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Research Article

Comparative Estimation of Nutritionally Important Chemical Constituents of Red Seaweed, *Gracilariopsis longissima*, Affected by Different Drying Methods

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In this study, the nutritional and phytochemical components of red seaweed, *Gracilariopsis longissima*, were assessed in relation to the effects of various drying methods (freeze, oven, and sun). *Gracilariopsis longissima*'s proximate composition differed significantly ($P < 0.05$) among the three drying techniques, with freeze-dried samples having significantly greater protein (30.63 ± 0.90% dry weight) and lipids (1.49 ± 0.05% dry weight) contents. Except for phosphorus and sulfur, the mineral concentrations were likewise considerably greater in the freeze-dried samples. The total amino acids (30.48 ± 0.06% dry weight) and fatty acids contents were substantially greater ($P < 0.05$) in the freeze-dried samples. In freeze-dried samples, the levels of essential amino acids (18.92 ± 0.02% dry weight) and unsaturated fatty acids (54.08 ± 0.07%) were substantially greater ($P < 0.05$). When compared to oven- and sun-dried samples, the total phenolic content (88.70 ± 2.19 mg GAE/g dry weight) and the flavonoid content (71.46 ± 2.17 mg QE/g dry weight) of freeze-dried samples was also substantially higher. Among the three distinct drying techniques used, the freeze-drying technique kept *G. longissima*'s higher nutritional and phytochemical components.

1. Introduction

Seaweeds have been utilized as a nutritional food component with health advantages over the past decade [1]. In response to the escalating demand for nourishing and health-enhancing meals, the food industry is integrating advanced technologies to engineer efficacious consumables [2]. Because of its significant physicochemical substance, seaweed offers a sustainable resource with the potential to be used as a functional element [3]. Due to seaweed's diverse nature and chemical components, seaweed displays a broad range of nutritional and biological activity [3]. Flavonoids, carotenoids, fiber, protein, lipids, essential fatty acids, vitamins, and minerals are the significant bioactive components found in seaweed. In addition, it has been proved in animal models that seaweed contains health-promoting minerals and phytochemicals with a strong antioxidant activity, effects on lowering cholesterol, and antiobesity qualities [4]. As seaweed is said to preserve biological activity with a potential medical value, seaweed and its extracts are deemed beneficial for health.

Approximately, 6,000 distinct species of red algae make up the biggest category of seaweeds [5]. Red algae are distinguished by the color of their pigments, which include

chlorophylls A and D, phycobiliproteins, and carotenoids [5]. Red algae have been suggested to be included in the human diet due to their high nutritional content compared to other seaweed, as well as their enormous amounts of minerals and vitamins [6–8]. The Gracilariopsis genus has species that are found all around the world [9]. Since it has the presence of bioactive compounds of biotechnological significance, *G. longissima* is economically pertinent as a source of phycocolloids for the food sector [10]. According to Suleria et al. [1], bioactive substances are metabolites that offer extra health benefits. They have considerable commercial success because of the rising consumer interest in organic product utilization. It is important to continue researching and using bioactive chemicals derived from seaweed since they exhibit substantial potential for improving human health [11].

Since seaweed is a marine plant, it possesses a lot of water when it is taken from the ocean; thus, it is often dried before being employed in research on nutrition or for manufacturing purposes [12]. Seaweed's moisture content, which sometimes exceeds 90% of its weight, makes its biomass susceptible to spoilage [12]. The effect of drying procedures on the stability of several kinds of bioactive substances and their antioxidant properties has been discussed in a number of studies [2, 13]. To maintain biomass quality and guarantee product safety, it is crucial to use the proper drying and storage procedures. Among the techniques employed are basic air drying and solar drying, as well as more advanced methods such as freeze drying and oven drying, each bearing its own advantages and drawbacks [13]. High temperatures, dehydration during the drying process, and prolonged drying times could affect the biochemical composition, phytochemical content, and antioxidant efficacy in seaweeds [14, 15]. Numerous factors, such as species, geographic location, maturation, and conditions of the environment, have a significant impact on their chemical composition [16]. Therefore, in order to manufacture high-quality seaweed powder, it is crucial to use the appropriate drying techniques.

There are currently no publications on the influences of drying methods on *G. longissima*'s nutritional properties, amino acids profile, fatty acids profile, and phytochemicals contents. In order to open up new possibilities for creating new food components and nutraceuticals from seaweeds, this paper looks into the effect of drying techniques on the nutritional properties, amino acids profile, fatty acids profile, and phytochemicals contents of red seaweed, *G. longissima*.

2. Materials and Methods

2.1. Raw Materials and Reagents. *Gracilariopsis longissima*, a red seaweed, was collected in December 2022 during low tide along the Nuniachara shore in Cox's Bazar, Bangladesh (91°57′52.0″E and 21°28′28.9″N). The size and age of the algae were not considered while selecting the collecting method. After being collected, samples of seaweed were washed with seawater in the field and then they were delivered to the lab in sealed bags. The seaweed was again cleaned with distilled water after they arrived at the lab to rid them of sand, epiphytes, and other surface pollutants. Voucher specimens of *Gracilariopsis longissima* (GL-01) were stored in BFRI, Patuakhali. All utilized chemical reagents were of analytical grade.

2.2. Sample Preparation. In this investigation, three distinct drying methods, i.e., freeze, oven, and solar drying were applied. Samples of seaweed were dried using a freeze drier (model: YJ-10A, Labocon, UK) for the freeze-drying process. Seaweed samples that were fresh were frozen for 48 hours at −80°C in a freeze drier. Seaweed samples were dried in an oven using a mechanical oven (model: LFDO-103, Labocon, UK). Fresh samples were placed on trays, equally distributed in one layer, and the dryer was set at 60°C for 36 hours. On a clear, bright day with a mean temperature of 33°C, the sun-dried sample was dried outdoors in one batch for four days. When adequate drying time produced a consistent dry weight, drying was deemed complete. Each drying procedure was carried out three times. To create a homogenous powder, the dry samples were finely crushed and sieved through a 500 μm siever. The seaweed powder was packed in an airtight plastic bag and kept in a glass bottle at 4°C until analysis.

2.3. Proximate Analysis. According to established protocols developed by the Association of Official Analytical Chemists (AOAC) [17], the moisture and ash contents were measured gravimetrically. Kjeltec 2300 ($N \times 6.25$) was used to estimate the protein content. These analytical techniques were used to assess the lipid content of the seaweed using Soxhlet extraction with petroleum ether as the solvent. Based on calculations by difference, the amount of carbohydrates was calculated [18]. There were triplicates of each measurement.

2.4. Mineral Content. A flame emission spectrophotometer (Spectrolab, UK) with appropriate filters was used to determine sodium (Na) and potassium (K); atomic absorption spectrophotometer (Model Varian, AAS Spectra 55B, Australia) was used to determine calcium (Ca) and magnesium (Mg); and a double beam UV-VIS spectrophotometer evaluated phosphorus (P) and sulfur (S) after the proper color development [17]. Each batch included the proper metal standard, blank, triplicate, and continual calibration verification throughout the elemental analysis [17].

2.5. Amino Acids Profile. The high-performance liquid chromatography (HPLC) amino acid analysis system (Shimadzu, Japan) was used for the amino acid analysis [19]. The system of the column filled with a very acidic cation exchange resin is used by the amino acid analyzer for separation. A binary gradient eluting technique was used to inject and separate the amino acids, and they were then each individually identified utilizing a fluorescence detector and postcolumn derivation detection at high sensitivity and 120 kg/cm^2 pressure. Triplicate measurements were made for each sample.

2.6. Fatty Acids Profile. With a minor alteration to the process used by Akabr et al. [20], the fatty acid profile of the extracted oils was assessed as their methyl esters. A test tube containing a small amount of extracted lipid was diluted with petroleum ether in this technique, and sodium methoxide was used to methylate the fat in the presence of a flame. After adding distilled water to dilute the solutions, the mixture was let to sit for a little while until the top of the tube became translucent. Fatty acids methyl esters (FAMEs) were extracted from the top and subjected to gas chromatography (GC) analysis. By measuring the retention times of the FAMEs with various standards and certain calibration curves, the FAMEs were determined. Each sample was examined three times.

2.7. Total Phenolic and Flavonoid Contents. The dried seaweed samples were finely crushed into a powder, as finer powder tends to yield better extraction results. In a nutshell, four grams of this finely powdered seaweed were soaked in 100 ml of methanol solvent. The mixture was placed in a shaking incubator (KC121, Labstac, United Kingdom) at 45°C for 24 hours, with intermittent shaking to enhance the extraction process. After incubation, the solution was filtered using Whatman No. 1 filter paper for separation. The remaining moist powder was subjected to another round of extraction using the respective solvents, intermittently shaken for 12 hours, and filtered to maximize the sample's yield. The methanol was then evaporated using a rotary vacuum evaporator (SCI100-Pro, SCILOGEX, USA) at 36°C, and the samples were stored at 4°C until the experiment. Finally, working solutions were prepared, each at a concentration of 5 mg·mL^{-1} for every extract.

The Folin–Ciocalteu technique of Martins et al. [21] with minor modification was used to estimate the phenolic content. In a nutshell, 0.1 mL of FC reagent solution was added together with 0.5 mL of extract solution. The solution was mixed with 2.5 mL of saturated Na_2CO_3 (7.5%) after 15 minutes, and the mixture was left to stand for 30 minutes at room temperature before the absorbance at 760 nm was measured using a spectrophotometer (model: C7200, Peak Instrument, USA). Results are presented as mg of gallic acid equivalent (mg GAE/100 g·dm). The triplicate of each measurement was made.

With a few minor adjustments, the aluminum chloride colorimetric technique published by Chia et al. [22] was used to calculate the total flavonoid concentration in the crude extracts. In a nutshell, 3 mL methanol, 0.2 mL 10% aluminum chloride, and 0.2 mL 1 M potassium acetate were combined with 1 mL of extract solution. After 30 minutes of room temperature incubation, the solution's absorbance at 420 nm was measured. The quantity of quercetin equivalent per 100 grams of dry matter (mg QE)/100 g·dm) was used to quantify the total flavonoid content.

2.8. Statistical Analysis. To identify significant variations among various drying techniques, the analysis of variance (ANOVA) utilizing Tukey's HSD was conducted. Data were represented as the mean ± standard deviations and analyzed using the Statistical Package for Social Science (SPSS Inc., Chicago, Illinois, USA) software version 25.0. Statistical significance was established for P values less than 0.05. Each analysis was carried out three times.

3. Results

3.1. Proximate Composition. The proximate content of red seaweed, *Gracilariopsis longissima*, altered by different drying methods is summarized in Table 1. All the proximate compositions such as moisture, protein, lipid, ash, and carbohydrate contents showed significant variations ($P < 0.05$) among the three different drying methods. However, it was found that significantly higher moisture (90.24 ± 0.52% fresh weight), protein (30.63 ± 0.90% dry weight), and lipid (1.49 ± 0.05% dry weight) content was present in freeze-dried samples compared to other drying techniques. Ash and carbohydrate contents were significantly higher ($P < 0.05$) in the oven- and sun-dried samples.

3.2. Mineral Content. The mineral content (%) of red seaweed, *G. longissima*, varied significantly among the different drying processes as can be seen in Table 1. The amounts of all minerals, except for phosphorus and sulfur, were substantially higher ($P < 0.05$) in the freeze-dried seaweed samples compared to the other two drying techniques. On the other hand, oven- and sun-dried samples had the significantly highest ($P < 0.05$) amount of phosphorus and sulfur.

3.3. Amino Acids. The amino acids profile (essential amino acid and nonessential amino acid) of all dried seaweeds showing significant variations ($P < 0.05$) under different drying conditions is reported in Table 2. A total of 14 amino acids were identified and measured in the current investigation. All amino acids were significantly higher ($P < 0.05$) in freeze-dried samples except glutamic acid, histidine, alanine, tyrosine, isoleucine, and lysine. Glutamic acid, alanine, tyrosine, isoleucine, leucine, and lysine were significantly higher ($P < 0.05$) in oven-dried samples. Sun-dried samples have significantly lower ($P < 0.05$) amino acids than the other two drying methods. The essential amino acid (EAA) content is the sum of histidine, threonine, tyrosine, valine, methionine, isoleucine, leucine, phenylalanine, and lysine. The nonessential amino acid (non-EAA) is the sum of aspartic acid, glutamic acid, serine, glycine, arginine, alanine, proline, and cysteine. The EAA and non-EAA ratio implies that this species of seaweed is enriched with EAA. The amount of EAA and non-EAA under different drying conditions is shown in Figure 1.

3.4. Fatty Acids. Ten (10) distinct fatty acids were measured in the red seaweed, *G. longissima*, comprising three saturated fatty acids (SFAs), three monounsaturated fatty acids (MUFAs), and four polyunsaturated fatty acids (PUFAs) (Table 3). Fatty acid profiles differ significantly ($P < 0.05$) among the three drying methods. The palmitic acid (C16 : 0),

Table 1: Proximate composition and mineral contents of dried red seaweed, *Gracilariopsis longissima*, by different processed methodologies.

Parameters	Drying method		
	Freeze dried	Oven dried	Sun dried
Proximate composition			
Moisture	90.24 ± 0.52^{a}	88.36 ± 0.65^{b}	88.01 ± 0.49^{b}
Protein (% DW)	30.63 ± 0.90^{a}	27.83 ± 0.5^{b}	27.26 ± 0.4^{b}
Lipid (% DW)	1.49 ± 0.05^{a}	1.26 ± 0.02^{c}	1.34 ± 0.04^{b}
Ash (% DW)	22.25 ± 1.1^{b}	24.71 ± 1.2^{a}	23.29 ± 0.9^{ab}
Carbohydrate (% DW)	30.45 ± 0.8^{b}	33.61 ± 0.7^{a}	32.98 ± 1.0^{a}
Mineral contents			
Sodium (%)	0.82 ± 0.02^{a}	0.72 ± 0.03^{b}	0.75 ± 0.02^{b}
Potassium (%)	4.47 ± 0.05^{a}	4.05 ± 0.04^{b}	4.14 ± 0.06^{b}
Calcium (%)	2.54 ± 0.04^{a}	2.36 ± 0.06^{b}	2.29 ± 0.03^{b}
Magnesium (%)	0.58 ± 0.02^{a}	0.47 ± 0.01^{b}	0.44 ± 0.01^{b}
Phosphorus (%)	0.31 ± 0.03^{b}	0.38 ± 0.02^{a}	0.39 ± 0.02^{a}
Sulfur (%)	1.56 ± 0.05^{b}	1.68 ± 0.06^{a}	1.63 ± 0.06^{a}
Na/K	0.18 ± 0.00	0.18 ± 0.01	0.18 ± 0.01

Mean values and standard deviation of measurements for the three replicates. Different superscripts in a row differ significantly ($P < 0.05$).

Table 2: Amino acids composition (% dry weight) of dried red seaweed, *Gracilariopsis longissima*, by different processed methodologies.

Amino acids (% dry wt.)	Drying method		
	Freeze dried	Oven dried	Sun dried
Aspartic acid	1.94 ± 0.03^{a}	1.15 ± 0.01^{c}	1.27 ± 0.01^{b}
Glutamic acid	2.36 ± 0.02^{c}	2.68 ± 0.02^{a}	2.49 ± 0.01^{b}
Serine	1.80 ± 0.01^{a}	0.94 ± 0.00^{c}	1.25 ± 0.00^{b}
Glycine	1.96 ± 0.02^{a}	1.59 ± 0.01^{b}	1.37 ± 0.01^{c}
Histidine	2.01 ± 0.01^{b}	1.75 ± 0.01^{c}	2.39 ± 0.02^{a}
Arginine	1.95 ± 0.01^{a}	1.85 ± 0.02^{b}	1.80 ± 0.01^{c}
Threonine	2.75 ± 0.01^{a}	1.58 ± 0.01^{b}	1.56 ± 0.00^{b}
Alanine	1.55 ± 0.02^{b}	2.17 ± 0.03^{a}	2.15 ± 0.01^{a}
Proline	Nd	Nd	Nd
Tyrosine	3.48 ± 0.03^{b}	3.60 ± 0.02^{a}	3.43 ± 0.02^{b}
Valine	2.08 ± 0.01^{a}	1.79 ± 0.01^{b}	1.65 ± 0.01^{c}
Methionine	1.75 ± 0.01^{a}	0.9 ± 0.00^{c}	0.99 ± 0.00^{b}
Cysteine	Nd	Nd	Nd
Isoleucine	2.89 ± 0.02^{b}	2.96 ± 0.03^{a}	2.61 ± 0.02^{c}
Leucine	1.80 ± 0.03^{a}	1.80 ± 0.02^{a}	1.71 ± 0.03^{b}
Phenylalanine	Nd	Nd	Nd
Lysine	2.16 ± 0.02^{c}	2.84 ± 0.02^{a}	2.28 ± 0.01^{b}
TAA	30.48 ± 0.06^{a}	27.60 ± 0.03^{b}	26.95 ± 0.02^{c}
EAA/non-EAA	1.64 ± 0.01^{a}	1.65 ± 0.02^{a}	1.61 ± 0.01^{b}

Mean values and standard deviation of measurements for the three replicates. Nd, not determined. Different superscripts in a row differ significantly ($P < 0.05$).

oleic acid (C18 : 1), and linoleic acid (C18 : 3) were the predominant fatty acids in the SFA, MUFA, and PUFA classes, respectively, for three different drying conditions. The saturated fatty acids and unsaturated fatty acids ratio implies that this species of seaweed is rich in unsaturated fatty acids. The omega-3 ($\omega 3$) and omega-6 ($\omega 6$) fatty acids ratio describes that $\omega 3$ fatty acid is predominant in this species. Saturated fatty acids were significantly higher ($P < 0.05$) in sun-dried samples ($47.60 \pm 0.05\%$), and unsaturated fatty acids were significantly higher ($P < 0.05$) in

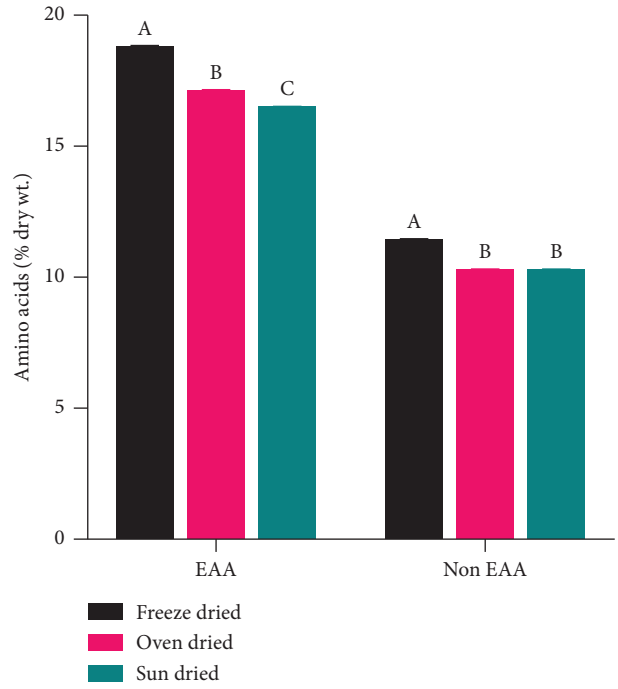

Figure 1: Total essential amino acid (EAA) and nonessential amino acid (non-EAA) compounds (% dry weight) of dried red seaweed, *Gracilariopsis longissima*, by different processed methodologies. Error bars are standard errors. Different small letters over bars denote significant differences at $P < 0.05$.

freeze-dried samples ($54.08 \pm 0.03\%$) among the three drying methods (Figure 2(a)). In the case of unsaturated fatty acids, oven-dried samples had substantially higher ($P < 0.05$) monounsaturated fatty acid (MUFA) while freeze-dried samples had significantly higher ($P < 0.05$) polyunsaturated fatty acid (PUFA) contents (Figure 2(b)).

3.5. Total Phenolic and Flavonoid Contents. Table 4 displays how the drying techniques affected the amounts of total phenolic content (TPC) and total flavonoid content (TFC) in the methanol extracts of the red seaweed, *G. longissima*. Upon comparing the three drying techniques, significant differences were observed in TPC and TFC ($P < 0.05$). TPC and TFC were significantly higher ($P < 0.05$) in samples that were freeze dried and much lower in samples that were sun dried.

4. Discussion

Plant materials shrank as they were dried and developed a crisp texture, which made it simpler to ground them into a powder for further research. According to accepted methods for drying seaweed, the drying conditions were selected. Generally, solar drying is the least expensive drying method [13], whereas freeze drying is more expensive than other drying methods [23].

The proximate composition of the dried seaweed samples was greatly impacted by the drying techniques. The three drying processes' proximal compositions differed

Table 3: Fatty acid composition (relative percentage, %) of dried red seaweed, *Gracilariopsis longissima*, by different processed methodologies.

Fatty acids (relative percentage (%))	Drying method		
	Freeze dried	Oven dried	Sun dried
Myristic acid (C14 : 0)	4.76 ± 0.00^{b}	4.85 ± 0.01^{a}	4.87 ± 0.01^{a}
Palmitic acid (C16 : 0)	39.64 ± 0.03^{b}	39.61 ± 0.04^{b}	40.91 ± 0.06^{a}
Palmitoleic acid (C16 : 1)	11.12 ± 0.02^{a}	10.52 ± 0.02^{c}	10.8 ± 0.02^{b}
Stearic acid (C18 : 0)	1.52 ± 0.00^{c}	1.72 ± 0.00^{b}	1.82 ± 0.01^{a}
Oleic acid (C18 : 1)	21.50 ± 0.02^{b}	23.63 ± 0.03^{a}	21.04 ± 0.04^{c}
Linoleic acid (C18 : 2)	4.52 ± 0.01^{a}	4.06 ± 0.01^{c}	4.28 ± 0.01^{b}
Linoleic acid (C18 : 3)	8.12 ± 0.02^{a}	7.52 ± 0.02^{c}	7.93 ± 0.02^{b}
Eicosenoic acid (C20 : 1)	2.57 ± 0.01^{a}	2.47 ± 0.00^{b}	2.55 ± 0.02^{a}
Arachidonic acid (C20 : 4)	3.20 ± 0.02^{a}	2.68 ± 0.01^{c}	2.91 ± 0.01^{b}
Docosahexaenoic acid (C22 : 6)	3.05 ± 0.01^{a}	2.94 ± 0.01^{b}	2.89 ± 0.00^{c}
UFA/SFA	1.18 ± 0.02^{a}	1.16 ± 0.02^{a}	1.10 ± 0.01^{b}
$\omega 3/\omega 6$	1.45 ± 0.01^{c}	1.55 ± 0.01^{a}	1.50 ± 0.02^{b}

Mean values and standard deviation of measurements for the three replicates. Different superscripts in a row differ significantly ($P < 0.05$).

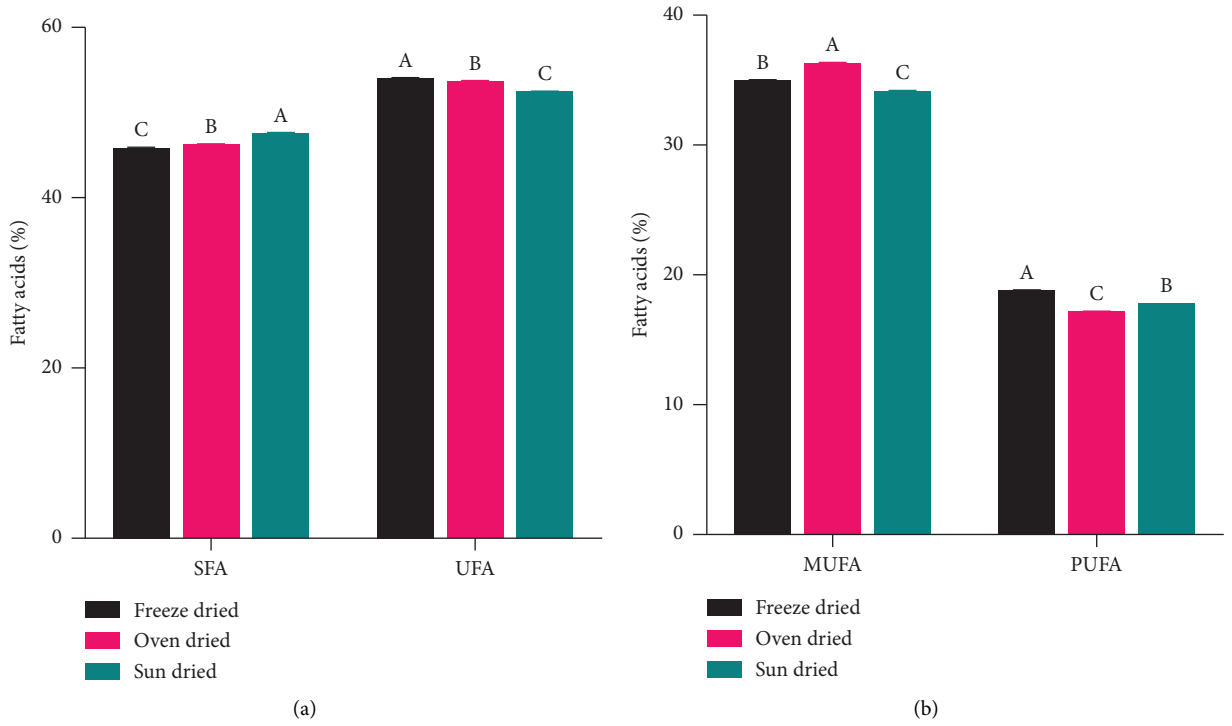

Figure 2: (a) Saturated fatty acid (SFA) and unsaturated fatty acid (UFA) compounds (%) and (b) monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) compounds (%) of dried red seaweed, *Gracilariopsis longissima*, by different processed methodologies. Error bars are standard errors. Different small letters over bars denote significant differences at $P < 0.05$.

significantly ($P < 0.05$). The range of moisture content from the three distinct drying techniques was from 88.01 ± 0.49 to $90.24 \pm 0.52\%$ of fresh weight, and there were significant variations ($P < 0.05$) among them. Compared to the oven-dried and sun-dried samples, the moisture content for freeze-drying was much greater. This is because freeze-drying eliminates freezable water and operates on the concept of sublimation under vacuum, whereas the other procedures are dependent on temperature, humidity, and air velocity [24]. High protein levels were found across all drying techniques. Protein concentrations varied from 27.26 ± 0.4 to $30.63 \pm 0.90\%$ of dry weight. This variation in protein concentration might simply be the result of different drying techniques being utilized. In comparison to other drying procedures employed in this investigation, samples that had been freeze-dried had more protein. These results agree with Sappati et al. [24], Uribe et al. [14], Badmus et al. [25], Regal et al. [12], and Uribe et al. [15], but they are in contrast to total proteins in Chan et al. [26], Wong and Chikeung Cheung [27], Neoh et al. [13], and López-Hortas et al. [28]. In order to facilitate the extraction of protein from seaweed, it would seem reasonable that freeze drying would

Table 4: Total phenolic and flavonoid contents of dried red seaweed, *Gracilariopsis longissima*, by different processed methodologies.

Drying methods	Total phenolic content (mg GAE/g dry weight)	Total flavonoid content (mg QE/g dry weight)
Freeze dried	88.70 ± 2.19^{a}	71.46 ± 2.17^{a}
Oven dried	81.53 ± 2.38^{b}	69.55 ± 2.51^{a}
Sun dried	73.85 ± 2.27^{c}	60.16 ± 1.97^{b}

Mean values and standard deviation of measurements for the three replicates. Different superscripts in a row differ significantly ($P < 0.05$).

be the ideal method of drying seaweed. This is because high-temperature drying procedures are likely to promote denaturing of the protein, which may make the protein less amenable to extraction. The various drying conditions led to a significant variation in the total lipid content. These findings support those of Neoh et al. [13], Uribe et al. [14], Uribe et al. [15], and López-Hortas et al. [28], who similarly showed variations in the lipid content of dried seaweed under various techniques; however, they disagree with Chan et al. [26]. According to Rodriguez et al. [29] and Wells et al. [30], the existence of this variance in lipid content after drying may be related to the heat input mechanisms of the various drying methods and a result of the extended time of drying that facilitated melting lipids to drip out from berries as a result of oxidation of lipids. According to this study, *G. longissima* has a significant amount of carbohydrates (more than 30% dry weight), which is similar to the study by Neoh et al. [13], Sappati et al. [24], and López-Hortas et al. [28]. However, the various drying techniques resulted in a substantial change in the total carbohydrate content. Seaweed has a greater ash concentration than any terrestrial plant [24]. This makes it an excellent source of primary macro and trace nutrients. The technique used for drying *G. longissima* samples had a substantial impact on the ash content. In the current study, the ash content of *G. longissima* varied from 22.25 ± 1.1 to $24.71 \pm 1.2\%$ of dry weight.

A high-quality diet that emphasizes vital nutrients should be used as support for the avoidance of malnutrition or illnesses that are connected to it. Due to their rich nutritional makeup, the inclusion of edible seaweeds in dietary choices can thus make it easier to maintain a balanced, healthy diet [28]. When the seaweed samples were dried using various methods, their mineral concentrations (Na, K, Ca, Mg, P, and S) varied substantially. These findings are consistent with Chan et al. [26] and López-Hortas et al. [28]. Freeze-dried samples of seaweed had the greatest concentrations of all minerals, except phosphorus and sulfur, among the three drying techniques. According to this study, *G. longissima* has higher concentrations of minerals, i.e., potassium, calcium, and sulfur than the other minerals. In this investigation, the Na/K value is under 1. According to the World Health Organization's diet recommendations, this edible marine product can be used to make meals for those who have symptoms of high blood pressure since the ratio of Na and K is close to 1 [31]. The longer exposure to air and its leaching impact during the drying process may be the cause of the considerably reduced mineral concentrations in the oven- and sun-dried seaweed samples. The preservation of most minerals within the samples was likely optimized through a rapid drying technique such as freeze-drying.

Aside from being the building blocks of proteins and essential nutrients for the development, growth, and health of humans and animals, amino acids are significant for their numerous regulatory roles in cells [32]. According to Wu [32], functional amino acids are recognized to control important metabolic pathways required for immunity, development, reproduction, and maintenance. It is generally recognized that amino acids can be lost, altered, or even destroyed during processing due to drying methods [14, 27]. According to this study's findings, there are substantial changes ($P < 0.05$) in amounts of each individual amino acid from the three different drying processes. In comparison to the other procedures, freeze-dried samples tended to have greater levels of total amino acids (essential and nonessential). The findings of Uribe et al. [14], Badmus et al. [25], and Uribe et al. [15] are comparable to this one. Tyrosine was found to predominate in the studied samples, which is contrary to Uribe et al. [15], who indicated that histidine was prominent. This finding is comparable to the amino acids profile described for the other seaweed species [14, 26]. A protein's nutritional value is primarily influenced by the quantity, ratio, and accessibility of its important amino acids. Although there were also acceptable amounts of nonessential amino acids, essential amino acids made up the majority of the seaweed's amino acid composition. The nonessential amino acids that were most prevalent were aspartic acid, glutamic acid, arginine, and glycine. Aspartic acid and glutamic acid were found to be the most prevalent nonessential amino acids in previous studies on several species of red seaweeds because they are responsible for the distinctive flavor and taste of seaweed [33]. According to Ranieri et al. [34], the diverse amino acid profiles obtained from various drying processes show that the drying method has an impact on the proteolytic activity during the process. Nevertheless, even after drying by any of the examined techniques, *G. longissima* remains to be a useful source of amino acids.

With the exception of Stabili et al. [10], who solely looked at the fatty acid profiles of *G. longissima*, there is no research on this species' protein and lipid fraction components. This experiment is the first to examine how various drying techniques affect this seaweed. Despite having a low fat content [35], seaweed is an essential functional ingredient due to its higher content of essential fatty acids, such as omega-3 and omega-6, than the majority of common terrestrial crops [36]. Comparing the three drying techniques, there were significant variations in the fatty acid profiles of *G. longissima*. This is consistent with the research by Neoh et al. [13], Uribe et al. [14], Badmus et al. [25], and Uribe et al. [15], whereas Wong and Chikeung Cheung [27] and Sappati et al. [24] found no discernible change in the fatty acids profile as a result of drying treatment. In comparison to the other methods, freeze-dried samples had much lower levels of saturated fatty acids (SFAs) and significantly greater levels of

polyunsaturated fatty acids (PUFAs). Due to their susceptibility to oxidation and degradation, PUFAs are thought to be influenced by the drying process [37]. According to Chan and Matanjun [38], eating more PUFA-rich foods and consuming less saturated fat both reduce the risk of heart disease. According to Hamid et al. [36], the $\omega 3/\omega 6$ ratio in prehistoric human diets was around 1 : 1. The drying methods used in the current study had an impact on the $\omega 3/\omega 6$ ratio; however, all treatments had a $\omega 3/\omega 6$ ratio that was near to 1. Prior studies by Ortiz et al. [39] and Uribe et al. [14] revealed a similar $\omega 3/\omega 6$ ratio. Due to a favorable $\omega 3/\omega 6$ ratio and the greater PUFA content, the fatty acid profile of dried *G. longissima* suggests that it has promise as a functional food.

According to Dang et al. [40] and Sappati et al. [24], seaweed contains significant levels of phenolic and flavonoid contents, which are also known to have antioxidant properties. The phenolic and flavonoid contents found in seaweed are extremely heat sensitive; as a result, processing conditions can significantly change their chemical activity [40]. Methanol was chosen as the extraction solvent in this investigation because of its better performance in other experiments [41, 42]. The phenolic and flavonoid components of *G. longissima* are significantly affected by the drying techniques ($P < 0.05$). The freeze-dried samples had the most phenolic and flavonoid components present. Wong and Chikeung Cheung [27], Sappati et al. [24], Uribe et al. [15], and Regal et al. [12] all came to similar conclusions. According to Sappati et al. [24], the greatest value in the freeze-dried sample may be owing to reduced oxidation at low temperatures and in the absence of much air under vacuum while drying, which led to generally higher amounts of phenolic and flavonoid contents. The least amount of phenolic and flavonoid contents was found in sun-dried extracts. Most of the research [13] showed that sun drying had the lowest phenolic and flavonoid contents. Our current finding was in line with those findings.

5. Conclusion

This is the first study to compare the effects of freeze, oven, and sun drying on the nutritional composition, fatty acids profile, amino acids profile, and phytochemical properties of red seaweed, *Gracilariopsis longissima*. In summary, various drying techniques had an impact on the nutritional content, amino acids, fatty acids, and phytochemical properties, suggesting that they change depending on the degree of dehydration. When compared to oven and sun drying techniques, the current study revealed that freeze drying is the most suitable drying method for maintaining the analyzed components of this seaweed. It is important to conduct more research on the seasonal variations in the nutritional constitution of this species and other kinds of seaweed, including the green and brown seaweeds from Bangladesh.

Data Availability

The data used to support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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