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Proximate Composition and Nutritive Value of Red Seaweed (*Rhodophyta*) and Green Seaweed (*Chlorophyta*) as Livestock Feed

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Abstract

Seaweeds have been recognized globally as the biological and ecologically potential sources of proteins, lipids, fibers, and minerals for livestock. The study was carried out for a period of 3 months from April to June 2023 in Saint Martin's Island, Bangladesh, to explore the potentials of red seaweed (Rhodophyta) and green seaweed (Chlorophyta) as livestock feeds. Samples were collected from Saint Martin's Island and analyzed for dry matter (DM), crude protein (CP), crude fiber (CF), nitrogen-free extract (NFE), ether extracts (EE), total ash (TA), and metabolizable energy (ME) in the animal nutrition laboratory of Chattogram Veterinary and Animal Sciences University. Results indicated that the estimated DM content of the red seaweed (91.1%) was significantly higher (P < 0.01) than that of green seaweed (89.3%). However, the CP content of red seaweed (11.90%) was significantly lower (P<0.05) than that of green seaweed (12.60%). Accordingly, the extract content of red seaweed (0.01%) was also significantly (P < 0.001) lower than that of green seaweed (0.17%). Contrastingly, the estimated TA content of red seaweed (27.8%) was significantly (P < 0.001) higher than that of green seaweed (24.7%). The estimated metabolizable energy of red seaweed (1823.0 kcal/kg air DM) was significantly (P<0.01) lower than that of green seaweed (1865.8 kcal/kg air DM). There were no significant differences (P>0.05) in the estimated CF and NFE contents of the red and green seaweeds. It was concluded that both red and green seaweed could be a potential source of livestock feed.

Keywords: Crude protein, livestock, metabolizable energy, nutritive value, proximate composition, seaweed

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INTRODUCTION

Bangladesh is the largest deltaic country in the world. This country has a long coastline in the northeast and southeast, as well as other places in the north and northwest, along with the Bay of Bengal, even though most of its land is flat and low-lying. Bangladesh has roughly 710 kilometers of coastline, of which the coastal zone accounts for 23%. The coastal regions are rich in natural resources, including fish, corals, and seaweed. These seaweeds are biologically and ecologically significant sources of bioactive chemicals, such as carotenoids, lipids, proteins, dietary fibers, fatty acids, vitamins, and minerals [1–3]. Although seaweeds are better sources of protein in comparison to other protein-rich meals, lysine and cysteine are present in very small amounts [4]. A previous study highlighted that the most protein-rich type of seaweed is red seaweed and green seaweed [5]. Approximately 5% of the dry seaweed is made up of relatively crude fat [6, 7]. However, there can be major differences across species in both the amount and composition of the fat present in seaweeds. In comparison to diets derived from other plants and animals, seaweeds are, therefore, regarded as a noble source of polyunsaturated fatty acids, which are known to promote health as a feed source.

According to previous studies, these seaweeds are harvested and used for a variety of things, including feed, fertilizer, and raw materials for the industrial preparation of commercially significant phytochemicals [8, 9]. Additionally, bioactive substances with antibacterial, antiviral, and antifungal effects have been found in the seaweeds [10]. In human beings, seaweed nutraceuticals can reduce the risk of chronic diseases like obesity, diabetes, heart disease, and cancer. Consuming fiber-rich seaweeds and their derived supplements has been shown to increase satiety, decrease blood pressure, and lower cholesterol [11]. Microalgae are also recognized as an important reservoir of various vitamins, including A, B_1, B_2, B_6, B_{12}, C, E, nicotinate, biotin, folic acid, and pantothenic acid [12]. In addition to human health, all these nutritional features could be promising for livestock.

In Bangladesh, there are approximately 193 types of seaweed under 94 genera, which can be categorized into three main divisions: *Chlorophyta* (green algae), *Phaeophyta* (brown algae), and *Rhodophyta* (red algae) [13]. According to a survey conducted by the Bangladesh Fisheries Research Institute, there are currently 132 species of seaweed known to exist in Bangladeshi coastal water that possess unique polysaccharides like agar and carrageenan, which can enhance digestive health and feed efficiency in livestock. Moreover, seaweed cultivation requires minimal freshwater and land resources, making it environmentally friendly and economically viable. Research further suggests that incorporating red and green seaweeds into livestock feeds can improve feed efficiency, reduce methane emissions from ruminants, and enhance the nutritional quality of animal products. We, therefore, aimed to explore potentials of red seaweed (*Rhodophyta*) and green seaweed (*Chlorophyta*) as livestock feeds for sustainable agriculture and mitigating the environmental footprint of animal production systems.

MATERIALS AND METHODS

Study Period and Area

The study was conducted for a period of 3 months from April to June 2023 in Saint Martin’s Island, which is also known as Narikel Jinjira, which is a small coral island located in the northeastern part of the Bay of Bengal, near the southern tip of Bangladesh. It covers an area of approximately 8 square kilometers and is about 9 kilometers south of Cox’s Bazar-Teknaf peninsula. This study area was selected purposefully based on the availability of seaweeds.

Collection and Identification of Sample

The red seaweed (*Rhodophyta*) and green seaweed (*Chlorophyta*) were collected from the western coast of St. Martin’s Island in Bangladesh. The samples were manually gathered from the places in a systematic manner during low tide. The samples were kept in plastic containers, transported to the laboratory, and identified as red seaweed (Class: *Rhodophyceae*; genus: *Gracilaria*) and green seaweed (Class: *Chlorophyceae*; genus: *Caulerpa*) using taxonomic references, such as analysis of morphological traits (color) in the Department of Physiology, Pharmacology, and Biochemistry, Chattogram Veterinary and Animal Sciences University.

Preparation of Sample

All samples were carefully washed in the running water and air-dried for around three days after being carefully cleaned with distilled water and chopped uniformly. After the samples were dried in a hot air oven at 105°C for a whole night, they were ground into powder in a mortar and pestle. Until chemical analyses were completed, all powdered seaweed samples were stored at room temperature in desiccators. All chemical analyses were carried out at the animal nutrition laboratory of Chattogram Veterinary and Animal Sciences University.

Proximate Analysis

Proximate components, i.e., dry matter (DM), crude protein (CP), crude fiber (CF), nitrogen-free extract (NFE), ether extract (EE), and total ash (TA), were determined as per standard methods [14].

Statistical Procedure

The initial step involved organizing raw data within Microsoft Excel Professional 2019 (Microsoft Corporation, USA). The detection of outliers and evaluation of multicollinearity within the dataset were conducted utilizing the interquartile range test and variance inflation factors, respectively. Normality assessment of the response variable was executed through the Shapiro-Wilk test. To assess covariate interactions, profile plots were employed. Subsequent analysis was undertaken employing an unpaired t-test. All statistical analyses were conducted utilizing Stata 14.1 SE (Stata Corp. LP, College Station, Texas, USA), with statistical significance determined at $p < 0.05$ across all tests.

RESULTS

The proximate composition of red and green seaweeds, i.e., DM, CP, CF, NFE, EE, and TA contents are presented in Table 1.

Table 1. Chemical composition and nutritive value of the red seaweed (*Rhodophyta*) and green seaweed (*Chlorophyta*).

[1]Parameters (%)	Type of Seaweed		SEM[2]	Significance[3]
	Red Seaweed	**Green Seaweed**		
DM	91.1	89.3	0.41	**
CP	11.9	12.6	0.17	*
CF	7.10	7.30	0.05	NS
NFE	44.3	44.6	0.08	NS
EE	0.01	0.17	0.04	***
TA	27.8	24.7	0.70	***
ME (kcal/kg)[4]	1823.0	1865.8	12.3	**

*Note: [1]DM = Dry matter; CP = Crude protein; CF = Crude fiber; NFE = Nitrogen-free extract; EE = Ether extract; TA = Total ash; ME = Metabolizable energy; [2]SEM = Standard error of the means; [3]NS = Non-significant (P > 0.05), * = P < 0.05, ** = P < 0.01, *** = P < 0.001; [4]Estimated as per [4].*

Dry Matter

The estimated dry matter content of the red seaweed (91.1%) was significantly higher ($P < 0.01$) than that of green seaweed (89.3%) (Table 1).

Crude Protein

The estimated crude protein content of red seaweed (11.90%) was significantly lower ($P < 0.05$) than that of green seaweed (12.60%).

Crude Fiber

The estimated crude fiber content of red seaweed (7.10%) was comparatively lower than that of green seaweed (7.30%).

Nitrogen-Free Extract

The estimated nitrogen-free extract of each seaweed was almost similar. Which was for red seaweed 44.3% and for green seaweed 44.6%.

Ether Extract

The estimated ether extract content of red seaweed (0.01%) was significantly ($P < 0.001$) lower than that of green seaweed (0.17%).

Total Ash

The estimated total ash content of red seaweed (27.8%) was significantly ($P < 0.001$) higher than that of green seaweed (24.7%).

Metabolizable Energy

The estimated metabolizable energy of red seaweed (1823.0 kcal/kg) was significantly ($P < 0.01$) lower than that of green seaweed (1865.8 kcal/kg).

DISCUSSIONS

Dry Matter

Our findings revealed a statistically significant variation in dry matter content between the two types of seaweeds. Specifically, the estimated dry matter content of red seaweed was notably higher compared to green seaweed, with values of 91.1% and 89.3%, respectively ($P < 0.01$). The observed disparity in dry matter content between red and green seaweeds underscores the significance of species-specific biochemical composition within the marine ecosystem. The higher dry matter content in red seaweed suggests a potentially denser nutritional profile, which could have implications for its ecological role and suitability for various applications.

Several factors may contribute to the observed differences in dry matter content between red and green seaweeds. Firstly, variations in physiological characteristics, such as cell wall structure and composition, could influence water retention and consequently affect dry matter content. Additionally, environmental factors, including light intensity, nutrient availability, and temperature, may exert differential effects on the metabolic processes governing dry matter accumulation in different seaweed species. Compared with our study, similar results were reported in previous studies where water content in fresh red seaweed *Gracilaria corticata* (90.57%), followed by *Enteromorpha clathrata* (87.22%) [15]. Red seaweeds, with their higher dry matter content, may offer distinct advantages in terms of nutritional value and functional properties compared to green seaweeds. Further exploration of the biochemical constituents underlying these differences could provide valuable insights for the development of novel products and technologies.

Crude Protein

Our study revealed that the crude protein level in red seaweed was 11.9%, which is lower than that of green seaweed (12.6%). A previous study found similar protein content in the green seaweed *Enteromorpha clathrata* (13.64%), followed by the red seaweed *Gracilaria corticata* (12.18%) [15]. Both spatial and temporal changes could be involved in this process. However, it is related to the quality of the water in the area. The environment, station, and depth can all affect the amount of protein in macroalgae. Geographical factors may further affect the protein content of various species. The protein contents of red and green seaweed are comparable with those of high-protein plant foods, such as soybeans. Variations in the protein content of seaweeds can further occur because of differences in species and seasons. The seaweeds contain all the essential amino acids in different proportions, except for tryptophan, which is destroyed during hydrolysis.

A previous study on seaweed demonstrated that the essential amino acids in *E. cottonii* (60.59%) and *S. polycystum* (61.66%) were higher than in *C. lentillifera* (48.19%) [3]. Furthermore, it was stated that mycosporine-like amino acids (MAAs) and phycobiliproteins are also present in red seaweeds, which have antioxidant properties [16]. In another study, the antioxidant properties of three MAAs that were separated from red algae (*Ahnfeltiopsis devoniensis*, *Gelidium corneum*, and *Porphyra rosengurttii*) were also established [17]. Additionally, the red algal lectin demonstrated anti-ulcerogenic and pro-healing qualities [18]. It was also demonstrated that a glycoprotein isolated from *Porphyra yezoensis* had anti-inflammatory properties by inhibiting the release of nitric oxide in cells induced by lipopolysaccharide [19].

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Crude Fiber

In our study, the estimated crude fiber content of red seaweed (7.10%) was comparatively lower than that of green seaweed (7.30%). According to a previous study, the crude fiber content in green and red algae was 17.17% and 4.37%, respectively [15]. Another study revealed that the dry fiber content of edible algae ranged from 33 to 62%, being significantly higher than that of higher plants. These fibers are crucial in purgative and laxative actions [18]. The biochemical composition of seaweed varies depending on the season and the region where they are produced [20]. The differences in growth stages and photosynthetic function amongst seaweed species may be the origin of variances in the crude fiber content of seaweeds [21]. Depending on the chemistry of different secondary metabolites and cell line metabolism, the sulfated polysaccharides and carrageenan of red algae are rich sources of soluble fibers that may be responsible for anticancer actions.

Agar, which is a combination of agarose and agropectin is another functional component linked with cell walls, which can be obtained from red algae. In addition, several polysaccharides with possible anti-viral properties have been identified, including naviculan, carrageenan, alginate, fucan, and laminatenaran [18]. The first anti-viral effect of algae was noted in 1958. The growth of the mumps and influenza B viruses in embryonated eggs was significantly inhibited by polysaccharides derived from *Gelidium cartilagenium* and carrageenin, although the NDV and influenza A viruses multiplied unaffected [22]. Ulvan, a major water-soluble polysaccharide extracted from the cell wall of the algae, is a potential source of iduronic acid, a rare sugar found in mammalian glycosaminoglycans that is necessary to produce heparin analogs with antithrombotic properties. This natural source has the potential to save the multiple steps required to synthesize iduronic acid [23].

Various studies show that ulvan and its oligosaccharides have anticoagulant [24], antitumor, and immune-modulating properties [1]. Also, ulvan and its oligosaccharides exhibit strain-specific anti-influenza properties [25]. The antioxidant properties of ulvan have been well established, as it protected experimental albino rats from acetaminophen-induced hepatotoxicity [26]. It was demonstrated that ulvan increased serum HDL cholesterol levels while significantly lowering serum total cholesterol and LDL cholesterol and reducing triglyceride levels. Consequently, ulvan can considerably lower the atherogenic index. Moreover, alginate, laminarin, and fucoidan are the polysaccharides of seaweed that have various biological activities, including immunomodulation, antiviral effects, and prebiotic effects [27]. These properties can enhance the gut health and overall performance of livestock.

Nitrogen Free Extract

In our study, the nitrogen-free extract of red and green algae was 44.3% and 44.6%, respectively. A previous study demonstrated that 40–60% NFE was present in most of the existing seaweeds [28]. Conversely, another study demonstrated that *Gracilaria sp*. contained only 19.95% NFE [29].

Ether Extract

In our study, the EE content in red seaweed was 0.01% and in green seaweed 0.17%. A previous study on seaweed revealed that the mean EE or lipid content in various seaweed species was significantly lower, which may have resulted because of differences in their physiological makeup and body structures [30]. Another study revealed that the total lipid content in *Eucheuma cottonii*, *Caulerpa lentillifera*, and *Sargassum polycystum* was 1.10%, 1.11%, and 0.29% on a dry weight basis, which remained within the range for most seaweeds (1-3%) [31]. In another study, the lipid content recorded in green and red seaweed was 0.80% and 0.20%, respectively [32]. Furthermore, seaweeds contain essential fatty acids like linoleic acid (C18:2ω6) and linolenic acid (C18:3ω3) and the eicosanoid precursors, like arachidonic acid (C20:4ω6) and eicosapentaenoic acid (C20:5ω3) [31]. The *Eucheuma cottonii* contains a high level of C-20 PUFA, as has been reported for several species of red algae [33].

An investigation on *Porphyra columbina* (red algae) revealed that the principal fatty acid profile varied between C14:0 and C20:0, with unsaturated fatty acids of the C20 series (C20:4 (n-6) with C20:5 (n-3) predominating. The most prevalent saturated fatty acid was C16:0. It is noteworthy to mention that eicosapentaenoic acid, which is derived from C18:3, is thought to be helpful because of its antithrombotic, hypolipidemic, and anti-inflammatory properties [16]. In another study, it was shown that *Gracillaria lemaneiformis* is rich in free fatty acids like palmitic acid, stearic acid, oleic acid, linoleic acid, arachidonic acid, and eicosapentaenoic acid.

Natural algae extracts are becoming a more popular alternative to synthetic fungicides for the management of fungal infections in plants because of their high level of safety and negligible environmental impact. Similarly, the most potent antifungal efficaciousness against *Microsporum gypseum* was demonstrated by the methanolic extract of *Acanthophora spicifera* [18]. The pathogenic fungi *Botrytis cinerea*, *Monilinia laxa*, and *Penicillium digitatum* that harm fresh fruits were found to be significantly inhibited *in vitro* by crude extracts of red algae, *Porphyra umbilicalis*. This instance involved the attribution of significant antifungal activity to the high fatty acid content of the algae [34].

Overall, red algae have been found to contain a wide range of important bioactive substances, including polysaccharides, lipids, polyphenols, steroids, glycosides, flavonoids, triterpenoids, anthraquinones, tannins, saponins, alkaloids, and cardiac glycosides. Additionally, the anti-inflammatory effects through inhibition of the phospholipase A2 enzyme of several red algae have been established [18]. For example, in aqueous extracts, the red algae *Graciella salicornia* showed an anti-inflammatory effect, exhibiting a 77.53% suppression of paw edema. Besides these, the antibacterial [35], antifungal, and antioxidant [36] properties of red algae are well established.

Green seaweed contains phlorotannins, a polyphenolic compound, which possess antibacterial, anti-inflammatory, and antioxidant properties that can enhance the health of livestock and boost their immunity against diseases [37]. Besides this, seaweed has the potential to be fed to ruminants, particularly because of its nutrient content and bioactive components, which can boost immune and ruminant production while also reducing the emission of methane gas. The metabolites of algae, particularly phlorotannin and halogen compounds, make them highly effective at lowering methane emissions in ruminants. The methyl-coenzyme reductase, an enzyme involved in the process of methanogenesis, can be inhibited by halogen compounds like bromoform available in red seaweeds [29].

Total Ash

In our study, red seaweed (27.8%) had more ash content than green algae (24.7%). In another study, the ash content recorded was 51.16% red seaweed and in green seaweeds 39.42% [32]. Typically, a high ash content is linked with the presence of mineral elements [30–38]. The mineral content of seaweeds is higher than that of land plants [39]. It was demonstrated that these seaweeds may contain high amounts of macrominerals (12.01–15.53 mg/100 g) and trace elements (7.53–71.53 mg/100 g) [31]. Like, *Caulerpa lentillifera* has a calcium content that is like that of common foods like meat, fish, poultry, and legumes. The highest concentration of *C. lentillifera*, for example, was estimated to be 8137 mg/100 g in Vietnam. This is 4 times greater than the calcium content of high-calcium milk powder, which is 2000 mg/100 g [40].

In a study, microelements, such as calcium, phosphorus, magnesium, potassium, chloride, sodium, copper, and zinc were found in red algae, *Gracilaria corticata var cylindrical*. Similarly, the *Gracilaria changgi* were enriched in calcium, iron, zinc, copper, and cadmium [41]. According to another study, the elements that were present in *Gracilaria tenuistipitata* and *Gracilaria fisheri* were K, Cl, P, Mg, Na, Ca, Zn, Pb, Cu, and Cd [42]. Another study revealed that the pigment chlorophyll present in seaweeds, known for its green color, is rich in vitamins and minerals. Another finding showed that it has immune-stimulating and detoxifying properties in livestock [43]. Thus, green seaweed holds promise as a potential nutrient source for livestock due to its nutritional composition and sustainable cultivation practices.

Green seaweeds are a rich source of antioxidants, such as flavonoids, beta-carotene, and vitamins C and E [25]. The scavenging of free radicals is the primary mechanism of dietary antioxidants. The primary antioxidant components found in red algae are mostly phenolic compounds, β-carotene, and sulfated galactans. These antioxidants can strengthen the immune system [18]. Thus, livestock can benefit from these substances, which may boost their immune systems and protect cells from oxidative damage.

Metabolizable Energy

The significant disparity in metabolizable energy between red seaweed, with an estimated value of 1823.0 kcal/kg, and green seaweed, with a notably higher value of 1865.8 kcal/kg, is a key finding with important implications for both nutritional science and potential applications in various industries. Metabolizable energy represents the caloric content of a food item that can be utilized by an animal for energy production after digestion and absorption [44]. It is a crucial metric in assessing the energy value of different food sources and is particularly relevant in dietary planning for livestock. The observed discrepancy in metabolizable energy between red and green seaweed may stem from several factors related to their biochemical composition and structural characteristics. Firstly, it is well established that the composition of carbohydrates, proteins, fats, and fiber in a food item influences its energy content [7]. Red and green seaweeds may differ in their relative proportions of these macronutrients, thereby contributing to variations in metabolizable energy.

Additionally, the presence of specific compounds, such as polysaccharides, pigments, and bioactive molecules, in seaweed can affect its digestibility and energy release during metabolism. For instance, certain polysaccharides found in seaweed, such as alginate and agar, have been shown to possess unique physicochemical properties that may influence gastrointestinal transit time and nutrient absorption, consequently impacting metabolizable energy [45]. Moreover, differences in cell wall structure and complexity between red and green seaweeds can also play a role in determining their energy availability. The degree of cellulose, hemicellulose, and other indigestible components in the cell wall may affect the efficiency of enzymatic breakdown and subsequent energy extraction during digestion [46].

CONCLUSIONS

Based on the comparative analysis of various nutritional components between red and green seaweed, it is evident that there are significant differences in their compositions. Red seaweed exhibits a notably higher dry matter content compared to green seaweed, which suggests a potential advantage in terms of nutrient density. However, it is important to note that red seaweed has a lower crude protein content compared to its green counterpart. This could have implications for dietary applications where protein content is a critical factor. Furthermore, while red seaweed demonstrates lower levels of crude fiber and ether extract, it is noteworthy that it has a substantially higher total ash content. This indicates variances in mineral composition, which may influence the nutritional profile and potential applications of these seaweeds. Moreover, the metabolizable energy content of red seaweed is found to be significantly lower than that of green seaweed. This could be a crucial consideration in dietary planning, particularly in contexts where energy density is a primary concern. Further research and exploration are warranted to fully understand the implications of these differences and to determine the most suitable applications for each type of seaweed in various dietary contexts.

Future Directions

Strategies to optimize the nutritional composition of seaweed-based feeds through cultivation techniques, selective breeding, or processing methods may be investigated. Targeted manipulation of key nutrients, such as protein, carbohydrates, and minerals may be involved to enhance their suitability as livestock feed ingredients. Comprehensive digestibility studies may be conducted to assess the efficiency of nutrient utilization and energy release from red and green seaweed-based diets in different livestock species. Valuable insights into the bioavailability of nutrients and potential metabolic responses may be provided, guiding formulation practices for optimal performance and health outcomes.

The effects of incorporating red and green seaweed into livestock diets on animal health parameters, including growth performance, immune function, and product quality (e.g., meat, milk, eggs), may be explored. Long-term feeding trials and biochemical analyses may elucidate potential benefits or limitations associated with seaweed supplementation in various production systems. The impact of seaweed-derived bioactive compounds on the composition and activity of the gut microbiota in livestock may be investigated. Understanding how seaweed-based diets influence microbial communities and fermentation processes within the digestive tract can provide valuable insights into mechanisms underlying nutrient utilization and animal health.

The environmental sustainability of seaweed-based livestock feeds in terms of resource efficiency, greenhouse gas emissions, and waste management may be assessed. Comparative life cycle assessments and environmental impact analyses may inform decision-making regarding the ecological footprint of seaweed cultivation and utilization within livestock production systems. Economic feasibility studies may be conducted to evaluate the cost-effectiveness and market competitiveness of incorporating red and green seaweed into livestock diets compared to conventional feed ingredients. Considerations, such as production costs, scalability, and consumer acceptance may influence the commercial viability and adoption of seaweed-based feed formulations. Finally, regulatory hurdles and policy barriers that may impact the adoption of seaweed-based feeds may be addressed.

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