

Nutritional Composition and Bioactive Compounds of Red Seaweed: A Mini-Review

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Abstract This review describes the nutritional composition and polyphenol content of red algae. The nutrient composition of red algae is highly varied between different genera. Red algae are low-calorie foods, given their high concentration of protein and dietary fiber. They also have higher protein content than brown and green algae, with average values as high as 18.8 g/100 g. The digestibility of red algae proteins is moderate, however, due to their high level of dietary fiber and polyphenols. They have low fat content, but the quality of their fatty acids is very high. They contain essential fatty acids, also oleic acid, arachidonic acid, EPA, and DHA, which are considered beneficial to health. The omega-6/omega-3 ratio is very low (median = 0.8) which is very beneficial for human health. Red algae also have very high amounts of dietary fiber-higher than in terrestrial vegetables-and are especially rich in soluble fiber. It also contains minerals, in high concentrations; among those sodium and iodine stand out. Their sodium/potassium ratio is low, so consumption of red algae would not imply risk for people with hypertension or cardiovascular diseases. The polyphenol content in red algae is very high, but is lower than brown algae.

Keywords: seaweeds, algae, rhodophyta, red algae, porphyra

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1. Introduction

In every marine coast worldwide, many valuable resources can be found, including algae, which, due to their diversity and in terms of taxonomy have multiple classifications: brown (Phaeophyta), green (Chlorophyta), red (Rhodophyta), and blue-green (Cyanophyta) [1]. Algae have many different nutritional components and bioactive compounds and are therefore being incorporated in the development and formulation of new food products [2,3]. In addition, they are associated with low incidence of numerous diseases [4,5,6].

From a nutritional point of view, seaweeds are very interesting to those working in the field of nutrition due to their high level of protein, minerals, vitamins, dietary fiber, antioxidants, and fatty acids, and their low caloric value [7,8]. Despite the fact that, like most flora, seaweed's nutrient content is affected by external factors, such as habitat and the environment, they can be considered a high-quality and natural source of nutrition with numerous bioactive compounds that can be used as ingredients in functional foods and have many applications in human health [9,10].

Some studies have indicated that including seaweed in diets has potential health benefits related to digestive

health and chronic diseases such as cardiovascular disease, diabetes, and cancer [5,11,12], as well as bacterial and viral diseases [13,14].

Red algae, which belong to the species known as Rhodophyta, a name derived from the greek terms *rhodo* (pink) and *phyta* (plant), are ancient, abundant, and marketable organisms, with a peculiar way of reproducing [15]. Their red color were attributed to their pigments, which include carotenoids and phycobiliproteins; they are also photosynthetic, have a special polysaccharide composition, lacks starch in their chloroplasts but use florid cytoplasmic starch as a reserve [16].

Red algae are located in the intertidal and subtidal zones of rocky coasts and many of them are found at greater depths than brown and green algae, in cold and temperate areas. This resource has economic importance as it is used directly or as an ingredient for human consumption and for the extraction of carrageenans [17,18].

More data on the nutritional composition and technological properties of red seaweeds it is necessary. Exists much different species of red algae, and all of them are of interest for their nutritional composition and bioactive compounds, as well as their technological properties.

The purpose of this study is to review the information regarding nutritional composition and polyphenols of red algae.

2. Materials and Methods

The following databases were used in the literature search: Web of Science, Scopus, PubMed, and Google Scholar. The search keywords included *Rhodophyta* and the English terms *chemistry*, *chemical composition*, *nutritional composition*, and *red seaweed*. No restrictions were made regarding language or date of publication. The included studies were published in food chemistry and bioenvironmental journals.

3. Red Algae

3.1. Nutritional Composition

Rhodophyta or red seaweed contain phycobilins (phycobiliproteins), which are proteins with linear tetrapyrrole prosthetic groups (bilines), covalently linked to cysteine residues. Phycobilins capture light energy, which is transform into chlorophyll during photosynthesis. There are two types of phycobilins: phycoerythrin and phycocyanin. These pigments capture blue light, present at

greater marine depths. Phycocyanin and phycoerythrin mask chlorophyll and carotenoids, resulting in red algae's color, which varies from red to violet [19].

Red algae are rich in carrageenans-sulfated galactans with diverse applications as thickening, texturizing, gelling, and stabilizing agents that are of great interest to the hydrocolloid industry [20].

Red algae's growth rate and nutritional composition is influenced by the temperature of the water as well as the amount of light (for photosynthesis) and nutrients in the water. These factors vary according to the locality and season [21].

As shown in Table 1, the amount of protein found in the included studies of red algae was very high, with an average of 18.8 ± 7 g/100 g. The highest amount was found in *Porphyra umbilicalis* (40.0 g/100 g) and the lowest concentration was found in *Gracilaria crassa* (5.2 g/100 g). Of all of the types of algae included in the table, more than half had a protein content above 15 g/100 g, and approximately 40% had more than 20 g/100 g; these are very high values, similar to those found in meats and dried legumes. Terrestrial vegetables and fruits have lower protein concentrations than red algae [22].

Table 1. Chemical composition of red algae: macronutrients (g/100g d.m)

SCIENTIFIC NAME	Protein	Fat	CH.	Dietary fiber	Ash	Energy (kcal)	Ref.
<i>Coralina mediterranea</i>	17,1	2,1	26,6	37,9	39,0	193	[55]
<i>Ceramium diaphanum</i>	14,0	1,2	-	-	11,4	-	[56]
<i>Euclima cottonii</i>	9,8	1,1	26,5	25,1	46,2	155	[57]
<i>Gelidium pristoides</i>	11,8	0,9	43,1	-	14,0	228	[58]
<i>Gelidium pusillum</i>	11,3	2,2	40,6	24,7	21,2	227	[40]
<i>Gracilaria birdiae</i>	16,2	1,3	-	-	22,5	-	[59]
<i>Gracilaria cervicornis</i>	19,7	0,4	63,1	5,7	10,5	335	[60]
<i>Gracilaria changii</i>	12,6	0,3	41,5	64,7	40,3	219	[61]
<i>Gracilaria crassa</i>	5,2	1,3	42,0	-	43,2	200	[62]
<i>Gracilaria domingensis</i>	13,8	1,3	-	-	23,8	-	[59]
<i>Gracilaria edulis</i>	14,3	0,9	32,4	63,2	7,6	195	[63]
<i>Gracilaria fisheri</i>	11,6	2,2	-	60,8	22,2	-	[64]
<i>Gracilaria gracilis</i>	22,5	2,2	-	-	20,5	-	[65]
<i>Gracilaria lemaneiformis</i> B.	20,9	0,9	61,6	-	16,7	338	[66]
<i>Gracilaria salicornia</i>	9,6	2,0	-	10,4	38,9	-	[67]
<i>Gracilaria</i> sp.	23,6	0,7	46,9	40,6	28,9	288	[68]
<i>Gracilaria tenuistipitata</i>	21,6	2,8	-	58,4	17,0	-	[64]
<i>Grateloupia turuturu</i>	22,9	2,6	-	60,4	18,5	-	[69]
<i>Grateloupia turuturu</i>	20,2	0,6	-	-	24,8	-	[59]
<i>Hypnea charoides</i>	18,4	1,5	7,0	50,3	22,8	115	[70]
<i>Hypnea japonica</i>	19,0	1,4	4,3	53,2	22,1	106	[70]
<i>Hypnea musciformis</i>	18,6	1,3	20,6	37,9	21,6	168	[71]
<i>Hypnea musciformis</i>	18,6	1,3	20,6	37,9	21,6	168	[40]
<i>Hypnea pannosa</i>	16,3	1,6	22,9	40,6	18,7	171	[40]
<i>Laurencia filiformis</i>	29,6	6,2	-	-	38,4	-	[59]
<i>Laurencia intricata</i>	11,1	1,1	-	-	33,5	-	[59]
<i>Nostoc flagelliforme</i>	27,7	0,6	54,1	-	17,6	333	[66]
<i>Osmundea pinnatifida</i>	23,8	0,9	-	-	30,6	-	[65]
<i>Porphyra columbina</i>	24,6	0,3	-	48,0	6,5	-	[72]
<i>Porphyra</i> sp.	27,0	2,8	-	49,8	-	-	[73]
<i>Porphyra</i> sp.	25,6	1,0	-	45,7	-	-	[73]
<i>Porphyra umbilicalis</i>	40,0	0,2	-	35,0	10,0	-	[74]
<i>Pyropia acanthophora</i>	15,9	2,1	45,3	56,7	5,8	263	[75]
<i>Pyropia orbicularis</i>	23,2	0,8	53,7	56,6	16,5	314	[76]
Average	18,8	1,5	36,3	43,8	22,9	223,2	
Standard deviation	6,98	1,09	17,25	16,32	10,99	73,95	
Median	18,6	1,3	41,1	46,9	21,6	209,7	
Maximum	40,0	6,2	63,1	64,7	46,2	337,8	
Minimum	5,2	0,2	4,3	5,7	5,8	105,9	

The protein concentration in the algae of the *Porphyra* genus is significantly higher than in other types of algae, reaching an average of 29.3 g/100 g. According to information from the Food and Agriculture Organization (2009), *Porphyra* is rich in protein and free amino acids and has an appealing flavor; it is a traditional food in Asia-mainly China, Japan, and Korea. This seaweed is known as *nori* or *luche*, and is included in sushi preparations, so its consumption has increased in Western countries. The algae of the *Grateloupia*, *Laurencia*, and *Pyropia* genus also have high protein content-an average of 21.6, 20.4, and 20.0 g/100 g respectively. Algae of the *Gelidium* genus have the lowest protein content, with an average of 11.6 g/100 g.

In general, red algae have a higher protein content than green and brown algae [23,24,25,26]. According to the literature found in this study, red algae have protein concentrations that range from 5.2% to 40% (dry weight). According to the authors of one study, *nori* algae (*P. umbilicalis*) stands out for its high percentage of protein, which is comparable to the protein content of soybeans [27]. However, the digestibility of algae protein is moderate compared to proteins of animal origin; this may be due to algae's high concentration of dietary fiber, which decreases the access of digestive and proteolytic

enzymes [28].

It should be noted that the concentration of protein as well as other nutrients varies depending on the season and other environmental factors [29,30].

The essential amino acid content of red algae is quite complete, as shown in Table 2; the only amino acid with a limited quantity appears to be tryptophan. The highest values for amino acids were for leucine, valine, threonine, and lysine. According to one study, red algae contain the essential amino acids leucine, valine, and methionine in amounts comparable to those found in egg albumin [31]. Other amino acids such as isoleucine and threonine are found in red algae in amounts similar to those contained in plants from the legume family.

While essential amino acid levels range from 22% to 44% of the total of brown algae and from 26% to 32% in green algae, red algae has between 14% and 19% [23]. However, according to Belghit *et al.* [32], the concentration of some amino acids, such as glutamate, ornithine, citrulline, serine, and glycine, are significantly higher in red algae than brown and green algae. The bioavailability of the amino acids that comes from the digestion of red algae protein, which can be affected by various antinutritional agents such as polyphenols, polysaccharides, and glycoproteins.

Table 2. Aminoacids in red algae. (mg/100g)

Scientific name	<i>Coralina mediterranea</i>	<i>Eucheuma cottonii</i>	<i>Gelidium pusillum</i>	<i>Gracilaria birdiae</i>	<i>Gracilaria changii</i>	<i>Gracilaria crassa</i>	<i>Gracilaria domingensis</i>	<i>Gracilaria edulis</i>	<i>Gracilaria fisheri</i>	<i>Gracilaria lemaneiformis</i> Bory	<i>Gracilaria salicornia</i>	<i>Gracilaria tenuisipitata</i>	<i>Hypnea charoides</i>	<i>Hypnea japonica</i>	<i>Hypnea musciformis</i>	<i>Hypnea pannosa</i>	<i>L. filiformis</i>	<i>L. intricata</i>	<i>Porphyra columbina</i>	<i>Porphyra purpurea</i>	<i>Porphyra sp</i>	<i>Porphyra sp</i>	<i>Porphyra umbilicalis</i>	<i>Pyropia columbina</i>	<i>Pyropia orbicularis</i>	<i>Undaria pinnatifida</i>
Asp	5,4	2,7	82,2	1,2	8,6	6,1	1,0	4,6	0,8	0,3	53,9	1,9	88,6	98,4	86,5	76,3	1,5	1,0	12,2	66,6	8,5	8,2			7,4	75,6
Thr	3,6	2,1	51,5	0,5	6,1	1,9	0,4	3,0	0,6	0,1	32,9	1,2	51,3	45,9	62,7	41,5	0,6	0,4	5,9	50,1	5,3	5,2	170	7,7	15,1	29,2
Ser	4,0	1,9	38,2	0,5	5,2	2,2	0,4	0,8	0,5	0,2	34,6	1,2	44,9	47,5	43,9	32,3	0,6	0,4	6,2	46,3	4,0	4,9		2,5	4,5	34,0
Glu	6,8	5,2	108,8	1,0	8,4	4,5	0,9	13,1	0,9	0,4	75,9	2,1	98,4	110	107	119	1,4	0,9	10,5	83,0	10,2	9,3			10,5	120,9
Gly	3,4	2,3	43,4	0,6	3,2	1,8	0,5	0,7	0,6	0,1	75,6	1,1	50,6	54,2	47,7	49,2	0,7	0,5	8,9	75,4	5,1	4,1		2,6	10,1	65,8
Ala	3,5	3,1	51,6	0,7	5,4	2,3	0,6	2,6	0,6	0,2	75,5	1,4	52,3	57,4	47,9	52,4	0,7	0,7	12,5	80,5	6,2	4,2		15,3	8,9	97,6
Val	3,5	2,6	44,7	0,5	4,8	1,1	0,4	1,7	0,5	0,1	41,4	1,1	61,4	56,3	55,8	53,7	0,5	0,3	5,9	48,0	5,2	4,5	192	2,6	3,8	58,5
Ile	3,3	2,4	42,1	0,4	5,2	2,0	0,4	1,1	0,5	0,1	30,3	1,0	48,5	44,8	42,1	48,2	0,5	0,3	2,7	34,4	3,1	3,3	130	1,1	1,4	50,8
Leu	4,5	3,4	75,2	0,7	6,6	2,7	0,7	0,4	0,6	0,2	76,6	1,5	72,3	97,9	84,8	77,4	0,8	0,5	7,4	53,2	5,5	5,9	116	3,5	6,4	86,1
Tyr	2,7	1,0	26,2	0,2	2,9	1,0	0,2	0,6	0,3	0,1	75,9	0,6	26,0	27,9	26,2	25,8	0,6	0,3	2,6	29,4	3,4	3,2	147	1,2	3,2	21,0
Phe	3,0	19,1	31,9	0,5	5,0		0,4	1,3	0,6	0,1	32,7	1,0	37,2	32,9	32,9	30,8	0,5	0,3	3,7	78,2	3,3	3,5	147	0,8	3,5	48,5
His	6,4	0,3	4,6	0,2	3,4	0,6	0,1	3,3		0,1	14,3		6,6	6,9	6,4	5,8	0,2	0,1	1,3	22,0	2,6	2,4	82,0	9,7	14,0	17,1
Lys	2,7	1,5	48,3	0,6	6,0	2,0	0,4	1,9	0,3	0,1	77,1	1,0	64,9	66,3	45,6	55,3	1,0	0,5	6,0	29,9	4,9	5,2	96,0	4,1		40,0
Arg	3,9	2,6	62,7	0,6	17,2	2,1	0,4	3,3	0,7	0,2	75,8	1,3	63,6	66,8	68,3	51,9	0,6	0,2	6,2	90,0	5,9	5,9		4,7	6,4	88,2
Pro	22,7	2,0	46,6	0,5	1,7	1,4	0,4		0,4	0,1	39,8	1,0	47,9	45,4	44,2	40,8	0,5	0,3	3,9	38,0	3,5	3,6		8,6	10,7	44,3
Cys	0,4			0,0		0,2	0,0										0,1	0,0	1,9	4,6	1,2	1,3	84,0	0,2		3,3
Met	1,4	0,8	15,8	0,2	2,0	0,4	0,2	1,7		0,1	77,5		18,5	16,2	16,2	14,6	0,3	0,1	1,7	13,7	1,8	1,7	84,0	0,2	2,2	1,4
Trp				0,2			0,2										0,2	0,1	0,6		0,7	0,7		2,0		
Ref	[55]	[57]	[59]	[60]	[62]	[63]	[60]	[77]	[64]	[66]	[67]	[64]	[70]	[70]	[40]	[40]	[59]	[59]	[72]	[78]	[73]	[73]	[74]	[72]	[76]	[78]

As shown in Table 1, fat content in red algae is fairly low, with an average of 1.5 g/100 g, a minimum value is 0.2 g/100 g (in the algae *P. umbilicalis*), and a maximum of 6.2 g/100 g (in *Laurencia filiformis*). In general, all algae contain low lipid concentrations, but this fat content is of high quality in terms of nutritional value [33].

The concentrations of myristic and palmitic acids were the highest. Some red algae have a very high concentration of palmitic acid, such as *G. crassa* (52.9%) and *G. edulis* (65.0%); overall, algae of the *Gracilaria* genus seems to contain a high amount of palmitic acid.

Some red algae have a monounsaturated fatty acid concentration higher than 30% (e.g., *G. lemaneiformis* B. and *Ceramium diaphanum*), but most have a concentration of only 10% to 20%. Oleic acid was found in all red algae analyzed in the studies, but the amount varied widely, with higher concentrations found in the genus *Gracilaria*. The minimum value was 0.09% (in *Gelidiella acerosa*, from India), and the maximum value was 31.1% (in *G. lemaneiformis* B., from China). Red algae also have the essential fatty acids (linolenic and linoleic), with maximum values of 22% and 11% respectively. The arachidonic acid content varies widely across different types of red algae, with an average of 8.6%.

Belghit *et al.* [32] analyzed red, brown, and green algae and concluded that monounsaturated and polyunsaturated fatty acids are more concentrated in red and green algae than in brown algae; red algae of the *Porphyra* genus had a higher content of fatty acids of 20 and 22 carbon atoms; and the oxylipine content was higher in red algae. This latter compound functions as a secondary metabolite, as part of the plant's immune system, and were derived from free fatty acids (mainly linoleic and linolenic). Oxylipins are suspected to have an anti-inflammatory effect, which has been studied in cancer therapies [34].

The fatty acids EPA and DHA, long-chain polyunsaturated of the omega-3 family, are found in fish and algae. According to the data found in this review, these substances have not been detected yet in some red algae, which yielded a value of zero (Table 3); while other types had concentrations as high as 48.4% of the total fatty acids, as in *G. changii* from Malaysia. With a median value of 12.8%, meaning that half the samples had even higher values, red algae concentration of these fatty acids is relatively high. Therefore, red algae can be consider a good font of EPA and DHA fatty acids. Overall, DHA content was higher than EPA content, with an average of 21% and 13% respectively.

Table 3. Fatty acid content of red algae

Scientific name	EPA+DHA (%)	Total saturated (%)	Total monounsaturated (%)	Total polyunsaturated (%)	Ratio $\omega 6/\omega 3$	Ref
<i>Brongniartella australis</i>	22,8	42,1	16,6	40,7	0,5	[79]
<i>Callophyllis rangiferina</i>	4,5	49,1	16,9	33,2	1,1	[79]
<i>Ceramium diaphanum</i>	0,0	62,9	35,6	1,5	1	[56]
<i>Ceramium rubrum</i>	18,9	39,0	16,2	44,2	0,7	[79]
<i>Champia viridis</i>	20,8	42,7	10,1	46,3	0,7	[79]
<i>Chondria succulenta</i>	7,9	40,1	22,5	35,8	0,8	[79]
<i>Corallina mediterranea</i>	14,9	52,4	21,6	26,0	0,11	[55]
<i>Dasyphloea insignis</i>	33,1	36,2	13,8	49,5	0,3	[79]
<i>Delisea pulchra</i>	8,1	35,8	14,9	48,5	0,4	[79]
<i>Echinothammion hystrix</i>	13,7	38,7	21,3	39,4	0,9	[79]
<i>Euclima cottonii</i>	25,0	25,2	23,3	51,6	0,1	[57]
<i>Euptilota articulata</i>	7,0	50,4	20,2	28,6	1,3	[79]
<i>Gelidiella acerosa</i>	0,0	46,1	18,0	35,9	1,24	[59]
<i>Gelidium asperum</i>	16,2	32,8	10,3	56,6	2	[65]
<i>Gelidium australe</i>	18,6	36,0	10,6	53,0	1,5	[51]
<i>Gigartina recurva</i>	22,6	32,5	19,1	47,9	0,5	[79]
<i>Gracilaria birdiae</i>	0,0	63,5	6,6	29,9		[79]
<i>Gracilaria birdiae</i>	0,4	49,6	27,5	18,6	7,4	[79]
<i>Gracilaria changii</i>	48,4	7,5	38,3	51,2	0,02	[80]
<i>Gracilaria crassa</i>	0,0	87,5	2,0	10,5		[81]
<i>Gracilaria domingensis</i>	0,0	77,7	7,5	14,8		[61]
<i>Gracilaria domingensis</i>	0,3	19,2	17,2	60,1	70	[62]
<i>Gracilaria edulis</i>	0,0	4,5	2,0	4,3		[81]
<i>Gracilaria edulis</i>	0,1	69,2	17,3	11,5	20,3	[77]
<i>Gracilaria gracilis</i>	0,0	63,5	15,2	21,2	15,4	[63]
<i>Gracilaria lemaneiformis</i> B.	0,0	39,0	32,7	28,3	6,4	[65]
<i>Gracilaria salicornia</i>	1,5	48,9	16,4	17,4		[66]
<i>Gracilaria turuturu</i>	29,9	42,7	11,5	45,7	0,46	[67]

Scientific name	EPA+DHA (%)	Total saturated (%)	Total monounsaturated (%)	Total polyunsaturated (%)	Ratio $\omega 6/\omega 3$	Ref
<i>Grateloupa subpectinata</i>	38,2	33,6	11,8	53,9	0,4	[79]
<i>Grateloupia turuturu</i>	12,0	67,4	11,6	19,1	0,6	[82]
<i>Grateloupia turuturu</i>	29,1	32,5	11,8	55,2	0,8	[79]
<i>Griffithsia ovalis</i>	38,4	37,3	10,3	52,2	0,2	[79]
<i>Griffithsia teges</i>	17,7	35,7	16,1	47,5	1,1	[79]
<i>Halopeltis wilsonis</i>	10,3	52,2	18,8	28,0	1,2	[79]
<i>Hemineura frondosa</i>	26,2	42,6	16,7	40,1	0,4	[79]
<i>Kappaphycus alvarezii</i>	10,3	59,3	13,8	17,6	0,71	[83]
<i>L. filiformis</i>	0,8	72,3	8,5	16,7	0,91	[59]
<i>L. intricata</i>	1,7	50,6	10,5	38,9	0,91	[59]
<i>Laurencia bitryoides</i>	16,0	42,7	19,1	37,5	0,5	[79]
<i>Laurencia filiformis</i>	18,3	38,5	18,5	41,8	0,8	[79]
<i>Laurencia sp</i>	21,3	42,3	16,4	41,1	0,4	[79]
<i>Lenormandia marginata</i>	12,0	44,6	21,3	33,6	1	[79]
<i>Lophurella pericladus</i>	22,2	43,7	17,4	38,3	0,5	[79]
<i>Nitospinosa tasmanica</i>	1,2	67,8	21,7	10,1	2,3	[79]
<i>O. pinnatifida</i>	15,6	58,1	18,9	23,0	0,42	[65]
<i>Osmundaria obtusiloba</i>	9,1	63,4	18,2	18,4	0,93	[84]
<i>P. umbilicalis</i>	36,3	35,7	9,5	56,4	0,11	[79]
<i>Plocamium angustum</i>	14,5	48,7	7,7	42,8	1,3	[79]
<i>Plysiphonia decipiens</i>	19,1	39,9	16,9	42,7	0,5	[79]
<i>Pollexfenia lobata</i>	19,3	44,5	14,0	41,1	0,7	[79]
<i>Polypes constrictus</i>	10,2	36,4	18,3	44,9	2,8	[79]
<i>Porphyra columbina</i>	28,4	26,8	13,8	59,5	0,5	[72]
<i>Porphyra sp</i>	20,9	35,7	18,6	44,8	0,6	[73]
<i>Porphyra sp</i>	10,4	44,5	20,7	33,9	1,8	[73]
<i>Pterocladia capillacea</i>	1,9	90,6	5,1	4,3	1,05	[84]
<i>Ptilonia australasica</i>	2,6	38,1	15,5	45,1	7	[79]
<i>Rhodoglossum gigartinoides</i>	27,4	32,6	12,1	54,8	0,6	[79]
<i>Rhodymenia leptophylla</i>	5,7	46,6	18,0	34,3	3,4	[79]
<i>Sarcotrichia dolichocystidea</i>	1,0	61,2	14,5	23,8	8,2	[79]
<i>Zymurgia chondriopsidea</i>	19,8	49,9	17,1	32,5	0,5	[79]
Average	13,9	45,8	16,1	35,4	3,2	
Standart deviation	12,00	16,27	6,81	15,29	9,86	
Median	12,8	42,7	16,5	38,6	0,8	
Maximum	48,4	90,6	38,3	60,1	70,0	
Minimum	0,0	4,5	2,0	1,5	0,0	

The fatty acids found in the highest concentrations in red algae, on average, were palmitic, DHA, EPA, arachidonic, and oleic (31%, 21%, 13%, 9%, and 8% respectively).

Many foods frequently consumed by the western population are very high in omega-6 fatty acids relative to the amount of omega-3 fatty acids, and this high omega-6/omega-3 ratio has been associated with various health problems including inflammation, and vasoconstriction, if the consumption of omega-6 is excessive [35]. Table 3 shows the values for the omega-6/omega-3 proportion in red algae, which are very low, median is 0.8 and average is 3.2. Except in *G.*

domingensis, which had a value of 70, as these algae have a high concentration of arachidonic acid. If this value were eliminated, the average $\omega 6/\omega 3$ ratio would be 2.0, a level considered very beneficial to health, as it implies a protective effect for the cardiovascular system and against metabolic syndrome [36].

The distribution of fatty acids in red algae appears to be saturated > polyunsaturated > monounsaturated; based on the data on fatty acids and the omega-6/omega-3 ratios of red algae, this type of fatty material is excellent quality and beneficial for health.

The carbohydrate content found in red algae varied widely across the study samples but in general was high.

The algae of the genus *Hypnea* had the lowest carbohydrate content, with an average of 15.1 g/100 g; algae of the genera *Gracilaria* and *Pyropia* had significantly higher concentrations (47.9 and 49.5 g/100 g respectively).

In red algae, stored carbohydrates are mainly amylopectin or floridean starch, which is a D-glucan. Floridoside corresponds to a valuable reserve of soluble carbon, which is usable by cells. It acts as an osmoregulator in aqueous solution and is responsible for the resistance of the algae cell wall against variations in the salinity of the medium. A study by Courtois *et al.* [24] showed that extract from the red algae *Mastocarpus stellatus* has a potentially positive effect on the immune system. The extract concentration increases in summer months and decreases in winter, the opposite of what occurs with protein content [21].

According to Lee *et al.* [37], the red algae cell wall contains an abundant amount of agar, a polysaccharide formed by D- and L-galactose, with some sulfated side chains, and methoxy groups, among others. Agar has applications as a phycocolloid in food, drugs, cosmetics, etc.

Red algae have a high amount of dietary fiber, as shown in Table 1. The median value was 46.9 g/100 g, with a maximum value of 64.7 g/100 g (in *G. changii*). These values are very high, and so are the proportions of soluble dietary fiber, which is considered beneficial for health as it reduces blood cholesterol and postprandial glucose levels and increases satiety [38].

While dietary fiber was not analyzed in all algae samples shown in Table 1, a wide variability in the values that were provided was found; the minimum value was 5.7 g/100 g (in *G. cervicornis*) and the maximum value was 64.7 g/100 (in *G. changii*). These values are higher than those of fruits and vegetables are.

The ash content of the red algae samples, shown in Table 1, is in general also high, with an average value of 22.9 ± 10.99 g/100 g, a much higher value than that found in terrestrial vegetables. This varies by geographic

location and season and is associated with mineral content [39,40].

The mineral concentrations in red algae are listed in Table 4. As shown, red algae have very high sodium content-higher than terrestrial vegetables-due to its contact with seawater. The average is 882 mg/100 g, with the maximum value found in *Gracilaria changii* (2118 mg/100 g). The potassium concentration is also very high, and so is the Na/K ratio (0.5), which, ideally, should be less than or equal to 1 (or lower), since high Na/K ratios (greater than 2.5) are associated with hypertension and cardiovascular diseases [41]. Red algae's high concentration of magnesium is another potential benefit to health, as this mineral is required for the construction of cell proteins and thus helps maintain the musculature structure. In most red algae, the level of magnesium exceeds the concentration found in sunflower seeds, almonds, hazelnuts, wheat germ, and soybeans-all foods that are considered magnesium-rich [42]. Levels of manganese, a mineral that is required by the immune system, affects reproduction and bone growth, and has a protective effect against reactive oxygen species, are very high in some red algae-higher than the levels found in terrestrial vegetables [42,43]. The zinc concentration in red algae was on average 3.0 mg/100 g-quite high. This mineral is found in high concentrations in meat, eggs, and fish, and affects growth, which is why its consumption in children is considered so important [22,42,43]. Iodine levels in red algae were also analyzed, but only in four studies, with large differences between them. The maximum value was found in the algae *G. lemaneiformis* (426.1 mg/100 g), and the median was 9.4 mg/100 g. Iodine is a structural part of thyroidal hormones, and excessive consumption must be avoided; adequate intake for adults is 150 µg/day [43]. Seafood and fish are characterized by high concentrations of copper, an essential mineral for growth in children, bone strengthening and maturation of red blood cells, iron transport, and uptake of glucose and cholesterol, and brain development. In red algae, the average concentration of copper is similar to that of legumes [43].

Table 4. Mineral content of red algae (mg/100g)

Scientific name	K	Na	Mg	Mn	Zn	I	Cu	Fe	Na/K	Ref.
<i>Corallina mediterranea</i>	86	26	53	0,1	0,0		0,0		0,30	[55]
<i>Euclima cottonii</i>	13155	1772	271		4,3	9,4	0,0		0,13	[57]
<i>Gelidiella acerosa</i>	522	129	0		0,4			1,5	0,25	[51]
<i>Gracilaria changii</i>	17614	2118	436		3,3		1,0		0,12	[61]
<i>Gracilaria edulis</i>	283	423		4,0	1,7		1,8		1,50	[63]
<i>Gracilaria lemaneiformis</i> Bory				0,7	6,4	426,1	0,3			[66]
<i>Gracilaria salicornia</i>	11380	1036		4,2			0,6	67,4	0,09	[67]
<i>Gracilaria sp.</i>	1595	1595	286	15,7	3,5		3,5		1,00	[68]
<i>Gracilaria tenuistipitata</i>	5792	292	581		4,5		0,6		0,05	[64]
<i>P. umbilicalis</i>	1407	1173	283	2,7	4,2				0,83	[74]
<i>Porphyra columbina</i>	1444	414	492		1,5		0,5		0,29	[72]
<i>Porphyra purpurea</i>	1602	728	234	2,5	3,3	0,5	0,6	10,5	0,45	[78]
Average	4989	882	293	4,3	3,0	145,4	0,9	26,5	0,5	
Standard deviation	6181,3	709,7	190,3	5,26	1,93	243,17	1,0	35,7	0,46	
Median	1595	728	283	2,7	3,3	9,4	0,6	10,5	0,3	
Maximum	17614	2118	581	15,7	6,4	426,1	3,5	67,4	1,5	
Minimum	86	26	0	0,1	0,0	0,5	0,0	1,5	0,1	

The energy contribution of the algae is low, the average found in the data (Table 1) is 223.2 ± 73.95 kcal / 100g; with a maximum of 337.8 and minimum of 105.9 kcal/100g. This low caloric intake is because its fat content is very low and dietary fiber is very high.

The vitamin content of red algae is shown in Table 5, little data found that reported vitamins. Vitamin levels was not quantified in all of the studies, and the values that were provided varied widely. Overall, there was a higher concentration of vitamin C than both vitamin A and vitamin E. According to Rajapakse and Kim [5], red and brown algae are rich in vitamin C and A. *Porphyra* red algae are rich in B vitamins [33]. Vitamin B12, which were synthesized by organisms of animal origin, and bacteria, has been detected in low concentrations in some algae, mostly due to bacterial production. A compound denominated pseudovitamin B12, which is not biologically active in humans, has also been detected in red algae [44].

Table 5. Vitamin content of red algae (mg/kg)

Scientific Name	Vitamin A	Vitamin C	Vitamin E	Ref.
<i>Euclima cottonii</i>		35.3		[57]
<i>Gelidiella acerosa</i>	0.0	5.1	1.3	[51]
<i>Gracilaria edulis</i>			1.0	[63]
<i>Gracilaria lemaneiformis</i> B.	0.0	33.4	1.0	[66]
<i>Porphyra purpurea</i>	23.8	9.7	9.3	[78]
<i>Undaria pinnatifida</i>	4.7	3.1	6.3	[78]
Average	7.1	17.3	3.8	
Standard deviation	9.83	14.08	3.41	
Median	2	10	1	
Max	23.8	35.3	9.3	
Min	0	3.1	1	

3.2. Polyphenol Content

Total polyphenol content (TPC) in red algae is shown in Table 6; the median is very high, 127 (mg GAE/100g), however, there is a lot of variability between the values; they have a maximum of 5121 and a minimum of 25.8 (mgGAE/100 g). The values are quite high-higher than those found in many fruits and vegetables-but lower than those found in brown algae. The types of polyphenols found in red algae are different from what is found in brown algae; red algae tends to have protocatechin, genetic acids, and hydroxybenzoic acid; in red algae they have been identified bromophenols. Red algae has diterpenes and sesquiterpenes phenolics. In brown algae the phlorotannins predominate [45]. There is a correlation between red algae's polyphenol content and antioxidant capacity; other antioxidants, such as ascorbic acid and carotenoids, make a contribution to the antioxidant capacity, but their contribution is less than that of polyphenols [45,46]. Brown algae have a higher polyphenol content and antioxidant capacity than red algae [46,47].

Table 6. Total polyphenols of red algae (mg GAE/100g)

Scientific name	Total Polyphenols	Ref.
<i>Asparagopsis taxiformis</i>	57,6	[46]
<i>Bryothamnion triquetrum</i>	5121,0	[85]
<i>Callophyllis</i>	1056,0	[86]
<i>Chondrus crispus</i>	36,3	[46]
<i>Chondrus</i>	530,0	[85]
<i>Chondrus crispus</i>	81,7	[87]
<i>Gracilaria biridae</i>	109,5	[88]
<i>Gracilaria chilensis</i>	309,9	[54]
<i>Gracilaria cornea</i>	88,5	[88]
<i>Gracilaria sp.</i>	1025,0	[86]
<i>Gracilaria vermiculophylla</i>	73,3	[87]
<i>Grateloupa lanceola</i>	25,8	[46]
<i>Kappaphycus alvarezzi</i>	115,0	[48]
<i>Laurencia sp.</i>	25,8	[85]
<i>Mastocarpus stellatus</i>	93,2	[87]
<i>Nemalion elminthoides</i>	65,5	[46]
<i>Palmaria palmata</i>	139,5	[87]
<i>Palmaria palmata</i>	500,0	[89]
<i>Palmaria palmata</i>	1280,0	[90]
<i>Polysiphonia fucoides</i>	1066,4	[87]
<i>Porphyra</i>	570,0	[47]
<i>Porphyra columbina</i>	30,0	[72]
<i>Porphyra purpurea</i>	323,7	[87]
<i>Porphyra spp</i>	291,0	[52]
Average	542	
Standard deviation	1049,52	
Median	127	
Maximum	5121	
Minimum	25,8	

Interest Conflict

The authors declare no conflict of interest.

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