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Nutrient profiling and *in-vitro* antioxidant activity assessment of selected red seaweed species of North-west coast of India

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Abstract

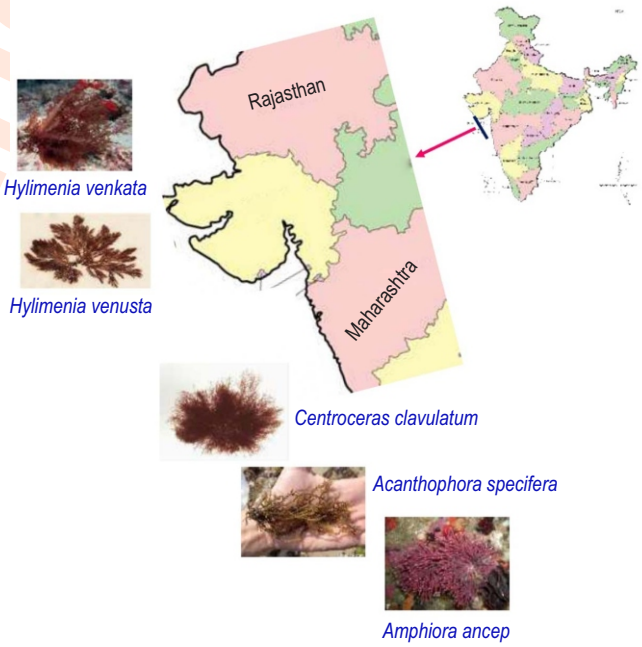
Aim: Seaweed offers benefits over many terrestrial crops and can be used as food and feed ingredients. The objective was to study the nutritional value of particular red seaweeds.

Methodology: Three species of red seaweed namely *Centroceras clavulatum, Acanthophora specifera* and *Amphiora ancep* from Wayangani coast, Ratnagiri, Maharashtra and two species such as *Hylimenia venkata* and *Hylimenia venusta* from Okha coast, Gujarat were collected and screened for biochemical characteristics, carotenoid composition, *in-vitro* antioxidant activity.

Results: The seaweed proximate composition: crude protein, fat, total ash, crude fiber and nitrogen free extract ranged between 4.17-13.12, 0.44-0.91, 37.27-63.82, 2.43-6.07, 26.07-44.92 %, respectively. All the seaweed species contained lutein and zeaxanthin, xanthophyll carotenoids. The range of the total phenolic content was 180.92-375.16 mg GAE/g. The % DPPH radical scavenging capacity ranged from 41.32-73.78%. The strongest positive association was found between TPC (r= 0.821, P=0.088) and total carotenoid; while the highest correlation was found between the antioxidant activity and TPC (r= 0.920, P=0.027).

Interpretation: *H. venusta* exhibits exceptional properties and significant potential as a functional ingredient in fish feed, contributing to enhanced aquaculture nutrition and sustainability.

Key words: Antioxidants, Biochemical composition, Carotenoids, Minerals, Red seaweed



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Introduction

The depletion of land resources is accelerating due to the alarming growth of the population with the projection of 9.7 billion by 2050 (FAO, 2022). This relentless increase in population is creating significant pressure on water, arable land, and natural sources leading to inadequate food supply. Thus, to avert future food shortages, there is a critical need to sustainable production and supply of alternative and more affordable novel food for the vast human population (Baweja *et al.,* 2016). In this regard, seaweeds or marine macroalgae (green, red and brown based on surface colour) could be a suitable alternative for human food (Gélébart, 2016). Red seaweeds are edible and potential sources of proteins (5 to 47% of dry weight) with higher levels in red seaweeds (30 to 40%), carbohydrates (20 to 76%) including fibre (33 to 62%), lipids (1 to 15%) on dry matter basis with rich in ω3 polyunsaturated fatty acids (ω3 PUFA) at 40% of total fatty acid, minerals (20-39% of dry weight), pigments or carotenoids and different bioactive compounds (Chopin *et al.,* 2021; Mwendwa *et al.,* 2023). Probably through their bioactive compounds mediated antioxidant capacity, antimicrobial activity, and anti-inflammatory and hepatoprotective properties, seaweeds can improve human health (Costa *et al.,* 2010; Mwendwa *et al.,* 2023).

Likewise, seaweeds can be potential additives or alternate ingredients for aquafeed and other livestock (Makkar *et al.,* 2016; Chopin *et al.,* 2021). It is reported that bioavailability of seaweeds derived minerals is higher than that of inorganic sources for animals and has potential to be employed as an ingredient in animal diets (Chopin and Buschmann, 2017; Zhang *et al.,* 2024). Moreover, seaweed-derived dietary carotenoids could improve colouration of ornamental fish to fetch high market price (Ebeneezer *et al.,* 2020). Other uses of red seaweeds include industrial production of fertilizer, nutraceuticals or functional food, pharmaceuticals or medicines, phycocolloids (agars, carrageenans and alginates), biofuel etc. (Roy and Anantharaman, 2016 Nunes *et al.,* 2024). Additionally, due to year-round availability and easy harvesting technology, seaweeds are becoming preferable alternatives for human food and animal feed (Rajapakse and Kim, 2011).

About 34 seaweed species are intensively cultivated globally in mariculture system (FAO, 2020). Accordingly, 97% of total 32.4 million tonnes seaweed production (wild and farmed) could be obtained through cultivation in 2019 (FAO, 2021). About 700 varieties of seaweed found throughout the Indian coast, (both inter-tidal and deep-water regions), approximately 60 species are commercially significant. Diverse seaweeds inhabit intertidal and subtidal regions along the West Coast of India. Agar-yielding red seaweeds like *Gracilaria* sp. and *Gelidiella acerosa* are harvested year-round.In India, among the recorded seaweed species, 16 species of chlorophytes (green algae), 13 species of rhodophytes (red algae) and 10 species of phaeophytes (brown algae) are abundant. Red seaweeds (Rhodophyta) are macroscopic, multicellular, benthic marine red algae (Zubia *et al.,* 2014), commonly traded as food items in East Asia, and employed in the phycocolloid (alginate, agar and carrageenan) industry as food additives due to gelling, water-retention, emulsifying and other physical properties (Chakraborty *et al.,* 2013). They are reported to be rich in phenolic compounds and other bioactive molecules represents superior antioxidative capacity (Chakraborty, 2015; Shahabuddin *et al.,* 2024). However, full potential of seaweeds to support global nutritional security is still underexploited. With this background, the present study was carried out to screen and evaluate biochemical composition and *in-vitro* antioxidant activities of selected seaweeds, which can be used as functional fish feed additive or alternate ingredient.

Materials and Methods

Seaweed collection and processing: Three species of red seaweed namely *Centroceras clavulatum, Acanthophora specifera* and *Amphiora ancep* from Wayangani coast, Ratnagiri, (16° 55' 55" N, 73° 17' 04" E) Maharashtra and two species, *Hylimenia venkata* and *Hylimenia venusta* from Okha coast (22° 28' 44.28" N, 69° 04' 42.51" E) Gujarat, India were collected during January 2022 and transported to the ICAR-Central Institute of Fisheries Education's Fish Nutrition and Feed Technology Laboratory, Mumbai, India. From the samples were the epiphytes and wastes were and removed, washed thoroughly to remove sand and salt particles followed by drying at room temperature (3 days) and then oven drying at 40 ^{0}C. Dried seaweeds were finely powdered and stored in amber glass bottle until further use.

Proximate Analysis: Proximate composition of seaweed meal was estimated on dry matter basis following the standard procedures of the AOAC (2005).

Mineral profiling: The mineral content of the selected red seaweed meals was determined following the protocol of Sugiura *et al.* (1998) using aICPAES, Perkin-Elmer, Optima 2000.

Amino acid analysis: Total amino acid content of specific red seaweed meals was analyzed following the method of El - Dahhar and El - Shazly (1993) using a HPLC.

Fatty acid analysis: The fatty acid composition of seaweed extracts was analysed using GC-MS (QP2010, Shimadzu, U.S.A) as described by Larbi Ayisi *et al.* (2018). A mixture of methanol and chloroform was used for total lipid extraction and KOH -methanol was used to prepare fatty acid methyl esters (Folch *et al.,* 1957).

Carotenoids and *in-vitro* antioxidant activity

Preparation of seaweed extract: Ethanolic extract of seaweed meal was prepared following the method of Fawole *et al.* (2013) to obtain a greasy crude seaweed extract.

Analysis of carotenoids: The carotenoids extracted from seaweed meal were separated as described by Shahidi and Joseph (1998) and expressed as µg g^{-1} d.wt.

Estimation of total phenolic content (TPC): The total phenolic content was estimated by Folin-Ciocalteu method as described by Singleton (1999) with slight modifications and expressed as mg of gallic acid equivalent per gram (mg GAE/g) dry weight.

2-Diphenyl-1-picrylhydrazyl (DPPH) assay: The DPPH radical scavenging capacity (DRSC) of various seaweed extracts was estimated by following the methodology described by Scherer and Godoy (2009) with slight modifications.

Statistical analyses: Data were statistically analysed through one-way ANOVA using IBM-SPSS software version 23.0 to estimate the mean values of parameters in different seaweed meals. Duncan's Multiple Range Test (DMRT) with post hoc analysis was performed to evaluate significant differences among the means at 5% probability level ($p < 0.05$). The analysed data were presented as mean ± SE.

Results and Discussion

The proximate composition of different selected red seaweed species like crude protein content varied significantly ($p<0.05$) with the highest (13.12±0.07%) and lowest (4.17±0.07%) values observed in *H. venkata* and *A. ancep*, respectively (Table 1). Dixit *et al.* (2017) revealed that the total protein content of red seaweeds generally ranged between 4-50% on dry weight basis, which is similar to our findings. All edible seaweeds have low lipid concentrations but high levels of polyunsaturated fatty acids (ω3 and ω6 families). The lipid content of all five red seaweed species varied significantly ($p<0.05$) with the highest (0.91%) and lowest (0.44±0.04 %) values reported in *H. venusta* and *C. clavulatum,* respectively. According to Poveda-Castillo *et al.* (2018), seaweeds have a comparatively low lipid content (1 to 5 % d.wt.). Shannon and Ghannam (2019) revealed that, seaweeds have a total lipid content that varies from 0.60 to 4.14% d.wt. Seaweeds possess relatively high content of total ash.Total ash content varied significantly ($p<0.05$) with the highest (63.82%) and lowest (32.27%) values found in *A. anceps* and *C. clavulatum,* respectively. High ash levels of seaweed lead to their promising usage as dietary supplements for minerals in animal feed (Rupérez, 2002). In the current investigation, the ash content of *A. spicifera* was found to be 43.47%, similar to the range reported by Dixit *et al.* (2018) in red seaweed species (47.04%) collected from the Kachchh coast. Crude fiber content varied significantly ($p<0.05$) with the highest (6.07%) and lowest (2.43%) values reported in *C. clavulatum* and *H. venkata,* respectively. Meng *et al.* (2022) reported that the brown macroalgae are good source of dietary fibre ranging between 4.68% and 13.77%. High fibre content macroalgae are excellent additives in fibre-free foods (Rawiwan *et al.,* 2022).

In the present study, the calcium content in all five red seaweed species varied significantly ($p<0.05$) with the highest (5.05%) and lowest (0.95%) values found in *A. spicifera* and *H. venkata,* respectively (Table 2). Phosphorus content in all five red seaweed species varied significantly ($p<0.05$) with the highest (0.7±0.02%) values found in *H. venkata* and the lowest (0.16%) values found in both *A. ancep* and *A. spicifera.* Calcium and phosphorus are directly involved in the development and maintenance of the skeletal system and participate in several physiological processes. Sodium in generally the present in high concentrations in seaweeds and significantly highest Na content (8.46±0.02%) was recorded in *H. venusta* and the lowest (0.35) was recorded in *A. ancep.* Meng *et al.* (2022) reported highest Na content (14.83%) in brown seaweed, *Laminaria japonica.* The magnesium content was found significantly highest (1.46) in *H. venusta* and lowest (0.33±0.00) in *C. clavulatum.* A vital co-factor of numerous enzyme processes in intermediate metabolism is magnesium. Fish can obtain the magnesium they need from their food or from the water. Potassium content in of all five red seaweed species varied significantly ($p<0.05$) with the highest (4.50%) and the lowest (0.56%) values recorded in *A. spicifera* and *A. ancep,* respectively. Dixit *et al.* (2017) found highest K content (7.64±0.04 %) in *A. spicifera,* which is higher to our present findings. The immune systems of higher vertebrates depend on trace minerals to maintain cellular functioning as coenzymes for metallo enzymes (Gupta *et al.,* 2022). Aluminium content varied significantly ($p<0.05$) with highest (3206.7±76.8 mg kg^{-1} d.wt.) and the lowest (200.0 mg kg^{-1} d.wt.) values in *C. clavulatum* and *H. venkata*, respectively. No conclusive evidence exists if aluminium has any essential function in animals. The cobalt content varied significantly with the highest (7.17 mg kg^{-1} d.wt.) and the lowest (3.00 mg kg^{-1} d.wt.) values recorded in *C. clavulatum* and *H. venkata,* respectively. Cobalt is a metal that is part of cyanocobalamin (B_{12}), which helps with C1 and C3

Table 1: Proximate composition(on % dry matter basis) of selected red seaweed species collected from Indian coasts

Seaweed species	Crude protein	Lipid	Total ash	Crude fiber	Nitrogen free extract (NFE)
C. clavulatum	11.30±0.06^{c}	0.44±0.04^{a}	37.27±1.15^{a}	6.07±0.39^{c}	44.92±0.92^{c}
H. venkata	13.12±0.07^{e}	0.83±0.07^{b}	42.99±1.17^{b}	2.43±0.16^{a}	40.62±1.23^{b}
A. ancep	4.17±0.07^{a}	0.53±0.05^{a}	63.82±0.86^{c}	5.42±0.13^{c}	26.07±0.65^{a}
A. specifera	7.91±0.15^{b}	0.57±0.09^{a}	43.47±0.64^{b}	3.77±0.20^{b}	44.28±0.49^{c}
H. venusta	12.23±0.34^{d}	0.91±0.05^{b}	45.62±0.34^{b}	2.61±0.07^{a}	38.63±0.54^{b}
p-value	*<0.001*	*0.001*	*<0.001*	*<0.001*	*<0.001*

Values are expressed as mean of three replicates ± S.E.; Mean values in the same column with different superscripts indicate significant differences ($p< 0.05$)

Table 2: Mineral composition (on dry matter basis) of selected red seaweed species collected from Indian coasts

Mineral	Seaweed species					p-value
	C. clavulatum	*H. venkata*	*A. ancep*	*A. specifera*	*H. venusta*	
Macroelements (%)						
Ca	1.89±0.03^{c}	0.95±0.02^{a}	2.11±0.02^{d}	5.05±0.02^{e}	1.03±0.01^{b}	<0.001
Na	2.22±0.01^{c}	7.57±0.07^{d}	0.35±0.00^{a}	1.62±0.02^{b}	8.46±0.02^{e}	<0.001
Mg	0.33±0.00^{a}	1.23±0.02^{c}	0.43±0.00^{b}	0.37±0.02^{a}	1.46±0.02^{d}	<0.001
P	0.17±0.01^{a}	0.70±0.02^{c}	0.16±0.01^{a}	0.16±0.03^{a}	0.36±0.03^{b}	<0.001
K	1.44±0.03^{b}	3.73±0.04^{d}	0.56±0.02^{a}	4.50±0.01^{e}	2.60±0.03^{c}	<0.001
Microelements (mg kg^{-1})						
Al	3206.67±76.88^{c}	200±15.28^{a}	246.67±12.02^{a}	2620. ±253.25^{b}	476.67±24.04^{a}	<0.001
Co	7.17±0.73^{b}	3.00±0.29^{a}	3.97±0.32^{a}	6.30±0.38^{b}	6.60±0.31^{b}	<0.001
Cr	4.73±0.48^{a}	ND	ND	8.00±0.46^{b}	15.13±0.35^{c}	<0.001
Cu	15.40±0.40^{b}	10.47±0.79^{a}	16.87±1.57^{b}	28.33±0.35^{c}	11.80±0.53^{a}	<0.001
Fe	4693.33±159.30^{d}	426.67±26.03^{a}	3580.0±102.63^{c}	10993.33±100.88^{e}	2653.33±40.55^{b}	<0.001
Mn	1023.33±34.80^{c}	19.07±0.52^{a}	236.67±8.82^{b}	260±17.32^{b}	61.87±11.70^{a}	<0.001
Zn	19.60±1.51^{a}	96.67±8.82^{c}	11.17±0.60^{a}	23.67±2.33^{a}	71.67±4.41^{b}	<0.001

*ND indicates not detected; Values are mean of three replicates ± S.E.; Mean values in the same row with different superscripts indicate significant differences (p< 0.05)

metabolism and prevents anaemia. The chromium content varied significantly (p<0.05) with the highest (15.13 mg kg^{-1} d.wt.) and the lowest (4.73 mg kg^{-1} d.wt.) values found in *H. venusta* and *C. clavulatum*, respectively. It was not detected in *H. venkata* and *A. ancep*. Chromium is involved in collagen formation and regulation of the rate of glucose metabolism by regulating insulin in fish. Copper (Cu) content varied significantly (p<0.05) with the highest (28.33 mg kg^{-1} d.wt.) and lowest (10.47 mg kg^{-1} d.wt.) values noted in *A. spicifera* and *H. venkata,* respectively. Copper is typically added as a supplement to the diet because animals requre more of it than is provided by usual feed ingredients (Li *et al.,* 2007). Iron content varied significantly (p<0.05) with the highest (10993.33 mg kg^{-1} d.wt.) and the lowest (426.67 mg kg^{-1} d.wt.) values reported in *A. spicifera* and *H. venkata,* respectively. Fe is required for cellular respiration process because of its electron transport and oxidation-reduction activity. It is an essential constituent of haem in haemoglobin, cytochromes, peroxidases. Manganese content varied significantly (p<0.05) with the highest (1023.33 mg kg^{-1} d.wt.) and the lowest (19.07 mg kg^{-1} d.wt.) values reported in *C. clavulatum* and *H. venkata*, respectively. Mn is a co-factor for arginase and a few other metabolic enzymes; it also has a role in the regeneration of erythrocytes and the development of bones. Zinc content varied significantly (p<0.05) with the highest (96.67 mg kg^{-1} d.wt.) and the lowest (11.17 mg kg^{-1} d.wt.) values recorded in *H. venkata* and *A. ancep* respectively. It is required for insulin structure, function and co-factor of carbonic anhydrase.

In the present study, Selenium and Iodine values were below the detectable levels in all five red seaweed species, indicating that seaweeds can be used as a substitute for mineral supplementation. The minerals in seaweed, a part from being abundant, exhibit high biological availability, making them easily absorbable and utilizable (Garcia-Casal *et al.,* 2007). The amino acid composition varied significantly (p<0.05) among the red seaweed species studied (Table 3). The total essential amino acid composition was significantly highest (23.91 g 100 g^{-1}) in *H. venkata* and lowest (1.01±0.02 g 100 g^{-1} protein) in *A. ancep.* The total NEAAs composition is significantly highest (69.76 g 100g^{-1}) in *H. venusta* and lowest (1.15±0.04 g 100g^{-1}) in *A. ancep.* The total amino acid composition was significantly highest (85.24±2.04 g 100g^{-1}) in *H. venusta* and lowest (2.16 g 100g^{-1}) in *A. ancep*. Methionine was found below the detectable level in *A. ancep.* Valine was found below the detectable levels in *C. clavulatum, H. venusta, H. venkata.* Cystine was below the detectable level in all five red seaweed species. Tryptophan was only detected in *A. ancep.* Aspartic acid was notably high in *H. venusta.* ASP supports general cellular health and function by assisting in the synthesis of nucleotides, the building blocks of DNA and RNA. Additionally, it supports other amino acid synthesis. Methionine, threonine, isoleucine, and lysine are among the amino acids that are synthesized with the aid of aspartic acid. Like glutamic acid in contributes to the umami taste, which is one of the five fundamental tastes combined with bitter, sour, salty and sweet flavors (Garcia-Vaquero *et al.* (2021). Umami is often described as a savoury or meaty taste. Proline content is high in *C. clavulatum,* while Glycine content is notably high in *H. venkata* (Zhang *et al.,* 2024).

Saturated fatty acid content varied significantly (p<0.05) with the highest (87.30 mg 100 g^{-1} d.wt.) and lowest (66.62 mg 100 g^{-1} d.wt.) values reported in *C. clavulatum* and *H. venkata,* respectively. C16:0 (palmitic acid) was the most common

Table 3: Amino acid composition (g 100 g^{-1} protein) of selected red seaweed species collected from Indian coasts

Amino acids	Seaweed species					p-value
	C. clavulatum	*H. venkata*	*A. specifera*	*A. ancep*	*H. venusta*	
Essential amino acids						
Methionine	0.22±0.02^{ab}	0.69±0.02^{b}	2.37±0.33^{c}	ND	0.33±0.04^{ab}	<0.001
Leucine	0.80±0.06^{a}	5.29±0.60^{c}	0.39±0.03^{a}	0.09±0.02^{a}	3.37±0.31^{b}	<0.001
Lysine	1.05±0.05^{b}	2.92±0.36^{d}	1.19±0.12^{b}	0.08±0.02^{a}	1.93±0.04^{c}	<0.001
Arginine	1.13±0.11^{b}	3.34±0.31^{d}	0.54±0.06^{a}	0.21±0.01^{a}	2.23±0.19^{c}	<0.001
Histidine	0.42±0.04^{ab}	1.49±0.26^{c}	0.54±0.04^{ab}	0.19±0.02^{a}	0.73±0.04^{b}	<0.001
Iso-leucine	0.78±0.03^{b}	3.21±0.23^{d}	0.42±0.03^{ab}	0.14±0.01^{a}	2.22±0.22^{c}	<0.001
Valine	ND	ND	0.61±0.07^{b}	0.02±0.01^{a}	ND	<0.001
Threonine	0.57±0.02^{a}	4.41±0.06^{c}	0.72±0.04^{a}	0.22±0.02^{a}	2.92±0.36^{b}	<0.001
Phenylalanine	1.64±0.13^{b}	2.56±0.04^{c}	3.81±0.33^{d}	0.06±0.01^{a}	1.76±0.19^{b}	<0.001
Tryptophan	ND	ND	ND	0.09±0.01	ND	-
Total EAA	6.62±0.03^{b}	23.91±0.62^{e}	10.59±0.79^{c}	1.01±0.02^{a}	15.48±1.00^{d}	<0.001
Non essential amino acids						
Proline	7.24±0.23^{d}	5.91±0.28^{c}	10.21±0.53^{e}	0.24±0.03^{a}	3.95±0.16^{b}	<0.001
Glycine	0.22±0.02^{a}	7.33±0.50^{c}	0.14±0.04^{a}	0.10±0.02^{a}	4.36±0.45^{b}	<0.001
Aspartic acid	3.48±0.20^{a}	7.52±0.35^{b}	3.42±0.27^{a}	0.20±0.02^{a}	47.81±2.45^{c}	<0.001
Tyrosine	0.50±0.07^{b}	1.64±0.11^{d}	1.68±0.12^{d}	0.10±0.01^{a}	1.08±0.07^{c}	<0.001
Glutamic acid	2.70±0.13^{b}	5.73±0.37^{d}	2.13±0.25^{b}	0.20±0.02^{a}	4.35±0.43^{c}	<0.001
Alanine	3.10±0.09^{b}	7.45±0.31^{d}	0.64±0.05^{a}	0.20±0.03^{a}	5.06±0.32^{c}	<0.001
Serine	3.25±0.12^{b}	4.97±0.32^{c}	0.33±0.03^{a}	0.11±0.01^{a}	3.15±0.25^{b}	<0.001
Cystine	ND	ND	ND	ND	ND	-
Total NEAA	20.49±0.63^{b}	40.55±1.35^{c}	18.55±0.43^{b}	1.15±0.04^{a}	69.76±2.98^{d}	<0.001
Total amino acids	27.11±0.63^{b}	64.46±1.86^{c}	29.14±0.43^{b}	2.16±0.06^{a}	85.24±2.04^{d}	<0.001
EAA/NEAA	0.32±0.01^{b}	0.59±0.01^{c}	0.57±0.06c	0.88±0.02^{d}	0.22±0.02^{a}	<0.001

*ND indicates not detected; Data are mean of three replicates ± S.E.; Mean values in the same row with different superscripts indicate significant differences ($p< 0.05$)

saturated fatty acid found in all species. The highest value was reported (63.67 mg 100 g^{-1} d.wt.) in *A. specifera* and lowest (42.45 mg 100 g^{-1} d.wt.) in *C. clavulatum.* High levels of saturated fatty acid are not beneficial and interfere with digestion.

Garcia-Vaquero *et al.* (2021) elucidated that saturated fatty acid can be high in some red seaweed species depending upon different climatic conditions. Monounsaturated fatty acid (MUFA) content was highest (25.77 mg 100 g^{-1} d.wt.) and lowest (6.78 mg 100 g^{-1} d.wt.) in *A. ancep* and *C. clavulatum,* respectively. The predominant MUFA in all species was oleic acid, C18:1(ω9); varied significantly ($p<0.05$) with the highest (11.75 mg 100 g^{-1} d.wt.) and lowest (1.68 mg 100 g^{-1} d.wt.) values reported in *A. ancep* and *C. clavulatum,* respectively. Nunes *et al.* (2024) reported that monounsaturated fats exhibit anti-inflammatory effects and strengthen the antioxidative defense of tissues and cells, contributing to the immune response in biological organisms. PUFA content was found highest (24.76 mg 100 g^{-1} d.wt.) and lowest (0.92 mg 100 g^{-1} d.wt.) in *H. venkata* and *H. venusta,* respectively. Notable PUFA include 18:2 (ω6) (linoleic acid) and 20:5(ω3) (eicosapentaenoic acid, EPA). Significantly the highest linoleic acid (2.09 mg 100 g^{-1} d.wt.) and EPA (7.85 mg 100 g^{-1} d.wt.) was observed in *H. venkata.* Due to greater levels of 20:5 (ω3), it has a substantial amount of total ω3 (7.85 mg 100 g^{-1}). Significantly the highest levels of (16.91 mg 100 g^{-1}) total ω6 was observed in *H. venkata* and the lowest (0.92 mg 100 g^{-1} d.wt.) was in *H. venusta.* The ratio of ω6 to ω3 is significantly the lowest in *H. venusta* and highest in *A. ancep,* suggesting a variation in the proportion of ω6 to ω3 fatty acids amongst the species. *H. venkata* had significantly the highest total fatty acid content (108.40 mg 100 g^{-1}), In conclusion, there are differences in the fatty acid composition of the various seaweed species. Significantly the highest total ω6 (16.91 mg 100 g^{-1} d.wt.) and total ω3 (7.85 mg 100 g^{-1} d.wt.) was observed in *H. venkata.* After examining 34 species of red and brown macroalgae, Dawczynski *et al.* (2007) discovered a considerable concentration of PUFA, accounting 31.8 to 74.7% of the total fatty acids, and these certain differences might have an impact on certain seaweed species' nutritional content and possible human health advantages.

Carotenoids are pigments produced by photosynthetic organisms with good antioxidant qualities. Fucoxanthin content in

Table 4: Fatty acid composition (mg 100 g^{-1} d. wt.) of selected red seaweed species collected from Indian coasts

Fatty acids	Seaweed species					p-value
	C. clavulatum	*H. venkata*	*A. ancep*	*A.specifera*	*H. venusta*	
Saturated fatty acids						
C4:00	26.68±0.58	ND	ND	ND	ND	-
C9:00	0.48±0.01	ND	ND	ND	ND	-
C12:00	0.36±0.01^{a}	ND	0.46±0.01^{b}	0.36±0.02^{a}	0.35±0.02^{a}	<0.001
C13:00	ND	ND	0.39±0.01^{b}	ND	0.29±0.01^{a}	<0.001
C14:00	2.80±0.06^{b}	1.85±0.01^{a}	4.85±0.03^{d}	2.90±0.02^{b}	4.32±0.07^{c}	<0.001
C15:00	1.69±0.02^{b}	1.06±0.01^{a}	2.73±0.02^{c}	2.97±0.04^{d}	3.40±0.02^{e}	<0.001
C16:00	42.45±0.23^{a}	58.86±0.62^{c}	54.07±0.52^{b}	63.67±0.20^{d}	58.65±0.34^{c}	<0.001
C17:00	2.16±0.03^{d}	0.53±0.02^{a}	1.37±0.02^{b}	1.63±0.03^{c}	3.95±0.04^{e}	<0.001
C18:00	5.68±0.01^{b}	4.33±0.06^{a}	6.11±0.07^{c}	7.86±0.09^{d}	12.08±0.17^{e}	<0.001
C19:00	ND	ND	ND	ND	0.57±0.01	-
C20:00	0.82±0.01	ND	ND	ND	ND	-
C22:00	3.48±0.01^{c}	ND	ND	0.67±0.01^{b}	0.61±0.01^{a}	<0.001
C27:00	ND	ND	ND	2.76±0.03	ND	-
C30:00	0.71±0.01	ND	ND	ND	ND	-
ΣSFA	87.30±0.84^{d}	66.62±0.66^{a}	69.96±0.50^{b}	82.82±0.25^{c}	84.22±0.48^{c}	<0.001
Monounsaturated fatty acids						
C16:1(n-7)	1.62±0.04^{b}	2.94±0.04^{c}	6.46±0.06^{d}	1.12±0.03^{a}	ND	<0.001
C18:1(n-3)	ND	ND	0.65±0.03	ND	ND	-
C18:1(n-5)	ND	ND	ND	ND	0.36±0.02	-
C18:1(n-9)	1.68±0.04^{a}	9.15±0.10^{d}	11.75±0.04^{e}	6.63±0.33^{c}	2.89±0.08^{b}	<0.001
C18:1(n-7)	3.48±0.25^{bc}	3.21±0.03^{b}	3.78±0.13^{c}	2.56±0.12^{a}	6.19±0.06^{d}	<0.001
C18:1(n-11)	ND	ND	ND	2.64±0.10	ND	-
C18:1(n-12)	ND	1.71±0.04^{a}	3.14±0.09^{b}	ND	4.69±0.18^{c}	<0.001
C18:1(n-13)	ND	ND	ND	ND	0.74±0.04	-
ΣMUFA	6.78±0.26^{a}	17.02±0.06^{d}	25.77±0.14^{e}	12.96±0.17^{b}	14.87±0.21^{c}	<0.001
Polyunsaturated fatty acid						
20:5(n-3)	ND	7.85±0.03^{c}	1.21±0.09^{a}	1.74±0.04^{b}	ND	<0.001
18:2(n-6)	0.96±0.03^{b}	2.09±0.07^{d}	1.50±0.07^{c}	0.96±0.04^{b}	0.48±0.02^{a}	<0.001
20:3(n-6)	ND	0.84±0.02	ND	ND	ND	-
20:4(n-6)	ND	6.13±0.08^{c}	1.53±0.06^{b}	1.54±0.04^{b}	0.44±0.03^{a}	<0.001
22:5(n-6)	ND	7.85±0.07	ND	ND	ND	-
ΣPUFA	0.96±0.03^{a}	24.76±0.17^{c}	4.23±0.15^{b}	4.24±0.04^{b}	0.92±0.06^{a}	<0.001
Σω3	ND	7.85±0.03^{c}	1.21±0.09^{a}	1.74±0.04^{b}	ND	<0.001
Σω6	0.96±0.03^{a}	16.91±0.18^{d}	3.02±0.06^{c}	2.50±0.00^{b}	0.92±0.06^{a}	<0.001
ω6/ ω3	0.96±0.03^{a}	2.16±0.03^{c}	2.53±0.17^{d}	1.44±0.03^{b}	0.92±0.06^{a}	<0.001
ΣFA	95.04±1.13^{a}	108.40±0.57^{c}	99.97±0.34^{b}	100.02±0.19^{b}	100.01±0.37^{b}	<0.001
%PUFA	1.01±0.03^{a}	22.84±0.25^{c}	4.23±0.16^{b}	4.24±0.04^{b}	0.92±0.05^{a}	<0.001

*ND indicates not detected; Values are mean of three replicates ± SE. Mean values in the same row with different superscripts indicate significant differences ($p< 0.05$); Abbreviations: SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; FA, fatty acids

all five red seaweed species varied significantly ($p<0.05$) with the highest (2.26 µg g^{-1} d.wt.) and the lowest (0.01 µg g^{-1} d.wt.) values reported in *C. clavulatum* and *H. venkata,* respectively (Table 5). Fucoxanthin represent main marine carotenoid and have many bioactive properties, potential to use in pharmaceutical, anti-aging cosmetic, fortified food, and supplement industries (Pereira *et al.,* 2021). Lutein content varied significantly ($p<0.05$) with the highest (1.84 µg g^{-1} d.wt.) and the lowest (0.20 µg g^{-1} d.wt.) values recorded in *H. venusta* and *A. ancep,* respectively. Lutein finds regular use in industries like cosmetics, pharmaceuticals and food due to its colour, bioactivities, and noteworthy anticancer properties. Zeaxanthin was found below the detectable levels in all seaweed sample except *A. ancep* (0.04 µg g^{-1} d.wt.). Zeaxanthin it is a structural isomer of lutein. Bhat *et al.* (2021)

Table 5: Carotenoid composition (µg g^{-1} d.wt.) of selected red seaweed species collected from Indian coasts

Seaweed species	Carotenoid composition			
	Fucoxanthin	Lutein	Zeaxanthin	β-carotene
C. clavulatum	2.26±0.03^{d}	0.79±0.02^{c}	ND	ND
H. venkata	0.01±0.00^{a}	0.32±0.02^{b}	ND	ND
A. ancep	0.79±0.01^{b}	0.20±0.01^{a}	0.04±0.00	ND
A. specifera	1.15±0.03^{c}	0.30±0.01^{b}	ND	ND
H. venusta	0.01±0.00^{a}	1.84±0.06^{d}	ND	0.93±0.01
p-value	<0.001	<0.001	-	-

*ND indicates not detected; Values are expressed as mean of three replicates ± S.E.; Mean values in the same column with different superscripts indicate significant difference ($p < 0.05$)

Table 6: Total phenolic content and DPPH radical scavenging capacity (on dry weight basis) of selected red seaweed species collected from Indian coasts

Seaweed species	Total phenolic content (mg GAE g^{-1})	DPPH radical scavenging capacity (%)
C. clavulatum	348.84±8.05^{c}	58.53±0.46^{b}
H. venkata	180.92±0.86^{a}	41.33±1.47^{a}
A. ancep	260.24±14.86^{b}	57.94±4.77^{b}
A. specifera	367.32±7.00^{c}	73.78±4.52^{c}
H. venusta	375.16±0.83^{c}	72.86±0.82^{c}
p-value	<0.001	<0.001

Values are of three replicate ± S.E. Mean values in the same column with different superscripts indicate significant difference ($p < 0.05$)

Table 7: Pearson correlations between proximate composition and antioxidant activity of selected red seaweed species collected from Indian coasts

	Crude protein	Lipid	Total ash	Crude fibre	Total carotenoid	TPC[1] DRSC[2]
Crude protein						
Crude lipid	0.820					
Total ash	-0.782	-0.440				
Crude fibre	-0.559	-0.751	0.195			
Total carotenoid	0.284	0.327	-0.416	0.335		
TPC	0.001	0.208	-0.294	0.200	0.821**	
DRSC	-0.197	0.183	-0.19	0.230	0.573	0.920**

[1]TPC: Total polyphenolic content; [2]DRSC: DPPH radical scavenging capacity; ** indicates significant correlation ($p < 0.01$)

reported 248.67 µg g^{-1} lutein and 50.20 µg g^{-1} zeaxanthin seaweed *Cladophora* sp. while *Bryopsis* sp. contained 42.72 µg g^{-1} of α-carotene. The provitamin-A carotenoids, α and β carotene levels did not reveal comparable content, only *H. venusta* showed the presence of β carotene (0.93 µg g^{-1}) while α carotene was below the detectable level in all studied seaweed samples (Nunes *et al.,* 2024). The total phenolic content of the sample ranged from 180.92 mg GAE g^{-1} to 375.16 mg GAE g^{-1} (Table 6). The highest (375.16±0.83 mg GAE g^{-1}) TPC was observed in *H. venusta,* while the lowest (180.92 mg GAE g^{-1}) was observed in *H. venkata.* Previous studies have demonstrated that higher the amount of phenolic compounds in red seaweed, higher the scavenging capacity of free radicals to prevent oxidative damage (Chakraborty *et al.,* 2013; Chakraborty *et al.,* 2015). The DPPH radical scavenging capacity of different selected red seaweed species is shown in Table 6. It varied significantly ($p<0.05$) with the highest (73.78 %) and lowest (41.33 %) values reported in *A. specifera, H. venusta and H. venkata*, respectively, and exhibited an increasing trend with increasing concentration of the extracts.

In the DPPH assay, the antioxidants convert the α, α-diphenyl-β-picrylhydrazyl free radical to α, α-diphenyl β-picrylhydrazine, causing a colour change of the solution from deep violet to colourless. The degree of the discolouration indicates the scavenging activity of the extracts (Shahabuddin *et al.,* 2024) Our current research clearly suggests that the presence

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of phenolic compounds in seaweed extracts may be the main factor contributing to the maximum antioxidant activity (Chakraborty *et al.,* 2015). Correlation measures the strength and direction of a linear relationship between antioxidant activity and the proximate composition (Crude protein, lipid, total ash, crude fibre), total carotenoids (Table 7).

The highest correlation coefficient was found between antioxidant activity and TPC (r=0.920; p=0.027). A strong positive correlation between TPC (r = 0.821, p = 0.088) and total carotenoid was found. Crude protein and total ash concentration showed a negative correlation with antioxidant activity. The antioxidant activity was moderate positively correlated with total carotenoid (r = 0.573, p = 0.313). The "p-value" indicates the significance of the correlation; a lower p-value suggests a more significant correlation. Meng *et al.* (2022) reported that the macroalgae studied showed a good association (correlation coefficient 0.926, P<0.01) and total flavonoid concentration (0.927, P < 0.01) with their antioxidant ability.

The present study visualizes the chemical composition, nutritional potential and *in-vitro* antioxidant activity of five red seaweed species of which *C. clavulatum, A. specifera* and *H. venusta* are good sources of phenolic compounds and other major macro and micromolecules. Antioxidant activity and high total phenolic content are associated, indicating that algal polyphenols are one of the primary active components of these extracts and prospective additive or ingredient for aqua feed.

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References

AOAC: Official Method of Analysis. 18th Edn., Association of Officiating Analytical Chemists, Washington DC, USA (2005).

Baweja, P., S. Kumar, D. Sahoo and I. Levine: Biology of seaweeds. In: Seaweed in Health and Disease Prevention. Academic Press, London, U.K. pp. 41-106 (2016). https://doi.org/10.1016/B978-0-12-802772-1.00003-8

Chakraborty, K., D. Joseph and N.K. Praveen: Antioxidant activities and phenolic contents of three red seaweeds (Division: Rhodophyta) harvested from the Gulf of Mannar of Peninsular India. *J. Food Sci. Technol.,* **52**, 1924-1935 (2015).

Chakraborty, K., N.K. Praveen, K.K. Vijayan and G.S. Rao: Evaluation of phenolic contents and antioxidant activities of brown seaweeds belonging to *Turbinaria* spp. (Phaeophyta, Sargassaceae) collected from Gulf of Mannar. *Asian Pacific J. Trop. Biomed.,* **3**, 8-16 (2013).

Chopin, P., C.P. Mubaya, K. Descheemaeker, I. Öborn and G. Bergkvist: Avenues for improving farming sustainability assessment with upgraded tools, sustainability framing and indicators. A review. *Agro. Sustain. Develop.,* **41**, 1-20 (2021).

Costa, L.S., G.P. Fidelis, S.L. Cordeiro, R.M. Oliveira, D.A. Sabry, R.B.G. Câmara, L.T.D.B. Nobre, M.S.S.P. Costa, J. Almeida-Lima, E.H.C. Farias and E.L. Leite: Biological activities of sulfated polysaccharides from tropical seaweeds. *Biomed. Pharma.,* **64**, 21-28 (2010).

Dawczynski, C., R. Schubert and G. Jahreis: Amino acids, fatty acids, and dietary fibre in edible seaweed products. *Food Chem.,* **103**, 891-899 (2007).

Dixit, D.C., C.R.K. Reddy, N. Balar, P. Suthar, T. Gajaria and D.K. Gadhavi: Assessment of the nutritive, biochemical, antioxidant and antibacterial potential of eight tropical macro algae along Kachchh coast, India as human food supplements. *J. Aquat. Food Product Technol.,* **27**, 61-79 (2018).

Ebeneezar, S., D.L. Prabu, S. Chandrasekar, C.S. Tejpal, K. Madhu, P. Sayooj and P. Vijayagopal: Evaluation of dietary oleoresins on the enhancement of skin coloration and growth in the marine ornamental clown fish, *Amphipriono cellaris* (Cuvier, 1830). *Aquaculture,* **529**, 735728 (2020).

El ‐ Dahhar, A. A. and K. El ‐ Shazly.: Effect of essential amino acids (methionine and lysine) and treated oil in fish diet on growth performance and feed utilization of Nile tilapia, *Tilapia nilotica* (L.). *Aqua. Res.*, **24**, 731-739 (1993).

FAO: The Global Status of Seaweed Production, Trade and Utilization; Globefish Research Programme. FAO: Rome, Italy, 2018; **Vol. 124**, 120 pages (2020).

FAO: Report of the expert meeting on food safety for seaweed – Current status and future perspectives. Rome, 28–29 0ctober 2021. Food Safety and Quality Series No. 13. Rome, Xiii+73 pages (2022).

FAO: Fishery and Aquaculture Statistics. Global Production Statistics 1950–2019. In: FAO Fisheries Division. Fish StaJ—Software for Fishery and Aquaculture Statistical Time Series, 132 pages (2021).

Fawole, F.J., N.P. Sahu, A.K. Pal and W.S. Lakra: Evaluation of antioxidant and antimicrobial properties of selected Indian medicinal plants. *Int. J. Med. Arom. Plants.,* **3**, 69-77 (2013).

Folch, J., M. Lees and G.S. Stanley: A simple method for the isolation and purification of total lipides from animal tissues. *J. Biol. Chem.,* **226**, 497-509 (1957).

García-Casal, M.N., A.C. Pereira, I. Leets, J. Ramírez and M.F. Quiroga: High iron content and bioavailability in humans from four species of marine algae. *J. Nutr.,* **137**, 2691-2695 (2007).

Garcia-Vaquero, M., G. Rajauria, M. Miranda, T. Sweeney, M. Lopez-Alonso and J. O'Doherty: Seasonal variation of the proximate composition, mineral content, fatty acid profiles and other phytochemical constituents of selected brown macroalgae. *Mar. Drugs,* **19**, 204 pages (2021).

Gélébart, E.L.: An innovative approach to develop sustainable marine active ingredients from macroalgae. The 22nd International Seaweed Symposium: Academia meets industry. *J. Appl. Phycol.,* **29**, 2155-2158 (2016).

Gupta, G., P.P. Srivastava, M. Gangwar, T. Varghese, T.I. Chanu, S. Gupta, M.P. Ande, G. Krishna and P. Jana: Extra-fortification of zinc upsets vitellogenin gene expression and antioxidant status in female of *Clarias magur* brooders. *Biol. Trace Elem. Res.,* **200**, 1861-1871 (2022).

Larbi Ayisi, C., J. Zhao and J.W. Wu: Replacement of fish oil with palm oil: Effects on growth performance, innate immune response, antioxidant capacity and disease resistance in Nile tilapia (*Oreochromis niloticus*). *PLoS ONE,* **13**, e0196100 (2018).

Li, Y.X., W. Li, J. Wu, L.C. Xu, Q.H. Su and X. Xiong: Contribution of additives Cu to its accumulation in pig feces: study in Beijing and Fuxin of China. *J. Environ. Sci.,* **19**, 610-615 (2007).

Makkar, H.P., G. Tran, V. Heuzé, S. Giger-Reverdin, M. Lessire, F. Lebas and P. Ankers: Seaweeds for livestock diets: A review. Anim. *Feed Sci. Technol.,* **212**, 1-17 (2016).

Meng, W., T. Mu, H. Sun and M. Garcia-Vaquero: Evaluation of the chemical composition and nutritional potential of brown macroalgae commercialised in China. *Algal Res.,* **64**, 102683 (2022).

Mwendwa, R., M. Wawire and P. Kahenya: Potential for use of seaweed as a fish feed ingredient: a review. *J. Agri. Sci.,* **15**, 96-108 (2023).

Nunes, A., G.Z. Azevedo, F. de Souza Dutra, B.R. dos Santos, A.R. Schneider, E.R. Oliveira, S. Moura, F. Vianello, M. Maraschin and G.P.P. Lima: Uses and applications of the red seaweed *Kappaphycus alvarezii*: a systematic review. *J. Appl. Phycol.,* **36**, 3409–3450 (2024).

Pereira, A.G., P. Otero, J. Echave, A. Carreira-Casais, F. Chamorro, N. Collazo, A. Jaboui, C. Lourenço-Lopes, J. Simal-Gandara and M.A. Prieto: Xanthophylls from the sea: algae as source of bioactive carotenoids. *Marine Drugs,* **19**, 188 (2021).

Poveda-Castillo, G.D.C., D. Rodrigo, A. Martínez and M.C. Pina-Pérez: Bioactivity of fucoidan as an antimicrobial agent in a new functional beverage. *Beverages,* **4**, 64 (2018).

Rajapakse, N. and S.K. Kim: Nutritional and digestive health benefits of seaweed. *Adv. Food Nut. Res.,* **64**, 17-28 (2011).

Rawiwan, P., Y. Peng, I.G.P.B. Paramayuda and S.Y. Quek: Red seaweed: A promising alternative protein source for global food sustainability. *Tren. Food Sci. Technol.,* **123**, 37-56 (2022).

Roy, S. and P. Anantharaman: A review: Therapeutic and medicinal utilities of marine macro algae. The 22nd International Seaweed Symposium: Academia meets industry. *J. Appl. Phycol.,* **29**, 134-140 (2016).

Rupérez, P.: Mineral content of edible marine seaweeds. *Food Chem.,* **79**, 23-26 (2002).

Shahabuddin, A.M., M.A. Hannan, M.F. Hossain, S. Hemal, R. Khanam, T. Afroz and A. Mustafa: Evaluation of ethanolic extract of red seaweed (*Gracilariopsis lemaneiformis*) on growth and haematological parameters of Nile Tilapia (*Oreochromis niloticus*). *Aquacul. Fish Fishe.,* **4**, e70011 (2024).

Shahidi, Fereidoon and A. Joseph: Carotenoid pigments in seafoods and aquaculture. *Crit. Rev. Food Sci.,* **38**, 1-67(1998).

Shannon, E. and N. Abu-Ghannam: Seaweeds as nutraceuticals for health and nutrition. *Phycologia,* **58**, 563-577 (2019).

Scherer, R. and H.T. Godoy: Antioxidant activity index (AAI) by the 2, 2-diphenyl-1-picrylhydrazyl method. *Food Chem*., **112**, 654-658 (2009).

Singleton, V.L., R. Orthofer and R.M. Lamuela-Raventos: Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Met. Enzymol*., **299**, 152-178 (1999).

Sugiura, Shozo H., M. Faye, C.K. Dong, K. Rathbone and H. Ronald.: Apparent protein digestibility and mineral availabilities in various feed ingredients for salmonid feeds. *Aquaculture*, **159**, 177-202 (1998).

Zhang, B., Y. Peng, P. Rawiwan, T. Wheeler, J. Fitzgerald, L. Huffman and S.Y. Quek: Effect of extraction processes on the physicochemical and functional properties of protein-rich extracts from the red seaweed *Pyropia Seriata* (Nori). *Future Foods,* **10**, 100501 (2024).

Zubia, M., Y. Freile-Pelegrín and D. Robledo: Photosynthesis, pigment composition and antioxidant defences in the red alga *Gracilariopsis tenuifrons* (Gracilariales, Rhodophyta) under environmental stress. *J. Appl. Phycol.,* **26**, 2001-2010 (2014).

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