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Research Article

Evaluation of Chemical, Functional, Spectral, and Thermal Characteristics of *Sargassum wightii* and *Ulva rigida* from Indian Coast

Yogesh Kumar,[1] **Ayon Tarafdar**,[2,3] **Deepak Kumar**,[1] **Kiran Verma**,[1] **Manjeet Aggarwal**,[4] **and Prarabdh C. Badgujar**[1]

[1]*Department of Food Science and Technology, National Institute of Food Technology Entrepreneurship and Management, Kundli-131 028, Sonipat, Haryana, India*
[2]*Department of Food Engineering, National Institute of Food Technology Entrepreneurship and Management, Kundli-131 028, Sonipat, Haryana, India*
[3]*Livestock Production and Management Section, ICAR-Indian Veterinary Research Institute, Izatnagar, 243122 Bareilly, Uttar Pradesh, India*
[4]*Department of Basic and Applied Sciences, National Institute of Food Technology Entrepreneurship and Management, Kundli-131 028, Sonipat, Haryana, India*

Correspondence should be addressed to Prarabdh C. Badgujar; prarabdh.badgujar@gmail.com

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Usage of seaweeds as a functional food/food ingredient is very limited due to paucity of scientific information about variations in the nutritional composition of seaweeds under diverse climatic conditions. *Sargassum wightii* and *Ulva rigida* seaweeds are found abundantly on the Southern Indian coastline and were thoroughly evaluated in this work. Crude fiber and lipid of *S. wightii* were higher (24.93 ± 0.23% and 3.09 ± 0.41%, respectively) as compared to *U. rigida*; however, *U. rigida* had higher crude protein content (27.11 ± 0.62%). Evaluation of mineral and CHNS content indicated that the concentration of potassium, magnesium, and calcium was 1.36 ± 0.08 mg/g, 8.39 ± 0.80 mg/g, and 14.03 ± 3.46 mg/g, respectively, that was higher in the *S. wightii*, whereas *U. rigida* contained higher value of iron, carbon, and sulphur (0.70 ± 0.13 mg/g, 37.72 ± 4.63%, and 2.61 ± 0.16%, respectively). Swelling capacity (19.42 ± 0.00 mL/g DW to 22.66 ± 00 mL/g DW), water-holding capacity (6.15 ± 0.08 g/g DW to 6.38 ± 0.14 g/g DW), and oil-holding capacity (2.96 ± 0.13 g/g DW) of *U. rigida* were significantly ($p < 0.05$) higher as compared to *S. wightii*. It was observed from DSC thermograms that *S. wightii* can be safely processed for food formulations even at a temperature of 134°C. The thermograms also revealed changes in the sulphated polysaccharide (fucoidan) profile due to the presence of hydroxyl and carboxyl groups with denaturation of proteins. TGA of *S. wightii* and *U. rigida* showed degradation temperature within the range of 200–300°C due to divergent polysaccharide compositions. FTIR spectroscopy suggested the presence of phenolic groups in both seaweeds (at 1219 cm^{-1}). Results of the study suggested that the manufacturing of functional food products from seaweeds could be beneficial and may aid in social upliftment of cultivators/fishermen.

1. Introduction

Seaweeds are potential source of bioactive compounds, phytochemicals, polysaccharides, dietary fibre, ω-3 fatty acids, essential amino acids, vitamins, and minerals such as calcium, potassium, sodium, and phosphorous [1]. Bioactive compounds extracted from seaweeds have many therapeutic properties such as antioxidant, anti-inflammatory, and antimicrobial activity [2]. The proximate composition, nutrients, and bioactive compounds present in seaweeds depend on several factors such as species, oxygen concentration, salinity of water, climatic season, intensity of UV radiation, and area of production [3, 4]. Seaweeds growing under such harsh conditions generate several

secondary metabolites that prevent their structural damage [5]. Commercially, seaweeds are utilized for extraction of stabilizers, thickening agents, agar, and gelling agents with diverse industrial applications.

Usage of seaweeds in Oriental and some European populations is significant, but not so among the Indian population. Countries like Japan, Malaysia, and France have legalized seaweeds as vegetables and condiments [6]. Indian coastal region is a rich source of seaweeds. Southern and South-eastern coast (Mandapam, Palk of Bay) of India are an industrial hub for seaweed cultivation, harvesting, and processing. Several species of brown, green, and red seaweeds are cultivated, as well as found, abundantly. Some genera of edible seaweeds among these are consumed by the coastal population but not by majority of the mainland people. Also, use of edible seaweeds in processed form is very scarce in India owing to palatability issues and unavailability of scientific data. Seaweeds therefore can be processed to bring them into palatable form, fit for various food applications considering their abundant availability, and miniscule consumption in the Indian diet. Moreover, due to growing consumer demand for nutritious food, seaweed can be easily popularized within the masses after establishing a strong scientific backbone to its merits.

Among brown seaweeds, *Sargassum* is an important genus. It is a good source of carbohydrate, minerals, proteins, essential amino acids (e.g., arginine, tryptophan, and phenylalanine), β-carotene, and vitamins [7]. Indian coast has more than 56 *Sargassum* species, and some species such as *Sargassum siliquosum* are utilized by local populations as an ingredient in salad, fish soup, and rice dishes [8]. Among *Sargassum*, *S. wightii* grows abundantly throughout the year on both eastern and western coasts. Significant variations in the nutritional composition of *S. wightii* have been reported with respect to seasonality and vegetative parts [7]. However, there are not many reports about its spectral and thermal characteristics and its relation with proximate, nutritional composition and functional properties. The present study is an attempt to elucidate these characteristics of *S. wightii*.

Same is the case of green seaweed (Chlorophyta). More than 43 genera of Chlorophyta have been recognized at the Indian coastal region [8]. In the Chlorophyta, *Ulva* is cultivated majorly. *Ulva* has various therapeutic properties due to the presence of ulvan, a sulfated polysaccharide that has antioxidant, antitumor, anticoagulant, immunomodulatory, wound dressing, tissue healing, and heavy metals binding ability [9, 10]. Among *Ulva*, *Ulva rigida* is a green macroalgae widely distributed in tropical oceans and Indian coastline. It is widely distributed in the Mandapam and adjacent areas of Tamil Nadu, south-eastern and Gujarat coast of India, respectively [7]. *Ulva* species is consumed in raw form or in soup preparations among the coastal residents [11].

Despite our best efforts, we could not find a study wherein thermal and spectral properties of these seaweeds are reported, and data regarding these properties shall help in processing of these seaweeds to formulate various processed food products, as well as functional foods/nutraceuticals. However, ulvan (sulfated polysaccharide) extracted from *Ulva lactuca* (Monastir-Tunisia Coast) was thermally characterized, and it was reported that these polysaccharides showed stability even at 180°C, while rhamnose sulphate and uronic acid functional groups were observed through infrared spectroscopy [12]. Thus, the aim of the present study was to catalogue the proximate composition, functional properties, and thermal and spectral attributes of *S. wightii* and *U. rigida* seaweeds. We believe that the results of this investigation will be of immense help to food processing and nutraceuticals industries in order to come up with processed products or functional foods, whereby seaweed consumption can be increased in mainstream population.

2. Materials and Methods

2.1. Chemicals. Petroleum ether, boric acid, sodium hydroxide, hydrochloric acid, and nitric acid were purchased from Thermo Fischer, India. Corn oil was procured from Sigma-Aldrich (Bangalore, India). All other solvents and chemicals used were of analytical grade.

2.2. Seaweed Collection and Processing. Green (*Ulva rigida*) and brown (*Sargassum wightii*) seaweeds were obtained from the seaweed traders from Kanyakumari (8°05'02"N 77°32'46"E) Tamil Nadu, India, and Mandapam (9°17' N and 79°11' E), Tamil Nadu, India, in September 2018 with the help of scientists of the research institute, CSIR-Central Salt and Marine Chemicals Research Institute, Mandapam, India. Collected seaweed was cleaned with tap water to remove epiphytes, sand, and debris and then shade-dried at room temperature up to a total moisture content of $21.53 \pm 0.05\%$ (wet basis). The shade-dried seaweeds were ground to powder using a mixer-grinder and passed through an 850 micron screen. The dried seaweed powder was stored at −20°C in air tight bags for further analysis.

2.3. Estimation of Chemical Composition of Seaweeds. Proximate composition including total carbohydrates, crude fat, crude protein, crude fiber, total ash, and total moisture content of seaweeds was determined according to AOAC [13]. The values are reported in % dry weight (DW) basis.

2.4. Functional Properties of Seaweeds

2.4.1. Swelling Capacity (SWC). Swelling capacity of *U. rigida* and *S. wightii* was measured by bed volume technique [6, 14]. Briefly, 200 mg of dried seaweed powder was taken and mixed with 20 mL of deionized water and stirred vigorously. The effect of temperature on SWC was measured by keeping tubes at 25°C and 37°C for 24 h. SWC of the seaweeds was calculated using the following formula:

$$\text{SWC} = \text{initial volume of water (mL)} - \text{volume of water after incubation (mL)}. \quad (1)$$

The swelling volume was expressed as mL of swollen sample per gram of sample dry weight.

2.4.2. Water Holding Capacity (WHC). Water holding capacity of both seaweeds was measured by a modified centrifugation method [6, 14]. Briefly, 200 mg of dried seaweed powder was taken and mixed with 20 mL deionized water in the centrifuge tube. The tubes were kept in an incubator shaker (New Brunswik Scientific, Eppendorf AG, Germany) at 25°C and 37°C for 24 h. Sample was centrifuged (Sigma 3-18KS, Germany) at 14000 g at 37°C for 30 min, and supernatant was discarded. The wet weight of *U. rigida* and *S. wightii* was noted. Samples were then kept in an oven at 120°C for 2 h, and their dry weight was taken. WHC of *U. rigida* and *S. wightii* was calculated using the following formula:

$$\text{WHC} = \text{wet weight of the sample (g)} - \text{dry weight of the sample (g)}. \quad (2)$$

WHC was expressed as weight in grams of water held by 1 g of dried sample.

2.4.3. Oil Holding Capacity (OHC). According to the method of Wong and Cheung [6], OHC of both seaweeds was measured. Briefly, 3 g of dried seaweed powder was mixed with 10.5 g of corn oil in a centrifuge tube. Tubes were kept in the shaker for 30 min at room temperature followed by centrifugation at 2500 g for 30 min, and oil supernatant was collected. OHC was calculated using the following formula:

$$\text{OHC} = \text{initial volume of oil (g)} - \text{volume of oil after incubation (g)}. \quad (3)$$

The OHC was expressed as number of grams of oil held by 1 g of dried seaweed.

2.5. Determination of Minerals in Seaweeds. Samples were prepared using wet digestion method [15] with minor modifications. Briefly, 0.4–0.5 g sample was taken in a 50 mL beaker. To this, 1 mL of hydrogen peroxide was added for oxidation. Sample was digested using 5 mL concentrated nitric acid (69%) with constant heating at 70°C in a water bath. Digestion was continued for 1.5–2 h till attainment of a pale yellow color. Digested sample was transferred to a 50 mL volumetric flask, and the volume was adjusted using Milli-Q water. Metal composition in seaweeds was determined using an ICP-OES (Optima 7000 DV, Perkin Elmer). A multielement standard was used for analysis of minerals. The equipment was calibrated using different concentrations of the standard (5, 10, 25, 50, and 100 ppb) in 5% HNO_3. Reference blank was taken as diluted (5%) HNO_3. Analysis was carried out in triplicates. Results were expressed in mg/kg of seaweeds.

2.5.1. Estimation of Elemental Content of Seaweeds Using the CHNS Analyzer. Carbon, hydrogen, nitrogen, and sulphur content in the shade-dried seaweed samples were determined using the CHNS/O elemental analyzer (Euro EA Elemental Analyzer, Germany).

2.6. Determination of Thermal Properties. Thermal properties were analyzed using a differential scanning calorimeter (DSC) (NETZSCH, Germany) and thermogravimetric analyzer (TGA) (NETZSCH, Germany). Both experiments were performed under a nitrogen atmosphere. For TGA test, 5–10 mg of the test sample was placed into an aluminum pan, and a scan was performed under a temperature range of 20 to 600°C. The heating rate was kept at 10°C/min. For DSC analysis, approximately 5–10 mg of shade-dried seaweed powder was taken in a DSC aluminum pan and hermetically sealed using a lid. The sealed pan was loaded into the equipment at room temperature. An empty pan was used as reference. Flow rate of nitrogen was adjusted at 60 and 40 mL/min in purge lines 1 and 2, respectively. Heating was linearly ramped from 30°C to 250°C at a rate of 10°C/min.

2.7. Fourier Transform Infrared (FTIR) Spectroscopy. Shade-dried seaweed powder was analyzed using Fourier transform infrared (FTIR) spectrometer (Alpha Bruker, USA) at the wavenumber range of 4000–600 cm^{-1} with resolution of 4 cm^{-1} and 22 spectral scans. Samples were analyzed by Attenuated Total Reflectance (ATR) technology using a ZnSe crystal, and the spectrum of each sample was normalized with the background measurement. Smoothening of the sample spectra was done using Opus computer software.

2.8. Statistical Analysis. All measurements were carried out in triplicate (three separate lots of each seaweed species), and the values were reported as mean ± standard deviation. Data were analyzed with independent sample t test using SPSS statistical software package v.20 (IBM, USA) at 5% level of significance ($p < 0.05$).

3. Results and Discussion

3.1. Chemical Composition. Table 1 shows proximate composition of brown (*S. wightii*) and green (*U. rigida*) seaweed. Crude protein content of *S. wightii* (6.43% DW) and *U. rigida* (27.11% DW) was found to be within the range of that reported for brown (3–15% DW) [7] and green (10–47% DW) seaweeds [6], respectively. Also, Balar et al. [16] reported protein content of *U. rigida* collected from Indian coastline in the range of 4.14–26.0% DW. Crude protein of *U. rigida* showed significantly ($p < 0.05$) higher value as compared to *S. wightii*. However, the crude protein of the *S. wightii* was found to be lower than that of other *Sargassum* species (8–16.9% DW) [7]. Higher protein in green seaweeds is in agreement with previous reports [17]. Furthermore, the crude protein content of *S. wightii* and *U. rigida* was almost comparable to the same species found in the Saurashtra coast

Table 1: Proximate composition (%) of *S. wightii* and *U. rigida*.

Composition (% DW)	*S. wightii*	*U. rigida*
Crude protein	6.43 ± 0.39	27.11 ± 0.62*
Total ash	19.87 ± 0.34	19.63 ± 0.63
Crude fibre	24.93 ± 0.23*	18.65 ± 0.78
Total carbohydrate	45.66 ± 0.50*	31.87 ± 0.26
Crude lipid	3.09 ± 0.41	2.71 ± 0.70
Total moisture	21.33 ± 0.05	22.61 ± 0.80

Results are expressed as mean ± ($n = 3$). Values bearing * are significantly different ($p < 0.05$) from the corresponding column/seaweed in an independent sample t test. DW, dry weight.

(Western Indian coast: 8% DW) and in the Portuguese coast (29.5% DW), respectively [7, 18]. Kasimala et al. [4] reported similar results of protein in brown seaweed, *S. subrepandum* (6.93%) collected from Eritrean red sea coast of Gurgussum and Hirgigo bay. Variations in the crude protein content were reported to be proportional to thallus maturation of the *S. wightii* with higher crude protein content in the winter season (January–March) at the time of their developing phase, and lower protein content has been reported in the months of July to September on the southern Indian coast [7]. Thus, crude protein content found in our *S. wightii* correlates well with the results of Kumar et al. [7]. Similar range of protein content in seaweeds was also reported by Rohani-Ghadikolaei et al. [19]. Protein content has been reported to vary with type of species and seasonal variations [6, 20].

Total ash content of *S. wightii* and *U. rigida* is observed as 19.87% DW and 19.63% DW, respectively, which was comparable to the reports of Wong and Cheung [6]. Total ash content of *U. rigida* was slightly lower than other *Ulva* species such as *U. lactuca* and *U. pertusa* [1].

Crude fiber content of *S. wightii* (24.93% DW) was significantly ($p < 0.05$) higher than *U. rigida* (18.65% DW) (Table 1). Crude fiber of *S. wightii* was found to be higher than the total dietary fiber of same species of *Sargassum*, while *U. rigida* showed lower value of crude fiber than other *Ulva* species [21]. Seaweeds are rich in dietary fibers. Soluble fraction of dietary fibers exhibits important functional properties such as antimutagenic, antioxidant, and anticoagulant [6, 22]. However, insoluble fibers and their physiological effects need much attention for further analysis.

In the present study, total carbohydrate content of *S. wightii* (45.66%) is significantly ($p < 0.05$) higher than *U. rigida* (31.87%) (Table 1). Kumar et al. [7] reported 48.9–57.2% total carbohydrate content in the thallus portion of the *S. wightii* (Western Indian coast), which was comparable to the present study and 33.5% in *S. polycystum*, 18% in *S. myriocystum*, while other species of *Sargassum* were reported to have higher carbohydrate content such as *S. thunbergii* (67.2%) (Jeju Do Island, Korea) and *S. vulgare* (67.8%) (Buzios beach in the Northwest of Brazil). Balar et al. [16] reported 16.63–65.93% DW carbohydrate content in Indian seaweed *U.* rigida. Total carbohydrate content is related to the soluble and insoluble carbohydrate content of the *S. wightii* (Tamil Nadu, India) and highest values found in March and lowest in July [7].

Lipid content of seaweeds generally ranges from 1 to 3% [6]. In the present study, crude lipid content of *S. wightii* and *U. rigida* was found to be 3.09% and 2.71%, respectively (Table 1). However, lipid content of same species of *Sargassum* was comparable, ranging from 2 to 3%, and other species of *Sargassum* were found to be less than 1%; e.g., 0.3% in *S. thunbergii*, 3.8% in *S. echinocarpum*, and 2.0% in *S. ilicifolium* [7,19]. Also, same species of *U. rigida* from Portuguese cost showed similar result of lipid content (2%). Lipid content of other species of *Ulva* was also comparable to *U. fasciata* (1.83%), *U. reticulata* (2.03%), and *U. lactuca* (3.6%) [19, 23]. Wong and Cheung [6] reported 14.6% lipid content of *Ulva lactuca* that was lower from the *U. rigida*, whereas Balbar et al. [16] reported 0.8–3.1% lipid content in *U. rigida* collected from Indian coastal line. Lipid content of the *Sargassum* differs with seasonal variation (least increased from July to March) and the species of the seaweed. Young blades and thallus portion of *S. wightii* were reported to have highest and least amounts of lipids, respectively [7].

Moisture is a quality factor in the preservation of food products and affects stability of the food materials [21]. The total moisture content of *S. wightii* (21.22%) and *U. rigida* was observed to be 21.22% and 22.61%, respectively. Syad et al. [21] reported similar value of moisture content of same species of *Sargassum* (22.4%). Wong & Cheung [6] reported lower value 10.6% of *U. lactuca* than *U. rigida*.

3.2. Functional Properties. Figure 1 illustrates functional properties (SWC, WHC, and OHC) of *S. wightii* and *U. rigida*. SWC and WHC of *S. wightii* and *U. rigida* increased with the increase in temperature. At 25°C, SWC of *S. wightii* was 12.71 ± 0 mL/g dry weight (DW), which increased to 15.89 ± 0 mL/g DW at 37°C. Similarly, WHC of *S. wightii* increased from 5.83 ± 0.04 g/g DW (at 25°C) to 5.92 ± 0.14 g/g DW (at 37°C).

In case of *U. rigida*, the SWC and WHC were 19.42 ± 0.00 mL/g DW and 6.15 ± 0.08 g/g DW, respectively, at 25°C, which increased slightly to 22.66 ± 00 mL/g DW and 6.38 ± 0.14 g/g DW. The value of WHC at 25°C and 37°C of *U. rigida* is significantly ($p < 0.05$) higher as compared to *S. wightii*. These values are higher than those reported for *S. wightii* (Gulf of Mannar, India) and *U. lactuca* (A Ma Wan, Hong Kong) [6, 14, 22].

WHC of *S. wightii* and *U. rigida* was lower than that reported for *G. edulis*, *Hypnea japonica*, *Hypnea charoides*, *U. lactuca*, *Laminaria*, and *Wakame* at 37°C. WHC value of both seaweeds at similar temperature was higher than the WHC of *S. wightii* (5.72 ± 0.14 g/g DW), *Fucus* (5.48 ± 0.42 g/g DW), and *Nori* (5.12 ± 0.15 g/g DW), which showed comparable results [22, 24].

SWC and WHC of seaweeds depend largely on the amount of protein and total dietary fibers present in their composition [6]. Also, lesser particle size with more surface area indicates higher WHC [25]. Both SWC and WHC directly affect the texture, mouthfeel, and freshness of the food products. Therefore, these help in avoiding loss of moisture from the products during processing [26]. In this study, SWC and WHC values were observed to increase with

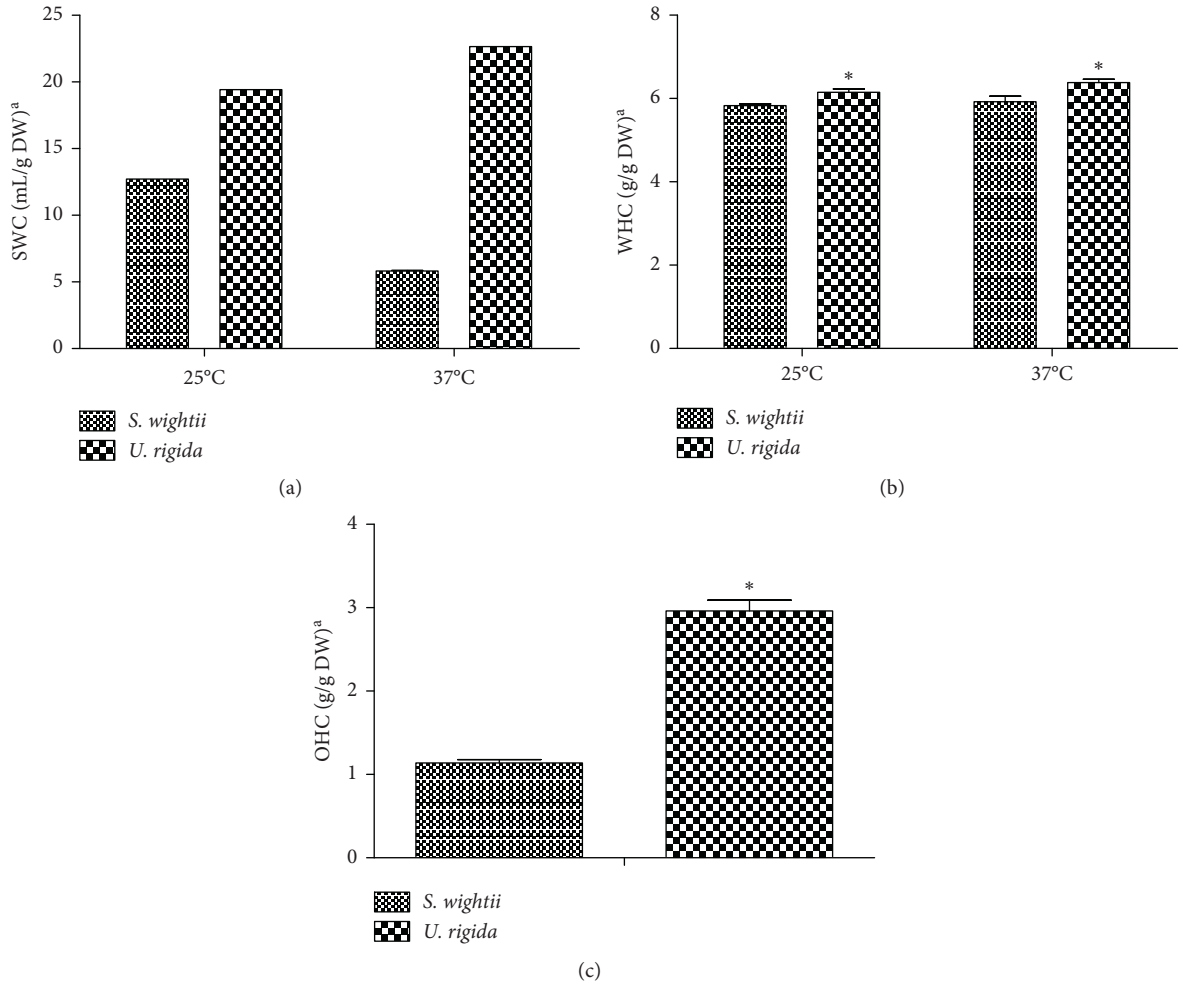


Figure 1: Functional properties of seaweeds *S. wightii* and *U. rigida*. [a]Results are expressed as mean ± SD ($n = 3$). Values bearing * are significantly different ($p < 0.05$) from the corresponding seaweed in an independent sample t test.

temperature, which may be due to the increased solubility of fibers and proteins that contribute to the functional behavior [21]. Among the two seaweeds, *U. rigida* showed higher SWC and WHC, which shows its potential for use as functional ingredient to modify texture and viscosity, avoid syneresis, and reduce calories [6].

OHC value of *U. rigida* (2.96 ± 0.13 g/g DW) was found to be significantly ($p < 0.05$) higher than *S. wightii* (1.14 ± 0.04 g/g DW) (Table 2). Comparable results were reported for *Laminaria, Nori*, and *G. edulis*, while it was higher than that of *H. japonica*, *H. charoides*, and *U. lactuca* [14, 22, 24]. According to Wong and Cheung [6], the hydrophobicity of proteins helps in fat absorption. The mechanism of OHC is mainly due to physical entrapment of oil by capillary attraction. Therefore, different proportions of polar side chains of amino acids present on the surface of protein molecules are responsible for variation in OHC of seaweeds. OHC of seaweeds is also related to hydrophilic nature, overall charge density, and particle size of the individual particles.

Table 2: Mineral composition of *S. wightii* and *U. rigida* analyzed by ICP-OES.

Name of the element	Observed concentration (mg/g)	
	S. wightii	*U. rigida*
Mg	8.39 ± 0.80*	6.07 ± 0.49
P	0.32 ± 0.00	0.44 ± 0.01*
K	1.36 ± 0.08*	0.27 ± 0.03
Ca	14.03 ± 3.46*	2.39 ± 0.17
Fe	0.30 ± 0.03	0.70 ± 0.13*
Cr	0.002 ± 0.00	0.003 ± 0.00
Mn	0.008 ± 0.00	0.02 ± 0.00*
Cu	0.007 ± 0.00	0.02 ± 0.01

Results are expressed as mean ± ($n = 3$). Values bearing * are significantly different ($p < 0.05$) from the corresponding column/seaweed tested in an independent sample t test.

3.3. Mineral Content. Table 2 shows mineral and trace element analysis of *S. wightii* and *U. rigida*. Analysis revealed higher potassium (1.36 ± 0.08) and calcium (14.03 ± 3.46)

content in *S. wightii* as compared to *U. rigida*. Potassium plays an important role in electrical conductivity and functioning of brain [21], whereas seaweed-sourced calcium (calcium carbonate) has been reported to be utilized more effectively as compared to cow milk's calcium [23]. *U. rigida* showed higher magnesium in comparison to *S. wightii* contain. Magnesium plays an important role in functioning of central nervous system and also helps in eliminating the symptoms of Parkinson's and Alzheimer's disease [21]. In addition to macrominerals, both the seaweeds contained trace elements, which also play a major function in the human body. Iron is one of the important trace elements, being a major component of hemoglobin. Iron content in *S. wightii* was found to be lower (0.30 mg/g) as compared to *U. rigida* (0.70 mg/g). Apart from iron, *S. wightii* and *U. rigida* had trace elements like chromium, manganese, and copper. Elemental bioaccumulation by seaweeds is affected by season, thallus age, pH, habitat, and exposure to residential and industrial effluents [23]. In the present study, *S. wightii* showed lower amounts of potassium, calcium, magnesium, iron, and copper as compared to that reported by Murugaiyan and Sivakumar [22] and Syad et al. [21] for *S. wightii* collected from Gulf of Mannar, India. This variation could be due to season, time of collection, climatic factors, etc. *Ulva rigida* showed slightly lower amounts of potassium, calcium, magnesium, iron, manganese, and copper as compared to the same species of *Ulva* obtained from northwest Iberian, Spain and Portuguese coast [24]. The results of mineral analysis hold significance for use of both seaweeds for nutraceuticals (dietary supplements functional foods industry). Also, Soares et al. [27] reported that subcritical water extracts of *Saccorhiza polyschides* (brown seaweed) are rich in minerals (Na, S, Ca, and Mg) that can be used in the development of fertilization products.

3.4. Elemental (CHNS) Composition. Table 3 shows carbon, hydrogen, nitrogen, and sulphur percentage of *S. wightii* and *U. rigida*. Nitrogen, sulphur, and hydrogen content of *U. rigida* was higher than that of *S. wightii*, while carbon content of *S. wightii* was found to be higher than *U. rigida*. Sulphur content of seaweeds represents amount of sulphur binds with the polysaccharides to form sulfated polysaccharides such as fucoidan in *S. wightii* and ulvan in *U. rigida*. These sulfated polysaccharides play critical role in free radical scavenging and show substantial antioxidant activity [12].

3.5. Decomposition and Glass Transition Temperature of Seaweeds. Thermogravimetric analysis (TGA) curves for *S. wightii* and *U. rigida* indicate the initial weight loss by water evaporation in the range of 0–100°C (*U. rigida* showed loss at 63.3°C) [28]. The decomposition of *S. wightii* and *U. rigida* occurred in the temperature range of 200–300°C, positioned at 282.4°C and 273.2°C, respectively (Figure 2(a)). Besides, *S. wightii* showed its second decomposition at 533.3°C. Chemical decomposition of organic material initiates at a temperature range of 200–300°C. At temperature ranges of 220–260°C and 315–390°C, decomposition of

Table 3: CHNS elemental analysis of *S. wightii* and *U. rigida*.

Seaweed	N %	C %	H %	S %
S. wightii	1.02 ± 0.06	33.16 ± 4.89	5.62 ± 0.79	0.70 ± 0.06
U. rigida	4.33 ± 0.09	37.72 ± 4.63	6.94 ± 0.82	2.61 ± 0.16

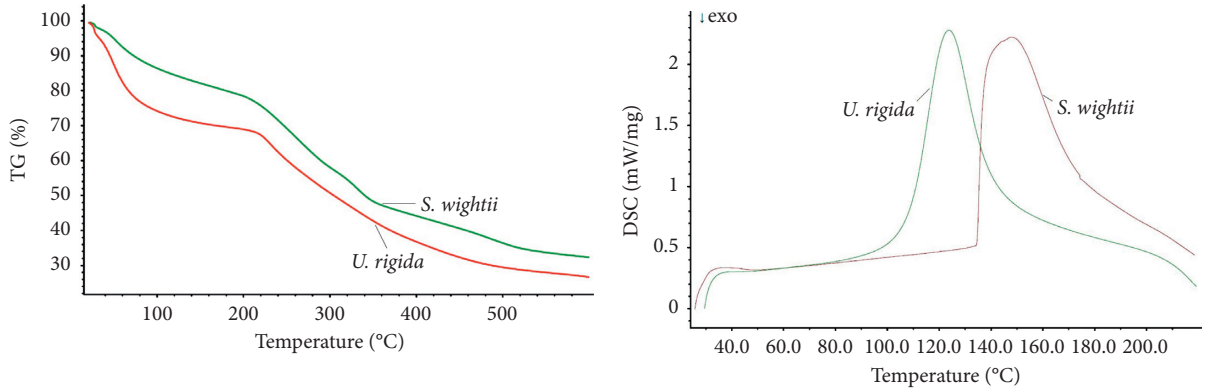
Results are expressed as mean ± SD ($n = 3$).

hemicellulose and cellulose, respectively, takes place [29]. For D-arabinose and D-mannose, pyrolysis reaction occurred at a temperature range of 120–310°C and for D-xylose within the range of 140–310°C [29], and final degradation above 500°C is associated with burning of carbonaceous residues triggered by intense heating [30].

Thermograms of the seaweed powder (*S. wightii* and *U. rigida*) showed a characteristic endothermic peak indicating their respective glass transition temperatures (T_g) and enthalpy. *S. wightii* and *U. rigida* exhibited a T_g of 134.7°C and 78.1 °C, respectively (Figure 2(b)). Glass transition temperature of *U. rigida* was found to be lower than *S. wightii.* This could be due to inter- and intramolecular hydrogen bonding formed by the polysaccharide hydroxyl and carboxylate groups [18]. Here, the lower T_g value of *U. rigida* may be due to higher concentrations of hydroxyl groups of polysaccharides. Rodriguez-Jasso et al. [20] reported that fucoidan extract of *Fucus vesiculosus* shows weight loss due to dehydration at a temperature range of 25°C and 110°C. They also reported that, at 120°C, pyrolysis of polysaccharide extract can take place, which could lead to phase transition.

Narrowing of the peaks was observed in both seaweed powders. The area under these peaks was used to determine the enthalpy of both seaweeds. Enthalpy of *S. wightii* and *U.* rigida was calculated as 224.484 J/g and 127.030 J/g, respectively. Increased enthalpy of *S. wightii* indicates more energy required for peptide and glycosidic bond-breakage. Therefore, the net enthalpy indicates the effects of endothermic events (breakdown of hydrogen bonds) [31]. Thermal data of both seaweeds provide appropriate temperature intervals, so that they can be used in the formulation of seaweed-based food products such as noodles. Kumar et al. [31] reported that glass transition temperature (T_g) of seaweed infused coffee varied from 121.3°C to 139.3°C that changes the flavor of seaweed infused coffee with increase in T_g. Therefore, only a specific range of temperature (<200°C) is appropriate for product formulation using seaweed, beyond which degradation could take place.

3.6. Functional Group Analysis. Table 4 shows the infrared spectrum analysis of the seaweeds in the form of % absorbance versus wave number (ν). *S. wightii* and *U. rigida* showed weak absorption peak above 3600 cm^{-1} which may be due to the presence of O-H stretching bend, which shows specific pattern of hydrated inorganic compounds [31]. Strong absorption peak was observed above 3200 cm^{-1} in *U. rigida*, while *S. wightii* showed weak absorption peak corresponding to N-H and O-H stretching possibly due to the presence of polysaccharides and amino acids, native to



(a) (b)

Figure 2: Thermograms of *S. wightii* and *U. rigida* from (a) TGA (20°C to 600°C) and (b) DSC (25°C to 250°C).

Table 4: FTIR absorption frequencies and functional group of *Sargassum wightii* and *Ulva rigida*.

Wavenumber		Functional group	Compounds	References
S. wightii	*U. rigida*			
3859	—	OH-stretching	Alcohol	[31]
3740	3750			[31]
3669	—			—
—	3245			—
2372	—	C-O stretching	Phosphorous	[10]
1684	1631	C=O stretching, N=O asymmetric stretching	Ester, pectin, amide	[32]
1527	1527	C=C stretching	Lignin	[32]
—	1417	C-O stretching, O-H bending	Cutin	[33]
—	1219	S=O stretching, C-O stretching	Sulphates, phenols	[33]
1023	1023	S=O stretching	Starch and polysaccharides	[33]
—	842	C-H bending	Glucose, galactose	[33]
699	666	C-S stretching, C=S stretching	Sulphates	[33]

seaweeds [31]. Weak absorption peak was observed above 2300 cm^{-1} in both seaweeds, which shows presence of C-O stretching. Strong absorption peak was observed above 1600 cm^{-1} indicating C=O, N=O stretching in both seaweeds suggesting a sign of ester and amide groups responsible for characteristic flavor of seaweeds [10, 32]. Peaks from 1400-1500 cm^{-1} and 1500–1600 cm^{-1} indicate several modes of C=C, C-O, O-H stretching, which may be due to the presence of lignin. Peaks above 1200 cm^{-1} and 650 cm^{-1} in both seaweeds indicate S=O, C-O, C-S, and C=S stretching resulting from the sulphate and phenols present in the seaweeds. Strong absorption peak at 1023 cm^{-1} in both seaweed points to S=O stretching indicating the presence of starch and polysaccharides. Weak absorption peak above 800 cm^{-1} in *U. rigida* corresponds to C-H stretching, which may be due to the presence of glucose and galactose [33]. Peaks above 1200 cm^{-1} in both seaweeds represent the phenol groups that indicate that both seaweeds are flourish in antioxidants, which can be utilized in development of functional food and their extract may be characterized for the bioactive compounds which can be useful in nutraceuticals formulation. It has also been reported that marine macroalgae produces wide variety of volatile organic compounds such as hydrocarbons, terpenes, phenols, alcohols, aldehydes, ketones, esters, fatty acids, and halogen or sulfur-containing compounds, which are responsible for its characteristic flavor and freshness, and these volatile compounds have been well identified by Spanish researchers in *U. rigida* [34].

4. Conclusions

The outcome of the present study is that we have very well documented proximate composition, few nutritional attributes, chemicofunctional properties, and thermal as well as spectral characteristics of seaweeds, *S. wightii* and *U. rigida*, collected in the month of September 2018 from the Southern coast of India. Both seaweeds were found to be a good source of nutrients such as crude protein, crude fiber, calcium, iron, and sulfur. The three functional properties, *viz.*, SWC, WHC, and OHC, were found to have direct relation with the fiber and proteins in the seaweeds. Also, it was observed that *S. wightii* can be safely processed up to 134°C as seen from the DSC thermograms without any major phase change phenomenon, whereas TGA results revealed that decomposition of organic material takes place within a temperature range of 200–300°C for both seaweeds. Therefore, both seaweeds may be utilized to develop fiber rich food products/

as an ingredient in products withstanding this much temperature. Moreover, FTIR spectra showed phenolic groups in both seaweeds, suggesting that they can act as potential antioxidants ultimately to be used for the development of functional foods and nutraceuticals. This seems to be the first report mentioning thermal (DSC and TGA) and spectral (FTIR) attributes of these seaweeds. We believe that large scale use of these seaweeds by food industry could raise socioeconomic status of the cultivators/fishermen. Nevertheless, future work shall be directed towards in vivo studies to establish bioavailability of nutrients and polyphenols present in these seaweeds so as to get comprehensive and conclusive data for their pertinent exploitation.

Data Availability

All data pertaining to this work are included within this article.

Conflicts of Interest

The authors declare no conflicts of interest.

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References

[1] S. Charoensiddhi, A. J. Lorbeer, C. M. M. Franco, P. Su, M. A. Conlon, and W. Zhang, "Process and economic feasibility for the production of functional food from the brown alga *Ecklonia radiata*," *Algal Research*, vol. 29, pp. 80–91, 2018.

[2] C. S. Kumar, P. Ganesan, P. V. Suresh, and N. Bhaskar, "Seaweeds as a source of nutritionally beneficial compounds—a review," *Journal of Food Science and Technology*, vol. 45, no. 1, pp. 1–13, 2008.

[3] R. Zhang, A. K. L. Yuen, M. Magnusson et al., "A comparative assessment of the activity and structure of phlorotannins from the brown seaweed *Carpophyllum flexuosum*," *Algal Research*, vol. 29, pp. 130–141, 2018.

[4] M. Kasimala, G. G. Mogos, K. T. Negasi, G. A. Bereket, M. M. Abdu, and H. S. Melake, "Biochemical composition of selected seaweeds from intertidal shallow waters of Southern Red Sea," *Indian Journal of Geo-Marine Sciences*, vol. 49, no. 7, pp. 1153–1157, 2020.

[5] B. Tanna, B. Choudhary, and A. Mishra, "Metabolite profiling, antioxidant, scavenging and anti-proliferative activities of selected tropical green seaweeds reveal the nutraceutical potential of *Caulerpa* spp," *Algal Research*, vol. 36, pp. 96–105, 2018.

[6] K. H. Wong and P. C. K. Cheung, "Nutritional evaluation of some subtropical red and green seaweeds," *Food Chemistry*, vol. 71, no. 4, pp. 475–482, 2000.

[7] S. Kumar, D. Sahoo, and I. Levine, "Assessment of nutritional value in a brown seaweed *Sargassum wightii* and their seasonal variations," *Algal Research*, vol. 9, pp. 117–125, 2015.

[8] V. A. Mantri, M. G. Kavale, and M. A. Kazi, "Seaweed biodiversity of India: reviewing current knowledge to identify gaps, challenges, and opportunities," *Diversity*, vol. 12, no. 1, p. 13, 2020.

[9] G. Toskas, R.-D. Hund, E. Laourine, C. Cherif, V. Smyrniotopoulos, and V. Roussis, "Nanofibers based on polysaccharides from the green seaweed *Ulva rigida*," *Carbohydrate Polymers*, vol. 84, no. 3, pp. 1093–1102, 2011.

[10] J. T. Kidgell, M. Magnusson, R. De Nys, and C. R. K. Glasson, "Ulvan: a systematic review of extraction, composition and function," *Algal Research*, vol. 39, Article ID 101422, 2019.

[11] M. B. Kasimala, L. Mebrahtu, P. P. Magoha, G. Asgedom, and M. B. Kasimala, "A review on biochemical composition and nutritional aspects of seaweeds," *Caribbean Journal of Science*, vol. 3, pp. 789–797, 2015.

[12] H. Yaich, A. B. Amira, F. Abbes et al., "Effect of extraction procedures on structural, thermal and antioxidant properties of ulvan from *Ulva lactuca* collected in Monastir coast," *International Journal of Biological Macromolecules*, vol. 105, pp. 1430–1439, 2017.

[13] Association of Official Analytical Chemists (AOAC), *Official Methods of Analysis*, Association of Official Analytical Chemists, Washington, DC, USA, 17th edition, 2000.

[14] R. Sakthivel and K. Pandima Devi, "Evaluation of physicochemical properties, proximate and nutritional composition of *Gracilaria edulis* collected from Palk Bay," *Food Chemistry*, vol. 174, pp. 68–74, 2015.

[15] R. Sirohi and J. P. Pandey, "Dilute acid hydrolysis of spoiled wheat grains: analysis of chemical, rheological and spectral characteristics," *Bioresource Technology*, vol. 283, pp. 53–58, 2019.

[16] N. Balar, P. Sharnagat, P. Kumari, and V. A. Mantri, "Variation in the proximate composition of edible marine macroalga *Ulva rigida* collected from different coastal zones of India," *Journal of Food Science and Technology*, vol. 56, no. 10, pp. 4749–4755, 2019.

[17] M. Kumar, P. Kumari, N. Trivedi et al., "Minerals, PUFAs and antioxidant properties of some tropical seaweeds from Saurashtra coast of India," *Journal of Applied Phycology*, vol. 23, no. 5, pp. 797–810, 2011.

[18] N. Blanco-Pascual, M. P. Montero, and M. C. Gómez-Guillén, "Antioxidant film development from unrefined extracts of brown seaweeds *Laminaria digitata* and *Ascophyllum nodosum*," *Food Hydrocolloids*, vol. 37, pp. 100–110, 2014.

[19] K. Rohani-Ghadikolaei, E. Abdulalian, and W.-K. Ng, "Evaluation of the proximate, fatty acid and mineral composition of representative green, brown and red seaweeds from the Persian Gulf of Iran as potential food and feed resources," *Journal of Food Science and Technology*, vol. 49, no. 6, pp. 774–780, 2012.

[20] R. M. Rodriguez-Jasso, S. I. Mussatto, L. Pastrana, C. N. Aguilar, and J. A. Teixeira, "Microwave-assisted extraction of sulfated polysaccharides (fucoidan) from brown

seaweed," *Carbohydrate Polymers*, vol. 86, no. 3, pp. 1137–1144, 2011.

[21] A. N. Syad, K. P. Shunmugiah, and P. D. Kasi, "Seaweeds as nutritional supplements: analysis of nutritional profile, physicochemical properties and proximate composition of *G. acerosa* and *S. wightii*," *Biomedicine & Preventive Nutrition*, vol. 3, no. 2, pp. 139–144, 2013.

[22] K. Murugaiyan and K. Sivakumar, "Seasonal variation in elemental composition of *Stoechospermum marginatum* (Ag.) *Kutz* and *Sargassum wightii* (Greville Mscr.) J.G. Agardh in relation to chemical composition of seawater," *Colloids and Surfaces B: Biointerfaces*, vol. 64, no. 1, pp. 140–144, 2008.

[23] G. Kumar and D. Sahoo, "Effect of seaweed liquid extract on growth and yield of *Triticum aestivum* var. *Pusa Gold*," *Journal of Applied Phycology*, vol. 23, no. 2, pp. 251–255, 2011.

[24] C. Taboada, R. Millã¡n, and I. Mã-guez, "Composition, nutritional aspects and effect on serum parameters of marine algae *Ulva rigida*," *Journal of the Science of Food and Agriculture*, vol. 90, no. 3, pp. 445–449, 2010.

[25] M. H. Waliullah, T. Mu, M. Ma, and J. Chen, "Effects of particle size on structural, physicochemical, and functional properties of potato residue from starch isolation and quality characteristics of residue-based starch noodles," *Food Science and Technology International*, vol. 27, no. 5, pp. 392–403, 2021.

[26] M. Nikitha and V. Natarajan, "Properties of South-Indian rice cultivars: physicochemical, functional, thermal and cooking characterisation," *Journal of Food Science and Technology*, vol. 57, no. 11, pp. 4065–4075, 2020.

[27] C. Soares, J. Švarc-Gajić, M. T. Oliva-Teles et al., "Mineral composition of subcritical water extracts of *Saccorhiza Polyschides*, a brown seaweed used as fertilizer in the north of Portugal," *Journal of Marine Science and Engineering*, vol. 8, no. 4, p. 244, 2020.

[28] H. Doh, K. D. Dunno, and W. S. Whiteside, "Preparation of novel seaweed nanocomposite film from brown seaweeds *Laminaria japonica* and *Sargassum natans*," *Food Hydrocolloids*, vol. 105, p. 105744, 2020.

[29] K. Kebelmann, A. Hornung, U. Karsten, and G. Griffiths, "Thermo-chemical behaviour and chemical product formation from Polar seaweeds during intermediate pyrolysis," *Journal of Analytical and Applied Pyrolysis*, vol. 104, pp. 131–138, 2013.

[30] D. S. Lakshmi, N. Trivedi, and C. R. K. Reddy, "Synthesis and characterization of seaweed cellulose derived carboxymethyl cellulose," *Carbohydrate Polymers*, vol. 157, pp. 1604–1610, 2017.

[31] Y. Kumar, A. Tarafdar, D. Kumar, and P. C. Badgujar, "Effect of Indian brown seaweed *Sargassum wightii* as a functional ingredient on the phytochemical content and antioxidant activity of coffee beverage," *Journal of Food Science and Technology*, vol. 56, no. 10, pp. 4516–4525, 2019.

[32] J. Li, B. Wang, Y. He et al., "A review of the interaction between anthocyanins and proteins," *Food Science and Technology International*, vol. 27, no. 5, pp. 470–482, 2020.

[33] S. Kannan, "FT-IR and EDS analysis of the seaweeds *Sargassum wightii* (brown algae) and *Gracilaria corticata* (red algae)," *International Journal of Current Microbiology and Applied Sciences*, vol. 3, no. 4, pp. 341–351, 2014.

[34] F. Sánchez-García, A. Mirzayeva, A. Roldán et al., "Evolution of volatile compounds and sensory characteristics of edible green seaweed (*Ulva rigida*) during storage at different temperatures," *Journal of the Science of Food and Agriculture*, vol. 99, no. 12, pp. 5475–5482, 2019.