BIO Web of Conferences **221**, 02001 (2026) https://doi.org/10.1051/bioconf/202622102001
7th EMBRIO International Symposium (EIS 2025)

Enhancing marine-derived functional drinks with natural antioxidants: a sustainable approach using seaweed and indigenous botanicals

Cahyuning Isnaini[1], *Wini* Trilaksani[1*], *Bambang* Riyanto[1], and *Sendy* Rindi Budiarto[1]

[1] Department of Aquatic Product Technology, Faculty of Fisheries and Marine Science, IPB University, Bogor, 16680, Indonesia

Abstract. Seaweed is a marine biomass known for its dietary fiber, bioactive compounds, and hydrocolloids. Carrageenan extracted from seaweed is suitable for the health-promoting beverages. Jelly drinks, while popular in the market, especially among children, often contain high levels of sugar and low nutritional value. This study aimed to formulate antioxidant-enriched functional jelly drinks by incorporating *Kappaphycus alvarezii* with natural colorants from roselle, curcuma, and beetroot. Formulations using different seaweed porridge -to-water ratios (1:8, 1:9, 1:10 V/V) were evaluated through hedonic sensory testing. The 1:10 ratio was found to be the most preferred based on overall liking. The selected formula was enriched with indigenous botanical at concentrations of 5% and 10% (w/w), respectively. Among these, the 10% concentration of each is better than 5% concentration. At this level, the antioxidant activity by DPPH assay IC_{50} values of 1153.08 ppm (roselle), 537.40 ppm (curcuma), and 409.04 ppm (beetroot). Meanwhile, the dietary fiber content in the control and botanical-enriched samples ranged from 1.88 to 2.82% (w/w). The selected product (1:10 seaweed porridge:water with 10% coloran) contained 83.89% water, 0.20% ash, 0.17% protein, 0.39% fat, 1.93% dietary fiber, and 15.42% carbohydrate. The addition of indigenous botanicals not only enhanced antioxidant capacity but also improved consumer acceptability at certain level.

1 Introduction

The beverage industry in Indonesia has experienced substantial growth over the past two decades, driven by evolving consumer preferences and a dynamic product at the small and medium sized enterprise level to the large scales industries [1]. Alongside the increase in product diversity, there is a growing public awareness of the importance of healthy dietary choices. Modern consumers increasingly seek functional foods and beverages that not only offer sensory appeal but also provide health benefits, particularly those supporting digestive health and overall well-being [2]. This trend is reflected in the rising market share of products enriched with probiotics, dietary fiber, and natural bioactive compounds [3].

Seaweed is one of the most promising marine-based resources for functional food development. It is rich in protein, minerals, vitamins, carbohydrates, and dietary fiber, yet low in fat [4]. Moreover, many seaweed species, including *Kappaphycus alvarezii*, contain

* Corresponding author: wtrilaksani@apps.ipb.ac.id

bioactive compounds with antioxidant and antimicrobial properties [4]. Seaweed is also a source of carrageenan, a long-chain sulfated polysaccharide widely used in the food industry as a gelling agent, stabilizer, and thickener [5]. The unique functional and nutritional attributes of carrageenan make it highly suitable for incorporation into health-oriented beverages such as jelly drinks.

Jelly drinks are semi-solid beverages characterized by a soft gel consistency, offering both textural appeal and convenience. However, most commercially available jelly drinks are high in sugar and contain synthetic additives, including artificial colorants, which may have negative health implications [6]. In response to increasing demand for clean-label and nutrient-rich products, the use of natural pigments from plant sources has gained attention. Plant-derived pigments such as anthocyanins from roselle (*Hibiscus sabdariffa*), curcuminoids from curcuma (*Curcuma longa*), and betalains from beetroot (*Beta vulgaris*) not only impart vibrant colors but also contribute antioxidant activity, enhancing the functional value of the final product [7, 8, 9].

Integrating seaweed with natural plant-based pigments represents a sustainable and innovative approach to beverage diversification. Such products align with the principles of marine biodiversity utilization and the blue bioeconomy, offering a pathway toward functional beverages that promote human health while supporting the sustainable use of marine resources. This study was conducted to develop seaweed-based jelly drinks enriched with roselle, curcuma, and beetroot extracts, evaluate their physicochemical and sensory properties, and determine their antioxidant potential.

2 Materials and methods

2.1 Materials

The materials used in the formulation of the jelly drink included fresh seaweed (*Kappaphycus alvarezii*, 45 days of cultivation), dried curcuma (*Curcuma longa*, 10 months of cultivation), dried roselle (*Hibiscus sabdariffa*) calyces (2 months of cultivation), and fresh beetroot (*Beta vulgaris*, 3 months of cultivation). For the antioxidant activity assay, the reagents employed were methanol (Merck), 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical, butylated hydroxytoluene (BHT), and ascorbic acid, which served as a reference antioxidant.

2.2 Research stages

This study was conducted in three main stages: (1) determination of the jelly drink formula by comparing different ratios of seaweed to water, (2) extraction of liquid natural colorants and formulation of jelly drinks with their addition, and (3) evaluation of antioxidant activity and dietary fiber content.

2.1.1 Determination of jelly drink formula

Seaweed was soaked for 24 hours and washed. The cleaned seaweed was blended to reach a slurry texture and cooked at 100 °C with different ratios of slurry to water, namely 1:8, 1:9, and 1:10 (modified from Trilaksani *et al.* [10]). The resulting seaweed drink was filtered to remove the residue. The filtrate was added with 10% sugar and 0.1% citric acid w/w (modified from Trilaksani *et al.* [10]). The jelly drink was cooled down to room temperature and packaged in a plastic cup. The selected formulation was chosen based on the consumer preference using hedonic sensory test.

2.1.2 Natural colorant extraction

Roselle petals (*H. sabdariffa*), curcuma (*C. longa*), and beetroot (*B. vulgaris*) was extracted to be natural colorants (modified procedure by Andarwulan and Faradillah [11]). Roselle extract was produced by sun-dried the fresh petal and boiled in water. Curcuma extract was produced by sun-dried the peeled rhizomes and boiled in water. Beetroot extract was produced by boiled the peeled tuber. All of them are boiled at ratio 1:5 and 1:10 (w/v) for 15 minutes and filtered to obtain the liquid free from residues.

2.1.3 Formulation of jelly drink with natural colorants

The best jelly drink formulation obtained from the previous step was subsequently enriched with natural colorants at 5% and 10% (w/w) of the total ingredient weight. The mixture was homogenized using a wooden stirrer to ensure uniform distribution of the pigments. The jelly drink was then cooled to 27 °C and packed in plastic cups.

2.3 Analysis

2.3.1 Sensory analysis (SNI 01-2346-2006 [12])

A total of 30 semi-trained panelists participated in this evaluation, and the assessment included five parameters: appearance, color, aroma, texture, and taste. The hedonic test was designed to measure consumer preference levels toward a product using structured scoring sheets. The scale used in this study ranged from 1 to 9, where: (1) dislike extremely; (2) dislike very much; (3) dislike moderately; (4) dislike slightly; (5) neutral; (6) like slightly; (7) like moderately; (8) like very much; and (9) like extremely. Since sensory evaluation is inherently subjective and relies on human perception, statistical analysis was applied to validate the results. The data obtained were analyzed using the non-parametric Kruskal–Wallis test, and significant differences were further examined through Multiple Comparison tests.

2.3.1 Proximate analysis

Proximate analysis (moisture, ash, protein, fat, and carbohydrate *by difference*) was conducted according to AOAC [13] methods. Moisture content was determined by oven-drying 5 g of sample at 105 °C for 5–8 h until constant weight. Ash content was measured by incinerating 5 g of sample in a muffle furnace at 600 °C for 1 h. Protein content was determined by the Kjeldahl method. Two grams of sample were digested with H_2SO_4, K_2SO_4, HgO, and H_2O_2, then distilled and titrated using 0.1 N HCl. Fat content was measured by Soxhlet extraction using hexane as solvent at 80 °C for 6 h. The solvent was evaporated, and the residue was dried at 105 °C. Carbohydrate content was calculated by difference.

2.3.2 Antioxidant DPPH analysis

Antioxidant activity was assessed using the DPPH radical scavenging method Brand-Williams [14]. Jelly drink extracts were prepared at various concentrations (200, 400, 600, and 800 ppm), mixed with 0.1 mM DPPH, incubated for 30 min at room temperature, and measured at 517 nm. The IC_{50} value was determined from linear regression of % inhibition against sample concentration, with BHT and ascorbic acid as references.

2.3.3 Dietary fiber analysis

Dietary fiber content was determined using the AOAC enzymatic–gravimetric method [13]. Samples were sequentially digested with α-amylase, protease, and amyloglucosidase, followed by ethanol precipitation and filtration. Residues were dried, weighed, and expressed as total dietary fiber (TDF), calculated as the sum of insoluble (IDF) and soluble dietary fiber (SDF).

2.3.4 Data analysis

A Completely Randomized Design (CRD) was employed for this study to evaluate the effects of different treatments on the jelly drink formulations. Sensory hedonic data were statistically analyzed using the Kruskal–Wallis test, followed by multiple comparison analysis in SPSS to determine significant differences among treatments. Additional data analyses, including descriptive and comparative statistics, were conducted using Microsoft Excel to support the interpretation of results.

3 Result and discussion

3.1 Determination of jelly drink formula

Development of the jelly drink formula was conducted with varying water-to-seaweed ratios. The produced jelly drinks were subsequently assessed using hedonic sensory evaluation. Figure 1 shown the result of hedonic organoleptic test of Jelly Drink.

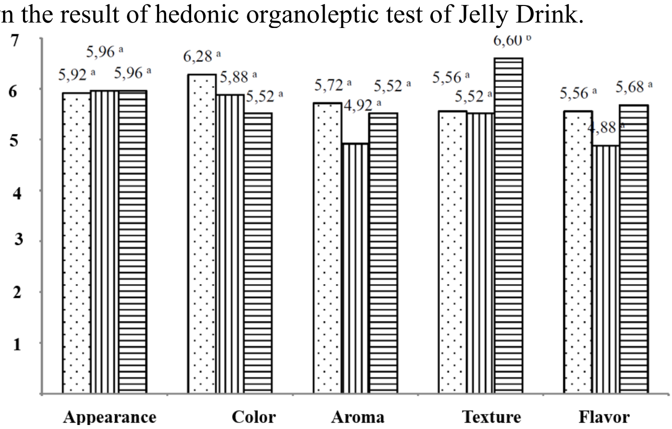

Fig. 1. Hedonic organoleptic result of Jelly Drink.

Note: ⊡ 1:8 seaweed:water ratio, ◫ 1:9 seaweed:water ratio, ⊟ 1:10 seaweed:water ratio

The appearance hedonic scores shown in the Figure 1 ranged from 5.92 to 5.96 or categorized as neutral but not significantly effect among the treatments as $p>0.05$. The overall appearance of the jelly drink formulations was characterized by the presence of finely ground seaweed granules and a slightly dark color and yellowish white color jelly which not significantly affected by the treatment. The use of fresh seaweed required soaking, which altered the original seaweed color, thereby influencing the brightness levels observed in the jelly drinks. The aroma likeness of jelly drinks with different seaweed-to-water ratios ranged from 4.92 to 5.72 (neutral). The aroma of the jelly drinks was primarily derived from seaweed, which was consistent across all formulations, as there were no differences in the amount of added ingredients. Importantly, the products did not exhibit a fishy odor, as increasing the seaweed proportion allowed the characteristic aroma to dissipate during the cooking process.Texture of jelly drinks ranged from 5.52 to 6.60 (slightly liked). The highest score was obtained at the 1:10 ratio, while the lowest was at the 1:9 ratio. Results from the Kruskal–Wallis test showed significant differences ($p < 0.05$) in texture preference among treatments. Further analysis using Multiple Comparison revealed that the 1:10 ratio (seaweed:water) was significantly different from the other treatments The desirable texture for jelly drinks is one that can be easily consumed through suction. Increasing the proportion of seaweed produced a softer, more fragile gel structure, which facilitated consumption. This is due to the presence of hydrocolloids, particularly carrageenan, in seaweed [15]. A higher concentration of hydrocolloids increases the ratio of solids to liquids, resulting in a stronger and stiffer gel. Furthermore, the carrageenan content of red seaweed plays a crucial role in gel formation, as it is an extracted hydrocolloid from Rhodophyta, which also contains floridean starch. This structural property contributes to the desired consistency in jelly drink formulations. Taste scores of jelly drinks with different seaweed-to-water ratios ranged from 4.88 to 5.68 (neutral). The highest preference score was observed at the 1:10 ratio, while the lowest was recorded at the 1:9 ratio. The Kruskal–Wallis test indicated that differences in seaweed-to-water ratios did not significantly affect ($p > 0.05$) the taste preference of the jelly drinks as found in Hu [15], the more concentrated seaweed to water ratio, the likeness preference is lower.

The similarity in taste among treatments was due to the standardized use of sugar and citric acid across all formulations, which provided consistent sweetness and sourness. Based on sensory evaluation, the 1:10 ratio (seaweed:water) was identified as the most preferred formulation by panelists. This optimized formula was then used in subsequent experiments to evaluate the effect of incorporating natural colorants into jelly drinks.

3.2 Sensory evaluation of jelly drinks with the addition of natural colorants

The selected jelly drink formulation (1:10 seaweed:water ratio) obtained from the previous step was subsequently enriched with natural colorants at 5% (w/w) and 10% (w/w) of the total ingredient weight and homogenized. The jelly drink was then cooled to room temperature and packaged in plastic cups. Sensory evaluation was conducted to assess the sensory attributes of the product. The parameters observed included appearance, color, aroma, texture, and taste.

3.2.1 Jelly drinks with roselle colorants

The results of sensory evaluation of jelly drinks enriched with roselle extract showed mean scores ranging from 4.60 to 6.92 (slightly liked) across the five parameters tested. Overall, the product formulated with 10% roselle extract received the highest scores for most parameters. Based on the results of the Kruskal–Wallis test, differences in the proportion of roselle extract significantly affected the appearance and color parameters ($p < 0.05$). The jelly drink with 10% roselle extract exhibited significantly higher scores for appearance and color preference compared to the 5% formulation. Further pairwise comparisons were conducted using multiple comparison procedures in SPSS confirmed that the 10% roselle formulation was significantly different from the other treatments in both appearance and color parameters. Hedonic test results are shown in the Figure 2.

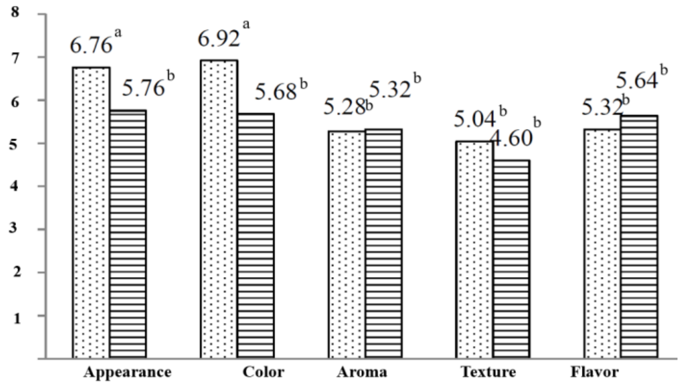

Fig. 2. Hedonic of jelly drinks with roselle colorants.

Note: ◻ 10% of roselle colorants, ⊟ 5% of roselle colorants

For roselle-enriched jelly drinks according to the Figure 2, the formulation with 10% extract achieved the highest scores for appearance, color, and texture, whereas the 5% formulation was preferred in terms of aroma and taste. The jelly drink had a sour taste with a distinctive roselle aroma [7]. Roselle petals are characterized by their high content of organic acids, including oxalic, tartaric, malic, and succinic acids [7].

The ratio of roselle to water during extraction influenced the color and appearance of the product, both of which were significantly affected. The total anthocyanin content in roselle extract decreased as the water-to-flower ratio increased, as larger water fractions dilute the concentration of anthocyanins. The red coloration of roselle is primarily derived from anthocyanin pigments, the stability or degradation of this red pigment is influenced by factors such as pH, light, temperature, and oxygen exposure [7].

3.2.2 Jelly drinks with curcuma colorants

The results of the sensory evaluation of jelly drinks enriched with curcuma extract showed in Figure 3 have mean scores ranging from 4.12 to 6.48 (slightly liked). Differences in the proportion of curcuma extract had a significant effect ($p < 0.05$) on the texture parameter, with the 10% formulation being preferred by panelists over the 5% formulation. Further analysis with the T-test confirmed that the 10% formulation was significantly different from other treatments for texture

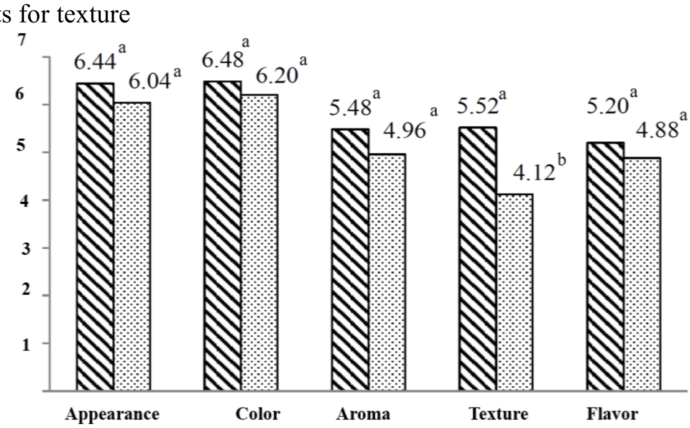

Fig. 3. Hedonic of jelly drinks with curcuma colorants.

Note: ◪ 10% of curcuma colorants, ⚀ 5% of curcuma colorants

For curcuma-enriched jelly drinks, the 10% (curcuma-to-water) formulation obtained the highest scores across all sensory parameters. This is attributed to the higher concentration of natural curcumin pigments in this treatment. Increased curcumin content in food products influences appearance, color, aroma, texture, and taste. The jelly drink with a 10% curcuma extract demonstrated a deeper yellow color compared to the 5% formulation, consistent with the higher curcumin concentration. Curcumin exhibits a bright yellow hue under acidic conditions and shifts toward a yellow-brown coloration under neutral or alkaline conditions [11]. Moreover, this formulation was estimated to have a lower pH, which affected both the texture and taste of the product. A lower pH in jelly drinks weakens gel strength, resulting in a texture that is easier to sip.

3.2.3 Jelly drinks with beetroot colorants

The beetroot-enriched jelly drinks sensory evaluation results showed mean scores ranging from 4.52 to 6.64 (slightly liked). Differences in the proportion of beetroot extract had a significant effect ($p < 0.05$) on the color parameter, with the 10% formulation being preferred by panelists compared to the 5% formulation. T-test results further confirmed that the 10% beetroot formulation was significantly different from other treatments in terms of color. The hedonic result of jelly drinks with beetroot colorants is shown in Figure 4.

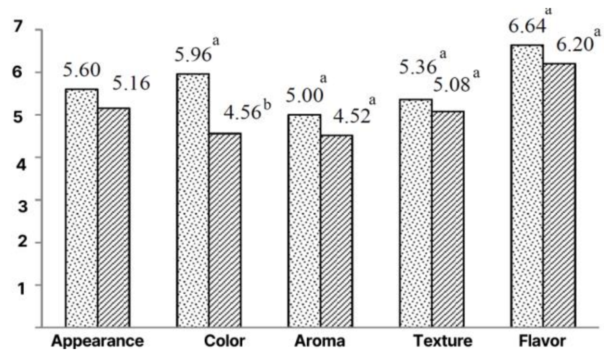

Fig. 4. Hedonic of jelly drinks with beetroot colorants

Note: ⚀ 10% of beetroot colorants, ▨ 5% of beetroot colorants

The seaweed jelly drink with 10% beetroot extract was the most preferred by panelists, which can be attributed to the higher concentration of betalain pigments in this formulation. According to Trishitman [9], the stability of betalains is influenced by both internal factors—such as pigment concentration, pH, and moisture—and external factors including temperature, light, and oxygen, all of which play an important role in optimizing pigment stability and maintaining color quality in food products.

The purple color observed in beetroot-enriched jelly drinks originates from betalain pigments, which are water-soluble and therefore readily extracted. Beetroot is recognized as a natural source of red-purple coloration derived from betalains, a combination of betacyanin (purple pigment) and betaxanthin (yellow pigment). Betacyanins share similar characteristics with anthocyanins as natural food colorants, with their stability being highly affected by temperature. In addition to its vibrant color, beetroot imparts a distinctive flavor attributed to the presence of the chemical compound geosmin [9].

Fruits and vegetables, including beetroot, are valuable sources of natural colorants. However, natural pigments also present some limitations, particularly their relatively high production costs and low stability compared to synthetic colorants. The acceptance score of jelly drinks with natural colorants increased because the flavor and aroma of the spices were able to mask the fishy odor of seaweed [15].

3.3 Chemical characteristic of natural colorants jelly drink

The chemical characteristics analyzed in this study included antioxidant activity, moisture, protein, ash, fat, carbohydrate, and dietary fiber contents of the seaweed-based jelly drink.The antioxidant activity of natural colorants jelly drink is shown in Table 1.

Table 1. Antioxidant activity of natural colorants jelly drink.

Samples	**% Inhibition**				**IC_{50} (ppm)**
	2 ppm	**4 ppm**	**6 ppm**	**8 ppm**	
BHT	28.35	31.37	33.42	36.52	18.24
	200 ppm	**400 ppm**	**600 ppm**	**800 ppm**	
Ascobic Acid	25.27	50.95	86.84	94.37	380.69
Roselle 10%	26.68	30.65	34.82	41.70	1,153.08
Roselle 5%	25.04	27.26	32.27	36.25	1,550.37
Curcuma 10%	24.15	25.90	27.51	32.00	537.40
Curcuma 5%	30.46	32.59	34.58	36.52	2,223.54
Beetroot 10%	37.27	42.91	49.15	59.07	409.04
Beetroot 5%	37.43	47.31	53.77	62.26	605.94

3.3.1 Antioxidant activity

Antioxidant activity was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, a widely adopted method for evaluating free radical inhibition. The key parameter used in this method is the IC_{50} value, which represents the concentration of sample required to inhibit 50% of the DPPH radicals [14].

As presented in Table 1, the IC_{50} value for jelly drinks enriched with 10% roselle extract was 1153.08 ppm, indicating the concentration required to achieve 50% free radical inhibition. By comparison, the 5% extract formulation showed a weaker activity with an IC_{50} of 1550.37 ppm. These values were significantly higher (indicating weaker antioxidant activity) compared to reference standards, namely ascorbic acid (380.69 ppm) and BHT (18.24 ppm). The higher activity observed in the 10% formulation is attributable to greater anthocyanin content, whereas reduced extract concentration at 5% resulted in lower pigment availability and weaker antioxidant capacity. reported that anthocyanin levels decline with increased dilution ratios during extraction. Anthocyanins in roselle not only function as antioxidants but also have additional benefits, including antihypertensive and gastrointestinal protective properties. However, the relatively weak antioxidant performance in jelly drinks compared to pure extracts is likely due to thermal degradation of anthocyanins during heating. According to Lai et al [7] anthocyanins are sensitive to pH and high temperatures, being more stable under acidic and low-temperature conditions.The IC_{50} value of jelly drinks supplemented with 10% curcuma extract was 537.40 ppm, markedly stronger than the 5%

formulation (2223.54 ppm). This demonstrates that higher concentrations of curcumin significantly enhanced antioxidant activity. Despite this improvement, the values remained higher (less active) compared to ascorbic acid and BHT standards. Curcumin, the primary pigment in curcuma, not only imparts a yellow coloration but is also recognized for its antioxidative and anticancer properties [8]. The superior performance of the 10% treatment is consistent with higher curcumin availability, which correlates with enhanced radical scavenging ability. Previous studies have also confirmed that curcumin functions effectively as a free radical scavenger and lipid peroxidation inhibitor. Nonetheless, both treatments were categorized as having weak antioxidant activity when evaluated against the classification proposed by Blois, which defines strong antioxidants as those with IC_{50} values below 100 ppm. The reduced activity is most likely attributed to curcumin degradation under heat and alkaline pH during processing [8].

According to Table 1, the IC_{50} value of jelly drinks formulated with 10% beetroot extract was 605.94 ppm, whereas the 5% formulation exhibited an IC_{50} of 409.04 ppm. This indicates that the 10% beetroot extract was more effective in achieving 50% DPPH radical scavenging compared to the 5% treatment. As explained by Brand-Williams et al. [14], lower IC_{50} values correspond to higher antioxidant activity.

The stronger antioxidant performance of the 10% beetroot formulation is attributed to the higher betalain content present in the extract. A greater proportion of water during extraction reduces pigment concentration, leading to diminished bioactivity. Betalains, the principal pigments in beetroot, are water-soluble nitrogen-containing compounds, consisting of two groups: betacyanins (red-violet pigments) and betaxanthins (yellow pigments). These pigments not only provide vibrant coloration but also possess biological activities including antioxidant, anti-inflammatory, hepatoprotective, and antitumor properties [5].

The antioxidant reference standards, ascorbic acid (380.69 ppm) and BHT (18.24 ppm), demonstrated substantially stronger activity than both beetroot formulations. Thus, although the beetroot-based jelly drinks showed functional antioxidant potential, their activity was relatively weak compared to pure antioxidant compounds. Nonetheless, the incorporation of beetroot extract provided dual benefits by enhancing product color and contributing bioactive compounds with health-promoting properties.

3.3.2 Proximate and dietary fiber of natural colorant jelly drink

The seaweed-based jelly drink formulations selected from sensory evaluation and antioxidant activity tests were further analyzed for proximate composition and dietary fiber content. The results are presented in Table 2.

Table 2. Proximate and dietary fiber of natural colorants jelly drink.

Parameter	**Roselle**	**Curcuma**	**Beetroot**
Water (%)	83.3	83.49	83.89
Ash (%)	0.20	0.20	0.20
Protein (%)	0.88	1.51	0.17
Fat (%)0.2	0.20	0.20	0.39
Carbohydrate (%)	15.42	14.59	15.34
Dietary fiber (%)	1.93	1.88	1.93

The proximate analysis indicated that the jelly drinks contained relatively high levels of carbohydrates, second only to moisture content, across all treatments with natural pigments. This composition was primarily derived from the seaweed (*Kappaphycus alvarezii*) used as the main raw material.

The dietary fiber content of the jelly drinks was relatively similar among the three types of natural pigments (roselle, curcuma, and beet). This is expected, as the fiber component mainly originated from seaweed. Kumar [4] reported that carrageenan extracted from *Eucheuma cottonii* contained dietary fiber levels of approximately 25.05%. Seaweed-derived fiber is considered superior to that from fruits and vegetables, as it contains acidic groups such as sulfate groups, which provide distinct physicochemical and physiological effects, including high water- and oil-binding capacity, swelling ability, and the ability to bind vitamins and minerals.

According to the Indonesian National Food and Nutrition Workshop (WNPG, 2004), the recommended daily intake of dietary fiber is 25 g/day. The seaweed jelly drinks supplemented with roselle, curcuma, and beet extracts contributed 15.44%, 15.04%, and 15.44%, respectively, of the daily fiber requirement per 200 g serving. Therefore, these jelly drinks can serve as a practical alternative to help fulfill daily dietary fiber intake. Moreover, dietary fiber functions as a nutrient source for beneficial gut microbiota, thereby supporting digestive health.

4 Conclusion

Seaweed-based jelly drinks enriched with natural pigments from roselle, curcuma, and beetroot at 10% concentration were more preferred by panelists compared to those with 5%, and antioxidant analysis confirmed that the 10% formulations exhibited lower IC_{50} values, indicating higher antioxidant capacity. Furthermore, the dietary fiber analysis showed that the enriched drinks contributed 15.44% (roselle), 15.04% (curcuma), and 15.44% (beetroot) of the recommended daily fiber intake per 200 g serving size, demonstrating their potential as functional beverages to support digestive health. To advance this innovation, further studies are recommended, particularly on shelf-life stability and packaging performance, as well as comparative evaluations between natural and synthetic colorants in terms of sensory quality and antioxidant activity, to better highlight the health-promoting and sustainable advantages of marine-based functional drinks.

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