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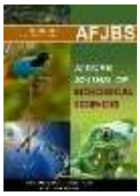

Evaluation of Physicochemical Properties of Surimi-Based Mackerel Otak-Otak with Kappa-Carrageenan During Frozen Storage

Yohana Fransiska Desi Pan , Abu Bakar Tawali*, Andi Hasizah

Department of Agricultural Technology, Faculty of Agriculture, Hasanuddin University,

Jl. Perintis Kemerdekaan Km. 10 Tamalanrea Makassar, Sulawesi Selatan, Indonesia, 90245

*E-mail: abubakar_tawali@yahoo.com

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ABSTRACT

Otak-otak are processed products derived from surimi. Surimi is a myofibrillar protein concentrate of fish origin. Extended frozen storage can induce protein denaturation, consequently affecting end-product quality. During frozen storage, κ-carrageenan is a stabilizer, maintaining protein stability. This study aimed to evaluate the effects of kappa carrageenan addition to mackerel surimi on its quality during frozen storage and the resultant characteristics of the *otak-otak* as the end product. This study utilized a two-factor Completely Randomized Design (CRD), examining κ-carrageenan concentrations (0%, 1%, 1.5%, 2%) and cryogenic storage durations (7, 14, 21, 28 days). Analyses focused on surimi's rheological properties (gel strength, water holding capacity) and otak-otak's characteristics (protein, moisture, lipid content, and sensory attributes). Results indicated that 2% κ-carrageenan optimally preserved surimi quality during frozen storage, yielding the highest gel strength (2146-600 g/cm) and water holding capacity (71.44-55.16%). *Otak-otak* produced from surimi with 2% κ-carrageenan addition demonstrated superior characteristics, with optimal protein content (9.97-9.15%), moisture content (56.59-59.53%), and lipid content (0.66-0.69%). The organoleptic evaluation revealed the highest acceptability for *otak-otak* with a 2% k-carrageenan addition. Findings indicate that 2% κ-carrageenan optimally preserves surimi's physicochemical and organoleptic properties during 28-day storage, enhancing the frozen quality and yielding dense, chewy *otak-otak* products.

Keywords: Frozen storage, Kappa-carrageenan, *Otak-otak*, Physicochemical, Surimi

INTRODUCTION

Otak-otak ikan is a product made from white meat fish with the addition of flour, coconut milk, egg whites, and spices wrapped lengthwise in banana leaves and then steamed, baked, or fried (Alam et al., 2021). It is then served with peanut sauce which has a savory and spicy taste. *Otak-otak* has become popular in several regions in Indonesia, Singapore, and Malaysia (Sartika et al., 2016) Although fish brains are often made with fresh fish meat, in the development of fishery product-based food technology, surimi has become an important raw material in various traditional and modern food preparations.

Surimi is a myofibrillar protein concentrate that is mostly derived from fish meat and serves as the main raw material in the manufacturing of surimi-based processed products. Fish myofibrillar protein is produced through a series of step-by-step processes, including heading, gutting, filleting, bone removal, washing, drying, meat shredding, and freezing (Park, 2005; Park et al., 2016). The main ingredients for making surimi are selected from marine fish species that have white meat, good taste (typical of fish), and have strong gel ability (Lanier, 1992; Park, 2014). One type of fish with white meat is mackerel. Mackerel fish has meat with a savory taste, bright white meat color, and a high meat yield of 57.23-58.57% (Yusman et al., 2015) In addition, fresh mackerel meat has a protein content of around 21.38-22.89%, consists of 16 types of essential and non-essential amino acids, and contains 535-550 mg/100g of plural unsaturated fatty acids which are beneficial for meeting nutritional needs (Yilmaz, 2021). These characteristics make it an ideal raw material for making surimi.

The advantages of surimi in the fishing industry include the stable availability of raw materials, making it easier to process serviced products, reducing storage and transportation costs, maintaining price stability, and saving labor (Barriuso et al., 2013a; Tolstorebrov et al., 2014a) Although surimi has many advantages, the freezing method used in the processing process also poses its challenges. The freezing method is one of the surimi processing processes that can extend the shelf life of surimi. However, surimi is subject to quality deterioration during freezing (Barriuso et al., 2013b; Tolstorebrov et al., 2014b; Van Ba et al., 2016). During frozen storage of surimi, myofibrillar proteins denature and then aggregate through chemical interactions with formaldehyde (Santana et al., 2018). The formation of ice crystals during frozen storage causes protein denaturation and decreases water binding capacity (Soladoye et al., 2015). This has an impact on reducing the quality of surimi, namely the gelation ability of myofibrillar proteins decreases so that the resulting gel becomes mushy and not strong (Fan et al., 2017). In a study (Uju, 2006) it was stated that storing surimi of kurisi fish at -15°C for 4 weeks caused a decrease in gel strength in fish meatball products and a decrease in the level of preference for color and taste. Therefore, food additives are needed that can suppress protein denaturation during storage to minimize the decline in the quality of surimi and its derivative products.

A frequently used additive in the surimi industry is a blend of 4% sorbitol and 4% sucrose. However, the shortcomings of these two ingredients can provide a sweet taste that contributes to changes in flavor characteristics (Nopianti et al., 2011). One alternative that can be used as an ingredient that can maintain the quality of surimi during storage is kappa carrageenan flour. Kappa carrageenan is a polysaccharide from *Eucheuma cottoni* seaweed (Nosa et al., 2020) which functions as a stabilizer in surimi to prevent protein denaturation and aggregation during frozen storage by forming hydrogen bonds with hydroxyl groups on its polymer chain. These bonds strengthen the gel structure and slow down the rate of protein denaturation. In addition, carrageenan interacts with myosin through strong intermolecular bonds thereby reducing protein denaturation and aggregation (Astutik et al., 2020; Walayat et al., 2021). The concentration of carrageenan flour used varies from 0.5-3% depending on the type of product (Winarno, 1990). Several studies have applied the addition of carrageenan to surimi, such as (Putra et al., 2015) with 1% kappa carrageenan in dumbo catfish surimi. Research by (Anggraeni et al., 2019) found that 2% kappa carrageenan concentration is best for flavor quality and protein content, while 1.5% is best for texture and fat content. However, this study did not store surimi as raw material. Therefore, the application of the addition of kappa carrageenan flour to surimi as a stabilizer during frozen storage to produce mackerel otak-otak food products that have a chewy texture has not been widely studied.

MATERIAL AND METHODS

Materials

The Mackerel (*Scomberomorus commersoni*) fish, whose total weight was 12 kg, was purchased from a local market in Daya, Makassar, South Sulawesi, Indonesia. The deceased fish was brought to the Teaching Industry, Hasanuddin University, Makassar. Kappa-carrageenan flour was purchased from an online store. Ice cubes, pepper, salt, sugar, eggs, Monosodium glutamate (MSG), coconut milk, garlic, fried onions, and tapioca flour were used to make otak-otak.

Research Procedure

Experimental Design

This research design used a factorial Complete Randomized Design (CRD) with 2 factors and 3 replications. The concentration of carrageenan flour used varies from 0.5-3% depending on the type of product (Winarno, 1990) Several previous studies have applied the addition of kappa carrageenan to surimi, such as (Putra et al., 2015) with 1.5% kappa carrageenan in kurisi fish surimi and (Saputro et al., 2018) with 1% kappa carrageenan in dumbo catfish surimi. The concentration of kappa-carrageenan in the study became the basis for this study.

The first factor is the addition of kappa carrageenan with five levels:

K1 = No carrageenan addition (0%)

K2 = 0.5% kappa carrageenan flour

K3 = 1% kappa carrageenan flour

K4 = 1.5% kappa carrageenan flour

K5 = 2% carrageenan kappa flour

The second factor is the length of storage with four levels:

P1 = 7 days storage

P2 = 14 days storage

P3 = 21 days storage

P4 = 28 days storage

Preparation of Surimi

The surimi production process is a meticulous procedure encompassing several crucial stages. It commences with the careful selection of raw materials and the initial preparation of fish, which involves a meticulous weeding process.

This process entails the removal of fish skin, belly, and bones to isolate the desired meat. Subsequently, the meat undergoes pulverization followed by thorough washing with cold water, typically maintained at approximately 5□ for 15 minutes per cycle, with this washing cycle repeated thrice to ensure thorough cleansing. After each washing cycle, the meat undergoes filtration and squeezing to eliminate excess water and impurities. Finally, carrageenan flour, widely utilized in surimi production for its gelling properties, is carefully incorporated into the mixture. The resultant surimi is then meticulously stored in a freezer (-20□) for preservation, ensuring its quality and longevity (Saputra, 2018).

Preparation of Otak-otak

Surimi undergoes blending with various supplementary components, including pepper, salt, sugar, eggs, monosodium glutamate (MSG), coconut milk, garlic, fried onions, and tapioca flour. Throughout the grinding process, ice cubes are introduced to sustain the temperature of the fish meat below 15°C. Subsequently, tapioca flour is incrementally integrated until a cohesive dough consistency is achieved. This dough is then subjected to kneading until it attains elasticity and non-adhesiveness. After this preparation, individual portions are encased in banana leaves and steamed at 60°C for 25 minutes or until fully cooked (Putra et al., 2015).

Analytical Methods

Analysis of Surimi

Gel Strength

The surimi gel strength was measured using a texture analyzer (CT33, Brookfield, UK) ((Badfar et al., 2022) and Surimi was carefully balanced and precisely positioned within a stainless steel plate container directly below the probe. Testing is carried out at ambient room temperature. The probe takes on a rounded shape (with a diameter of 5 mm) and operates at a 60 mm/minute speed to ensure elasticity. Gel strength is determined using the formula: Gel strength (g.cm) = Hardness (g) x Deformation (cm) (Nugroho et al., 2019).

Water Holding Capacity

Water holding capacity was measured using the Filter Paper Press Method. Samples (0.3 g) were positioned atop Watman 41 filter paper and compressed between two glass plates under a 35 kg weight for 5 minutes. Following this duration, the filter paper and sample were carefully extracted. Subsequently, the wetted region and the compressed meat sample area were delineated on transparent plastic material. The circular area of the sample was quantified, along with the area of the peripheral circle created by the presence of water. Consequently, the area attributed to free water could be determined by subtracting the outer circle's area from that of the inner circle. The area representing free water accumulation is a proxy for the quantity of water that remains unabsorbed by the material, or conversely, it reflects the material's water-holding capacity (Grau and Hamm, 1956).

Chemical Analysis of Mackerel Fish Otak-otak

Protein Content

The protein content was quantified using the Kjeldahl method. A precisely weighed sample (1 ±1.1 g) was subjected to heat in a fume hood until the formation of a greenish liquid. Subsequently, this liquid underwent dilution and treatment with specific chemicals. The ammonia liberated during this chemical treatment was absorbed in a boric acid solution and quantified through titration. The protein content was determined based on the titration results obtained (Devitria and Sepriyani, 2021a)

Moisture Content

An empty porcelain cup underwent preheating in an oven set at 100°C for approximately 30 minutes. Subsequently, it was allowed to cool within a desiccator until reaching ambient temperature, after which its weight was measured. Approximately 2 gs of each sample were meticulously weighed and introduced into the cup. The cup and its contents underwent a drying process within a vacuum oven set at a temperature range of 100±105°C for 6 hours, maintaining a pressure of 100 mmHg. Post-drying, the cup was transitioned into a desiccator for further cooling before subsequent weight measurement (Devitria and Sepriyani, 2021b).

Fat Content

A measured sample weighing 2 and 3 gs was enclosed in a filter paper sleeve and securely sealed with fat-free cotton to mitigate sample loss. Subsequently, the sample assembly was introduced into the Soxhlet extractor, accompanied by an overhead condenser and a collection flask housing hexane or petroleum benzene solvent. The solvent was then heated to reflux, traversing the system and extracting fat constituents from the sample. The distillation process was terminated after achieving clarity in the solvent collected within the flask. The extracted fat flask was subsequently dried in an oven set at 105°C until attaining a consistent weight. Following cooling within a desiccator, the flask underwent reweighing (AOAC, 2005).

Sensory Evaluation

This study utilized a sensory evaluation employing a hedonic method to assess liking. The hedonic testing approach is commonly employed for measuring consumer preferences toward a product. It employs a hedonic scale, a rating system encompassing options such as "very like," "like," "somewhat like," and so forth, which can be expanded or condensed as needed to accommodate the desired range. In this investigation, 35 panelists evaluated samples presented randomly (Suryono et al., 2018).

Data Analysis

The results of this study were obtained and analyzed using a one-way analysis of variance (ANOVA) with a significance level set at $p < 0.05$. Post-hoc analysis was conducted using Duncan's Multiple Range Test when significant differences among the treatments were observed. The data were processed using statistical software packages such as SPSS and Microsoft Excel for robust estimation.

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RESULT AND DISCUSSION

Sensory Evaluation of Otak-otak

Color

Color is an important aspect of the first impression of a product. An attractive color can increase the attractiveness of the product and invite panelists to taste the product (Lamusu, 2018).

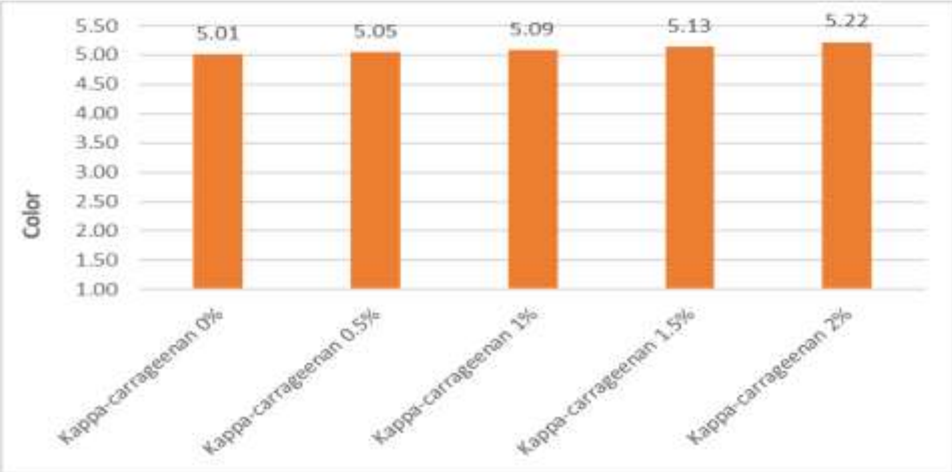

Figure 1. Effect of Kappa Carrageenan Addition to Surimi on the Color of Fish Otak-otak

Figure 1 illustrates the results of organoleptic testing of the color of mackerel otak-otak with variations in the addition of different concentrations of kappa carrageenan. The average level of panelists' liking for the color of the five treatments ranged from 5.01-5.22 (like). Treatment K1 (without the addition of kappa carrageenan) obtained a level of liking of 5.01 (like). Treatment K2 (addition of 0.5% kappa carrageenan) obtained a favorability level of 5.05 (like). K3 treatment (addition of 1% kappa carrageenan) obtained a favorability level of 5.09 (like). Treatment K4 (addition of 1.5% kappa carrageenan) obtained a favorability level of 5.13 (like). Treatment K5 (addition of 2% kappa carrageenan) obtained a level of favorability of 5.22 (like).

Analysis of variance (ANOVA) shows that the addition of kappa carrageenan to surimi as a raw material for making otak-otak does not have a significant effect ($p>0.05$) on the color parameters of mackerel otak-otak. This is because kappa carrageenan flour is colorless, so it does not affect the color of the mackerel otak-otak. According to (Basito et al., 2018) which states that carrageenan as a stabilizer is colorless. Carrageenan is inert and does not change the physical properties of the product. The kappa mechanism of carrageenan only binds water in the product, so there is no color change in fish otak-otak products (Saluri and Tuvikene, 2020).

The brownish color of the otak-otak product is produced from additional ingredients such as spices used in the mackerel otak-otak dough. (Anggraini et al., 2017) explained that the formation of color in otak-otak products is influenced by the composition of the constituent ingredients. In addition, the color of fish otak-otak can be influenced by the heat temperature during the steaming process. Kusnandar, (2019) stated that color changes in food products occur due to the maillard reaction. The maillard reaction is a reaction between compounds containing amine groups and reducing sugars at high temperatures which will produce brown materials. (Potabuga et al., 2021), concluded that panelists preferred cork fish brains steamed for 20 minutes because they have a brownish-white color and are not slimy. During the steaming process, a Maillard reaction occurs which causes the appearance of cork fish brains to change. The Maillard reaction occurs because the reducing sugar contained in sago starch reacts with amino acids in the cork fish meat, resulting in a color change in the cork fish otak-otak.

Taste

Taste is a sensory attribute that determines consumer acceptance. Even if other attributes have good hedonic quality, the product will not be accepted by consumers if the taste of the food product is not good.

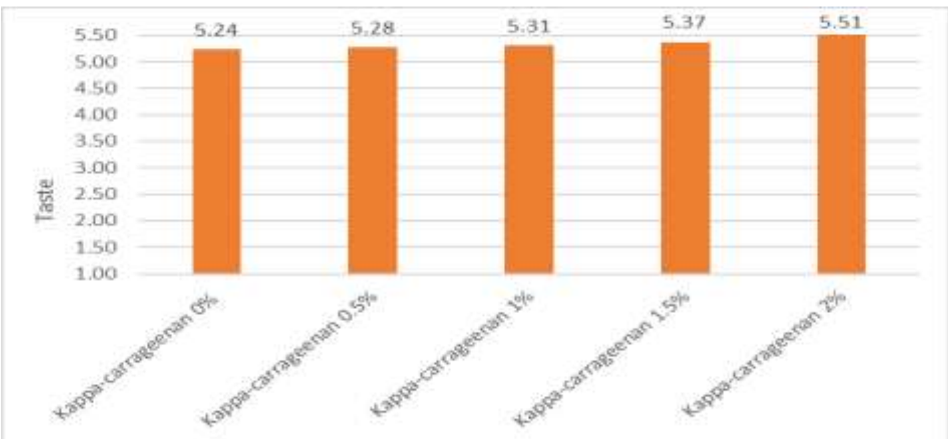

Figure 2. Effect of Kappa Carrageenan Addition to Surimi on the Taste of Fish Otak-otak

Figure 2 illustrates the results of organoleptic testing of the color of mackerel otak-otak with variations in the addition of different concentrations of kappa carrageenan. The average level of panelists' liking for the color of the five treatments ranged from 5.24-5.51 (like). Treatment K1 (without the addition of kappa carrageenan) obtained a favorability level of 5.24 (like). Treatment K2 (addition of 0.5% kappa carrageenan) obtained a favorability level of 5.28 (like). K3 treatment (addition of 1% kappa carrageenan) obtained a favorability level of 5.31 (like). Treatment K4 (addition of 1.5% kappa carrageenan) obtained a favorability level of 5.37 (like). Treatment K5 (addition of 2% kappa carrageenan) obtained a level of favorability of 5.51 (like).

The results of analysis of variance (ANOVA) showed that the addition of carrageenan to surimi as a raw material for mackerel otak-otak did not have a significant effect ($p>0.05$) on the taste of mackerel otak-otak. This is due to the nature of the kappa carrageenan flour added to the mackerel otak-otak dough which has no flavor. According to (Watson, 2005) which states that it has odorless, colorless, and tasteless characteristics. The research of (Sipahutar et al., 2020) showed that the addition of 5% carrageenan did not affect the taste of tilapia ecado. The taste of tilapia ecado is influenced by the constituent components in fish ecado such as protein.

The taste of mackerel otak-otak is dominated by the flavor of the fish and the spices used. (Saputro, Winarni Agustini, and Rianingsih, 2018a) explained that the taste of catfish otak-otak is dominated by the taste of catfish and strong spices. According to (Ardianti et al., 2014), spices such as garlic contain several bioactive components that affect flavor. Sulfide compounds that are abundant in garlic play an important role in this regard. When oxidized, sulfide compounds turn into alysis which has a similar effect to other phenolic compounds, namely causing flavor in food ingredients. In addition, processing techniques can affect the flavor of fish otak-otak products. (Wahyuningsih, 2021), explained that the taste of cork fish otak-otak produced varies according to the processing technique. Processing fish brains by steaming produces a very strong cork fish flavor. Processing with frying produces a savory taste, and the taste of cork fish begins to decrease.

Processing by burning produces a strong flavor of fish and other ingredients due to the maturation of the ingredients that are still not optimal.

Flavor

Aroma is a quality factor that plays an important role in determining consumer acceptance of a food product. The assessment of a product cannot be separated from its distinctive aroma, which varies depending on the constituent ingredients and the way the product is processed (Kinteki et al., 2018)

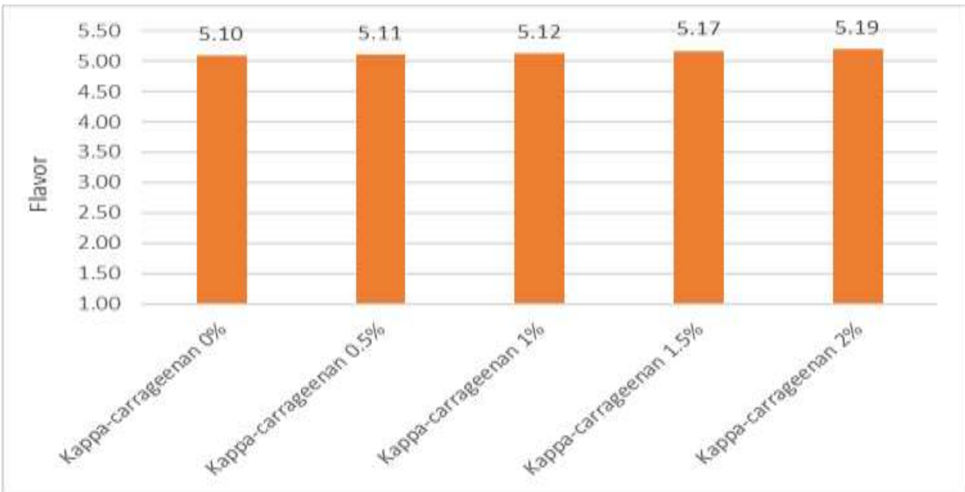

Figure 3. Effect of Kappa Carrageenan Addition to Surimi on the Flavor of Fish Otak-otak

Figure 3 illustrates the results of organoleptic testing of the color of mackerel otak-otak with variations in the addition of different concentrations of kappa carrageenan. The average level of panelists' liking for the color of the five treatments ranged from 5.10-5.19 (like). Treatment K1 (without the addition of kappa carrageenan) obtained a level of liking of 5.10 (like). Treatment K2 (addition of 0.5% kappa carrageenan) obtained a favorability level of 5.11 (like). K3 treatment (addition of 1% kappa carrageenan) obtained a favorability level of 5.12 (like). Treatment K4 (addition of 1.5% kappa carrageenan) obtained a favorability level of 5.17 (like). Treatment K5 (addition of 2% kappa carrageenan) obtained a level of favorability of 5.19 (like).

The results of the analysis of variance (ANOVA) showed that the addition of kappa carrageenan to surimi as a raw material for mackerel otak-otak did not have a significant effect ($p>0.05$) on the aroma of mackerel otak-otak. This is due to the nature of carrageenan which has characteristics that are not distinctive, so it does not contribute to the aroma of mackerel otak-otak products. This is in line with the statement (Ginanjar and Komarudin, 2021) which states that the addition of carrageenan has the characteristic of not having a distinctive aroma, so it does not affect the aroma of the product.

The distinctive aroma in otak-otak products is due to the presence of volatile compounds found in fish meat. These volatile compounds are naturally occurring in fish meat and contribute to the formation of the characteristic aroma. During processing, the addition of salt, spices, and tapioca increases the intensity of the aroma through chemical reactions that occur during heating. The cooking process facilitates the formation of new volatile compounds and increases the solubility of aromatic compounds in the final product, resulting in a stronger and more distinctive aroma in the otak-otak (Alam et al., 2021)

Texture

The texture is the sensation of pressure felt when food is bitten, chewed, and swallowed. This sensation can be observed with the mouth and fingers. Texture is one of the important aspects of organoleptic testing. Texture plays a very important role in all types of food products. Food products that have a good texture will be preferred and have a higher selling value.

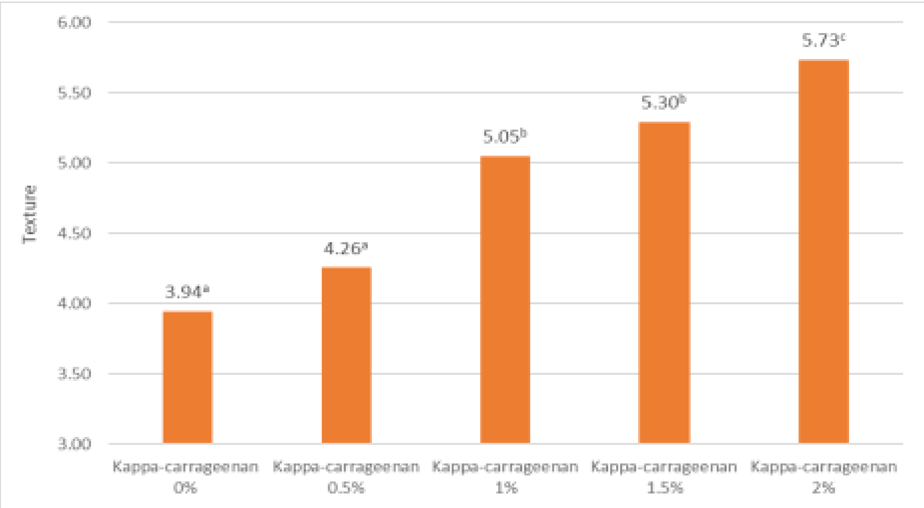

Figure 4. Effect of Kappa Carrageenan Addition to Surimi on the Texture of Fish Otak-otak

Figure 4 illustrates the results of organoleptic testing of the color of mackerel brain-brain with variations in the addition of different concentrations of kappa carrageenan. The average level of panelists' liking for the color of the five treatments ranged from 3.94 (somewhat dislike) - 5.73 (like). Treatment K0 (without the addition of kappa carrageenan) obtained a level of liking of 3.94 (rather like). Treatment K1 (addition of 0.5% kappa carrageenan) obtained a level of liking of 4.26 (somewhat like). Treatment K2 (addition of 1% kappa carrageenan) obtained a favorability level of 5.05 (like). Treatment K3 (addition of 1.5% kappa carrageenan) obtained a level of preference of 5.30 (like). Treatment K5 (addition of 2% kappa carrageenan) obtained a level of favorability of 5.73 (like).

The results of the analysis of variance (ANOVA), showed that the addition of carrageenan as an additive to surimi used as raw material for mackerel otak-otak had a significant effect ($p<0.05$) on the texture of the final product. Mackerel otak-otak with the addition of 2% carrageenan showed a more compact and dense texture compared to the control, so it was preferred by panelists. This is in line with the opinion of (Weiner, 2014), which states that the addition of carrageenan can improve the palatability of food products. Carrageenan can affect the texture and mouthfeel of food, thus making it more preferred by consumers.

In addition, carrageenan also plays a role in binding water in food, forming a gel that is useful for maintaining texture. The research (Saputro, 2018a) concluded that the texture of dumbo catfish otak-otak with the addition of 0.5% carrageenan was preferred by panelists because it had a dense texture. According to (Mussayadah et al., 2020) the use of carrageenan serves to maintain texture and prevent the release of fat from tissues in fish or meat-based products. Carrageenan also has hydrocolloid properties that allow it to absorb water.

Description Of The Best Treatment Based On Organoleptic Testing

Organoleptic testing involves color, taste, aroma, and texture parameters. The overall average value of the organoleptic assessment on each treatment was then compared to determine the treatment that was most favored by the panelists.

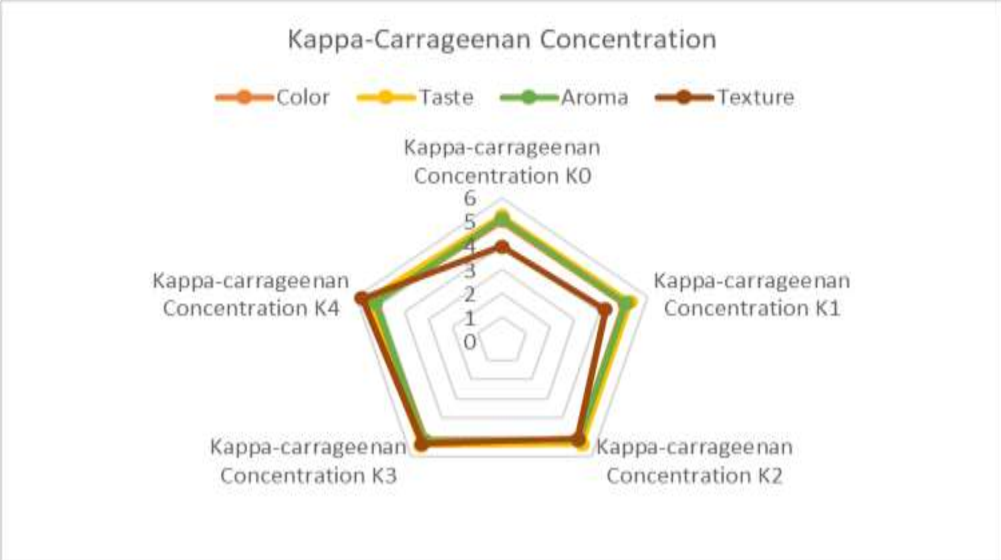

Figure 5. Description Of The Best Treatment Based On Organoleptic Testing

Figure 5 illustrates that the addition of K3, K4, and K5 concentrations obtained the highest average values on the parameters of taste, aroma, color, and texture. This indicates that panelists' preferences favored these treatments organoleptically. Each treatment that had the lowest average value (disliked) was not included in further testing. The best concentrations obtained were K3 (1% Kappa carrageenan), K4 (1.5% Kappa carrageenan), and K5 (2% Kappa carrageenan). The three concentrations will be applied to mackerel surimi, then stored for 28 days at -20°C with observations every 7-day interval. Furthermore, analysis will be carried out including gel strength and water binding capacity to evaluate the physical characteristics of surimi), protein content, fat content, and moisture content to assess the quality of fish otak-otak as the final product of frozen surimi.

Physical Analysis of Surimi During Storage

Gel Strenght of Surimi

Gel strength is a critical determinant of the final quality of surimi-based products. This parameter significantly influences the functional properties of surimi, including its textural characteristics and water-holding capacity (Susanti et al., 2019)

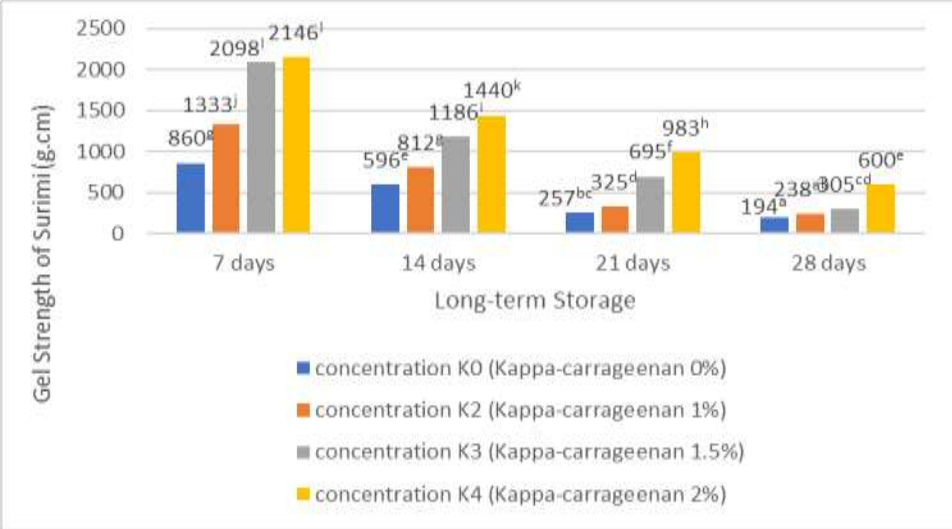

Figure 6. Effect of Kappa Carrageenan Flour Addition on Gel Strength of Surimi During Storage

Figure 6 illustrates the gel strength of surimi during 28 days of storage at -20°C. The mean gel strength values exhibited a decline correlating with the duration of surimi storage. In treatment K1 (without kappa carrageenan addition), the gel strength decreased from 860 g.cm on day 7 to 194 g.cm on day 28. Treatment K3 (1% kappa carrageenan addition) showed a reduction from 1333 g.cm on day 7 to 238 g.cm on day 28. For K4 (1.5% kappa carrageenan addition), the gel strength diminished from 2098 g.cm on day 7 to 305 g.cm on day 28. Treatment K5 (2% kappa carrageenan addition) demonstrated a decline from 2146 g.cm on day 7 to 600 g.cm on day 28.

Analysis of variance (ANOVA) revealed that storage duration, kappa carrageenan concentration, and their interaction significantly influenced ($p<0.05$) the gel strength of surimi during storage. According to the Indonesian National Standard (SNI, 2013), the minimum gel strength for surimi is 600 g.cm. Treatment K5 (surimi with 2% kappa carrageenan addition) exhibited a decline over the storage period. However, the gel strength values for K5 remained compliant with SNI requirements, measuring 2146 g.cm at 7 days of storage and 600 g.cm at 28 days. This phenomenon can be attributed to the increased concentration of carrageenan, which strengthens the interaction between carrageenan and surimi proteins. This aligns with (Latifa et al., 2014) who stated that the hydrocolloid content in kappa-carrageenan flour functions as a gelling agent, enhancing gel

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strength. Carrageenan can interact with charged molecules such as proteins, influencing the gel formation process in surimi. This is corroborated by (Subagio et al., 2004) who asserted that surimi proteins can interact with various compounds, both directly and indirectly, affecting functional properties such as gel formation. The deterioration of gel strength in surimi may be caused by the denaturation of myofibrillar proteins during storage (Santoso et al., 2008). Protein denaturation occurs due to ice crystal formation during frozen storage, which can alter the structure of myofibrillar proteins and reduce the gel-forming ability of surimi (Chen et al., 2021) The freezing process can damage surimi cells through two mechanisms: first, mechanically, where ice crystals formed during freezing can physically alter cell shape, causing damage; second, through chemical and osmotic processes within the cell due to freezing. This phenomenon is known as "solution effect injury." As water within the cell freezes, the concentration of solutes in the unfrozen water between ice crystals increases, compressing the cell and causing dehydration, ultimately damaging the cell (Wowk, 2007).

Water Holding Capacity

Water-holding capacity is the ability of muscle meat to retain moisture within the meat. Water holding capacity is closely related to taste, juiciness, color, and other quality parameters. Water holding capacity is an important factor in surimi production ((Liu et al., 2021)

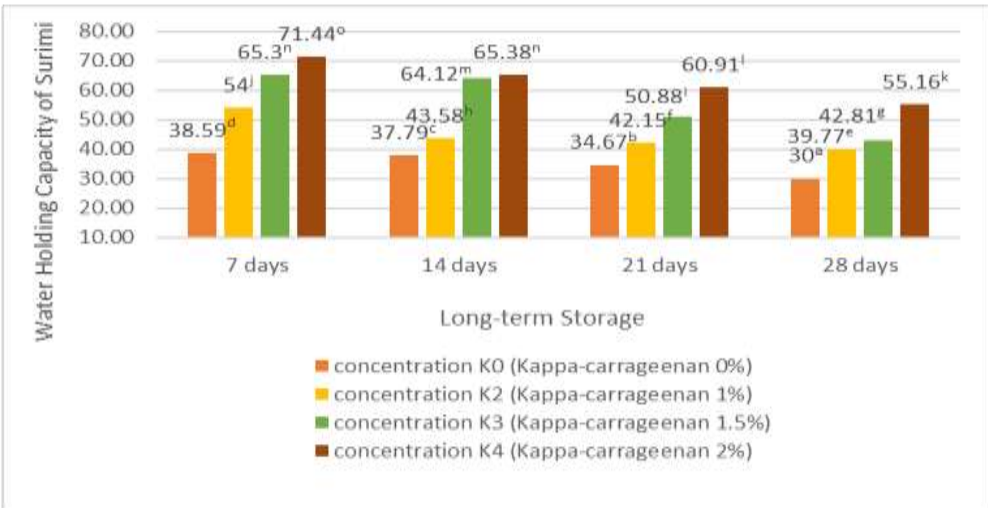

Figure7. Effect of Kappa Carrageenan Flour Addition on Water Holding Capacity of Surimi During Storage

Figure 7 illustrates the water holding capacity (WHC) of surimi during a 28-day storage period in a freezer. The average WHC values decreased over time. In treatment K1 (without the addition of kappa carrageenan), the WHC on day 7 was 38.59%, which decreased to 30% on day 28. For treatment, K3 (1% kappa carrageenan addition), the WHC on day 7 was 54%, which decreased to 39.77% on day 28. Treatment K4 (1.5% kappa carrageenan addition) showed a WHC of 65.30% on day 7, which dropped to 42.81% on day 28. Treatment K5 (2% kappa carrageenan addition) had a WHC of 71.44% on day 7, decreasing to 55.16% on day 28.

The ANOVA results indicated that storage duration, kappa carrageenan concentration, and their interaction significantly affected ($p<0.05$) the WHC of surimi. The WHC in K5 (surimi with 2% kappa carrageenan addition) decreased during storage but remained high, attributed to kappa carrageenan's stabilizing characteristics that enable it to bind water. Increasing the kappa carrageenan concentration enhanced the WHC of surimi. This aligns with the findings of (Walayat et al., 2022), who stated that kappa carrageenan could form a robust and stable thermoreversible gel structure through the formation of a three-dimensional double helix network. The gel structure contributes to the increased water-holding capacity in myofibrillar protein gel during frozen storage by binding water molecules within its network. Furthermore, kappa carrageenan interacts directly with myofibrillar proteins through ionic and hydrogen bonding, playing a crucial role in maintaining gel stability and texture during frozen storage. According to (Zhu et al., 2022), the WHC of surimi decreases during storage due to muscle filament contraction and protein denaturation or changes in protein tertiary structure.

The WHC correlates with the gel strength of surimi. Testing surimi gel showed that treatment K5 (surimi with 2% kappa carrageenan addition) had high gel strength over the 28-day storage period. High gel strength enhances WHC during storage, consistent with the findings of Saputro, et.al., (2018) who stated that carrageenan could increase gel strength by enhancing water-holding capacity. The charge balance in the surimi gel system can form a strong carrageenan and protein gel matrix. Therefore, the higher the concentration of carrageenan used, the more optimal the gel's ability to trap water (Pérez-Mateos and Montero, 2000).

Chemical Analysis of Mackerel Fish Otak-otak Based on Surimi

Protein Content

Protein content is one of the indicators that consumers consider when choosing food products.

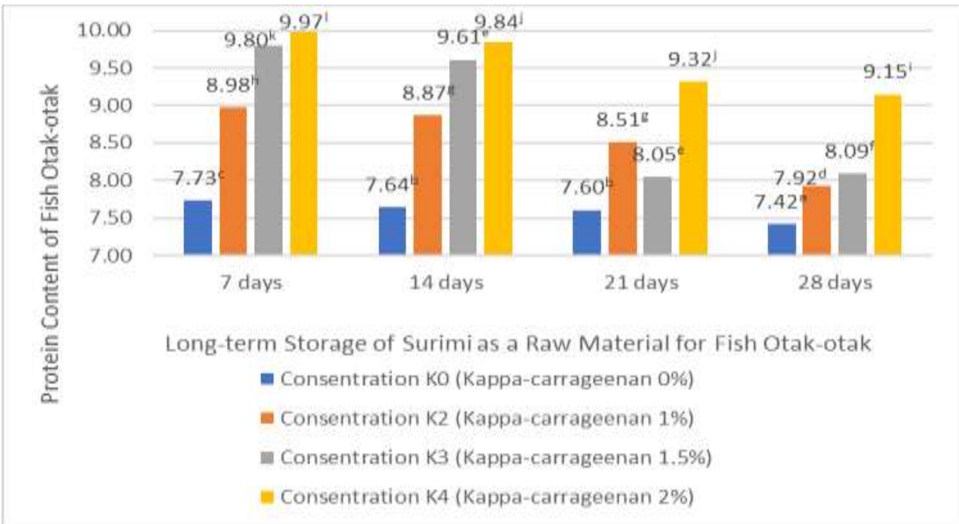

Figure8. Effect of Adding Kappa Carrageenan to Surimi as Raw Material During Storage on the Protein Content of Fish Otak-otak

Figure 8 illustrates that the protein content of fish otak-otak decreases over the storage duration of surimi as a raw material. The mean protein content values for treatment K0 (surimi without kappa carrageenan) ranged from 7.73% to 7.42%. Treatment K2 (surimi with 1% kappa carrageenan addition) showed values from 8.98% to 7.92%. Treatment K3 (surimi with 1.5% addition) ranged from 9.80% to 8.09%. Treatment K5 (surimi with 2% addition) exhibited values from 9.97% to 9.15%.

The analysis of variance (ANOVA) results indicate that storage duration, kappa carrageenan concentration, and their interaction significantly affect ($p<0.05$) the protein content of fish otak-otak. The highest protein content in fish otak-otak is observed in those using surimi with 2% kappa carrageenan addition during storage. This is due to the kappa carrageenan's ability to bind water molecules. Higher concentrations of carrageenan can form a stronger gel network, thus preserving the hydrophilic myofibrillar proteins during boiling and storage. This mechanism prevents protein denaturation, thereby maintaining the protein content in the otak-otak product. This aligns with the study by (Harmain et al., 2017), which stated that carrageenan absorbs water, thus retaining proteins in fishery products during processing and storage. This ability makes carrageenan a potential food additive for improving the quality of processed fishery products, particularly otak-otak.

In addition to carrageenan concentration, the type of fish can influence the protein content in mackerel fish otak-otak. This is consistent with the opinion of (Sitompul et al., 2017) who stated that the protein content in meatballs can be affected by the type of fish used. Marine fish have higher protein content compared to brackish and freshwater fish.

Moisture Content

Water content is the amount of water contained in a substance, expressed as a percentage. Water content is a crucial characteristic of food materials because it can affect appearance, texture, and flavor (Mulia and Anggraini, 2018).

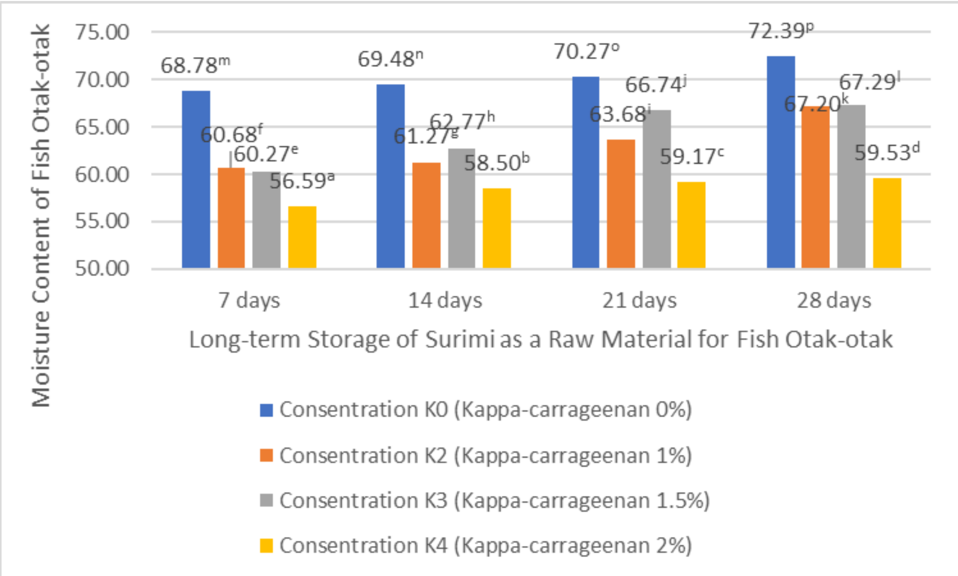

Figure9. Effect of Adding Kappa Carrageenan to Surimi as Raw Material During Storage on the Moisture Content of Fish Otak-otak

Figure 9 illustrates that the moisture content increases with the prolonged storage of surimi as a raw material for otak-otak products. The mean moisture content values for treatment K0 (surimi without kappa carrageenan) ranged from 68.78% to 72.39%. Treatment K2 (surimi with 1% kappa carrageenan addition) showed values from 60.68% to 67.20%. Treatment K3 (surimi with 1.5%

addition) ranged from 60.27% to 67.29%. Treatment K5 (surimi with 2% addition) exhibited values from 56.59% to 59.53%.

Analysis of variance (ANOVA) revealed that storage duration, kappa carrageenan concentration, and their interaction had a significant effect ($p<0.05$) on the moisture content of otak-otak. This can be attributed to the hydrocolloid properties of kappa carrageenan, which can form a gel matrix, thus limiting water mobility in the fish otak-otak product. This aligns with research by (Candra et al., 2014) which stated that carrageenan is composed of polymer chains containing negatively charged sulfate groups. The presence of these sulfate groups gives carrageenan the ability to bind water.

Mackerel otak-otak based on surimi with 2% carrageenan addition had a moisture content ranging from 56.59% to 59.53%. These moisture content values meet the quality requirements for fish otak-otak, which specify a maximum of 60% (SNI, 2013). Moisture content plays a crucial role in determining the quality of food products. Proper moisture control through the application of food technology is key to producing high-quality, safe, and long-lasting products.

Fat Content

Fat content is a critical determinant in the physicochemical and organoleptic properties of food matrices.

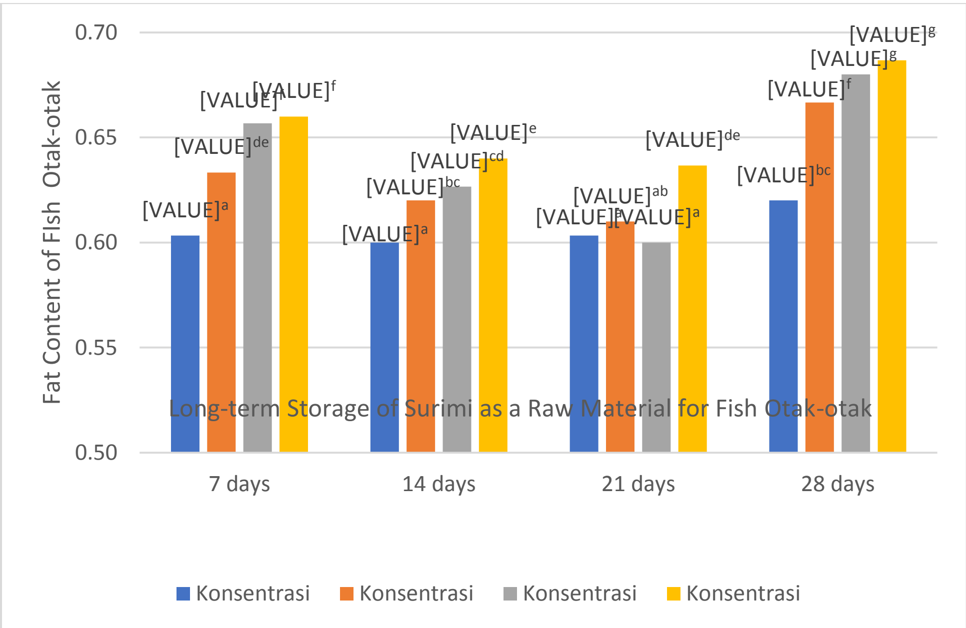

Figure 10. Effect of Adding Kappa Carrageenan to Surimi as Raw Material During Storage on the Fat Content of Fish Otak-otak

Figure 10 illustrates that the use of surimi as a raw material for fish cake products experiences fluctuations along with the storage duration of the raw materials used. The average fat content values for treatment K1 (surimi without kappa carrageenan) range from 0.60% to 0.62%. For treatment K2 (surimi with 1% kappa carrageenan added), the values range from 0.63% to 0.67%. Treatment K3 (surimi with 1.5% addition) shows values from 0.66% to 0.68%. Treatment K5 (surimi with 2% addition) has values ranging from 0.66% to 0.69%.

The analysis of variance (ANOVA) results indicate that storage duration, kappa carrageenan concentration, and their interaction exert a significant effect ($p<0.05$) on the lipid content of fish cakes. This phenomenon can be attributed to the hydrophilic nature of kappa carrageenan, which preferentially binds water over lipids. When kappa-carrageenan binds water molecules, these molecules become unavailable for lipid binding, resulting in the separation of lipids from the dough matrix. This observation aligns with the findings of (Putra et al., 2015), who reported that carrageenan functions more effectively as a water-binding agent than a lipid-binding agent. This is due to carrageenan's insolubility in lipids, while it can form bonds with proteins. Typically, lipids are bound by the positive polar regions of proteins. However, the introduction of carrageenan enhances the water-binding capacity of proteins, consequently diminishing their lipid-binding capability. The hydroxyl and sulfate groups present in carrageenan exhibit hydrophilic properties, whereas the 3,6-anhydro-D-galactose moiety is predominantly hydrophobic. This hydrophobic characteristic contributes to the observed increase in lipid content in surimi-based mackerel fish cake products (Hambleton et al., 2009). Additionally, the lipid content of the raw materials employed can influence the lipid content of the final product (Irawan and Marwita, 2021). The lipid content values of the fish cakes across all treatments comply with the quality standard for fish cake lipid content, which stipulates a maximum of 16% (SNI, 2013).

CONCLUSIONS

Based on this study's findings, the optimal concentration of kappa-carrageenan is 2%. The application of 2% kappa carrageenan as a hydrocolloid additive demonstrates efficacy in preserving the physicochemical and organoleptic properties of surimi over a 28-day storage period. Incorporating 2% kappa-carrageenan effectively enhances the quality of surimi throughout frozen storage, resulting in otak-otak products characterized by a dense and chewy texture.

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CONFLICT OF INTERESTS

The authors declare that they have no conflicts of interest.

ETHICAL CONSIDERATION

The authors have confirmed ethical issues, such as plagiarism, misconduct, fabrication and falsification of information, consent to publish, duplication of publication and submission, and redundancy.

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