

Effect of Seaweed Flour Addition (*Eucheuma cottonii*) on Mackerel Fish Crackers (*Rastrelliger kanagurta*) as an Alternative of Nutritious and Halal Food

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ABSTRACT

In Indonesia, there is a growing demand for nutritious and halal food products, particularly among consumers and producers. Seaweed flour emerges as a promising alternative ingredient, with the potential to enhance the nutritional value and quality of fish crackers. This study contributes to delve deeper into the impact of incorporating seaweed flour (*Eucheuma cottonii*) in mackerel (*Rastrelliger kanagurta*) crackers, exploring its role as a nutritious and halal food alternative. The experimental laboratory method employed a quantitative descriptive analysis (chemical test) and a descriptive (organoleptic test). Cracker samples were prepared with varying levels of seaweed flour (4%, 8%, and 12%). The results demonstrated that the F1 treatment (4%) yielded optimal chemical content (proximate), exhibiting a protein content of 6.97%, a fat content of 13.58%, a moisture content of 0.01%, an ash content of 0.03%, a carbohydrate content of 85.63%, and a crude fiber content of 0.19%. The results of the organoleptic (sensory) test demonstrated that the F1 (4%) treatment produced the optimal characteristics, exhibiting sensory attributes in the components of appearance ((8.1% (whole, neat, clean, even thickness, bright))), odor ((7.7% (less product-specific))), taste ((8.3% (product-specific))), and texture ((8.8% (very dry and crispy))). The outcomes of the chemical analysis (proximate) and the organoleptic test (sensory) have satisfied the quality criteria outlined in the SNI Ready to Eat Fish Crackers 8646: 2018. 8646:2018 standard. This study contributes to the development of functional food products by demonstrating that the addition of seaweed flour can improve the nutritional profile and sensory quality of fish-based snacks, while also offering an innovative solution that aligns with halal dietary standards.

KEYWORDS

Fish crackers; Halal, Mackerel; Nutritious; Seaweed

1. INTRODUCTION

The halalness of food products is very important for Indonesian people, both consumers and producers. For producers, the halalness of the product makes the product have status and trust from consumers, so it becomes one of the product requirements to penetrate the global market, both local and international [1]. Halal certification is a key requirement in Indonesian food markets, as it ensures products comply with Islamic dietary laws and builds consumer trust. In parallel, consumers increasingly seek convenient snacks with added health benefits beyond basic nutrition. Seaweeds offer a rich source of nutrients (dietary fibre, protein, vitamins, minerals) and have attracted attention as functional food ingredients. In particular, the red seaweed *Eucheuma cottonii*, widely cultivated in Indonesian waters, is rich in carrageenan (a natural hydrocolloid) and dietary fibre [2]. In the production of a product, it is important to consider the raw materials used. This is because in the halal certification process, it is feared that the raw materials used consist of haram raw materials so that the resulting product will later be tainted by its halalness. Apart from the raw materials, it is equally important that the facilities and infrastructure used in the production process are clean, properly maintained and not contaminated by non-halal materials.

In addition to additional ingredients, raw and auxiliary materials must be halal in the process must also be carried out hygienically according to good food preparation procedures [3].

Mackerel (*Rastrelliger kanagurta*) is a type of pelagic fish that is very economical and easily found in Indonesian waters. Fresh mackerel has a protein content of 18.54%, fat content of 0.59%, carbohydrate content of 2.91%, moisture content of 76.47%, and ash content of 1.48%. Mackerel also contains omega 3 and omega 6, which are good for disease prevention and brain intelligence. In addition, mackerel also has a delicious and savory taste, so it is very popular among the public [4].

Fish crackers are one of the most popular processed fish foods in the community, usually used as an accompaniment to the main meal. Fish crackers are crackers made from the basic ingredients of fish dough with flour. Fish crackers have different qualities depending on the composition of the fish used to make the crackers. The greater the amount of fish used as raw material for crackers, the better the quality of crackers [5]. In general, the existence of crackers is very easy to find both from large stores to small shops. Currently, the marketing of crackers is not only developing domestically, but has reached the export stage to foreign countries such as the Netherlands, Singapore, Hong Kong, Japan, Suriname, and America [6].

Tapioca flour is one of the main raw materials used in the production of crackers. In addition, other ingredients such as rice, sago or other ingredients are usually added to increase the nutritional value of crackers. One of them is the addition of fish meat, which acts as a taste and smell and serves as an enhancer of the protein content in crackers [7]. Seaweed, a natural product of the sea, possesses numerous benefits and can be processed into various types of food due to its high nutritional content, which includes protein, fibre, carbohydrates, vitamins, and minerals. Seaweed (*Eucheuma cottonii*), a species of red algae, is found in nearly all Indonesian waters and is cultivated for various applications. This seaweed is abundant in carrageenan, a polysaccharide that functions as a stabilizer and water binder, thereby enhancing the development of protein in food products [8]. Seaweed flour serves as an alternative ingredient, capable of elevating the nutritional value and quality of fish crackers.

The incorporation of seaweed flour during the manufacturing process of fish crackers can augment the fibre content, while concurrently providing a superior texture and a more appealing appearance to the final product. Furthermore, the inclusion of carrageenan, a constituent of seaweed (*Eucheuma cottonii*), functions as a binder and stabilizer, thereby reinforcing the structural integrity of the crackers and preserving their softness [9]. The incorporation of seaweed flour into fish crackers has the potential to offer additional health benefits, including increased mineral and vitamin levels, which can contribute to consumer health. The incorporation of seaweed flour in fish crackers has been shown to enhance sensory attributes such as taste, aroma, and texture, while concurrently augmenting the nutritional value of the product [10].

However, the use of seaweed flour in fish cracker production also presents several challenges. These include determining the optimal concentration of seaweed flour that enhances nutritional value without negatively affecting sensory qualities such as taste, texture, and appearance [11]. Inappropriate formulation can lead to an unfavourable aroma or texture that may reduce consumer acceptance. Moreover, integrating new ingredients into traditional food products requires careful evaluation to ensure compliance with halal certification, nutritional standards, and food safety regulations.

In light of these observations, it is imperative to undertake a comprehensive study to assess the impact of incorporating seaweed flour (*Eucheuma cottonii*) in mackerel crackers (*Rastrelliger kanagurta*) on the quality, nutritional value, and diversification potential of fish crackers. This research endeavor aims to make a substantial contribution to the enhancement of the quality and added value of fish crackers, thereby providing new avenues for the diversification of nutritious and halal food products.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this research are mackerel (*Rastrelliger kanagurta*) and seaweed (*Eucheuma cottonii*) which were obtained directly from suppliers or farmers, fresh eggs, garlic, water (Cleo), sugar (Gulaku), salt (Cap Kapal), tapioca flour (Rose Brand), pepper powder (Ladaku), cooking oil (Tropical), baking powder (Hercules), KOH, aquadest, 95–97% Sulfuric Acid (H_2SO_4), 4% Boric Acid (H_3BO_3), Ethanol (C_2H_5OH), 0.1% Methyl red, 0.1% Bromocresol green, 50% Sodium Hydroxide (NaOH), 0.2 N

Hydrochloric Acid (HCl), Di-sodium tetraborate decahydrate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$), 30-35% Acid Peroxide (H_2O_2), Catalyst Tablet (Kjeldahl), Boiling Stone, n-Hexane, 0.325 N H_2SO_4 , 1.25 N NaOH, hot water, and 95% alcohol. The equipment used in this research is an oven (Mettler UN30), analytical balance (Ohaus Pioneer), furnace (Carbolite ELF 1100), Soxhlet, desiccator, distillatory, blender (Phillips), sieve 20 cm, measuring cup and Erlenmeyer 250 ml (Iwaki).

2.2. Preparation of Flour

The seaweed flour process begins by weighing 100 g of wet seaweed, which was then placed into a basin and thoroughly washed under running water to remove any adhering impurities. A 10% KOH solution was prepared by mixing 2 L of distilled water with 160 g of KOH until a homogeneous solution was obtained. The seaweed was subsequently soaked in the 10% KOH solution at a ratio of 1:20 for two days to break down the cell walls and accelerate the drying process. The function of KOH in this step is to extract carrageenan from the seaweed. After soaking, the seaweed was rinsed again under running water until all residual alkali was removed. The pH of the solution was then measured and adjusted to neutral using pH paper.

Next, the seaweed was cut into pieces measuring $\leq 4\text{--}5$ cm and subjected to a drying process for a maximum of two days. Once dried, the seaweed was ground using a blender and sieved through a mesh to obtain finer carrageenan. The resulting seaweed carrageenan was ready for use [11]. The proportion of seaweed flour to tapioca flour was formulated at concentrations of 4%, 8%, and 12%, based on the ratio of seaweed flour (10 g, 20 g, and 30 g, respectively) to tapioca flour (250 g), calculated using equation (1).

$$\text{Concentration (\%)} = \frac{\text{weight of seaweed flour (g)}}{\text{weight of tapioca flour (g)}} \times 100\% \quad (1)$$

2.3. Preparation of Fish Crackers

The procedure begins with cleaning the mackerel until clean. Next, make the dough by mixing the component ingredients such as seaweed flour, tapioca flour, eggs, sugar, salt, baking powder and pepper powder with water, the ratio of the size of the ingredients used as described in Table 1.

Table 1. Formulation of mackerel crackers with added seaweed flour.

Ingredients	Formulation			
	Control	F1	F2	F3
Mackerel (g)	250	250	250	250
Seaweed Flour (g)	0	10	20	30
Tapioca Flour (g)	250	250	250	250
Fresh Egg (item)	1	1	1	1
Sugar (g)	25	25	25	25
Salt (teaspoon)	1.5	1.5	1.5	1.5
Water (ml)	100	100	100	100
Pepper Powder (teaspoon)	0.5	0.5	0.5	0.5
Baking Powder (teaspoon)	1	1	1	1

The dough is stirred by hand until smooth. The next process is moulding, followed by steaming for two hours or until the desired level of maturity is achieved. After steaming, the dough is left at room temperature for some time before being transferred to the refrigerator for 24 hours, this is intended to increase the compaction of the dough. After the cooling process, the dough is cut into pieces with a thickness of 2–3 mL. The pieces are then dried in the sun for approximately two days. The dried mackerel crackers are then fried at low temperatures until they expand and are perfectly cooked [3].

2.4. Protein Content Analysis

Protein content analysis was carried out using the Kjeldahl method [12]. Sample was weighed 2 g using Whatman paper, then folded and put into a deconstruction tube. After that, two Kjeldahl catalyst tablets and 3–5 boiling stones were added. Next, 15 mL of concentrated H₂SO₄ (sulfuric acid) (95–97%) and 3 ml of H₂O₂ (hydrogen peroxide) were added slowly, then allowed to stand for ± 10 minutes until the steam disappeared. The deconstruction process is carried out at 410 °C for 2 hours or until the solution becomes clear. After the deconstruction is complete, the solution is cooled at room temperature. then the distillation stage is carried out using a 4% H₃BO₄ (boric acid) solution as much as 25 mL containing the indicator prepared in an Erlenmeyer flask as a distillate container. The flask containing the deconstruction results was installed in a series of steam distillation devices, then 50-75 mL of sodium hydroxide solution and 50 mL of distilled water were added. The distillation process is carried out until the volume of distillate reaches 150 mL, which is marked by a change in the color of the distillate to green. then the titration stage is carried out by working on blanks with the same method as the sample, and the test is carried out in duplicate to ensure the accuracy of the results. The distillate that has been obtained is then titrated with 0.2 N HCl (*hydrogen chloride*) solution that has been standardized until the color changes from green to pink. Protein levels and HCl standardization calculations can be calculated using equations (2) and (3).

$$\text{Molarity } \left(\frac{n}{v}\right) = \frac{\text{weight of Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O} \times 1000}{\text{volume of titration HCl} \times 190.69} \quad (2)$$

$$\text{Protein content (\%)} = \frac{(\text{VA} - \text{VB})\text{HCl} \times \text{N HCl} \times 14.007 \times 6.25 \times 100\%}{\text{weight of sample} \times 1000} \quad (3)$$

2.5. Fat Content Analysis

This study used the Soxhlet technique to analyze the fat content. Samples were processed in a blender or finely ground. Then, the samples were analysed for fat content using the soxhlet technique [13]. The samples were weighed on Whatman paper, folded, and inserted into the fat sleeve. Next, the samples were placed in the oven for approximately 30 minutes. Then, the samples were placed in a Soxhlet apparatus for 2 hours, with 4 cycles. The extracted sample was dried in the oven until its weight stayed the same, and then weighed. The fat content of mackerel crackers made with seaweed flour can be calculated using equation (4). Symbol A is the weight of the empty fat cup (g), B is the weight of the sample (g), and C is the weight of the cup and the extracted fat (g).

$$\text{Fat content (\%)} = \frac{(C - A)}{B} \times 100\% \quad (4)$$

2.6. Moisture Content Analysis

The gravimetric method was employed to determine the moisture content of mackerel crackers incorporated with seaweed flour [14]. Initially, an aluminum cup or container was weighed, and subsequently, a sample with a maximum weight of 2 g was weighed and placed in the container. The material was then subjected to a dehydration process by placing it in an oven set at 105 °C for a duration of 24 hours. The dehydrated sample was then cooled using a desiccator for 15 minutes, after which it was weighed until a consistent weight was obtained. This analysis was carried out with two repetitions. The moisture content of fish crackers was calculated using equation (5), where A is the weight of the empty cup (g), B is the weight of the cup containing the sample (g), and C is the weight of the cup containing the sample after drying (g).

$$\text{Moisture content (\% wb)} = \frac{(B - C)}{(B - A)} \times 100\% \quad (5)$$

2.7. Ash Content Analysis

The ash content was analysed using the gravimetric method, which involved subjecting the sample to an oven dry at 105 °C for one hour [15]. Following this, the sample was cooled in a desiccator for 15 minutes and subsequently measured. The sample was weighed precisely to 2 g and transferred into a cup. Subsequently, the cup was heated at 550 °C in a furnace for a duration of four hours or until the formation of white ash. Subsequently, the cup was transferred to a desiccator for a period of 15 minutes, following which it was weighed. The ash content of mackerel crackers incorporated with seaweed flour can be calculated using equation (6), where A is the weight of the empty cup (g), B is the weight of the cup containing the sample (g), and C is the weight of the cup containing the sample after drying (g)

$$\text{Ash content (\%)} = \frac{(C - A)}{(B - A)} \times 100\% \quad (6)$$

2.8. Carbohydrate Content Analysis

The analysis of carbohydrate content is conducted through the reduction of 100% with water, protein, fat, and ash. The carbohydrate content is thus contingent upon the reduction factor. This is due to the significant influence of carbohydrates on other nutrients [5]. The calculation of carbohydrate content can be performed using the following equation (7).

$$\text{Carbohydrate content (\%)} = 100 - (\text{water content} + \text{ash content} + \text{fat content} + \text{protein content}) \quad (7)$$

2.9. Crude Fiber Analysis

The pulverized sample was weighed precisely to 2 g and transferred into an erlenmeyer flask. Then, 100 mL of 0.325 N H₂SO₄ was added to the flask. The flask was placed in a water bath at 105 °C for 15 minutes. After that, 50 mL of 1.25 N NaOH was added. The mixture was then subjected to a second heating cycle, lasting 15 minutes. Subsequently, the mixture was filtered using a vacuum filter or filter paper. The filter paper was then washed successively with hot water, 25 mL of 0.325 N H₂SO₄, hot water, and finally 25 mL of acetone/alcohol. The filter paper was then subjected to oven drying at a temperature of 105 °C for a duration of one hour, with the drying process being continued until the initial weight of the paper was recorded [16]. Crude fiber calculation can be calculated using equation (8).

$$\text{Crude fiber (\%)} = \frac{(\text{fiber residue in filter paper (g)} - \text{dry filter paper (g)})}{\text{initial weight of materials}} \times 100\% \quad (8)$$

2.10. Sensory Analysis

Sensory analysis of mackerel fish crackers was conducted to determine the level of panelist acceptance and determine the percentage based on the assessment criteria of each sensory test. This sensory organoleptic test involved 30 untrained panelists aged between 18–25 years, each panelist was given a preference score ranging from 5 to 9, where 5 indicates neutral, 7 indicates like, and 9 indicates very like with sensory parameters including appearance, smell, taste, and texture in accordance with SNI 2346:2015 [16].

2.11. Statistical Analysis

The experiment used a completely randomized design with four treatments and was repeated three times. The results of the chemical tests were analyzed using a one-way ANOVA statistical test with significance ($\alpha < 0.05$) with IBM SPSS Statistic 27 software and continued with the Duncan test if there was a difference, while the organoleptic test was analyzed descriptively quantitatively.

3. RESULTS AND DISCUSSION

3.1. Protein Content

Based on Table 2, it can be seen that from each evaluation, the highest average protein content is found in the F1 treatment (4%), which is 6.97%, and the lowest is found in the F3 treatment (12%), which is 5.32%. The results of the Anova test analysis showed that the addition of seaweed flour to mackerel crackers had no significant effect ($p > 0.05$) on the protein content. The protein content of all treatments ranged from 5.32% to 6.97%.

Table 2. Protein content of fish crackers with seaweed flour.

Component	SNI 8646: 2018	Control	F1 (4%)	F2 (8%)	F3 (12%)
Protein (%)	Min. 2	6.76 ± 0.30^a	6.97 ± 0.56^a	6.95 ± 0.28^a	5.32 ± 1.11^b

Different letters (a,b,c) within a similar row indicate significant differences ($p < 0.05$).

Duncan's further results at 5% level showed that the control, F1 (4%) and F2 (8%) had no significant difference, but were significantly different in the F3 treatment. Table 2 shows that the protein content of fish crackers decreased as the addition of seaweed flour increased. This also happened in the other study [17], who explained that the decrease in protein content of food was due to the process of protein denaturation caused by repeated heating, namely steaming and drying. Despite the decrease in protein content, it still meets the quality requirements for ready-to-eat fish cracker products (SNI 8646: 2018) [18], which is at least 2%. Based on the data from the analysis of the protein content of several samples of mackerel crackers with the addition of seaweed flour revealed that the F1 (4%) treatment had the highest protein content, with 6.97%. However, the data showed that there were differences in protein content in each treatment due to the different composition of mackerel and seaweed [19].

The variation in protein content is not solely attributable to the quantity of ingredients utilized, but also to the processing technique employed in the fabrication of fish cracker dough. It is noteworthy that the majority of proteins undergo denaturation within the temperature range of 60 to 90 °C. Furthermore, protein denaturation can be triggered by various factors, including high-speed mechanical stirring, such as whisking, kneading, and blanching, which can cause protein denaturation. Furthermore, the use of a rotating stirrer during high-speed stirring has been shown to cause cavitation, leading to enhanced protein denaturation [20]. In addition, research has indicated that the heating process during steaming of basic ingredients can also affect the amount of protein content. It has been observed that an extended steaming duration results in a reduction of protein content, suggesting that proteins subjected to denaturation may undergo damage [21], [22].

The extent of protein denaturation is directly proportional to the decrease in soluble protein content. The analysis of variance (ANOVA) test results indicates that the incorporation of seaweed into mackerel crackers does not exert a significant impact on protein content, with the exception of treatment F3, which exhibited a 12% reduction. The reduced protein content can be attributed to the high carrageenan content of seaweed, which has been observed to decrease the protein content of fish crackers and increase their moisture content. Despite these fluctuations, the percentage value for each treatment remains relatively high and falls within the acceptable range for ready-to-eat fish crackers, which is a minimum of 2%.

3.2. Fat Content

The test results of fat content in mackerel crackers (Table 3) increased from F1 to F2 treatment, which was 3.17%. The control treatment had the lowest fat content because there was no addition of seaweed flour in the production of crackers. The results of the analysis of fat content showed no significant difference ($p > 0.05$) in crackers without the addition of seaweed flour (control) with F1 treatment crackers (4%) Likewise with F2 treatment crackers (8%) and F3 treatment (12%) also did not give a significant effect ($p > 0.05$).

The fat content of crackers with added seaweed flour ranged from 13.58% to 16.75%. The fat content of crackers without added seaweed flour was 13.43%. These results still comply with the quality requirements for ready-to-eat fish crackers (SNI 8646: 2018) [18], which is a maximum of 12%. The fat

content of mackerel crackers with the addition of seaweed flour is higher than the fat content value in the other research [23], which is 0.14% - 3.01%. The more the addition of fish meat and the more the addition of flour used, the more the fat content of the product will also increase [24].

Table 3. Fat content of fish crackers with seaweed flour.

Component	SNI 8646: 2018	Control	F1 (4%)	F2 (8%)	F3 (12%)
Fat (%)	Max. 30	13.42 ± 0.60 ^a	13.58 ± 2.13 ^a	16.75 ± 0.87 ^b	16.27 ± 2.02 ^b

Different letters (a,b,c) within a similar row indicate significant differences ($p < 0.05$).

The analysis of the fat content test results from several treatments of mackerel crackers with the addition of seaweed flour revealed that the highest fat content was found in treatment F2 (8%), which amounted to 16.75%. The results of the fat content test on mackerel crackers showed an increase in fat content from treatment F1 to F2, with an increase of 3.17%. This increase is hypothesized to be attributable to the incorporation of seaweed flour (*Eucheuma cottonii*), a nutrient-rich ingredient, into the cracker formulation. While seaweed is widely recognized as a source of dietary fiber and minerals, it also contains negligible amounts of lipids, which can contribute to the overall fat content of the crackers. Furthermore, it has been demonstrated that an increase in the concentration of seaweed meal results in a concomitant increase in the probability of other components, such as lipophilic compounds derived from seaweed, becoming integrated within the matrix of the crackers [25].

The crackers produced in the absence of seaweed flour (designated as the "control" group) exhibited the lowest fat content, which was 13.43%. This is attributable to the absence of supplementary ingredients with lipids, resulting in the fat content deriving exclusively from the mackerel as the primary ingredient and the oil absorbed during the frying process. In contrast, crackers with added seaweed flour in treatments F1 (4%), F2 (8%), and F3 (12%) exhibited fat content ranging from 13.58% to 16.75%. Although there was an increase in fat content as the percentage of seaweed flour increased, the results of statistical analysis showed that there was no significant difference between treatments ($p > 0.05$).

Notably, all treatments were found to comply with the quality standards for ready-to-eat fish crackers as outlined in SNI 8646:2018 [18], which stipulates a maximum fat content of 12%. This indicates that the final product is safe and suitable for consumption. The fat content of mackerel crackers with the addition of seaweed flour tends to be higher. This discrepancy may be attributed to various factors, including the type of fish utilized, the composition of additional ingredients, and processing techniques, particularly the frying process. The frying process plays a pivotal role in determining the fat content, as the product absorbs varying amounts of oil contingent on the composition of the raw materials and the dough structure [26], [27].

3.3. Moisture Content

The results of the study in Table 4 show that the control treatment, F2 and F3 have a moisture content value of 0.2% while the F1 treatment has a moisture content value of 0.1%, the F1 treatment is the smallest moisture content of the F2 and F3 treatments. The results of the analysis show that the addition of seaweed flour has no significant effect on the moisture content of mackerel crackers. This can be seen in table 4 which shows that there is no difference between treatments because the results of the Kruskal Wallis test show the value of *Asymp.Sig.* $> 0,05$.

Table 4. Moisture content of fish crackers with seaweed flour.

Component	SNI 8646: 2018	Control	F1 (4%)	F2 (8%)	F3 (12%)
Moisture (%)	Max. 4	0.020 ± 0.060 ^a	0.010 ± 0.060 ^a	0.020 ± 0.002 ^a	0.020 ± 0.004 ^a

Different letters (a,b,c) within a similar row indicate significant differences ($p < 0.05$).

The greater the fish concentration used, the resulting moisture content will also increase. The use of different raw materials will cause differences in water absorption in both the kneading and steaming processes [28], [29], [30]. The value of the moisture content produced still meets the quality requirements

of fish crackers in accordance with (SNI 8646: 2018), namely the maximum moisture content of 4%.

The moisture content in all treatments was found to be within the acceptable range for ready-to-eat fish crackers, as defined by SNI 8646:2018 [18], which stipulates a maximum limit of 4% moisture. This observation indicates the efficacy of the processing methods employed, specifically the drying and frying steps, in reducing the moisture content of the final product. The significance of low moisture content lies in its role in producing a crunchy texture and extending the shelf life of the product by reducing the risk of microorganism growth [30]. The slight variation in moisture content among the treatments, particularly in the F1 treatment, which exhibited the lowest moisture content, might be attributable to the hydrocolloid nature of seaweed flour (*Eucheuma cottonii*).

While this flour possesses the capacity to absorb water, it is possible that the concentration utilized in treatment F1 (4%) was not sufficiently high to elicit a discernible effect on the overall moisture content. Variations in raw materials, such as the type of fish and additives employed, can influence water absorption during the kneading or steaming process. This finding aligns with the conclusions of other studies, which underscore the necessity of meticulous formulation of additives to ensure the final quality of the product remains optimal [31].

3.4. Ash Content

The average results of the highest ash content of mackerel crackers were found in treatments F2 (8%) and F3 (12%), which amounted to 0.04%. Based on Table 5, it can be seen that each treatment does not significantly affect the value of ash content in the product because the test results from Kruskal Wallis show the *Asymp. Sig.* >0,05.

Table 5. Ash content of fish crackers with seaweed flour.

Component	SNI 8646: 2018	Control	F1 (4%)	F2 (8%)	F3 (12%)
Ash (%)	Max. 0.3	0.020 ± 0.005 ^a	0.030 ± 0.006 ^a	0.030 ± 0.006 ^a	0.040 ± 0.008 ^a

Different letters (a,b,c) within a similar row indicate significant differences (p<0.05).

The different ash content is influenced by the amount of concentration of seaweed flour added. Seaweed has a relatively high mineral content, so the higher the amount of flour addition, the higher the ash content in the product. The increase in the amount of ash content after the addition of seaweed flour was due to the mineral content contained in seaweed flour [32]. The increase in ash content occurs due to the addition of mineral content contained in seaweed flour, namely the minerals Ca, Cu, and Fe. The ash content of a food indicates the presence of inorganic mineral content in the food. In this study, the ash content increased as the concentration of seaweed flour used increased. The difference in ash content can also be influenced by the processing process, such as frying. The frying process can reduce the moisture content but does not significantly affect the mineral content, so the ash content tends to be stable [33], [34].

This is also reinforced in the other research which examined the effect of the cooking process on the composition of nutrients, in the study a comparison was made between boiled and fried treatments. Generally, boiled food decreased while fried food increased ash content. The highest decrease in ash content in boiled food was found in tofu (0.57%) followed by tempeh (0.54%), mackerel (0.23%) and the lowest was found in slaughtered chicken (0.1%). In fried food, the largest increase in ash content occurred in mackerel (0.56%) followed by cut chicken (0.54%) and tofu (0.1%). Meanwhile, fried tempeh decreased the ash content by 0.21% from the fresh ingredients [35], [36].

Although it did not have a statistically significant effect, the ash content values obtained in this study still meet the quality standards for ready-to-eat fish crackers based on SNI 8646:2018. This standard sets the maximum acceptable ash content at 2%. Thus, mackerel cracker products with the addition of seaweed flour not only meet the quality requirements, but also have a higher mineral content, providing added nutritional value to the product.

3.5. Carbohydrate Content

Based on the Table 6 of the average value of carbohydrate content of mackerel crackers with the addition of seaweed flour, it shows the highest value in the F1 treatment (4%) with a value of 85.63% and the lowest value in the F2 treatment (8%) with a value of 83.99%. Then seen from Table 6, it can be seen that each treatment does not show a significant difference. The decrease in carbohydrate content of crackers can be caused by an increase and decrease in other proximate contents because the results of carbohydrate content are highly dependent on the reduction factor. The lower the proximate content such as protein, fat, water and ash content, the higher the carbohydrate content, on the contrary, if the higher the proximate content of protein, fat, water and ash content, the lower the carbohydrate content [11].

Table 6. Carbohydrate content of fish crackers with seaweed flour.

Component	SNI 8646: 2018	Control	F1 (4%)	F2 (8%)	F3 (12%)
Carbohydrate (%)	-	84.46 ± 3.84 ^a	85.62 ± 2.76 ^a	83.99 ± 6.33 ^a	85.25 ± 2.85 ^a

Different letters (a,b,c) within a similar row indicate significant differences (p<0.05).

Based on the results of the study, the highest carbohydrate content was in the F1 treatment (4%) with an average value of 85.63%. Carbohydrate content is an important component in cracker products, as carbohydrates contribute to crunchy texture characteristics. In this study, carbohydrate content was influenced by other proximate contents such as protein, fat, water, and ash. The high carbohydrate content in the F1 (4%) treatment was due to an increase in the protein content in the F1 (4%) treatment, which was 6.97%.

The decrease in carbohydrate levels in the F2 (8%) and F3 (12%) treatments was also related to the increase in fiber content in seaweed flour. Dietary fiber contained in seaweed flour contributes to the proximate composition, thus reducing the proportion of carbohydrates measured. This is in accordance with the results of other studies which show that ingredients with high fiber content can reduce carbohydrate levels in the final product [5].

3.6. Crude Fiber Content

Based on Table 7, it can be seen that the highest fiber content value is found in the F3 treatment at 0.25% and the lowest at 0.14%, namely the treatment without the addition of seaweed flour. The results of Duncan's analysis showed that the addition of seaweed flour did not significantly affect the value of crude fiber in mackerel crackers.

Table 7. Crude fiber content of fish crackers with seaweed flour.

Component	SNI 8646: 2018	Control	F1 (4%)	F2 (8%)	F3 (12%)
Crude Fiber (%)	-	0.14 ± 0.01 ^a	0.19 ± 0.04 ^{ab}	0.23 ± 0.06 ^b	0.24 ± 0.04 ^b

Different letters (a,b,c) within a similar row indicate significant differences (p<0.05).

Seaweed has a fairly high fiber content [28]. The highest fiber content is at 12% seaweed substitution of 4.05%, then the lowest fiber content is 0% seaweed substitution which is 2.27%. The higher the percentage of seaweed substitution, the higher the fiber content in fish crackers [37]. Based on the results of crude fiber research analysis using Duncan's further test, it was found that each addition treatment did not have a significant effect (P>0.05) [5]. Although the results of statistical analysis using the Duncan test showed that the addition of seaweed flour did not have a significant effect on the crude fiber of mackerel crackers, the trend of increasing fiber content with increasing concentrations of seaweed flour remained descriptive.

Red seaweed, especially *Eucheuma cottonii*, is known to have a very high food fiber content, which is 81.94% based on dry weight [38]. This food fiber consists of 38.77% soluble food fiber and 43.17% insoluble food fiber, which contributes to increasing fiber content in processed products, including crackers. The addition of dietary fiber from *Eucheuma cottonii* seaweed flour had a significant effect on increasing fiber content in *dodol* products [39].

In this study, the higher crude fiber value was found in treatment F3 (12%), this occurred because the crude fiber content in seaweed is both soluble and insoluble, so the addition of seaweed flour plays an important role in increasing the crude fiber content in fish crackers. Although, the statistically insignificant results may be due to the relatively low crude fiber of mackerel crackers compared to other products, so the difference between treatments is not large enough to produce a real effect.

These results suggest that seaweed meal still contributes positively to the fiber content of mackerel crackers, although the effect is not statistically significant. In other words, the increase in crude fiber tends to occur gradually as the concentration of seaweed meal used increases.

3.7. Sensory Analysis

Based on Table 8, it can be seen that from each of the results of appearance evaluation, the highest average value in organoleptic test was found in F1 (4%) treatment, namely 8.1, and the lowest was found in F3 (12%) treatment, namely 7.1, while for the results of odor evaluation, the highest was found in F3 (%) treatment, namely 7.8, and the lowest was found in F2 (8%) treatment, namely 7.6. Furthermore, the highest taste evaluation results were found in F1 (4%) treatment, namely 8.3 and the lowest was found in F3 (12%) treatment, namely 7.8 and the highest texture evaluation results were found in F1 (4%) and F2 (8%) treatments, namely 8.8 and the lowest was found in F3 (12%) treatment, namely 8.6.

Table 8. Sensory analysis of fish crackers with seaweed flour.

Component	SNI of Fish Crackers Ready to Eat	Control	F1 (4%)	F2 (8%)	F3 (12%)
Appearance	Minimum 7.0	7.7	8.1	7.3	7.1
Smell	Minimum 7.0	8.2	7.7	7.6	7.8
Taste	Minimum 7.0	8.4	8.3	7.9	7.8
Texture	Minimum 7.0	8.7	8.8	8.8	8.6

Based on the panelists' assessment, the appearance of mackerel fish crackers with the addition of seaweed flour showed that the F1 treatment produced a golden-yellow color, while the F2 and F3 treatments tended to have a yellowish-brown hue. For the aroma attribute, the organoleptic test results indicated that the control and F3 treatments were generally highly favored by the panelists, receiving an average score in the "highly liked" category score of 9. Meanwhile, the F1 and F2 treatments were rated in the "liked" category with an average score of 7. Regarding taste, the highest preference was given to the F1 treatment, which was mostly rated as "highly liked" score 9 by the panelists. For texture, the highest proportion of panelists rated the F1 and F2 treatments as "highly liked," indicating that the crispiness of these fish crackers was well accepted.

Organoleptic testing includes assessment of appearance, aroma, taste, texture, and overall preference. In general, crackers with the addition of seaweed obtained good sensory acceptance. Seaweed crackers showed higher color, crispiness, and overall preference values compared to the control [40]. At low to medium concentrations (4–8%), the color change of the yellowish-white crackers was still acceptable, and the fish aroma-flavor remained dominant with the addition of a light marine aroma. Other studies have stated that certain processing methods (such as retorting or re-freezing) can increase crispiness and reduce the fishy taste of chips [41]. The panel test in this study showed no significant decrease in overall preference between treatments, indicating that an addition of up to 12% is still acceptable to consumers [42]. These results are consistent with the literature stating that the addition of seaweed as a functional ingredient can increase nutritional value without sacrificing sensory acceptance.

Importantly, all formulations met Indonesian quality criteria (SNI) for fish crackers. The optimal 4% formula delivered higher nutritional value (notably fiber) while passing sensory acceptance tests. As such, *Eucheuma cottonii* flour appears to be a viable ingredient for developing nutritious, Halal-certified fish crackers. The fish (mackerel) and seaweed are naturally Halal, and the production process was hygienic, so the product aligns with Halal standards. This work supports the broader concept of using local marine resources to create value-added, healthful snacks [43], [44], [45].

4. CONCLUSION

The incorporation of seaweed flour (*Eucheuma cottonii*) into mackerel crackers (*Rastrelliger kanagurta*) exhibited no substantial impact on the chemical (proximate) and organoleptic (sensory) attributes of the product, as evidenced by the Anova test results, which yielded a P-value > 0.05. The optimal treatment identified in this organoleptic (sensory) test research is F1 (4%), which elicits sensory characteristics of the appearance component 8.1% (whole, neat, clean, even thickness, bright), odor 7.7% (less product-specific), taste 8.3% (product-specific), and texture 8.8% (very dry and crispy). The overall panelist liking level was 40% (liked). In addition, the chemical test (proximate analysis) revealed that treatment F1 (4%) exhibited the highest protein content (6.97%), followed by fat (13.58%), moisture (0.01%), ash (0.03%), carbohydrates (85.63%), and crude fiber (0.19%).

AUTHOR CONTRIBUTION

All authors contributed to the preparation of this paper and approved the final manuscript. **Nurul Ma'rifatul Azizah:** Writing (original draft), investigation, data collection, laboratory experiments, formal analysis, and data analysis. **Misbakhul Munir:** Supervision, conceptualization, methodology, validation, and writing (review & editing). **Dian Sari Maisaroh:** Supervision, validation, writing (review & editing), and formal analysis.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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