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Contact information:

Nong Lam University
Room 404, Thien Ly Building
Linh Xuan Ward, Ho Chi Minh City, Vietnam
Tel: (84-28)37245670
Email: jad@hcmuaf.edu.vn

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CONTENT

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Production of healthy snack with addition of *Monostroma nitidum*

Trang H. P. Tran, Thu Q. D. Dinh, Thanh T. Le, Trinh A. Nguyen, & Tuyen C. Kha*
Faculty of Chemical Engineering and Food Technology, Nong Lam University, Ho Chi Minh City, Vietnam

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***Corresponding author**

Tuyen Chan Kha
Email:
khachantuyen@hcmuaf.edu.vn

ABSTRACT

Monostroma nitidum, a green seaweed of the *Ulvophyceae*, remains underutilized despite its significant nutritional potential. In response to the growing global demand for healthy snack options, consumers are increasingly seeking innovative and nutrient-rich products. This research investigated the proximate composition of dried green seaweed and developed a nutritious snack. The most suitable conditions for steaming (90°C for 30 min) and air-drying temperature (60°C) were determined based on sensory evaluation and texture analysis. The findings demonstrate that the developed seaweed-added snack is suitable for large-scale production, with processes aligned to practical manufacturing requirements. This innovative product is expected to introduce a new and healthy option to the snack market.

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1. Introduction

Seaweeds are nutrient-rich marine vegetables containing polysaccharides, proteins, and essential and non-essential amino acids, making them a valuable and renewable marine resource for food applications (Marsham et al., 2007; Patarra et al., 2011; Peña-Rodríguez et al., 2011). Their increasing consumption reflects growing awareness of the link between diet and health. Emerging marine-based products offer enhanced nutritional benefits and potential disease risk reduction. Research indicates that incorporating seaweeds into food systems can enhance shelf life, nutritional value, texture, and sensory attributes (Roohinejad et al., 2017).

The green seaweed *Monostroma nitidum* has garnered significant attention for its nutritional value and health benefits. In East Asian and Southeast Asian countries such as Japan, China, Korea, and Vietnam, it is sustainably cultivated and harvested to meet consumer demand for traditional food products (Kaur et al., 2023). *Monostroma nitidum* is particularly valued for its high dietary fiber content, including rhamnan sulfate, which has been shown to lower blood lipids and cholesterol while alleviating vascular inflammation (Terasawa et al., 2023). Its rich nutritional profile, comprising essential minerals and vitamins, makes it highly versatile for incorporation into various products, including soups, salads, and snacks (Suzuki & Terasawa, 2020).

Traditional snack foods have faced increasing scrutiny for their high levels of calorie, sugar, salt, and unhealthy fat, raising significant health risks. Despite these concerns, the global snack market has experienced rapid growth, fueled by consumer demand for convenient, quick-consumption options that are both natural and healthy-focused. This trend highlights an opportunity to develop innovative, healthier alternatives, such as seaweed-based products.

This research investigated the potential of *Monostroma nitidum* in developing seaweed-added snacks as healthier alternatives to conventional options. Leveraging its nutritional benefits and environmental advantages, incorporating this seaweed into snack products could diversify healthy snack offerings and support the growth of the aquaculture sector. The research aimed to determine the best formulation, steaming conditions, and air-drying temperatures to produce a product with desirable sensory characteristics and texture. These findings align with the industry's "Better-for-You" snack trend and highlights its potential to advance sustainable food production practices.

2. Materials and Methods

2.1. Materials

Dried seaweed was sourced from a local market in Ninh Thuan province, Vietnam. Although the exact harvesting process was undocumented, local farmers reported the seaweed was sun-dried on shelves to a moisture content of approximately 20%. It was subsequently stored in expanded polystyrene boxes and transported to the laboratory. Upon arrival, the seaweed was thoroughly washed with tap water to remove crustaceans and debris, hot air-dried to a final moisture content of 12%, and stored in sealed containers at ambient temperature for further use. Tapioca starch (12%, w.b.) and wheat flour (12%, w.b.) were supplied by Taikyfood and Meizan CLV, respectively. All chemicals used were of analytical grade and purchased from Duksan, Scharlau, and Sigma-Merck.

2.2. Seaweed-added snack procedure

To prepare the seaweed-added snack (Figure 1), 24 g of the previously prepared dried seaweed was soaked in drinking water at 30°C for 20 min. The softened seaweed was then drained, reweighed, and blended with drinking water, salt, and sugar, as specified in Table 1. The mixture was processed into a fine paste and boiled for 90 sec with continuous stirring.

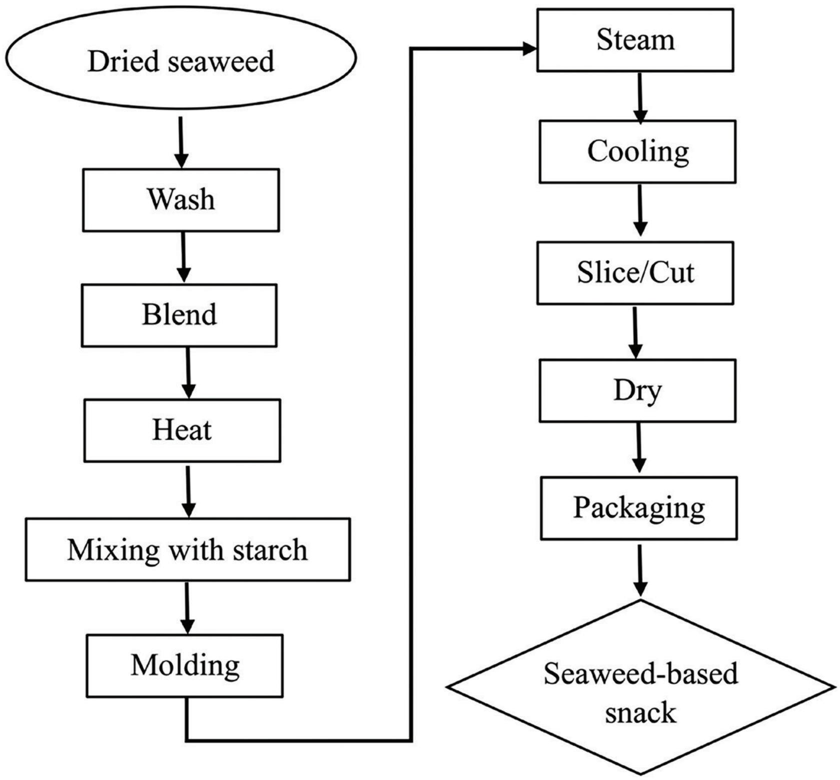

Figure 1. Procedure of seaweed-added snack.

Table 1. Formulation of seaweed-added snack products

Ingredients	Formula 1 (%)	Formula 2 (%)	Formula 3 (%)
Seaweed (d.b)	5.56	7.28	8.93
Tapioca starch (d.b)	30.17	29.61	29.08
Wheat flour (d.b)	5.70	5.61	5.5
Water	46.32	45.47	44.66
Salt	1.16	1.14	1.12
Sugar	5.56	5.46	5.36

The seaweed paste was mixed with tapioca starch and baking powder until smooth, then poured into cylindrical molds (radius ~1.5 cm, height ~3 cm). The molds were steamed under four conditions: 85°C for 30 min (1) and 45 min (2), 90°C for 30 min, and 95°C for 30 min. After steaming, the molds were cooled to ambient temperature and refrigerated at 8 - 10°C overnight to allow the dough to fully set.

The firm dough was sliced into thin chips (~1.5 mm thick) and hot-air dried at 55, 60 and 65°C until crispy, with a final moisture content of 5 - 6%. The dried seaweed chips were stored in polyethylene bags and placed in a desiccator for subsequent analysis.

Preparation of fried seaweed-added snack: Samples (3 cm in diameter) from each formulation were fried in vegetable oil at approximately 175°C. During frying, the chips were gently pressed with chopsticks to ensure even puffing and were fried until they turned light golden.

2.3. Analytical methods

2.3.1. Proximate analysis of dried seaweed

The proximate composition of dried seaweed was analyzed in triplicate using AOAC standard methods, including moisture (950.46.b), ash (920.153), crude fat (960.39), crude protein (984.13), and crude fiber (978.10). Total carbohydrate was calculated as:

Total carbohydrate (%) = 100 - Moisture (%) - Ash (%) - Protein (%) - Lipid (%)

2.3.2. Water activity

Water activity was measured at 25°C using an Aqualab Series 3 water activity meter (Decagon Devices, USA).

2.3.3. Color measurement

The color of seaweed chip samples was assessed using a Minolta Chroma Colorimeter (CR-400 Konica Minolta Sensing, Inc., Tokyo, Japan), based on CIE Lab coordinates: lightness (L), redness/greenness (a), and yellowness/blueness (b). Ten replicates were measured per sample. Chroma (C), hue angle (H°), and total color difference (ΔE) were calculated using the following equations:

$$C = \sqrt{a^2 - b^2} \qquad (Eq.2)$$

$$H^o = Arctan\left(\frac{b}{a}\right) \qquad (Eq.3)$$

$$\Delta E = \sqrt{(a - a_o)^2 + (b - b_o)^2 + (L - L_o)^2} \qquad (Eq.1)$$

2.3.4. Shear force analysis of seaweed-added snack

Shear force analysis of fried seaweed chips was performed using a Materials Testing Machine (zwickiLine Z1.0, ZwickRoell, Germany) with a Kramer shear cell (99 × 100 × 90 mm: height × width × depth). A 500 N load cell was used at a crosshead speed of 60 mm/min. Four chip samples were tested per run, with six replicates. The measured parameters included Fmax, WFmax, W, and n (number of maxima).

2.3.5. Sensory evaluation

A sensory evaluation was conducted with a trained panel of 25 members (aged 24 - 50 years). Panelists evaluated texture and overall acceptability using a randomized presentation order and a 9-point scale (0 = dislike extremely; 9 = like extremely). The scores were converted to numerical values for statistical analysis.

2.4. Statistical analysis

Experiments were designed as a completely randomized single-factor model, with snack formulations, steaming conditions, and drying temperatures as factors. Data were analyzed using SPSS (version 20.0, IBM Corp., USA). All experiments were conducted in triplicate, and results are expressed as means ± standard deviations. Duncan's multiple range test was applied to identify significant differences *(P* < 0.05*)* between treatment means.

3. Results and Discussion

3.1. Proximate analysis of green seaweed and seaweed-added snack products

The chemical composition of dried green seaweed revealed the following: moisture content (28.34 ± 0.33%), carbohydrate (38.62 ± 0.93%), protein (6.52 ± 0.44%), fat (1.02 ± 0.35%), ash (25.50 ± 0.95%), and fiber (0.93 ± 0.02%). Although studies on its nutritional composition are limited, this seaweed is closely related to *Ulva lactuca*, a green seaweed with notable commercial applications. *Monostroma nitidum* is recognized for its rhamnan sulfate-rich cell walls, which have demonstrated bioactivities such as anticoagulant, thrombolytic, antiviral, anti-obesity, and anti-inflammatory effects (Terasawa et al., 2020; Shimada et al., 2021).

The protein content of dried *Monostroma nitidum* is lower than that of red and brown seaweeds (Fleurence, 1999) but comparable to other green seaweeds, such as *Ulva lactuca* (4.3 and 16.21%) (Smith & Young, 1955; Castro-González et al., 1996; Fleurence, 1999). Its lipid content is very low, consistent with other green seaweeds. Protein and lipid levels in algae vary due to external factors like seasonality, maturity, and environmental conditions (Fleurence, 1999; Madhusudan & Baskaran, 2023).

For comparison, *M. oxyspermum* from the Hawaiian Islands showed ash (22.4 ± 0.5%), protein (9.6 ± 0.2%), carbohydrate (31.8 ± 0.8%), and lipid (3.8 ± 0.1%) contents (McDermid & Stuercke, 2003). Similarly, *M. undulatum Wittrock* from Southern Argentina showed protein levels (12.9 - 21.9%), ash (33.9 - 40.1%), lipid (0.3 - 1.5%), fiber (14.4 - 19.6%), and digestible carbohydrates (20.9 - 32.5%) (Risso et al. (2003).

Although *M. nitidum* has lower protein content than *M. oxyspermum* and *M. undulatum*, it remains a valuable source of macronutrients and dietary fiber. Its rhamnan sulfate polysaccharide offers unique bioactive properties, supporting its potential application in developing healthy snack products.

3.2. Effect of seaweed addition on the quality of seaweed-added snack

The color profiles of the seaweed-added snacks, influenced by varying seaweed additions, are presented in Table 2 and Figure 2. The highest chroma value was observed at 7.28% seaweed addition, likely due to the presence of natural pigments, enhancing the color saturation. The added seaweed interacts with the starch/flour mixture, blending its greenish pigment with the off-white color. This blending can cause a color perception shift towards the yellow spectrum. Changes in the color of the product provide insight into the degree of cooking and pigment degradation during frying (Han & Tran, 2018). The color differences were found to be significantly different as the percentage of seaweed added increased: 1.17 (5.56 vs 7.28%), 2.49 (7.28 vs 8.93%), and 2.48 (5.56 vs 8.93%). These measurements ensure that the seaweed snacks maintain a consistent and appealing appearance, influencing consumer perception and preference.

Table 2. Color parameters of seaweed-added snack products

Formula	Lightness (L)	Hue angle (H°)	Chroma (C)
1	45.2 ± 1.2^{a}	88.8 ± 0.3^{b}	216.2 ± 22.2^{b}
2	45.1 ± 0.7^{a}	89.4 ± 0.1^{a}	240.7 ± 24.0^{a}
3	42.7 ± 1.5^{b}	89.0 ± 0.2^{b}	224.0 ± 25.3^{ab}

The data represent mean values ± standard deviation (n = 10). Values with different superscript letters in the same column for each experiment are significantly different (P < 0.05).

Figure 2. Seaweed-added snack samples.

Tables 3 and 4 demonstrate the impacts of formulations on the textural properties and sensory evaluation of the seaweed-added snack, respectively. The texture of the fried products was influenced by the frying process, as oil absorption and expansion occur, as well as the snacks' oil content. Incorporating seaweed fiber into the polymer network of the snacks resulted in notable textural changes. Kramer shear test results revealed significant differences in the force and work required to break the snack pieces, providing a detailed assessment of their physical properties.

Table 3. Texture measurement parameters of seaweed-added snack products

Formula	F_{max}	F_{with}	W_{Fmax}	W	n (Maxima)
1	221.0 ± 53.1^{a}	33.1 ± 8.3^{a}	1159.4 ± 343.7^{a}	1591.3 ± 353.2^{a}	27.1 ± 4.2^{a}
2	170.2 ± 16.1^{b}	26.3 ±1.8^{b}	936.8 ± 133.7^{b}	1288.7 ± 98.3^{b}	26.4 ± 4.2^{a}
3	158.6 ± 15.0^{b}	23.1 ± 2.1^{b}	821.6 ± 135.7^{b}	1129.3 ± 109.9^{c}	23.7 ± 2.9^{b}

The data are the mean values ± standard deviation (n = 3). Values with different superscript letters in the same column for each experiment are significantly different (P < 0.05).

Table 4. Sensory properties of the fried seaweed-added snack

Formula	Color	Flavor	Texture	Overall
1	6.7 ± 0.8^{b}	6.6 ± 0.8^{a}	5.9 ± 0.8^{b}	6.3 ± 0.8^{b}
2	7.2 ± 0.9^{ab}	7.0 ± 1.0^{a}	7.1 ± 1.2^{a}	7.4 ± 0.9^{a}
3	7.2 ± 0.7^{a}	7.0 ± 0.8^{a}	7.2 ± 1.0^{a}	7.0 ± 0.7^{a}

The data represent mean values ± standard deviation (n = 3). Values with different superscript letters within the same column for each experiment are significantly different (P < 0.05).

F_{max} or maximum force, represents the peak force required to shear through the snack, reflecting its resistance to breaking and correlating with its crunchiness or hardness. A higher F_{max} indicates a harder texture. At lower seaweed content, the F_{max} values are significantly higher, suggesting harder snacks requiring more force to break. Conversely, higher seaweed content (7.28 and 8.93%) produces more porous, resulting in lower F_{max} values. This is due to the ingredient network; higher tapioca starch incorporation forms a denser structure with fewer air pockets, leading to higher hardness and reduced crispiness.

Increasing seaweed fiber content reduces cohesiveness, creating more air cells with thinner walls and softer snacks. While starch is critical for puffing (Anton et al., 2009; Oliveira et al., 2017), fortifying snacks with seaweed fiber enhances both physical properties and nutritional value. This adjustment slightly reduces hardness and firmness while maintaining a desirable texture.

Work (W) and work to maximum force (WF_{max}) measure the total energy required during the shearing process or to reach the maximum force, reflecting the snack's firmness and resistance to breaking. Higher work values indicate a tougher texture. Increased fiber content results in less dense structures with larger, more uniform pores, leading to greater expansion, which is evident visually and through mouthfeel. Consequently, the snacks become softer and crispier, aligning with the desired textural characteristics of the final product. These findings contrasts with Delić et al. (2023), who reported differing effects of fiber-rich additions in extruded products. This discrepancy may be attributed to the type of fibers used, warranting further investigation.

Hanand Tran (2018) studied corn snacks with high fiber content and found that different fiber types influence hardness and crispness in distinct ways. The impact of fiber addition is determined not only by its content but also on the molecular weight and structu1re of the polymer (Peressini et al., 2015).

3.3. Effect of steaming conditions on the seaweed-added snack

Table 5 presents the effect of steaming conditions on snack color. Natural pigments in seaweed are best preserved at 90°C for 30 min, ensuring proper hydration and starch gelatinization. Higher temperatures or longer durations may cause over-steaming or pigment degradation, reducing color intensity. The ΔE values comparing different conditions are as follows: 85°C for 30 min vs. 85°C for 45 min, 90°C for 30 min, and 95°C for 30 min were 2.79, 1.52, and 2.04, respectively. Comparisons between 85°C for 45 min vs. 90°C for 30 min and 95°C for 30 min yielded ΔE values of 2.04 and 3.85, respectively, while the difference between 90°C for 30 min and 95°C for 30 min was 2.11. Most ΔE values were significantly different ($1.5 < \Delta E < 3$), except for the comparison between 85°C for 45 min and 90°C for 30 min, where the difference was highly significant. These findings suggest that lower temperatures with longer durations are less effective in preserving color.

Table 5. Color parameters of seaweed-added snack products

Treatment	Lightness (L)	Hue angle (H°)	Chroma (C)
85°C (1)	47.3 ± 1.3^{b}	88.6 ± 0.3^{c}	278.1 ± 18.9^{b}
85°C (2)	45.1 ± 0.7^{a}	89.4 ± 0.1^{b}	240.7 ± 24.0^{c}
90°C	47.2 ± 1.0^{b}	89.4 ± 0.2^{b}	314.4 ± 31.6^{a}
95°C	45.4 ± 2.2^{a}	89.8 ± 0.1^{a}	292.1 ± 32.7^{b}

The data represent mean values ± standard deviation (n = 10). Values with different superscript letters in the same column for each experiment are significantly different (P < 0.05).

Steaming plays a crucial role in the dough's internal structure, influencing subsequent drying and frying processes. The effects of steaming on the texture and sensory evaluation are shown in Tables 6 and 7, respectively. Proper gelatinization and hydration of starch are the crucial factors for attaining the desired texture in the final fried product. During gelatinization, starch granules swell and become cohesive, with the extent of gelatinization dependent on steaming temperature and time. Adequate hydration allows better interaction between starch and other ingredients, resulting in a more uniform structure.

Well-steamed dough exhibits a higher expansion ratio and enhanced oil absorption, contributing to improved crispiness. Extended steaming at 85°C for 45 min results in higher work values required to break the snacks, as the well-developed starch network creates a firmer, denser texture. At 90°C for 30 min, starch gelatinization is sufficient to produce a firm texture without excessive toughness. Sensory evaluation revealed superior overall acceptability at 90°C, correlating with desirable textural properties (minimized key parameters) and desirable chroma values. Although steaming at 95°C yielded higher lightness and hue angle, the 90°C treatment achieved a well-balanced combination of sensory attributes, texture, and color, while reducing energy consumption. Sensory analysis further confirmed that snacks processed under these conditions exhibited a crisp, firm texture with a pleasant crunch.

Table 6. Effects of steaming conditions on texture measurement parameters of seaweed-added snack products

Treatment	F_{max}	F_{with}	W_{Fmax}	W	n (Maxima)
85°C (1)	169.5 ± 26.4^a	20.4 ± 2.2^c	724.3 ± 134.4^b	979.5 ± 118.4^c	23.4 ± 3.0^b
85°C (2)	170.2 ± 16.1^a	26.3 ± 1.8^a	936.8 ± 133.7^a	1288.7 ± 98.3^a	26.4 ± 4.2^a
90°C	157.3 ± 16.5^a	20.3 ± 3.0^c	736.7 ± 140.1^b	982.1 ± 151.2^c	22.7 ± 3.5^b
95°C	157.3 ± 21.9^a	23.3 ± 3.3^b	810.6 ± 201.7^b	1139.8 ± 167.4^b	23.0 ± 3.6^b

The data are the mean values ± standard deviation (n = 3). Values with different superscript letters in the same column for each experiment are significantly different (P < 0.05).

Table 7. Effects of steaming conditions on sensory properties of the fried seaweed-added snack

Treatment	Color	Flavor	Texture	Overall
85°C (1)	6.3 ± 1.3^c	6.5 ± 0.6^a	6.4 ± 0.7^b	6.6 ± 0.8^b
85°C (2)	7.2 ± 0.9^a	7.0 ± 1.0^a	7.1 ± 1.2^a	7.5 ± 0.9^a
90°C	6.7 ± 0.9^{ab}	7.0 ± 0.9^a	7.0 ± 0.71^a	7.3 ± 0.7^a
95°C	6.4 ± 1.2^{bc}	6.5 ± 0.8^a	6.6 ± 0.7^{ab}	6.5 ± 0.8^b

The data represent mean values ± standard deviation (n = 3). Values with different superscript letters within the same column for each experiment are significantly different (P < 0.05).

3.4. Effect of drying temperature on the seaweed-added snack

Drying experiments were conducted at 55, 60 and 65°C, as illustrated in Figure 3. The drying process begins with a rapid decrease in moisture content at all temperatures due to surface water evaporation. Following this, the drying rate slows, reflecting the removal of water from within the seaweed structure. At 65°C, the moisture content decreased from 56.11 to 3.48% in 210 min, making it the fastest drying time. However, higher temperatures may cause thermal degradation of heat-sensitive pigments and nutrients.

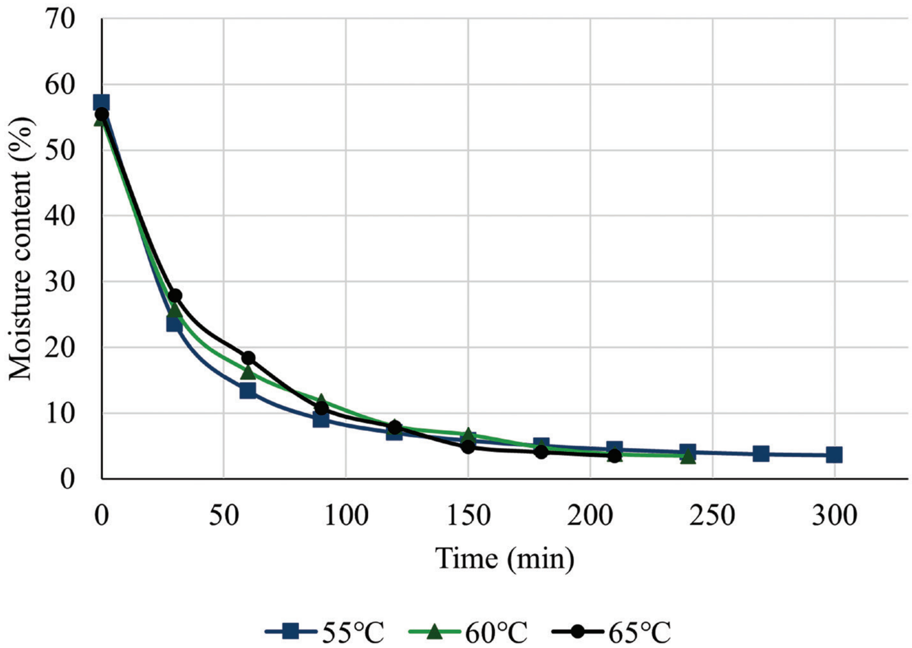

Figure 3. Drying curve of seaweed-added snack product.

At 60°C, the drying curves show steeper initial slopes, indicating a faster drying rate and shorter drying time compared to 55°C. Lower temperatures result in slower drying, which may better preserve heat-sensitive components but require longer drying times. However, prolonged drying at lower temperatures can lead to oxidation, affecting color and texture. Faster drying at higher temperatures may cause crust formation, trapping moisture inside and resulting in uneven drying. Preliminary studies suggest the desired moisture content of 4 - 5% is reached when the snack can be broken in half by hand, confirming both proper drying and optimal texture.

The drying process affects the final color intensity of the snack product (Table 8). Excessive temperatures can degrade heat-sensitive pigments, leading to color loss, as indicated by decreases in the L and C values, while the H° value remains consistent at 88-89°. The H° value represents the perceived color, which is critical for product consistency. Prolonged drying exposes pigments to oxidation, dulling the color, while rapid drying can stress cell structures, causing pigment loss. These findings suggest that increased thermal energy accelerates browning. The ΔE value showed significant differences between 55 and 60, and 65°C, but the difference between 60 and 65°C was less than 1.5, indicating no significantly variation.

Table 8. Color parameters of seaweed-added snack products

Drying Temperature (°C)	L*	Chroma (C)	Hue angle (H°)
55	44.3 ± 2.4[a]	222.0 ± 29.4[a]	89.1 ± 0.2[a]
60	39.3 ± 2.3[b]	206.1 ±23.4[ab]	88.9 ± 0.2[b]
65	39.0 ± 2.6[b]	185.5 ±30.7[b]	89.0 ± 0.1[ab]

The data represent mean values ± standard deviation (n = 10). Values with different superscript letters in the same column for each experiment are significantly different (P < 0.05).

The addition of fiber to seaweed-added snacks creates a more complex and porous network, as evidenced by the texture measurement (Table 9) and sensory evaluations (Table 10). Fibers affects moisture distribution and retention, creating micro-cavities that disrupts the starch structure, resulting in a lighter, more brittle texture. Slow drying at lower temperatures preserves the fiber-starch network, leading to higher WF_{max} and W values, while rapid drying at higher temperatures weakens this network, making the structure softer and less cohesive. Moisture migration also contributes to the formation of cavities, enhancing the brittle, porous texture (Liang et al., 2024).

Table 9. Texture measurement parameters of seaweed-added snack products

Temperature (°C)	F_{max}	F_{with}	W_{Fmax}	W	n (Maxima)
55	195.1 ± 17.6[a]	28.0 ± 4.3[a]	907.7 ± 92.9[a]	1374.4 ± 232.4[a]	23.6 ± 4.7[a]
60	165.2 ± 15.9[b]	25.3 ± 3.1[a]	772.0 ± 154.5[b]	1234.7 ± 153.3[a]	24.0 ± 2.6[a]
65	147.9 ± 10.5[c]	20.1 ± 1.4[b]	724.9 ± 92.6[b]	977.8 ± 71.0[b]	20.9 ± 2.3[a]

The data are the mean values ± standard deviation (n = 3). Values with different superscript letters in the same column for each experiment are significantly different (P < 0.05).

Table 10. Sensory properties of the fried seaweed-added snack

Temperature (°C)	Color	Flavor	Texture	Overall
55	6.7 ± 0.8[b]	6.6 ± 0.7[b]	6.9 ± 0.8[a]	6.8 ± 0.7[b]
60	7.3 ± 0.8[a]	7.1 ± 0.9[a]	7.3 ± 0.63[a]	7.2 ± 0.7[a]
65	6.8 ± 0.7[b]	7.0 ± 0.8[ab]	7.0 ± 0.8[a]	6.8 ± 0.7[b]

The data represent mean values ± standard deviation (n = 3). Values with different superscript letters within the same column for each experiment are significantly different (P < 0.05).

3.5. Correlation between sensory and instrumental texture measurements

Flavor, hardness, and crispness are key sensory attributes of snack foods. A linear negative correlation between instrumental texture data and sensory scores was observed, with higher force or work correlating to lower sensory scores (approaching -1). The correlation coefficients for texture and sensory scores, including F_{max}, F_{with}, W_{Fmax}, W, and n (Maxima) are detailed in Table 11. Flavor scores were high, suggesting that seaweed incorporation does not negatively impact sensory perception. The preferred sample contained 7.28% seaweed, steamed at 90°C for 30 min, and dried at 65°C, offering the best texture and sensory qualities for a crisp and flavorful snack.

Table 11. Correlation coefficients between instrumental texture measurement and sensory evaluation for fried seaweed-added snack

	F_{max}	F_{with}	W_{Fmax}	W
Texture	-0.996	-0.974	-0.967	-0.966
Overall	-0.839	-0.755	-0.737	-0.734

4. Conclusions

Proximate composition analysis identifies *Monostroma nitidum* as a rich source of carbohydrates, protein, and essential minerals, highlighting its potential as a key ingredient in healthy snack formulations. The developed seaweed-added snack production process (containing 7.28% seaweed, steamed at 90°C for 30 min, and dried at 65°C) demonstrated industrial feasibility and strong consumer appeal. Future research should explore dietary fiber and polysaccharide composition of *Monostroma nitidum* to further enhance its nutritional value and optimize product properties. Comprehensive studies on both the raw seaweed and the final snack product will provide deeper insights into its potential applications in the snack food industry.

Conflict of interest

There is no conflict of interest involved in the publication of this article.

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