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RESEARCH PAPER

Formulation and evaluation of plant-based burger patty incorporated with *Gracilaria changii*

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Abstract

The rising demand for sustainable and healthier meat alternatives has driven interest in plant-based formulations enhanced with functional ingredients. This study developed a plant-based burger patty incorporating *Gracilaria changii* to enhance its nutritional and functional properties. Three formulations (0%, 5%, and 10% seaweed) were evaluated for proximate composition, total phenolic content (TPC), energy value, and sensory attributes. Moisture was measured using a moisture analyser, ash was determined by the dry ashing method, protein was measured using the Kjeldahl method, fat was extracted using the Soxhlet extraction method, fibre was determined by a chemical method, and carbohydrates were calculated. TPC was determined using the Folin-Ciocalteu assay, pH as measured with a pH meter, and energy was calculated using Atwater factors. The sensory evaluation used a 5-point hedonic scale. The results showed that the 10% seaweed formulation (F2) had the highest protein (14.16%), fibre (7.8%), and ash (17.04%), with lower fat (6.4%) and energy (143.17 kcal/100g), while demonstrating increased TPC, which may indicate potential antioxidant activity, and comparable sensory acceptability to commercial patty. The results suggest *Gracilaria changii* is a viable addition to sustainable and healthier meat substitutes.

1. Introduction

The increasing global demand for healthier, sustainable, and ethical food products has fuelled the rapid growth of the plant-based food industry. These alternatives offer environmental and health benefits, appealing to consumers concerned about reducing their carbon footprint and improving dietary habits (Tyndall *et al*., 2024). Among plant-based food products, burger patties have emerged as a versatile and a convenient option for consumers seeking to replace traditional meat with nutrient-dense alternatives (Tyndall *et al*., 2024). However, commercial plant-based patties often face challenges such as insufficient protein content, excessive use of sodium and artificial additives, and suboptimal sensory qualities that may not meet consumer expectations (Das *et al*., 2021).

To address these limitations, this research explored novel ingredients that can enhance nutritional and functional attributes of plant-based patties. Seaweed, particularly red seaweed species, such as *Gracilaria changii*, has garnered significant attention due to its bioactive compounds, dietary fibre content, and antioxidant properties (Rogel-Castillo *et al*., 2023). These attributes make seaweed an excellent candidate for improving the nutritional profile of plant-based burger patties while maintaining desirable sensory characteristics. Furthermore, incorporating seaweed aligns with the industry's efforts to create sustainable and innovative products that cater to health- conscious consumers. Therefore, this study focuses on the development of the plant-based burger patty fortified with nutraceuticals to enhance its nutritional profile to create nutritionally rich, high protein content, bioactive compounds, and nutraceutical properties to promote health and meet the growing demand for alternative protein sources (Rogel-Castillo *et al*., 2023; Espinosa-Ramírez *et al*., 2023).

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Table 1. Formulation of the plant-based burger patty.

Formulation	Control (%)	F1(%)	F2 (%)
Red seaweed	0	5	10
Red bean	30	30	30
Soy chunks	30	30	30
Quinoa	13	13	13
Canola oil	6	6	6
Nutritional yeast	5	5	5
Sugar	3	3	3
Lemon powder	2.5	2.5	2.5
Black pepper	2	2	2
Smoked paprika	2	2	2
Soy sauce	2	2	2
Vinegar	2	2	2
Methylcellulose	2	2	2
Beetroot powder	0.5	0.5	0.5
Coating	-	-	-

2. Materials and methods

2.1 Formulation of plant-based burger patty incorporated with red seaweed

As depicted in Table 1, three formulations were prepared with varying levels of seaweed (0%, 5%, and 10%) to evaluate the effect of increasing seaweed incorporation on the product's properties (Sivaraman *et al*., 2023). Ingredients included quinoa, soy chunks, red beans, spices, lemon juice, canola oil, and ethylcellulose (Vila-Clarà *et al*., 2024). The control patty contained no seaweed.

2.2 Selection and preparation of red seaweed (Gracilaria changii)

The dry samples of the red seaweed *Gracilaria changii* were collected from Muar, Johor, Malaysia, an area known for its abundant and high-quality seaweed. Fresh red seaweed, authenticated with a voucher specimen (FSMP 01), was cleaned to remove impurities and soaked to rehydrate before being incorporated into the patties (Chan and Matanjun, 2017).

2.3 Preparation of ingredients and molding the burger patty

All ingredients were prepared by cleaning and chopping as referred to in Table 1. The rehydrated seaweed, quinoa, soy chunks, and red beans were blended into a homogeneous mixture using a high-speed mixer. The mixture was then molded into each weighing 100 g, using a patty mold.

2.4 Freezing

The molded patties were arranged on a tray and frozen at -18°C overnight. This process ensures the structural integrity of the patties during cooking and improves shelf life.

2.5 Frying

The frozen patties were pan-fried in a preheated non-stick pan at 180–200°C. A small amount of canola oil was used to ensure even cooking and prevent sticking. Each patty was cooked for 3–5 minutes on each side or until golden brown. The frying process ensured a crispy exterior while retaining the patty's moisture and flavour integrity (Rajaretnam and Malik, 2023).

2.6 Proximate analysis of plant-based burger patty incorporated with red seaweed

The proximate composition of the patties, including moisture, ash, protein, fat, fibre, and carbohydrate levels, was determined using standard methods of the Association of Official Analytical Chemists (AOAC) (Azlan *et al*., 2021). Moisture content was determined using a Moisture Analyser (MX-50, Japan), and ash was obtained through incineration at 550°C (Chan and Matanjun, 2017; Vila-Clarà *et al*., 2024). The protein content was determined using the Kjeldahl method, with a conversion factor of 6.25 (Chan and Matanjun, 2017; Rajaretnam and Malik, 2023). The Soxhlet method was used to extract crude fat, while acid and alkaline digestion were used to determine fibre (Shahzadi *et al*., 2021; Rajaretnam and Malik, 2023). The calculations for proximate analysis were performed using the method described by Gul and Safdar (2009). The Malaysian Food Composition Database was used to calculate carbohydrate content by subtracting 100 from the sum of moisture, ash, protein, fat, and fibre (National Technical Working Group of Malaysian Food Composition Database, 2011).

2.7 Determination of pH value

The pH of the patties was determined by homogenising the sample in distilled water and recording the results with a digital pH meter (Hanna Instruments, USA) (Rajaretnam and Malik, 2023).

2.8 Determination of total phenolic content

Total phenolic content (TPC) was determined using the Folin-Ciocalteu method (microplate format) and expressed as mg GAE/g sample based on a gallic acid standard curve (Fernandes *et al*., 2023)

2.9 Energy content

Energy content was calculated using Atwater factors (Protein × 4 + Carbohydrate × 4 + Fat × 9).

2.10 Sensory evaluation of plant- based burger patty

A nine-point hedonic test was administered to 30 panellists to assess appearance, taste, texture, aroma, flavour, and overall acceptability (Rajaretnam and Malik, 2023).

2.11 Statistical analysis

The data were analysed with International Business Machines (IBM) Statistical Package for the Social Sciences (SPSS) version 24.0. Two-way Analysis of Variance (ANOVA) and Tukey's b-test were used, with

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Table 2. Proximate analysis based on formulations.

Formulation	Control (CBP)	Control without seaweed	Formulation 1 (5%)	Formulation 2 (10%)	*Seaweed*[a]	Soy chunks[b]
Moisture	57.27 ± 0.9[b]	54.37 ± 0.5[a]	55.40 ± 0.7[a]	55.19 ± 0.1[a]	32.45 ± 0.013	32.9
Ash	13.71 ± 0.9[a]	15.79 ± 0.7[b]	15.90 ± 0.6[b]	17.04 ± 0.1[b]	30.50 ± 0.14	3.0
Protein	14.16 ± 0.05[b]	13.83 ± 0.05[a]	13.76 ± 0.05[a]	14.13 ± 0.05[b]	11.99 ± 0.17	20.4
Fat	5.81 ± 0.0[d]	5.60 ± 0.0[c]	4.74 ± 0.0[a]	4.91 ± 0.0[b]	10.86 ± 0.04	9.60
Fibre	2.32 ± 0.0[c]	2.12 ± 0.0[a]	2.12 ± 0.0[a]	2.22 ± 0.0[b]	8.94 ± 0.03	-
Carbohydrate	6.71 ± 0.6[a]	8.28 ± 0.3[b]	7.46 ± 0.4[ab]	6.39 ± 0.3[a]	30.50 ± 0.14	-

Note: [a] from Danthanarayana and Yasas, 2024; [b] from Varada *et al*., 2023

significance set at $p < 0.05$. The results are presented as mean ± SD (n = 3)(Azlan *et al.*, 2021; Botella-Martinez *et al*., 2022).

Table 3. pH value based on formulations.

Formulation	pH value
Control (CBP)	5.8 ± 0.02[a]
Control without seaweed	6.3 ± 0.0[c]
Formulation 1 (5%)	6.0 ± 0.02[b]
Formulation 2 (10%)	5.9 ± 0.02[b]

Values are means of triplicates; [abcd] means in same row with different superscripts are significantly different (p<0.05)

3. Results and discussion

3.1 Moisture content

As presented in Table 2, the moisture content of plant-based burger patties varies significantly among formulations, with the commercial patty exhibiting the highest moisture level at 57.29 ± 0.9%, likely due to its proprietary blend of water-retaining ingredients (Vila-Clarà *et al*., 2024). In contrast, formulations incorporating seaweed, specifically *Gracilaria changii*, resulted in moderate moisture levels of 55.40 ± 0.7% and 55.19 ± 0.1%, as the seaweed's low intrinsic water content limits its moisture-enhancing capabilities (Sinurat *et al*., 2024). Other studies have reported that the moisture content of raw plant-based patties can range from 50.5% to 77.9%, indicating that many formulations exceed the moisture levels observed in this study (Baba and Basri 2024). Excess moisture negatively impacts texture, cooking properties, and shelf life, leading to a less desirable product (Herawati and Kamsiati, 2021). Overall, while seaweed may not significantly increase moisture levels, it serves as a natural acidifier and can enhance shelf life, contributing to flavour balance in plant-based burger patties.

3.2 Ash content

In this study, the ash content of burger patties incorporating *Gracilaria changii* was at 17.04±0.1% for Formulation 2 and 15.90 ± 0.6% for Formulation 1, indicating the presence of mineral content from accumulated inorganic materials, as depicted in Table 3. In comparison, the Commercial Plant-Based Burger Patty (CBP) exhibited an ash content of 13.71 ± 0.9%, indicating the presence of mineral content, albeit at a lower level than the formulations enriched with *Gracilaria changii*. The ash content obtained in this research exceeded the value reported for a seaweed-based vegan burger patty formulated with *Ulva fasciata* (11.59±0.06), demonstrating the potential of seaweed to enrich the nutritional profile of such products (Danthanarayana and Yasas, 2024). Overall, the total ash content was determined as an indicator of mineral presence. However, the specific mineral composition was not analyzed in this study.

3.3 pH value

As presented in Table 3, the control formulation without seaweed exhibited the highest pH of 6.3 ± 0.0. However, the incorporation of *Gracilaria changii* in formulations 1 and 2 resulted in significantly lower pH values of 6.0 ± 0.02 and 5.9 ± 0.02, respectively ($p < 0.05$). This decrease can be attributed to the acidic amino acid side chains and organic acids naturally identified in red seaweed, which typically have a slightly acidic to neutral pH range of 6.2-7.0 depending on its maturation stage (Suhaimai *et al*., 2025). Since the control sample containing soy chunks and red beans but no seaweed had a higher pH, the observed reduction in formulations 1 and 2 can reasonably be attributed to the inclusion of *Gracilaria changii* rather than other ingredients. Red beans have a near-neutral to slightly acidic pH of around 6.0, which does not result in strong acidity unless they are fermented or further processed (Kusumah *et al*., 2020). Similarly, soy protein products in food formulations typically have a pH close to neutral (Nestlé Professional, 2024). As a result, the presence of *Gracilaria changii* may account for the decrease in pH of seaweed-incorporated formulations. Lower pH levels can complicate preservation efforts, making it more challenging to store these patties for extended periods (Fernandes *et al*., 2023). Thereby justifying the need for thermal processing and refrigerated storage before consumption (Bakhsh *et al*., 2021). The CBP's acidity is primarily due to vinegar, which contains acetic acid and contributes to its lower pH (Kusumah *et al*., 2020). Overall, the incorporation of *Gracilaria changii* affects the acidity of plant-based burger patties, which has implications for their preservation and consumer safety.

3.4 Protein content

As indicated in Table 2, the protein content of the different formulations of plant-based burger patties demonstrates that the CBP contains 14.16 ± 0.05%, while the control without seaweed contains 13.83 ±

0.05%. Formulation 1 has a protein content of 13.76 ± 0.05%, and Formulation 2, which incorporates 10% seaweed has a slightly higher protein content of 14.13 ± 0.05%. Although the analysis indicated a significant difference in protein content among the formulations ($p < 0.05$), no significant difference was observed between the control without seaweed (13.83%) and Formulation 1, (13.76%). This suggests that the incorporation of 5% seaweed did not substantially affect the protein content, as the contribution of seaweed protein at this level was minimal or possibly diluted by other ingredients. Formulation 2, containing 10% seaweed, had a higher protein content, demonstrating the effect of increased seaweed incorporation. The (CBP) also had a high protein content due to its different formulation. According to Nestlé Professional (2024), the CBP contains 19% soy protein, which explains why the protein content of Formulation 2 was lower, despite the percentage of seaweed addition being lower and nearly reaching the CBP. It was explained that the protein content in seaweed ranges from 10% to 47% (Chan and Matanjun, 2017). In comparison, other research reported a lower protein content of plant-based burger patties at 8.01 ± 0.14% (Fernandes *et al*., 2023). Thus, the incorporation of 10% *Gracilaria changii* improved the protein profile of plant-based burger patties, suggesting its potential as an alternative protein source for vegetarians and others seeking nutritious options. This effect, however, was not observed in Formulation 1.

3.5 Carbohydrate content

The carbohydrate content of various burger patty formulations demonstrates significant differences, particularly highlighting the impact of incorporating *G. changii*, as presented shown in Table 6. The CBP contains 6.71 ± 0.6 g of carbohydrates, which is lower than the control formulation without seaweed, which contains 8.28 ± 0.3 g. When is incorporated at low percentages (5% and 10%), its contribution to the overall carbohydrate *Gracilaria changii* content may not be substantial enough to alter total carbohydrate levels significantly. This research supports the notion that low-carb diets can aid in weight loss and management (Leandro *et al*., 2020). Reducing carbohydrate intake may help decrease overall calorie consumption and promote fat loss (Leandro *et al*., 2020). Other studies suggested that diets with higher protein content and lower carbohydrate intake can improve body composition and metabolic health (Mueller *et al*., 2020). Thus, incorporating high-protein ingredients alongside seaweed can effectively lower the overall carbohydrate contribution of a food product while still providing essential nutrients (Mueller *et al*., 2020). Overall, the addition of *Gracilaria changii* affects carbohydrate levels aligning with dietary trends that favour lower carbohydrate intake while enhancing nutritional value (Suhaimai *et al*., 2025).

3.6 Fat content

The results in Table 2 indicate that the fat content of each formulation differs significantly $p < 0.05$, confirming that the addition of varying percentages of seaweed *Gracilaria changii* impacts the fat levels in the patties. The CBP (5.81 ± 0.0%) demonstrated the highest fat content, which was significantly higher ($p < 0.05$) than the control without seaweed (5.60 ± 0.0%) and the formulations with seaweed (4.74 ± 0.0% and 4.91 ± 0.0%, respectively). Formulation 1 and Formulation 2 have lower fat contents at 4.74% and 4.91%, respectively. The lower fat content in patties with seaweed is due to seaweed's low lipid content, which ranges from 0.5% to 4.5% of dry weight (Leandro *et al*., 2020). This reduction in fat, along with a favourable fatty acid profile, can contribute to improved heart health by replacing saturated fats with unsaturated fats from source such as seaweed, potentially lowering Low-Density Lipoprotein (LDL) cholesterol levels and reducing the risk of heart disease (Chan and Matanjun, 2017). Other studies reported a fat content of 5.15 ± 0.01%, which exceeds that of Formulations 1 and 2 (National Technical Working Group of Malaysian Food Composition Database, 2011). The other researchers found fat levels ranging from 9.62 to 10.03 g, which are higher than those in formulations incorporating seaweed (Kowalczewski *et al*., 2024). In summary, incorporating *Gracilaria changii* into plant-based burger patties reduces fat content. It may improve their overall nutritional profile, thus supporting their potential as functional foods with heart health benefits (Suhaimai *et al*., 2025).

3.7 Crude fibre content

The fibre contentas demonstrated in Table 2, significantly differs among the control, and the two formulations with seaweed (*Gracilaria. changii*). The commercial patties have slightly higher fibre content than Formulation 2, despite *Gracilaria changii* being a good fibre source (Chan and Matanjun 2017). The soy protein in the commercial patty contributes more fibre due to its higher percentage compared to seaweed (Nestlé Professional, 2024). The lower proportion of *Gracilaria changii* relative to other ingredients can dilute overall fibre content, and some soluble fibres may be lost during processing (Chan and Matanjun 2017). In summary, while *Gracilaria changii* has the potential to enhance fibre levels in plant- based burger patties, its effectiveness is limited by its proportion and processing effects (Chan and Matanjun 2017).

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Table 4. Total phenolic content based on formulation.

Formulation	Total phenolic content
Control (CBP)	10.16 ± 3.65[a]
Control without seaweed	34.05 ± 6.76[b]
Formulation 1 (5%)	36.28 ± 3.60[b]
Formulation 2 (10%)	43.74 ± 2.71[b]

Values are means of triplicates; [abcd] means in same row with different superscripts are significantly different ($p<0.05$)

3.8 Total phenolic content

As shown in Table 4, the total phenolic content (TPC) indicates significant differences at $p < 0.05$ between the commercial plant-based burger patty, the control without seaweed, and the two formulations incorporating *Gracilaria changii*. The commercial patty has the lowest TPC at 10.16 ± 3.65, indicating fewer phenolic compounds compared to the other formulations. In contrast, the control without seaweed has the highest TPC at 34.05 ± 6.76, likely due to the presence of other plant-based ingredients rich in phenolic compounds, such as red beans and quinoa (Wang *et al*., 2025). Formulations with *Gracilaria changii* demonstrate even higher TPC values of 36.28 ± 3.60 for Formulation 1 and 43.74 ± 2.71 for Formulation 2, attributed to the phenolic compounds in the seaweed itself, which enhance antioxidant properties (Leandro *et al*., 2020). The research revealed that higher levels of seaweed incorporation (40%) reduced oxidative damage by increasing phenolic content (Kowalczewski *et al.,* 2024). In this study, even at lower incorporation levels (5-10%),phenolic content increased, indicating that seaweed has the potential to enhance the antioxidant potential in patties. High TPC in plant-based burger patties can provide significant health benefits due to their antioxidant and anti-inflammatory propertieswhich help neutralize free radicals and reduce the risk of chronic diseases such as cancer and heart disease (Minatel *et al*., 2017). In summary, incorporating *Gracilaria changii* has the potential to boosts the TPC and potential health benefits of plant-based burger patties (Suhaimai *et al*., 2025).

3.9 Energy content

As Table 5 indicates, the energy content of plant-based burger patties, particularly those with *Gracilaria changii,* significantly impacts their nutritional value. The CBP contains 26.84 ± 2.5 g of carbohydrates, 56.68 ± 0.23 g of protein, and 52.32 ± 0.05 g of fat, totaling 153.49 kcal per 113 g serving. In comparison, the control formulation without seaweed has higher carbohydrates (33.12 ± 1.3 g) and slightly lower protein (55.32 ± 0.23 g), resulting in 156.93 kcal per serving. Seaweed formulations (F1 and F2) have reduced fat content (42.72 g and 44.25 g) and moderate carbohydrate levels (29.84 g and 25.56 g), while maintaining comparable protein levels.

Incorporating *Gracilaria changii* into plant-based burger patties may improve their nutritional profile by lowering calorie content while increasing protein levels. The *Gracilaria changii* contains a significant protein content, with studies indicating values around 17.11 g to 25.29 g per 100 g (Amarowicz *et al*., 2017). This seaweed is rich in essential amino acids, which are crucial for maintaining muscle health and overall well-being (Moreira *et al*., 2022). Additionally, its high dietary fiber content promotes satiety and digestive health (Moreira *et al*., 2022). Therefore, the inclusion of *Gracilaria changii* not only contributes to a balanced macronutrient distribution making plant-based burger patties more appealing to health-conscious consumers seeking higher protein options.

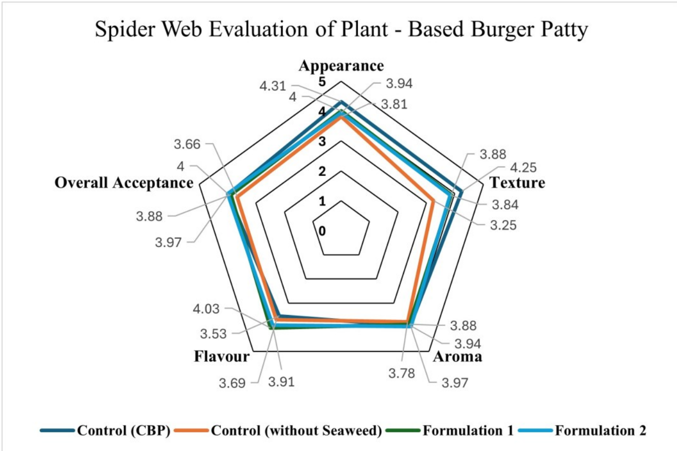

Figure 1. The sensory evaluation of a plant-based burger patty incorporated with seaweed of different formulation.

3.10 Sensory evaluation

As illustrated in Figure 1, the sensory evaluation of burger patties demonstrates significant differences in consumer preferences among formulations. The commercial plant-based burger patty (CBP) scored highest in appearance (4.31) compared to the control without seaweed (3.81), while Formulations 1 and 2 scored 4.00 and 3.94, respectively, indicating that seaweed enhances visual appeal (Ainsa *et al*., 2022). Although the CBP led in texture (4.25), both seaweed formulations improved texture compared to the control. Formulation 2 slightly outscored the CBP in aroma (3.97

Table 5. Energy value based on formulation.

Formulation	Carbohydrate	Protein	Fat	Energy value
Control (CBP)	26.84 ± 2.5[a]	56.68 ± 0.23[b]	52.32 ± 0.05[d]	153.49 kcal
Control without seaweed	33.12 ± 1.3[b]	55.32 ± 0.23[a]	50.43 ± 0.05[c]	156.93 kcal
Formulation 1 (5%)	29.84 ± 1.6[ab]	55.06 ± 0.23[a]	42.72 ± 0.05[a]	144.21 kcal
Formulation 2 (10%)	25.56 ± 1.3[a]	56.9 ± 0.23[b]	44.25 ± 0.05[b]	143.17 kcal

Values are means of triplicates; [abcd] means in same row with different superscripts are significantly different ($p<0.05$)

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vs. 3.94), suggesting a positive contribution from seaweed's aromatic compounds (Ainsa *et al.*, 2022). Notably, both seaweed formulations excelled in flavor, scoring 3.53, due to the unique umami taste of *Gracilaria changii's* (Ainsa *et al.*, 2022). Overall acceptance was higher for Formulation 2 at 3.97 compared to the control at 3.66, indicating that improvements in flavor and aroma make seaweed formulations more appealing, despite minor differences in texture. In summary, incorporating *Gracilaria changii* enhances sensory attributes and overall consumer acceptance compared to commercially available plant-based burger patties.

Conclusion

In this study, formulation for a plant-based burger patty incorporating seaweed was developed, achieving the optimal combination of 30% red bean, 30% soy chunks, 13% quinoa, and 10% red seaweed, resulting in a flavorful and nutritionally balanced patty. The nutritional content requirements were fulfilled as shown by the results demonstrating that red seaweed *Gracilaria changii* improved the nutritional value of the patty, with significant increases in mineral content, reductions in fat and carbohydrates, and the maintenance of protein content comparable to that of commercial patties. In terms of consumer acceptance, the 10% red seaweed formulation proved to be most preferred. This suggests that red seaweed can be successfully incorporated into plant-based burger patties, providing a healthier and more nutritious alternative to traditional meat burgers while also meeting consumer preferences in terms of taste and texture. The study supports the feasibility of red seaweed as a valuable ingredient in the development of nutrient-dense plant-based foods.

Conflict of interest

The authors confirm that there are no conflicts of interest related to the publication of this paper.

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