavor refers to the combined perception of aroma (odor) and taste experienced simultaneously during consumption, whereas the taste attribute refers specifically to gustatory sensations. Statistical analysis showed that flavor did not differ significantly among the carrageenan concentrations (H = 5.000; $p = 0.082$; $p > 0.05$). Similar to taste, the flavor or aroma of the product is more strongly influenced by volatile compounds derived from the fish raw material during thermal processing rather than by carrageenan. The absence of a significant effect indicates that carrageenan was essentially neutral toward the product's aroma profile at the concentrations tested. The mean flavor scores followed the same pattern as color, namely 4.00 ± 0.00 (0.5%), 5.00 ± 0.00 (1.0%), and 3.00 ± 0.00 (1.5%) (Table 1).

2.2 Sensory Texture Evaluation

The sensory texture evaluation showed that the 1.0% carrageenan treatment produced the best texture quality, characterized by grade A in the folding test and a chewy texture in the biting test. In contrast, the 0.5% and 1.5% carrageenan treatments received grade B in the folding test and exhibited breakage during the biting test. These findings further support the sensory evaluation results, indicating that the addition of 1.0% carrageenan produced the most favorable gel structure. The results of the sensory texture evaluation are presented in Table 3.

Table 3. Physical Test Results of Patties from Tuna Trim Surimi with Carrageenan Addition

Carrageenan (%)	Folding Test	Biting Test
0,5	B	Broken
1,0	A	Chewy
1,5	B	Broken

In surimi products, the folding test and biting test are practical indicators for assessing gel elasticity and cohesiveness (Park, 2005; Shaviklo & Johannsson, 2006). Samples that do not crack when folded and exhibit a chewy texture when bitten indicate the formation of a more stable protein network. The results of this study indicate an optimum point at a carrageenan concentration of 1.0%. At this concentration, carrageenan appears to interact effectively with myofibrillar proteins, thereby forming a compact and elastic structure. At 1.5%, excessive carrageenan addition was presumed to produce a structure that was overly dense or heterogeneous, making the product more susceptible to breakage. This finding is consistent with previous reports that κ-carrageenan can improve gel quality, whereas excessive concentrations may disrupt the network structure and promote gel fragmentation (Lan *et al.*, 2023; Wei *et al.*, 2024).

Based on the data presented in Table 3, the 0.5% carrageenan treatment produced grade B in the folding test, indicating that the product did not crack when folded in half but was unable to maintain structural integrity when folded into quarters (Park, 2005). This condition indicates that a 0.5% carrageenan concentration was insufficient to develop a sufficiently strong gel network, resulting in limited elasticity. This finding was further supported by the biting test, which showed breakage, indicating low cohesiveness and elasticity of the gel matrix at this concentration (Shaviklo & Johannsson, 2006). The relatively low carrageenan concentration may have resulted in suboptimal ionic interactions between the sulfate groups of carrageenan and myofibrillar proteins, preventing the formation of a sufficiently strong three-dimensional network to withstand mechanical stress (Imeson, 2010).

The 1.0% carrageenan treatment exhibited the best results, receiving grade A in the folding test, indicating that the product did not crack when folded into quarters, while also exhibiting a chewy texture in the biting test. Grade A represents the highest category in the standard evaluation of surimi gel quality and reflects the formation of a highly elastic and cohesive gel structure (Park, 2005; Shaviklo & Johannsson, 2006). The chewy texture observed in the biting test indicates that the product exhibited good elastic deformation, allowing it to recover its original shape after being subjected to pressure. At this concentration, carrageenan appears to function optimally as a binding agent, facilitating the formation of protein–polysaccharide complexes, strengthening the actomyosin gel network, and enhancing water-holding capacity uniformly, thereby producing a more homogeneous and elastic texture (Lan *et al.*, 2023; Wei *et al.*, 2024).

In contrast, the 1.5% carrageenan treatment showed a decline in physical quality, receiving grade B in the folding test and exhibiting breakage in the biting test, similar to the 0.5% treatment. The decline in quality at the highest concentration indicates a non-linear relationship between carrageenan concentration and gel quality (Wei *et al.*, 2024). At 1.5%, excessive carrageenan addition may have resulted in competition between carrageenan molecules and myofibrillar proteins for water binding, leading to uneven water distribution within the gel matrix (Lan *et al.*, 2023). Furthermore, excessive carrageenan concentrations may promote polysaccharide aggregation, disrupting the continuity of the protein network and producing a brittle structure that is more susceptible to fracture (Imeson, 2010). This quadratic response pattern further indicates that 1.0% carrageenan represents the optimum concentration for gel formation in tuna trim surimi patties.

The sensory texture evaluation (folding test and biting test) in this study was conducted using two replicates for each treatment level, and both replicates produced consistent categorical results (Table 3). Nevertheless, the evaluation was qualitative and categorical, based on visual and sensory assessment, without instrumental quantification. For future studies, instrumental texture analysis, such as Texture Profile Analysis (TPA) or gel strength measurement using a texture analyzer, is recommended to obtain quantitative data that can support and strengthen these qualitative findings.

3. Implications for Product Development

Overall, the Kruskal–Wallis test showed that all proximate and sensory parameters evaluated had p-values > 0.05, indicating that the addition of carrageenan at the concentrations tested did not significantly affect the characteristics of tuna trim surimi patties. Statistically, these findings indicate that the variation in carrageenan concentration used in this study had not reached an effective threshold sufficient to produce measurable significant changes in the parameters evaluated.

From a food technology perspective, these findings have important practical implications. The absence of statistically significant differences in proximate and sensory parameters indicates that all three carrageenan concentrations were acceptable in terms of chemical composition and sensory acceptance. However, the physical tests demonstrated that the structural quality of the product was still influenced by carrageenan concentration, with 1.0% carrageenan producing the most stable gel structure, whereas 0.5% and 1.5% tended to produce products that were more susceptible to breakage. The 1.0% carrageenan concentration is considered the most advantageous formulation because it does not require the highest concentration, which would incur higher production costs, given that carrageenan is a food additive with relatively high economic value (Bixler & Porse, 2011). Therefore, 1.0% carrageenan is recommended as the optimal balance between production cost efficiency and physical product quality, consistent with the conclusion of this study.

CONCLUSION

The addition of κ-carrageenan to tuna trim surimi patties at different concentrations did not result in substantial changes in the proximate composition or sensory quality of the products. However, based on the physical evaluation, the addition of 1.0% κ-carrageenan produced the most favorable textural characteristics, as indicated by better folding resistance and a chewier texture than those observed in the other treatments. Considering the overall chemical, sensory, and physical quality, a κ-carrageenan concentration of 1.0% can be recommended as the most suitable formulation for the development of tuna trim surimi patties. These findings should be further confirmed through subsequent studies using an adequate number of replicates and instrumental texture analysis to obtain more comprehensive information on the product characteristics and quality stability.

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AUTHOR CONTRIBUTIONS STATEMENT

The authors declare that the contributions of each author to this work are as follows: MK, as the lead contributor and corresponding author, was responsible for research design, conceptualization, data collection, data analysis, validation of data analysis, manuscript editing, and providing additional discussion. NF, IA, DHN, R, SWF, and EG, as contributing authors, were responsible for research design, conceptualization, data collection, data analysis, validation of data analysis, and manuscript editing.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest with any party regarding the publication of this article

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DECLARATION OF GENERATIVE AI

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) for language editing, improving readability, and enhancing clarity. All AI-assisted outputs were carefully reviewed, verified, and edited by the authors. The authors take full responsibility for the accuracy, integrity, originality, and content of the published article.

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