The Development of Hybrid Food as Meat Analog Strips Based on Seaweed *Ulva ohnoi* and Surimi

Arlin Maulida[1], *Wahyu* Ramadhan [1,2,*], *Joko* Santoso[1].

[1]Department of Aquatic Product Technology, Faculty of Fisheries and Marine Sciences, IPB University, Jl Agatis Kampus IPB Dramaga, Bogor, West Java 16680, Indonesia.
[2]Center for Coastal and Marine Resources Studies (PKSPL), International Research Institute for Maritime, Ocean and Fisheries (i-MAR), IPB University, IPB Baranangsiang Campus, Jl. Raya Pajajaran, Bogor, West Java, 16127 Indonesia.

Abstract. Meat analogues have been gaining popularity as a sustainable and health-conscious alternative to traditional meat products, driven by increasing consumer awareness of environmental benefits. However, there remains a gap in the market for meat analogues that not only mimic meat texture but also offer enhanced nutritional benefits, particularly in terms of fiber content. Meat analogue strips from *Ulva ohnoi* and surimi underwent proximate, fiber, and texture profile analysis. The aim of the study was to determine the best formula between the ratio of *Ulva ohnoi* and surimi inclusion in meat analogue strips along with evaluating the physicochemical characteristics of the resulting product. This study also involved panelists to assess the hedonic level of consumer acceptance of the produced products. The results showed that F5, with 5% *Ulva ohnoi* and 20% surimi, was the best formula with a sensory value of color 7.21 and texture 6.08. The chemical composition of meat analogue strip F5 includes 2.63 ± 0.54% moisture content, 10.12 ± 2.28% ash content, 3.89 ± 0.87% fat, 13.86 ± 0.31% protein, 59.26 ± 1.93% carbohydrate, and 10.23 ± 0.00% fiber. Eventually, this study opens up new alternatives, showing that meat analogue strips not only serve as an energy source but also as a potential high-fiber healthy snack.

1 Introduction

Snacks are loved by everyone and are consumed worldwide. Changes in people's lifestyles and the increasing demand for good food can help grow the market, especially for snacks. This market is expected to increase annually by 1.2%. Snack foods tend to be energy-dense and low in nutritional value due to their high sugar, sodium, and saturated fat content [1]. As a result, the healthy food trend has introduced a new category of low-fat, healthy snacks, which are currently being developed. According to Farida [2], healthy snacks are not only rich in energy but also contain fiber, protein, antioxidants, and various vitamins and minerals

* Corresponding author: wahyu.ramadhan@apps.ipb.ac.id

that are important for health. The combination of animal and plant proteins is acceptable to consumers with low levels of involvement, offering more environmentally friendly protein sources. The hybrid food trend is currently one of the most popular food products, especially among vegetarians, with 54% of them favoring such products.

Hybrid foods typically combine meat and plant-based ingredients such as vegetables, plant proteins, mushrooms, or grains to produce beneficial products [3]. Hybrid meat products contain a mix of meat and plant-based ingredients to offer more sustainable options with reduced meat, fat, and cholesterol compared to traditional meat products. Hybrid foods aim to meet the demand for healthy nutrition while providing authentic flavors and textures that appeal to consumers [4]. Currently, hybrid foods are dominated by imitation foods such as meatballs, sausages, crab sticks, and meat analogs. Meat analogs are plant protein-based food products that mimic the sensory properties of meat [5]. The expansion of the meat analog (plant-based meat) market is rapidly outpacing vegetarian consumer demand, with an annual growth rate of 7.9% [6]. The global meat analog industry is projected to grow from $4.6 billion in 2018 to $85 billion by 2030. Meat analogs (plant-based meat) are made from soy or wheat gluten and other additives to improve the sensory quality of the resulting product [7]. One of the trends in the development of meat analogs is the use of surimi [8,9].

Since the modernization era, surimi has become one of the most developed products in Indonesia. The demand for surimi continues to increase every year. Based on export data, surimi demand from 2017 to 2020 increased from 16,000 tons to 20,000 tons in 2020. Surimi is made from fish meat pieces through a washing and heating process [10]. This product has gained popularity in recent years in China, Korea, Japan, Thailand, and other Asian countries due to its unique textural properties and low-fat content [11]. In China, silver carp (*Hypophthalmichthys molitrix*) is a cultivated freshwater fish and the main raw material in surimi production. In 2018, surimi production generated profits of $4.06 billion [12]. Surimi is low in dietary fiber and high in protein, so it has been widely researched to fortify foods and increase their nutritional value, one example being fortification with *Ulva ohnoi* seaweed.

Ulva ohnoi seaweed is one of the most underutilized aquatic commodities [13]. This type of macroalgae is classified as a polymorphic species, with its morphology depending on water salinity levels [14] or its association with bacteria [15]. Generally, macroalgae, also known as seaweeds, contain high amounts of carbohydrates (up to 60%), proteins (10-47%), and low amounts of lipids (1-3%), with varying mineral content. Seaweeds from the Ulva genus can be considered a nutrient source, including essential amino acids, dietary fiber, polyunsaturated fatty acids, minerals, and vitamins. The genus has also demonstrated biological activities such as antioxidant, antimicrobial, antiviral, anticoagulant, and anticancer properties. The presence of various bioactive compounds in *Ulva ohnoi* can be utilized as a nutrient-rich food source [16]. Previous studies have incorporated *Ulva ohnoi* into the food industry due to its nutrient density [17]. *Ulva ohnoi* seaweed fortification has been widely applied in various foods, including soups, bread [18], beverage [19] and nori-like products [20]. However, the combination of surimi-based meat analogs with *Ulva ohnoi* enrichment has not been reported, particularly to enhance the nutritional intake of the resulting food products. Therefore, it is important to conduct this research.

2 Materials and methods

2.1 Equipment and Materials

The equipment used for the preparation and handling of *Ulva ohnoi* seaweed includes containers, sieves, dehydrators, and digital scales. For the production of surimi-based meat analog strips, the tools utilized were a food processor, steaming pot, stirring spoon, spatula, stove (Maspion), baking sheet, digital scale (I-2000), and a dehydrator. The equipment used for proximate analysis included porcelain cups (Pyrex), an oven (B-One FCD3000), desiccators (Duran®), a furnace, filter paper, fat flask, Soxhlet apparatus, Kjeldahl flask (Pyrex), burette, analytical balance (Mettler Teledo, USA), and a texture analyzer (TA-XT21).

The primary materials used in this research were *Ulva ohnoi* seaweed sourced from PT Razindo Global Nusantara, Lombok, West Nusa Tenggara, Indonesia, along with kurisi fish surimi, wheat flour (Bogasari Blue Triangle, Jakarta), cornstarch, instant yeast, pepper, sugar, table salt, and water. The chemicals required for proximate analysis included distilled water, hexanes, Kjeldahl tablets, NaOH, boric acid (H3BO3), Brom Cresol Green-Methyl Red indicator, and 0.1 N HCl.

2.2 Seaweed Preparation and Characterization

Ulva ohnoi seaweed was thoroughly washed with water to remove any sand or debris collected during harvesting. The cleaned seaweed was then dehydrated for 6 hours and ground using a blender. The pulverized seaweed was further processed using a food processor and sieved through an 80-mesh sieve. Proximate analysis was conducted on the seaweed, evaluating its moisture, ash, fat, protein, and carbohydrate content.

2.3 Formulation of *Ulva ohnoi*-Enriched Surimi-Based Meat Analog Strips

The formulation for the surimi-based meat analog strips was adapted from the research of [21], with modifications to include *Ulva ohnoi* seaweed flour in a quantity of 22.5 grams. The specific formulation details for the meat analog strips can be found in Table 1.

Table 1 Ratio *Ulva ohnoi* dan surimi

Ingredients	Component (g)					
	F1	F2	F3	F4	F5	F6
Seaweed flour	22.5	17.5	12.5	10	5	0
Surimi	0	5	10	12.5	17.5	22.5
Wheat flour	20	20	20	20	20	20
Corn flour	7.5	7.5	7.5	7.5	7.5	7.5
Garlic	3	3	3	3	3	3
Shallot	3	3	3	3	3	3
Salt	1	1	1	1	1	1
Ground pepper	0.5	0.5	0.5	0.5	0.5	0.5
Sugar	0.5	0.5	0.5	0.5	0.5	0.5
Water	42	42	42	42	42	42

The preparation of meat analog strips begins with mixing *Ulva ohnoi* seaweed flour and surimi according to the formulation using a food processor and adding water. The dough is then steamed at 90°C for 30 minutes and salt, sugar and ground pepper are added. The dough was molded in a baking pan and cut. The pieces were dried using a dehydrator at 80°C for 2 hours to obtain meat analog strips. The flowchart for the production of *Ulva ohnoi* and surimi-based meat analog strips is presented in Figure 1.

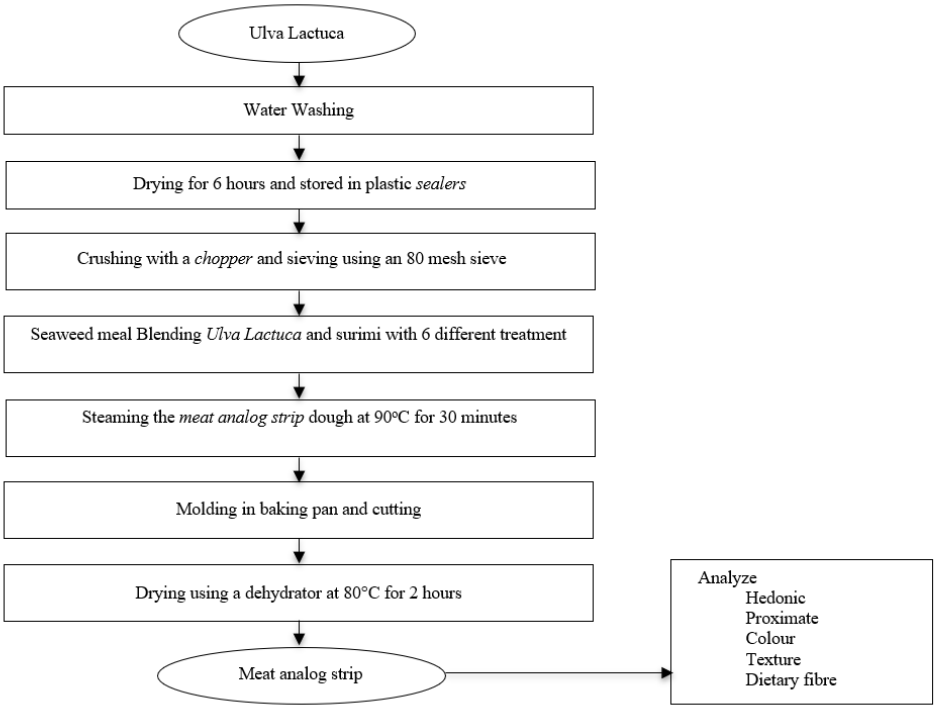

Fig. 1. Making *Ulva ohnoi* and surimi-based meat analog strips

2.4 Analysis

2.4.1 Sensory Test

Sensory tests are carried out using the human senses in determining the quality of quality in a food ingredient against several indicators. Sensory test indicators include appearance, color, aroma, taste, and texture. This test requires semi-trained panelists who will fill out a rating sheet with a scale of 1-9 consisting of: (1) very strongly dislike; (2) very much dislike; (3) dislike; (4) somewhat dislike; (5) normal/neutral; (6) somewhat like; (7) like; (8) very much like; (9) very much like. The untrained panelists used were 40 panelists.

2.4.2 Proximate Analysis

Proximate analysis aims to determine the chemical content in a food ingredient. Proximate analysis in this study carried out several determinations, including the determination of water content, ash content, fat content, protein content, and carbohydrate content. Determination of moisture content using the oven method, ash content using the dry method, fat content using the Soxhlet method, protein content using the Kjeldahl method, and determination of carbohydrate content by difference.

Moisture Content Analysis

Moisture content analysis is carried out to determine the water content contained in the sample. The water content test uses the gravimetric method by drying the porcelain cup in an oven at 105ºC for 60 minutes. Then, the cup is placed into a desiccator for ± 15 minutes before the weighing process is carried out. Weighing the sample is done, placed into a cup and dried using an oven at 105ºC for 5-8 hours. Place the cup back into the desiccator for ± 30 minutes and the weighing process is carried out again. Calculation of moisture content using the following formula:

$$\text{Moisture content (\%)} = \frac{(W1-W2)}{W} x\ 100\% \qquad (1)$$

Description :

W = Weight of sample (g)

W1 = Weight of cup + initial sample (g)

W2 = Weight of cup + dry sample (g)

Ash Content Analysis

Ash content testing is carried out through the process of burning samples at high temperatures. The ash content analysis stage begins with drying an empty porcelain cup in an oven at 105ºC for 60 minutes. The cup was put into a desiccator for ± 15 minutes and then weighed and recorded the weight. Samples as much as 5 g were placed into the cup and put into an ash furnace for 1 hour at 600ºC until ash was obtained. The cup containing the ash was then cooled again in a desiccator before weighing and recording the weight. The ash content test can be calculated using the following formula:

$$\text{Ash content (\%)} = \frac{(W1-W2)}{W} x\ 100\% \qquad (2)$$

Description :

W = Weight of sample (g)

W1 = Weight of cup + fumigated cup (g)

W2 = Weight of empty cup (g)

Fat Content Analysis

Fat content testing aims to determine the fat content contained in the sample. The analysis begins with weighing the sample as much as 2 g, then put into filter paper before being placed into the sleeve and fat flask that has been weighed. The sleeve is connected to the extractor chamber and flushed using hexane solvent. The flask was connected to a distillation device and heated for 6 hours at 80ºC using an electric heater so that the hexane solution contained therein could evaporate completely. The fat that has been separated from the hexane solvent is then oven dried at 105ºC and cooled in a desiccator for 20-30 minutes before weighing again. Calculation of fat content can be calculated using the following formula:

$$\text{Fat content (\%)} = \frac{(W1-W2)}{W} x\ 100\% \qquad (3)$$

Description :

W = Weight of sample (g)

W1 = Weight of fat flask without fat (g)

W2 = Weight of cup + dry sample (g)

Protein Content Analysis

The protein content test carried out has three main stages, namely deconstruction, distillation, and titration. This analysis begins by preparing a sample of 2 g then put into a 50 mL Kjeldahl flask and adding 7 g K_2SO_4; 0.005 g HgO; 15 mL concentrated H_2SO_4 and 10 mL H_2O_2

slowly into the flask and let stand for 10 minutes in the acid room. The sample was deconstructed for ± 2 hours at 410ºC until the solution changed color to yellowish green. Distilled water as much as 50 mL and NaOH 40% as much as 20 mL were added to the Kjeldahl flask for the distillation process at 100ºC. The distillation results were collected in a 125 mL Enlenmeyer flask and added bromocresol green-methyl red. The distillation process is carried out until the volume of the Enlenmeyer reaches 150 mL of green distillate. Titration is the final step in testing protein content. Titration is done by using distillate until pink with the addition of 0.1 N HCl. The next process is to analyze the blank solution and can be calculated by the following formula:

$$\text{Fat content (\%)} = \frac{mL\ HCl - mL\ blanko\ x\ N\ HCl\ x\ 14{,}01\ x\ 6{,}25\ x\ FP}{mg\ sampel}\ x\ 100\% \quad (4)$$

Description :

mL HCl	= HCl volume used for titration (mL)
N HCl	= Normality value of HCl solution used for titration (N)
14,01	= Atomic weight of nitrogen
6,25	= Nitrogen to protein conversion rate
FP	= Dilution factor
Mg sample	= Sample weight (mg)

Carbohydrate Analysis

Carbohydrate content analysis was carried out using the by difference method. It is known that the carbohydrate content of the sample is obtained from the subtraction of the total percentage of the overall moisture content, fat content, protein content, and ash content from 100%. The calculation of carbohydrate content is as follows:

Carbohydrate content (%) = 100% - (water content + fat + protein + ash)%.

2.4.3 Food Fiber Analysis

Food fiber analysis was carried out by weighing a sample of 1 g and then putting it into a 400 mL goblet, adding 0.1 thermamyl and 50 mL of phosphate buffer with pH 6.0 before the goblet was closed using aluminum foil. Place the glass cup into boiling water for ± 15 minutes and do a short movement for 5 minutes. Add 0.275 N NaOH solution to change the pH value to 7.5. The solution that has been cooled first, added 5 mL of protease enzyme and incubated in a water heater for 30 minutes at 60ºC and agitated continuously. The solution obtained was then allowed to stand at room temperature to reduce the temperature and 0.325 M HCL was added until the pH reached 4.0-4.5. The amynoglycoside enzyme was added to the sambel and incubated for 30 minutes at 60ºC under tightly closed conditions using aluminum foil. The next process was the addition of 95% ethanol solution to the sample at room temperature for 60 minutes to precipitate soluble dietary fiber (SDF). The precipitate that has been obtained is then filtered using filter paper to get the residue. The residue was washed using acetone and 78% ethyl alcohol, 95% ethyl alcohol, and acetone successively. The filter paper containing the residue and has gone through the washing stage, then dried in an oven at 105ºC for 12 hours and then weighed again.

2.4.4 Color Analysis

Color analysis is done by taking a photo of the product to be analyzed with good quality. Upload the photo in PowerPoint and select the eyedropper feature. Press and hold the mouse button to see the RGB (red, green, and blue) color coordinates. Visit the Colormine.org website and upload the product photos that have been taken. Select the "Color Picker" feature to convert RGB colors to LAB. The numerical value that has been obtained shows the results of visual color analysis.

2.4.5 Texture Analysis

Texture analysis was performed using a texture analyzer. Sample analysis was conducted after 48 hours of making meat analog strips. The meat analog strip samples analyzed were in the form of blocks with a size of 1 cm high x 2 cm wide. The meat analog strip pieces were compressed continuously until the height reached 50% of the original height. A cylindrical probe with a diameter of 50 mm with a pre-test speed of 1 mm/s, and a post-test speed of 10 mm/s was used during the experiment.

3 Result and discussion

3.1 Characteristics of *Ulva ohnoi* Seaweed

Ulva ohnoi is the main raw material in the manufacture of meat analog strips. This seaweed can be found in Indonesian waters [22], but its utilization is not optimal. *Ulva ohnoi* seaweed used in this study has characteristics in the form of green talus in the form of wavy thin sheets. *Ulva ohnoi* can be used as a raw material for making meat analog strips because it contains high fiber. Generally, this seaweed often experiences blooming in the dry season, thus experiencing high production levels. According to Dominguez [23], stating that the talus sheets on *Ulva ohnoi* seaweed will fuse in the form of a holdfast. The chemical composition contained in *Ulva ohnoi* seaweed is presented in Table 2.

Table 2. Chemical composition of *Ulva ohnoi*

Parameter	*Ulva ohnoi*	*Ulva ohnoi* [24]
Moisture content	11.26 ± 0.16	6.32 ± 0.25
Ash content	30.61 ± 0.43	28.91 ± 1.21
Fat content	9.13 ± 0.12	14.36 ± 0.23
Protein	0.48 ± 0.00	0.45 ± 0.01
Carbohydrate	48.52 ± 0.71	62.06 ± 0.60
Dietary fiber	39.75 ± 0.66	28.4 ± 0.25

The chemical composition of *Ulva ohnoi* seaweed in Table 2 shows that the results of proximate analysis in the study had a moisture content of 11.26%, ash content of 30.61%, protein 9.13%, fat 0.48%, carbohydrates 48.52%, and dietary fiber 39.75%. Sinurat [24] reported that the chemical composition of *Ulva lactuca* seaweed has a water content of 6.32%, ash content 28.91%, protein 14.36%, fat 0.45%, carbohydrates 62.06%, and food fiber 28.4%. The chemical composition of seaweed used in research with literature has different results. The difference can be influenced by several factors such as water temperature, pH, salinity level, substrate, and harvest time. These factors will affect the process of nutrient absorption and photosynthesis process so that it has a varied chemical composition.

3.2 Characteristics of Surimi

Surimi has a good gel-forming ability that can be used in the food industry. Surimi is also one of the potential products used in the food industry as an ingredient in the manufacture of various food products such as kamaboko, meat analog, and meatballs because it has a unique texture and good nutritional content [25]. The chemical composition contained in surimi can be seen in Table 3.

Table 3. Chemical composition of Surimi

Parameter	Surimi	Surimi*	Indonesia Standard of Surimi
Moisture content	82.23 ± 0.24	75.39± 0.19	Maks 80%
Ash content	0.91 ± 0.01	0.70 ± 0.02	1.5%-2.5%
Fat content	12.65 ± 0.20	15.33 ± 0.03	12%-20%
Protein	3.29 ± 0.03	1.42 ± 0.04	2.02%-2.19%
Carbohydrate	0.93 ± 0.00	-	2.53%-4.73%

The chemical composition of surimi in Table 3 shows that the results of proximate analysis in the study have a moisture content of 82.23%, ash content of 0.91%, prorein 12.65%, fat 3.29%, and carbohydrates 0.93%. The results of the proximate analysis of the surimi used in the study were not much different from the surimi kurisi fish (*Nemipterus* spp.) has a proximate composition with a moisture content of 75.39%, ash content of 0.70%, protein 15.33%, and fat 1.42%. The value of the proximate composition of surimi is influenced by the type and condition of the washing process during production [26]. The purpose of the washing process in making surimi is to remove protein, sarcoplasm, blood, fat, and other components [27].

3.3 Characteristics of Meat Analog Strip

3.3.1 Color Analysis of Meat Analog Strip

The color of the meat analog strip was quantified using a color analyzer. The values obtained from color analysis include L* (lightness), a* (redness/greenness), and b* (yellowness/blueness). The results of color analysis on meat analog strips using a color analyzer can be seen in Table 4.

Table 4. Color analysis of meat analog strip

Parameter	Treatment					
	F1	F2	F3	F4	F5	F6
Lightness (L*)	10.38 ± 0.42^{c}	6.80 ± 0.64^{a}	5.65 ± 0.44^{a}	8.96 ± 0.73^{b}	19.33 ± 0.31^{d}	68.82 ± 0.90^{e}
Redness (a*)	1.29 ± 0.87^{d}	0.08 ± 0.96^{cd}	-0.77 ± 0.53^{abc}	-2.13 ± 0.22^{a}	-0.16 ± 0.65^{bcd}	0.72 ± 0.81^{ab}
Yellowness (b*)	3.16 ± 1.15^{a}	1.93 ± 0.57^{a}	2.50 ± 0.47^{a}	6.16 ± 1.61^{b}	13.38 ± 0.76^{c}	33.04 ± 0.22^{d}

Notes: Different superscript letters in the same row indicate significantly different results at $p<0.05$.

The a* (redness) value on the meat analog strip ranged from -2.13-1.29. The lowest redness value in treatment F4 (15% surimi addition) was -2.13 and the highest redness value was obtained in treatment F1 (without surimi) at 1.29. Meat analog strip without surimi has the highest degree of redness. This is due to the high chlorophyll content in *Ulva ohnoi* which can cause the resulting color to be unstable because chlorophyll tends to degrade during storage and high temperature treatment. When drying with a dehydrator using a temperature of 60°C, the heat coming from the equipment directly hits the material so that the meat analog strips without surimi are reddish in color.

The value of b* (yellowness) in meat analog strips is between 1.93-33.04. Meat analog strip formulations F1 with F2 and F3 did not show significant differences ($p>0.05$), but F4, F5, and F6 showed significant differences ($p>0.05$). This is due to the increase in the proportion of surimi and the decrease in *Ulva ohnoi* used. Meat analog strip product F6 had the highest b* value of 33.04, while the lowest was 1.93 in F2. The high b* value is due to the amino acid content in surimi. The use of high temperatures will encourage the release of these compounds, thus accelerating the color change process. The low b* value of meat analog strip was caused by the reduced proportion of *Ulva ohnoi* used.

3.3.2 Hedonic of Meat Analog Strip

Hedonic test is a test to measure the level of consumer preference for a product. The hedonic test conducted in the study involved 40 semi-trained panelists with a score range of 1 to 9. The assessment was carried out on 6 formulas of meat analog strip products, namely F1, F2, F3, F4, F5, and F6 (b/w). The parameters include appearance, aroma, taste, color, and texture. The hedonic value of meat analog strips with various concentrations of surimi is presented in Table 5.

Appearance is a parameter in the hedonic test that presents the visible state and gives consumers an impression of a product produced. The product has a good appearance can give the view that the product has good quality. The results of the hedonic test of meat analog strips with the addition of surimi on the appearance parameter showed that the panelists' favorability scores ranged from 6.36 to 6.97 with the category somewhat like. The appearance preferred by panelists was meat analog strip F5. The addition of surimi to the meat analog strip on the taste parameter is not significantly different. Based on Table 4, it can be seen that the meat analog strip has a similar appearance, but has an inhomogeneous color appearance between *Ulva ohnoi* seaweed and surimi.

Table 5. Hedonic value of meat analog strip

Parameter	Treatment					
	F1	F2	F3	F4	F5	F6
Appearance	6.36 ± 0.84[a]	6.41 ± 0.88[ab]	6.59 ± 0.88[bc]	6.82 ± 0.88[bc]	6.97 ± 0.98[c]	6.79 ± 0.86[bc]
Aroma	5.95 ± 0.82[a]	6.08 ± 0.70[ab]	6.49 ± 0.94[bb]	6.10 ± 0.88[ab]	6.28 ± 0.88[ab]	6.49 ± 0.91[b]
Taste	6.33 ± 0.95[a]	6.92 ± 1.32[b]	6.64 ± 1.18[ab]	7.00 ± 1.31[bc]	7.10 ± 1.09[b]	6.67 ± 1.06[ab]
Color	6.49 ± 0.94[a]	6.56 ± 0.94[ab]	6.56 ± 0.94[ab]	7.00 ± 0.94[bc]	7.21 ± 0.92[c]	7.00 ± 1.07[bc]
Texture	5.92 ± 0.73[a]	6.05 ± 0.85[a]	5.97 ± 0.90[a]	6.08-± 0.95[a]	6.08 ± 0.80[a]	6.26 ± 0.91[a]

Notes: Different superscript letters in the same row indicate significantly different results at $p<0.05$.

Aroma is a hedonic test parameter that uses the sense of smell. Aroma plays an important role because it has its own appeal in determining the first assessment of consumers. The results of the meat analog strip test with the addition of surimi on the aroma parameter showed that the panelists' favorability scores ranged from 5.95-6.49 with the category somewhat liked. The aromas preferred by panelists were meat analog strips F3 and F6. The addition of surimi to the meat analog strip on the aroma parameter was not significantly different. This is thought to be because *Ulva ohnoi* seaweed and surimi have aromas that are not much different.

Taste is a hedonic test parameter that is carried out using the sense of taste, namely the tongue. Taste is one of the most important factors in determining consumer decisions on the acceptance of a product. The results of the hedonic test of meat analog strips with the addition of surimi on the taste parameter showed that the panelists' favorability scores ranged from 6.33-7.10 with the category of liking. The taste preferred by panelists was meat analog strip F5. Duncan test results showed that F2, F4, and F5 had a significant effect on meat analog strips ($p<0.05$). The addition of surimi F3, and F6 did not significantly affect the taste of meat analog strips. *Ulva ohnoi* seaweed has a characteristic fish flavor and a slight vegetable flavor. This is thought to cause panelists to dislike the taste of meat analog strips without surimi. Increasing the amount of surimi concentration resulted in a more intense fish flavor, so the liking value decreased in treatment F6.

Color is a visualization of a product that is seen directly by consumers. Color is one of the fastest and easiest responses to give a good impression. Food that has good taste and good texture will not necessarily be liked by consumers if the food has a color that deviates from the color it should be. The results of the hedonic test of meat analog strips with the addition of surimi on the color parameter showed that the panelists' liking value ranged from 6.49-7.21 with the category of liking. The color preferred by panelists was meat analog strip F5. The results of Duncan's further test showed that the addition of surimi F2, and F3 did not significantly affect the meat analog strip, while the treatment of F4, F5, and F6 significantly affected the meat analog strip ($p<0.05$). This can be caused by surimi which tends to be white so that meat analog strips with the addition of surimi have a paler color than meat analog strips without surimi.

Texture is one of the hedonic test parameters that affect the appearance of a product because sensory sensitivity is determined by the consistency of the texture [28]. The results of the hedonic test of meat analog strips with the addition of surimi on the texture parameter showed that the panelists' favorability scores ranged from 5.92-6.26 with the category somewhat liked. The texture preferred by panelists was meat analog strip F6. The addition of surimi to the meat analog strip on the taste parameter was not significantly different. This is because the meat analog strip has a rough and uneven texture on the edges.

3.3.3 Chemical Composition of Meat Analog Strip

Proximate analysis is a macronutrient analysis that involves determining the chemical composition of a material [29]. The results of proximate analysis of meat analog strips with the addition of surimi are presented in Table 6.

Table 6. Chemical composition of meat analog strip

Parameter (%)	Treatment					
	F1	F2	F3	F4	F5	F6
Moisture content	7.87 ± 0.41^{c}	6.12 ± 1.68^{bb}	6.73 ± 0.22^{bc}	3.07 ± 0.30^{a}	2.63 ± 0.54^{a}	2.71 ± 0.43^{a}
Ash content	14.74 ± 0.27^{c}	13.56 ± 0.22^{c}	11.37 ± 0.68^{b}	10.70 ± 1.05^{b}	10.12 ± 2.28^{b}	2.68 ± 0.27^{a}
Fat content	2.14 ± 0.51^{a}	2.57 ± 0.25^{a}	2.28 ± 0.14^{a}	7.62 ± 1.47^{c}	3.89 ± 0.87^{b}	2.62 ± 0.61^{a}
Protein	10.12 ± 0.05^{a}	10.90 ± 0.33^{bb}	11.98 ± 0.15^{c}	12.72 ± 0.11^{d}	13.86± 0.31^{e}	15.92 ± 0.47^{f}
Carbohydrate	45.00 ± 0.60^{a}	47.69 ± 0.86^{b}	50.75 ± 0.30^{c}	53.19-± 0.36^{d}	59.26 ± 1.93^{e}	72.26 ± 0.62^{f}

Notes: Different superscript letters in the same row indicate significantly different results at $p<0.05$.

Moisture content is one of the main components in proximate analysis because it can affect the texture, flavor, and appearance of food ingredients. Determination of moisture content can significantly affect the overall chemical composition of an ingredient [30]. The value of water content based on Duncan's further test showed that the treatment of F2, F4, F5, and F6 had a significant effect on the control meat analog strip, while the treatment of F3 had no significant effect on water content. The highest moisture content was found in the F1 meat analog strip at 7.87%, while the lowest moisture content was found in the F5 treatment at 2.63%. Differences in moisture content in a material, caused by environmental factors such as temperature and relative humidity affect moisture content.

Ash content is a mixture of minerals or inorganic components found in food. In general, food consists of water and 96% inorganic materials, while the rest are other elements such as Na +, K +, Ca2 +, and minerals. This element is referred to as ash content with the aim of showing the total minerals in a food ingredient [31]. The value of ash content based on Duncan's further test showed that the treatment of F3, F4, F5, and F6 had a significant effect on the control meat analog strip. The highest ash content was found in the control meat analog strip at 14.74%, while the lowest ash content was found in treatment F6 which was 2.68%. This is due to the processing of food ingredients that can reduce ash content [32].

Fat refers to the amount of lipids that contain the elements C, H, and O. Fat is an important component and serves as an energy storage unit [33]. The results of further tests on fat analysis showed that treatment F4, and F5 had a significant effect on the control meat analog strip, but treatment F2, F3, and F6 had no significant effect on fat content. The highest fat content was found in meat analog strips with treatment F4 of 7.62%. High fat content of meat analog strip can occur due to the use of oil that cannot be controlled during printing.

Protein is one of the food components that is chemically composed of amino acid monomers connected through peptide bonds. The composition of meat analog strips in Table 5 shows that surimi can increase protein content. The results of Duncan's further test on protein analysis showed that the treatment had a significant effect on the meat analog strip produced. The highest protein content is found in meat analog strip F6 which is 15.92%. The results of the proximate analysis conducted showed that the treatment of adding surimi to meat analog strips was able to increase protein levels.

Carbohydrates play an important role in daily life because they serve as the main source of energy. Carbohydrates can fulfill 60-70% of energy needs in the body [34]. The results of further tests on the carbohydrate component in F1 were significantly different from all treatments. The results of carbohydrate analysis in Table 5 show that the addition of surimi increases the carbohydrate value of meat analog strips. However, these results are not in accordance with the research which states that the use of surimi in a product can reduce carbohydrate content. This is due to the influence of the processing techniques used and further research needs to be done.

3.3.4 Food Fiber Composition of Meat Analog Strip

Fiber is divided into two types: dietary fiber and crude fiber. Dietary fiber is part of food but cannot be hydrolyzed by digestive enzymes, while crude fiber is part of food that cannot be hydrolyzed by chemicals. Based on its solubility, dietary fiber is divided into two, namely soluble and insoluble dietary fiber [35]. Soluble dietary fiber (SDF) is a fiber component that can dissolve in water and form a gel when interacting with water. Insoluble dietary fiber (IDF) is fiber that cannot dissolve in water, such as cellulose and hemicellulose. The fiber content found in seaweed is relatively high at 67.5% which consists of 39.47% insoluble dietary fiber and 26.03% soluble dietary fiber [36]. The food fiber composition of meat analog strips is presented in Table 7.

Table 7. Food fiber composition of meat analog strip

Treatment	Dietary fiber
F1	20.11 ± 0.002^{f}
F2	19.14 ± 0.001^{e}
F3	16.89 ± 0.001^{d}
F4	12.68 ± 0.002^{c}
F5	10.23 ± 0.000^{b}
F6	3.80 ± 0.002^{a}

Notes: Different superscript letters in the same row indicate significantly different results at $p<0.05$.

The results of the analysis of total dietary fiber content in meat analog strips in the treatment and concentration of *Ulva ohnoi* seaweed ranged from 3.80-20.11%. The average total dietary fiber content of *Ulva ohnoi* and surimi-based meat analog strips was highest in the control treatment (without surimi) and lowest in treatment F6. Based on Table 6 above, there is a decrease in total dietary fiber content in meat analog strips along with the reduction of seaweed substitution. This shows that, the lower the concentration of seaweed, the lower the fiber content. The total dietary fiber content shows that there is a decrease in each treatment of surimi substitution, this is because seaweed has a fairly high dietary fiber content. According to Perdani [37], stated that the food fiber content of seaweed, especially the type of *Ulva ohnoi*, generally contains insoluble food fiber ranging from 34.37% to 33.3% and 20.53% to 27.2% soluble food fiber. Research results [38] also showed that the fiber content in biscuits was influenced by seaweed substitution. The results of research [39] also showed that there was an effect of seaweed substitution on the fiber content of the nori-like produced.

3.3.5 Texture Profile Analysis of Meat Analog Strip

Texture Profile Analysis (TPA) is a method used to evaluate the textural properties of a product. This method involves compressing the product in order to mimic the chewing process and the resulting force displacement curve to determine various texture attributes. Attributes evaluated using texture profile analysis (TPA) include hardness, cohesiveness, adhesiveness, and chewiness. The results of the texture profile analysis (TPA) test on *Ulva ohnoi* grass-based meat analog strips and surimi are presented in Table 8.

Table 8. Texture profile analysis of meat analog strip

Treatment	Hardness	Cohesive	Adhesive
F1	1073.43 ± 319.25^{a}	7.03 ± 1.21^{b}	-0.227 ± 0.03^{bc}
F2	1745.41 ± 517.66^{c}	10.04 ± 1.81^{c}	-0.242 ± 0.07^{bc}
F3	1169.55 ± 270.33^{ab}	6.72 ± 1.22^{b}	-0.192 ± 0.06^{c}
F4	2287.52 ± 483.97^{d}	11.33 ± 1.54^{d}	-0.334 ± 0.10^{a}
F5	1428.76 ± 198.13^{b}	9.31 ± 1.20^{c}	-0.260 ± 0.18^{b}
F6	868.10 ± 87.54^{a}	5.13 ± 0.59^{a}	-0.215 ± 0.04^{bc}

Notes: Different superscript letters in the same row indicate significantly different results at $p<0.05$.

Hardness is one of the parameters contained in texture profile analysis (TPA) by using force pressure on a product so that there is a change in the shape of the product. The results of the texture profile analysis (TPA) test of meat analog strips on the hardness parameter ranged from 868.10 to 287.52. Based on Table 7, it can be seen that the use of *Ulva ohnoi* seaweed and surimi can affect the level of hardness produced. The proportion of *Ulva ohnoi* seaweed and surimi added to meat analog strips in excess can affect the level of hardness [40]. Structural changes in protein networks and the effect of antioxidant compounds in *Ulva ohnoi* seaweed and surimi [41] can also affect the hardness of meat analog strips.

Cohesive power or referred to as cohesiveness aims to determine the change in the shape of a material before it is destroyed. According Tian [42], the cohesiveness value is related to the compactness of a product. The results of the texture profile analysis (TPA) test of *Ulva ohnoi* seaweed-based meat analog strips and surimi stated that the cohesiveness value ranged from 5.13-11.33. The highest cohesiveness was meat analog strip with 15% surimi addition (F5). The addition of surimi to meat analog strips on the cohesiveness parameter is significantly different. This can be caused by various factors such as processing methods, species and quality of raw materials used [43]. Chemical changes during processing and storage of the product may contribute to the resulting cohesiveness value. The interaction between additives and protein molecules can also affect the cohesiveness value of meat analog strips.

Adhesiveness is one of the important parameters in texture profile analysis (TPA) because it can measure the surface roughness of the food material to be adhered. Lower surface roughness can increase the adhesive bond strength if, higher adhesive bond strength, the adhesive value produced is more effective. The results of the texture profile analyss (TPA) test of meat analog strips on the adhesiveness parameter ranged from -0.192 to -0.334. Changes in product moisture content, temperature, pressure, and time can affect the resulting adhesiveness value. This is in accordance with the research [44] which states that excessive moisture can cause a decrease in adhesiveness due to disruption of the protein network.

4 Conclusion

The research findings indicate that the optimal meat analog strip formulation, as determined by the hedonic test, is F5, which incorporates 20% surimi and 5% *Ulva ohnoi* seaweed. This specific formulation was favored by consumers for its sensory properties, including taste, texture, and overall acceptability. The combination of surimi and seaweed not only enhances the product's nutritional profile but also aligns with current trends toward hybrid foods that merge animal and plant-based ingredients for improved sustainability and health benefits.

Nutritional analysis of the F5 formulation revealed a protein content of 13.86% and dietary fiber content of 10.23%, positioning it as a nutrient-dense food product. These values meet the criteria for high-protein and high-fiber foods as outlined by the Food and Drug Administration (FDA), making it a viable option for health-conscious consumers. The inclusion of *Ulva ohnoi* seaweed, known for its rich nutrient profile and bioactive compounds, further elevates the product as a functional food with potential health-promoting properties.

The authors extend their sincere gratitude to PT. Ijo Inovasi Indonesia for their generous financial support, which made this research possible. Special thanks are directed to Dr. Eng. Wahyu Ramadhan, S.Pi., M.Si., for his invaluable guidance and expertise throughout the project. His contributions have significantly enhanced the quality and depth of this research, and his continued encouragement has been instrumental in its successful completion.

We would also like to acknowledge the support of all team members and collaborators who provided their technical expertise and insight during the study. Their assistance, both in the lab and through thoughtful discussions, played a crucial role in refining the research process and achieving the desired outcomes.

References

1. JM Hess, JI Slavin. The benefits of defining "snacks". Phyiology and Behavior. 193, 284-287 (2018).
2. F Farida, AH, Santoso, N Rahman. Modification of snack bar cheubit with addition of seaweed (*Eucheuma cottonii*) an beet (*Beta vulgaris* L) as a snack alternative for elementary school children obesity. *Journal of Local Theraphy*. 1(1), 24-29 (2022).
3. W Ramadhan, S Purwaningsih, S Nafisah. Effects of microwave cooking on the physicochemical and sensory properties of seaweed-based analogue rice. *International Journal of Food Science and Technology*. 59(3), 1770-1780 (2024).
4. E Mindarwati E, BB Sedayu, TD Suryaningrum, I Mardiyana, N Prodiana, A Supriyanto, W Ramadhan. Sustainable hybrid snack product: impact of dual fortification with Gracillaria seaweed and pressure-cooked milkfish broth by-products on nutritive, physical, texture, and sensory properties. *International Journal of Food Science and Technology*. 59(9), 6111-6129 (2024).
5. FK Schreuders, M Schlangen, K Kyriakopoulou, RM Boom, AJ van der Goot. Texture methods for evaluating meat and meat analogue structures: *A review. Food control*. 127, 108103 (2021)
6. F Bouktd. Plant based meat analogues from niche to mainstream. *European Food Research and Technology*. 247(2), 297-308 (2020).
7. T Zhang, W Dou, Zhang X, Zhao, Yu, Y Zhang, IZ Jtang, X Sui. The development history and recent updates on soy protein-based meat alternatives. *Trends in Food Science and Technology*. 109, 702-710 (2021).
8. M Nurimala, W Ramadhan, AN Putri. Characteristics of tilapia fish scale gelatin and its application in surimi. In Bio Web of Conferences. 112, 09001 (2024).
9. W Ramadhan, J Santoso, W Trilaksani. Moisture sorption isotherm and shelf-life estimation of freeze-dried surimi powder. In Bio Web of Conferences. 112, 09003 (2024).
10. M Yingchutrakul, N Wasinnitiwong, S Benjakul, A Singh, Y Zheng, E Mubango, Y Luo, Y Tan, H Hong. Asian carp an alternative material for surimi production: progress and future. *Foods*. 11(9), 1318 (2022).
11. A Yousefi, M Moosavi-Nasab. Textural and chemical attributes of minced fish sausages produced from Talang Queenfish (*Scromberoides commersonnianuus*). *Iranian Journal of Fisheries Sciences*. 13(1), 228-241 (2014).
12. SK Saini, MS Dasgupta MS, KN Widell, S Bhattacharyya. Comparative analysis of a few novel multi-evaporator CO2NH3 cascade refrigeration system for seafood processing and storage. *International Journal of Refrigeration*. 131, 817-825 (2021).
13. RF Pari, Uju, AT Wijayanta, W Ramadhan, SD Hardiningtyas, KA Kurnia, M Goto. Prospecting *Ulva lactuca* seaweed in Java Island, Indonesia, as a candidate resource for industrial applications. *Fisheries Science*. 1-14 (2024)
14. AS Rybak. Spesies of Ulva (*Ulvophyceae, Chlorophyta*) as indicators of salinity. Ecological Indicators. 85, 253-261 (2018).
15. T Wichard, B Charrier, F Mineur, JH Bothwell, OD Clerck, JC Coates. The green seaweed *Ulva*: a model system to study morphogenesis. *Frontiers in Plant Science*. 6:72 (2015).
16. BK Tiwari, DJ Troy. Seaweed sustainability food and non-food applications. In Seaweed Sustainability. 1-6 (2015).
17. W Ramadhan, Z Khoirunnisa, K Tarman, V Oktaviarty. Meta-analysis on the effect of ingredients on chemical quality of nori-like product. *Coastal and Ocean Journal* (COJ). 6(2), 63-72 (2022).

18. EH Mohan, S Madhusudan, R Baskaran. The sea lettuce ulva sensu lato: Future food with health promoting bioactives. *Algal Research*. 103069 (2023).
19. W Ramadhan, FA Ramadhani, D Sevica, SD Hardiningtyas, D Desniar. Synthesis and characterization of Ulvan-Alginate hydrogel beads as a scaffold for probiotic immobilization. In Bio Web of Conferences. 92, 02020 (2024).
20. E Sinurat, A Supriyanto, TD Suryaningrum, D Fransiska, B Utomo, B Sediadi, AL Muzayyanah. Optimati formulai nori-like product dari *Ulva* spp., *Gracilaria* sp., dan gliserol menggunakan metode mixture design. *Indonesian Fisheries Processing Journal*. 26(3) (2023).
21. B Riyanto, UD Syafitri, J Santoso, EF Yasmin. Karakteristik daging tiruan (meat analogue) dengan optimasi formulasi substitusi rumput laut menggunakan mixture design. *Jurnal Pengolahan Hasil Perikanan Indonesia*. 25(2) (2022).
22. GB Mandegani, H Sumarto, A Perdana. Kertas seni berbehan limbah pewarna alam rumput laut jenis *Sargassum*, *Ulva* dan pelepah Pisang Abaka. *Dinamika Kerjainan dan Batik*. 33(1), 33-44 (2016).
23. H Dominguez, EP Loret. *Ulva lactuca*, a source of troubles and potential riches. *Marine drugs*. 17(6), 357 (2019).
24. E Sinurat, S Sihono, F Fateha, A Supriyanto, TD Suryaningrum, N Nurhayati, W Waryanto. Proximate composition sensory evaluation, physical properties, mineral content and amino acid profile of nori-like product from *Ulva lactuca* and *Glacilaria*. *Research Square*. (2023).
25. M Kazir, YD, Livney. Plant-based seafood analogs. *Molecules*. 26(6), 1559 (2021).
26. K Long, T Zhang, JW Park, J Park, T Yin. Effect of modified washing process on water usage, composition and gelling properties of grass carp surimi. *Journal of the Science of Food and Agriculture*. 102(15), 7136-7143 (2022).
27. X Zhang, Y Zhang, H Ding, W Zhang, Z Dai. Effect of washing times on the quality characteristics and protein oxidation of silver carp surimi. *Foods*. 11(16), 2397 (2022).
28. C Marques, E Correia, LT Dinis, A Vilela. An overview of sensory characterization techniques: From classical descriptive analysis to the emergence of novel profiling methods. *Foods*. 11(3), 255 (2022).
29. JJA Saclot, RT Jumdain, MLB Tom-Farquerabao, KO Ajik, MH Jumsali, AB Tahiluddin. Sensory characteristics and storage analysis of newly developed spider conch balls from the spider conch (*Lambis lambis*). *The Philippine Journal of Fisheries*. 31(1), (2024).
30. A Ganogpichayagrai, C Suksaard. Proximate composition, vitamin and mineral composition, antioxidant capacity, and anticancer activity of Acanthopanax trifoliatus. *Journal of Advanced Pharmaceutical Technology and Research*. 11(4), 179-183 (2020).
31. R Kulkarni. Ash contents of trace metals and concentration of oil in the fresh water fish, Notopterus. *Acta Scientific Veterinary Sciences*. 4(2), (2022).
32. US Ndidi, CU Ndidi, A Olagunju, A Muhammad, FG Billy, Okpe O. Proximate antinutrients and mineral composition of raw and processed (Boiled and Roasted) *Sphenostylis stenocarpa* seeds from Southern Kaduna, Northwest Nigeria. *ISRN Nutrition*. 280837, (2014).
33. SH Kabir, AK Das, MS Rahman, SK Singh, M Morshed, ASH Marma. Effect of genotype on proximate composition and biological yield of maize (*Zea mays* L). *Archieves of Agriculture and Environmental Science*. 4(2), 85-189 (2019).
34. AC Godswill. Proximate composition and functional properties of different grain flour composites for industrial applications. *International Journal of Food Sciences*. 2(1), 43–64 (2019).
35. R Penalver, JM Lorenzo, G Ros, R Amarowicz, M Pateiro, G Nieto. Seaweeds as a functional ingredient for a healthy diet. *Marine Drugs*. 18(6), 301 (2020).

36. T Yu-Qing, K Mahmood K, R Shehzadi, MF Ashraf. *Ulva lactuca* and its polysaccharides: *Food and biomedical aspects. Journal of Biology Agriculture and Healthcare*. 6(1),140-151 (2016).
37. AW Perdani, N Ratnanigsih, I Chayati, NN Utami. Nutritional, physicochemical and sensory evaluation of biscuits enriched with *Ulva* sp. from Gunungkidul coast. *Food Research.* 8(2), 22-29 (2024).
38. E Sinurat, D Fransiska, BSB Utomo, Subaryono, Nurhayati, Sihono. Characteristics of nori-like product prepared from seaweeds growing in Indonesia. *Journal of Aquatic Food Product Technology.* 31(6), 525-535 (2022).
39. PH Huang, CY Hou, CW Hsieh, KC Cheng, JY Ciou, YT Qiu, SH Hazeena. Investigation of the physicochemical properties of the thin slices of dried pork meat paper mixed with squid. *Journal of Food Science and Technology*. 60(5), 1590-1599 (2023).
40. AR Monto, M Li, X Wang, GYA Wijaya, T Shi, Z Xiong, R Gao. Recent developments in maintaining gel properties of surimi products under reduced salt conditions and use of additives. *Critical Reveiews in Food Science and Nutrition*. 62(30), 8518-8533 (2022).
41. AJ Rosenthal, P Thompson. What is cohesiveness? A linguistic exploration of the food texture testing literature. *Journal of Texture Studies*. 52(3), 294-302 (2021).
42. Z Tian, X Jiang, N Xiao, Q Zhang, W Shi, Q Guo. Assessing the gel quality and storage properties of *Hypophythalmamichthys molitrix* surimi gel prepared with epigallocatechin gallate subject to multiple freeze-thaw cycles. *Foods.* 11(11), 1612 (2022).
43. H Jannat-Alipour, M Rezaei, B Shabanpour, M Tabarsa, F Rafipour. Addition of seaweed powder and sulphated polysaccharide on shelf life extension of functional fish surimi restructured product. *Journal of Food Science and Technology*. 56, 3777-3789 (2019).