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Monthly variation in the chemical composition of *Eisenia arborea* J.E. Areschoug

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Abstract The brown alga *Eisenia arborea* is the second most abundant brown alga along the western coast of the Baja California Peninsula of Mexico. Samples of *E. arborea* were collected in Bahía Asunción, BCS, over 10 months. Chemical composition was analyzed from dried alga (%, dw): moisture (10.34%), protein (9.44%), ash (24.77%), lipids (0.60%), fiber (5.22%), and carbohydrates (49%). Gross energy was 9.8 kJ g^{-1}. Seven minerals were analyzed and the four most abundant were K, Na, Mg, and Ca, ranging from 907 to 7,946 mg.100 g^{-1}. The concentrations of six vitamin levels were also determined: A, C, E, D_3, B_2, and B_1. Seventeen amino acids were analyzed and the most abundant were glutamic acid, aspartic acid, and leucine. Total fatty acids ranged from 21 to 65 mg.100 g^{-1} (dw). Individual concentrations were also determined for arachidonic acid, alpha linolenic acid, linoleic acid, eicosapentaenoic acid, and docosahexaenoic acid. Saponins, cyanogenic glycosides, and alkaloids were not detected. Our results suggest that *E. arborea* is a good candidate to be tested as supplement food for animals, including humans. It contains essential amino acids, is low in lipids and fiber, and could be a source of vitamins and minerals.

Keywords Algae · Kelp · *Eisenia arborea* · Nutrition · Minerals · Vitamins · Amino acids · Fatty acids

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Introduction

The southern sea palm or stiped kelp, *Eisenia arborea* J.E. Areschoug, is distributed from British Columbia, Canada (Druehl 1970) to Bahía Magdalena, Baja California Sur (BCS), Mexico (Aguilar-Rosas et al. 1990), and can form dense beds from the intertidal to 35 m depth (Spalding et al. 2003). This species is able to survive El Niño effects and recruit in high densities (Edwards and Hernández-Carmona 2005). Surveys on the Pacific side of the Baja California Peninsula showed that *E. arborea* is the second most abundant brown alga after *Macrocystis pyrifera* (L.) C. Agardh. Populations of this species are difficult to assess as it grows predominantly below the low intertidal and therefore, there are as yet no estimates of total biomass. Nevertheless, some data regarding density exists. During normal years (no El Niño events), such as early 1997 and 1998, the density in Bahía Asunción, BCS was 6.6 plants m^{-2} (Hernández-Carmona et al. 2000). In Bahía Magdalena, BCS, the density was 19 plants m^{-2} in 2002 (Arvizu et al. 2007). Alginate content of *E. arborea* range from 22.4% to 28.6% (Hernández-Carmona 1985; Arvizu et al. 2007) with viscosity from 793 to 2,210 mPa s in 1% solution (Arvizu et al. 2007). Although these data suggest that *E. arborea* could be used as a raw material for

alginate production, the alginate industry may face various difficulties, such as harvesting the alga economically, producing good quality alginate at low cost to compete with other countries and finding a market niche.

Most of the studies on *E. arborea* deal with ecological aspects (Gaylord and Denny 1997; Matson and Edwards 2007) and very little is known about its chemical composition except for: phlorotannin (Van Alstyne et al. 1999; Ragan and Glombitza 1986; Glombitza and Gerstberger 1985); bromoform, methylene bromide, and methyl iodide (Manley et al. 1992), and gross chemical composition (Serviere-Zaragoza et al. 2002; Arvizu et al. 2007). Details of the chemical composition and nutritional value of *E. arborea* have not been reported. Our objective was to determine seasonal variation in the chemical composition of *E. arborea* and discuss its potential as a supplement food.

Material and methods

Collecting area Bahía Asunción, is located on the west coast of the central part of the Baja California Peninsula, Mexico (27°6′ N; 114°17′ W). The coastline is sandy interspersed with rocks, and provides habitat for commercially important species such as abalone and lobster (Ponce-Díaz et al. 2003).

Eisenia arborea samples were obtained using SCUBA at a 10-m depth along a 500-m transect parallel to the coast line. A minimum of 30 plants were collected every month in 1997, except during bad weather in January and February. The algae were cut with a knife at the base of the stipe and transported by boat to the coast. They were sun-dried, milled in a standard hammer mill to 2 cm^2, and stored in sealed plastic bags in a warehouse at room temperature (average 25°C). Prior to the chemical analysis, samples were milled again in a second hammer mill (Thomas Scientific, model 5) to obtain 1 mm^2 particle size.

Proximate analysis Moisture content of the sun-dried alga was determined by drying at 60°C (method 934.01; AOAC 1990). Lipids were determined by direct extraction with diethyl ether in a Soxhlet apparatus (method 920.39; AOAC 1990). Crude fiber was obtained by acid and alkaline digestion (method 962.09; AOAC 1990), Crude protein was determined using the Kjeldahl method (976.05; AOAC 1990). Ash was measured by burning the sample at 550°C in an oven (method 942.05; AOAC 1990). Carbohydrates were estimated subtracting the sum of all the above fractions from 100. *Gross energy* was determined using a bomb calorimeter Parr. No. 207 M. Parr ASTM (method E 144-64; Parr 1987). The *minerals*, potassium, sodium, magnesium, calcium, iron, copper, and zinc, were determined using an atomic absorption spectrophotometer (Perkin Elmer model 2380, method 965.09; AOAC 1990). Six *vitamins* (A, D_3, E, C, B_1, and B_2) were determined by high-performance liquid chromatography (HPLC: Shimadzu; model LC10A), using a stainless steel column LC-18 for reverse phase (25 cm× 4.6 mm ID, 5 µm particle diameter and cartridge C18, Supelco). Chromatographic conditions were: isocratic system, flow at 1.2 mL min^{-1}, injection volume 20 µL, detection UV 242 nm, room temperature, and 7 min running time. The mobile phase was methanol 100% grade HPLC (Rougereau et al. 1997). Seventeen *amino acids* were determined by HPLC (Waters Millennium 2010) equipped with a column NovaPak C18 and an ultraviolet detector model 470. Samples were hydrolyzed with HCL 6 N at 116°C during 24 h. The derivatization was carried out with HCL 20 mM, borate buffer solution and AccQ-Fluor was the derivatizant reagent. For the mobile phase, the eluting buffer was acetate–phosphate (AccQ TAG), acetonitrile solution (60%) and Mill-Q water. As external standard we used a mix

Table 1 Monthly proximate chemical analyses in *Eisenia arborea*

Month	Moisture[3] (%)	Protein[3] (%)	Ash[2] (%)	Lipids[5] (%)	Fiber[4] (%)	Carbohydrates[1] (%)	Gross energy (kJ g^{-1})
MAR	10.56 ± 0.03^{1}	5.54 ± 0.02^{1}	29.32 ± 0.01^{1}	0.64 ± 0.02^{1}	6.44 ± 0.05^{1}	47.59 ± 0.05^{1}	8.74 ± 0.2^{1}
APR	10.49 ± 0.02^{1}	9.10 ± 0.08^{2}	26.15 ± 0.02^{2}	0.63 ± 0.01^{1}	4.77 ± 0.01^{2}	48.86 ± 0.01^{2}	10.08 ± 0.1^{2}
MAY	9.91 ± 0.04^{2}	11.68 ± 0.00^{3}	24.97 ± 0.01^{3}	0.45 ± 0.01^{2}	4.59 ± 0.01^{3}	48.37 ± 0.01^{3}	9.50 ± 0.1^{2}
JUN	10.92 ± 0.01^{3}	10.82 ± 0.01^{4}	23.04 ± 0.02^{4}	0.56 ± 0.02^{3}	4.46 ± 0.01^{4}	50.20 ± 0.01^{4}	10.13 ± 0.3^{2}
JUL	10.17 ± 0.03^{4}	9.01 ± 0.01^{2}	26.88 ± 0.04^{5}	0.66 ± 0.04^{1}	4.67 ± 0.01^{5}	48.61 ± 0.01^{5}	10.67 ± 0.0^{2}
AUG	10.11 ± 0.02^{4}	9.67 ± 0.02^{5}	23.07 ± 0.02^{4}	0.65 ± 0.02^{1}	5.06 ± 0.01^{6}	51.46 ± 0.01^{6}	10.75 ± 0.1^{3}
SEP	10.04 ± 0.01^{4}	10.33 ± 0.03^{6}	19.25 ± 0.00^{6}	0.64 ± 0.00^{1}	5.44 ± 0.01^{7}	54.30 ± 0.01^{7}	10.84 ± 0.1^{3}
OCT	10.16 ± 0.01^{4}	6.28 ± 0.05^{7}	23.37 ± 0.02^{7}	0.66 ± 0.02^{1}	6.17 ± 0.01^{8}	53.36 ± 0.01^{8}	9.71 ± 0.3^{2}
NOV	10.27 ± 0.02^{4}	10.33 ± 0.03^{6}	24.45 ± 0.02^{8}	0.65 ± 0.02^{1}	4.32 ± 0.01^{9}	47.98 ± 0.01^{9}	9.50 ± 0.3^{2}
DEC	10.86 ± 0.04^{3}	11.68 ± 0.00^{3}	27.22 ± 0.01^{9}	0.60 ± 0.01^{1}	6.28 ± 0.04^{10}	43.32 ± 0.04^{10}	9.46 ± 0.0^{2}

Values are means (%, dw)±SD, n=3, gross energy in kJ g^{-1}. Different superscripts indicate significant differences among components, and months

Table 2 Monthly variation of the minerals in *Eisenia arborea*

Month	Potassium[1]	Sodium[2]	Magnesium[3]	Calcium[3]	Iron[4]	Zinc[4]	Copper[4]
MAR	4907.68 ± 78.54[1]	2084.64 ± 14.45[1]	1039.20 ± 20.06[1]	1142.04 ± 2.99[1]	725.81 ± 4.25[1]	2.30 ± 0[1]	1.17 ± 0.01[1]
APR	6592.73 ± 45.15[2]	2329.22 ± 13.07[2]	982.27 ± 05.13[1]	1911.19 ± 1.04[2]	585.82 ± 4.30[2]	0.98 ± 0[2]	1.34 ± 0.02[2]
MAY	5043.75 ± 45.66[1]	2227.04 ± 53.02[2]	682.27 ± 14.66[2]	1285.25 ± 75.58[3]	1030.33 ± 15.16[3]	2.59 ± 0[3]	0.87 ± 0.00[3]
JUN	7946.10 ± 17.05[3]	2255.78 ± 26.66[2]	836.63 ± 09.62[3]	1594.23 ± 5.13[4]	498.55 ± 1.19[4]	0.78 ± 0[4]	0.89 ± 0.02[3]
JUL	3581.66 ± 02.55[4]	1987.22 ± 1.94[1]	2741.66 ± 42.51[4]	980.70 ± 4.45[5]	621.44 ± 2.19[2]	0.44 ± 0[5]	0.58 ± 0.00[4]
AUG	2781.18 ± 03.54[5]	2358.23 ± 34.54[2]	2795.42 ± 36.29[4]	1051.44 ± 3.76[6]	620.78 ± 1.59[2]	0.50 ± 0[6]	0.69 ± 0.01[5]
SEP	1980.70 ± 04.52[6]	2729.24 ± 67.14[3]	2849.18 ± 30.06[4]	1122.17 ± 3.07[1]	620.11 ± 0.99[2]	0.55 ± 0[7]	0.80 ± 0.02[3]
OCT	2420.23 ± 04.95[7]	2003.88 ± 3.52[1]	1574.25 ± 04.13[5]	909.70 ± 4.54[7]	457.39 ± 1.26[4]	0.65 ± 0[8]	0.91 ± 0.02[3]
NOV	5416.63 ± 11.61[8]	2151.25 ± 2.10[1]	1866.70 ± 07.54[6]	827.39 ± 1.75[8]	560.80 ± 1.54[2]	0.59 ± 0[9]	1.26 ± 0.01[1]
DEC	6783.75 ± 61.42[2]	3101.81 ± 13.26[4]	788.56 ± 03.67[3]	907.35 ± 0.00[7]	431.52 ± 0.00[4]	0.04 ± 0[10]	1.21 ± 007[1]

Values are means (mg per 100 g, dw)±SD, n=3. Different superscripts indicate significant differences among minerals, and months

of hydrolyzed amino acids and as internal standard the alpha-aminobutyric acid (Millipore Waters Chromatography 1993). For *fatty acids*, the lipids were extracted first, using the method described by Folch et al. (1957). From the lipidic residues, fatty acids were methylated and five were identified and quantified using a gas chromatograph Varian 3400 CX, equipped with a DB23 column (30 m x 0.25 ID), and auto sampling and flame detector. Nitrogen was the carrier, and the flow was 30 mL $min^{-1.}$ Temperatures were: column 230°C, injector 150°C, and detector 300°C. Retention times were compared with standards (SIGMA) (method 923.07; AOAC 1990). *Saponins* were determined by the foam method, using potassium phosphate solution (Monroe et al. 1952). *Cyanogenic glycosides* were determined using a filter paper strip with sodium picrate (method 936.11; AOAC 1990). *Alkaloids* were determined gravimetrically by precipitation with Mayer, Dragendorff, Wagner, and Sönnenschein reagents (Domínguez 1979). Measurements were made in triplicate. One-way ANOVA was used to test significant differences of monthly means within the year (p<0.05; Statistic Ver. 6.0) after checking for normality and homoscedasticity. Tukey HSD post hoc test was used to identify where the specific significant differences occurred (p<0.05). Data are reported as mean±standard deviation (SD). Because of the low variability and the accuracy of the equipment used, in some cases these intervals were very small and only one decimal place is reported for the standard deviation.

Results

For all analysis, significant differences found among groups of components or within months were differenced with superscripts numbers in the tables.

Proximal analysis Residual moisture of the sun-dried alga *E. arborea*, varied significantly (p<0.05) from 9.91% (May) to 10.92% (June), the trend was lower moisture during summer time and higher in winter. Protein varied by 6.1% from 5.5% in March to 11.6% in May, and December (p<0.05). Ash varied by 10% from 19.2% in September to 29.3% in March (p<0.05). Lipid content was low and not significantly different most of the year, except in May and June, which were significantly lower (p>0.05). Mean values ranged from 0.45% (May) to 0.66% (July and October). Maximum difference over a year was 0.21% (p< 0.05). Fiber varied (over 2.1%; p<0.05), from 4.3% in November to 6.4% in March. Carbohydrates varied (p< 0.05) during the year from 43.32% in December to 54.30% in September (Table 1).

Gross energy A significant difference of 2.1 kJ g^{-1} (p< 0.05) was observed over the year. Minimum values were obtained in March (8.74 kJ g^{-1}) and maximum in September (10.84 kJ g^{-1} in Table 1).

Table 3 Monthly variation of vitamins in *Eisenia arborea*

Month	Vitamins					
	A (IU)	C[2]	E[2]	D3[1]	B2[3]	B1[4]
MAR	874.9	33.8	6.3	5.2	0.85	0.10
APR	661.7	35.4	8.9	3.5	0.88	0.08
MAY	625.6	37.9	6.2	4.5	0.85	0.11
JUN	554.7	41.5	8.6	6.5	0.91	0.14
JUL	506.5	38.5	0.9	7.6	0.80	0.10
AUG	464.4	32.5	9.3	7.4	0.73	0.08
SEP	422.2	26.4	9.6	7.1	0.65	0.06
OCT	579.4	22.8	8.3	4.7	0.70	0.08
NOV	495.3	36.9	9.4	4.6	0.92	0.12
DEC	585.6	38.7	8.3	5.3	0.87	0.10

Values are means (mg per 100 g, dw)±SD, n=3, except for vitamin A (*IU* International Units). Different superscripts indicate significant differences among vitamins

Table 4 Monthly variation of amino acids in *Eisenia arborea*

Month	Glutamic acid[1]	Aspartic acid[2]	Leucine[3]	Arginine[4]	Alanine[5]	Valine[6]	Lysine[7]	Isoleucine[7]
MAR	9.93 ± 0.04[1]	7.15 ± 0.01[1]	5.19 ± 0.03[1]	4.75 ± 0.09[1]	3.95 ± 0.04[1]	4.02 ± 0.01[1]	3.71 ± 0.01[1]	3.17 ± 0.07[1]
APR	9.90 ± 0.01[1]	5.85 ± 0.00[2]	5.23 ± 0.02[1]	4.78 ± 0.01[1]	4.06 ± 0.01[2]	4.06 ± 0.01[1]	3.78 ± 0.01[2]	3.24 ± 0.02[1]
MAY	10.12 ± 0.01[2]	7.84 ± 0.00[3]	5.53 ± 0.01[1]	5.32 ± 0.01[2]	4.58 ± 0.00[3]	4.03 ± 0.00[1]	3.89 ± 0.00[3]	3.43 ± 0.01[1]
JUN	10.26 ± 0.01[3]	6.26 ± 0.03[4]	5.55 ± 0.01[1]	4.88 ± 0.01[3]	4.86 ± 0.00[4]	4.21 ± 0.00[2]	3.87 ± 0.03[3]	3.32 ± 0.01[1]
JUL	10.52 ± 0.01[4]	6.35 ± 0.03[5]	5.89 ± 0.00[1]	4.88 ± 0.01[3]	4.87 ± 0.03[4]	4.25 ± 0.00[3]	3.84 ± 0.02[3]	3.33 ± 0.00[1]
AUG	10.20 ± 0.01[3]	6.19 ± 0.02[4]	5.79 ± 0.00[1]	4.92 ± 0.01[3]	4.73 ± 0.05[5]	4.26 ± 0.00[3]	3.88 ± 0.01[3]	3.32 ± 0.00[1]
SEP	9.88 ± 0.01[1]	6.04 ± 0.02[6]	5.69 ± 0.01[1]	4.97 ± 0.01[3]	4.59 ± 0.07[3]	4.27 ± 0.01[3]	3.92 ± 0.00[3]	3.30 ± 0.01[1]
OCT	10.12 ± 0.01[2]	7.21 ± 0.02[7]	5.20 ± 0.02[1]	4.94 ± 0.01[3]	4.21 ± 0.00[6]	4.04 ± 0.01[1]	3.58 ± 0.02[4]	3.20 ± 0.02[1]
NOV	9.97 ± 0.01[1]	6.23 ± 0.014	5.74 ± 0.02[1]	5.26 ± 0.01[2]	4.88 ± 0.01[4]	2.88 ± 0.02[4]	3.88 ± 0.00[3]	3.37 ± 0.03[1]
DEC	10.22 ± 0.01[3]	7.88 ± 0.01[3o]	5.23 ± 0.01[1]	5.38 ± 0.00[2]	4.86 ± 0.01[4]	4.28 ± 0.00[3]	3.97 ± 0.01[5]	3.04 ± 0.71[1]

Values are means (g per 100 g of protein)±SD, n=3. Different superscripts indicate significant differences among amino acids, and months

Minerals Four groups of minerals significantly different were obtained. Potassium and sodium were different between them and from all others, the third group was for calcium and magnesium, and the fourth group included copper, iron, and zinc ($p<0.05$). Significant monthly differences were also found during the year for all the seven minerals analyzed ($p<0.05$). The values are described from the more concentrated to the less concentrated. All values are expressed in mg/100 g (dw). Potassium was the most concentrated mineral (1,980 in September–7,946 in June). Sodium presented the second highest concentration (1,987 in July–3,101 in December), followed by calcium (827 in November to 1,911 in April). Magnesium ranged from 682 in May–2,849 in September. Iron (431 in December to 1,030 in May) copper (0.04 in December to 2.59 in May) and zinc (0.58 in July to 1.34 in April) were in the lower range (Table 2).

Vitamins The values are presented from most to least concentrated (mg/100 g, dw). Significant differences were obtained among vitamins ($p<0.05$). Highest concentration was for vitamin C (22.8 in October to 41.5 in June), followed by vitamin E (6.2 in May to 9.6 in September). Vitamin D_3 ranged from 3.5 in April to 7.6 in July. Vitamins B_2 and B_1 presented the lower values ranging from 0.65 in September to 0.92 in November and from 0.06 in September to 0.14 in June, respectively. Vitamin A was expressed in international units (IU), and ranged from 422 in September to 874.9 in March (Table 3).

Amino acids Significant differences were found in the concentration among amino acids (ten groups), and during the year ($p<0.05$), except for isoleucine, leucine, and threonine ($p>0.05$). Significant differences are presented in Table 4. All values are expressed as g/100 g of protein. The results will be described from highest to lowest concentration in three arbitrary selected groups. In the more concentrated group were glutamic acid (9.88–10.52), aspartic acid at (5.85–7.88), leucine (5.19–5.89), arginine (4.75–5.38), alanine (3.95–4.88), and valine (2.88–4.28; Table 4). In the second group were lysine (3.58–3.97), isoleucine (3.04–3.43), threonine (2.56–3.45), glycine (2.28–3.26), proline (2.41–2.99), and tyrosine (2.47–2.96). The final group included the less concentrated amino acids including: serine (2.41–2.99), phenylalanine (2.3–2.67), methionine (1.4–1.73), histidine (1–1.46), and cysteine (0.67–0.9; Table 4).

Fatty acids Comparison among the fatty acid analyzed showed significant different concentration, forming three groups (mean concentration expressed in mg.100 g^{-1}; dw): high concentration for arachidonic acid (ARA; 25.14), medium concentration for linoleic acid (LA; 7.19), alpha linolenic acid (ALA; 6.98) and eicosapentaenoic acid (EPA; 4.9) and significant lower concentration in docosahexaenoic acid (DHA; 0.26; $p<0.05$). All fatty acids showed significant minimum values in October and maximum in May. Total fatty acids (TFA) showed significant variation throughout the year ($p<0.05$), ranging from 21.37 to 65.52. The annual variation was 44.15 (Table 5).

Saponins, cyanogenic glycosides, or alkaloids were not detected in *E. arborea*.

Discussion

The moisture content of dried *E. arborea* was lower than 11% throughout the year, below 13%, the maximum suggested for dried foods (De León 1983). Moisture level assures the stability and quality of other components as it prevents microorganism to grow and allows longer storage times without loss of quality. Table 6 shows the main chemical components of *E. arborea* and various seaweeds reported by other authors. The protein content differs in brown, red, and green algae, with the highest concentrations in red algae (35–47%; Burtin 2003). Green algae have lower protein concentrations (8.5–28.1%). The protein

Threonine[8]	Glycine[8]	Proline[8]	Tyrosine[8]	Serine[8]	Phenylalanine[8]	Methionine[9]	Histidine[9]	Cysteine[10]
2.56 ± 1.34[1]	2.86 ± 0.04[1]	2.45 ± 0.01[1]	2.53 ± 0.01[1]	2.45 ± 0.01[1]	2.30 ± 0.02[1]	1.40 ± 0.02[1]	1.00 ± 0.02[1]	0.67 ± 0.02[1]
2.62 ± 0.00[1]	3.22 ± 0.01[2]	2.56 ± 0.02[2]	2.56 ± 0.00[1]	2.56 ± 0.02[2]	2.34 ± 0.01[1]	1.43 ± 0.01[1]	1.06 ± 0.01[2]	0.70 ± 0.01[1]
2.88 ± 0.01[1]	3.23 ± 0.01[2]	2.71 ± 0.00[3]	2.87 ± 0.01[2]	2.71 ± 0.00[3]	2.54 ± 0.00[2]	1.48 ± 0.00[2]	1.11 ± 0.01[2]	0.72 ± 0.00[2]
2.71 ± 0.00[1]	2.35 ± 0.00[4]	2.89 ± 0.00[3]	2.66 ± 0.02[3]	2.89 ± 0.00[4]	2.41 ± 0.00[3]	1.56 ± 0.02[3]	1.34 ± 0.02[3]	0.75 ± 0.00[2]
2.70 ± 0.01[1]	2.33 ± 0.00[4]	2.41 ± 0.01[4]	2.60 ± 0.02[4]	2.41 ± 0.01[1]	2.37 ± 0.01[3]	1.48 ± 0.01[2]	1.35 ± 0.02[3]	0.73 ± 0.03[2]
2.70 ± 0.01[1]	2.30 ± 0.00[4]	2.48 ± 0.01[5]	2.53 ± 0.02[1]	2.48 ± 0.01[1]	2.46 ± 0.01[4]	1.51 ± 0.00[2]	1.34 ± 0.01[3]	0.75 ± 0.02[2]
2.70 ± 0.01[1]	2.28 ± 0.00[4]	2.56 ± 0.02[2]	2.47 ± 0.02[5]	2.56 ± 0.02[2]	2.55 ± 0.01[2]	1.54 ± 0.00[3]	1.33 ± 0.00[3]	0.78 ± 0.01[2]
2.86 ± 0.01[1]	2.96 ± 0.00[5]	2.99 ± 0.00[6]	2.60 ± 0.01[4]	2.99 ± 0.00[5]	2.39 ± 0.00[3]	1.40 ± 0.02[1]	1.08 ± 0.00[2]	0.74 ± 0.00[2]
2.75 ± 0.01[1]	2.36 ± 0.01[4]	2.70 ± 0.02[3]	2.88 ± 0.02[2]	2.70 ± 0.02[3]	2.67 ± 0.02[5]	1.73 ± 0.02[4]	1.46 ± 0.01[4]	0.90 ± 0.01[3]
3.45 ± 0.72[1]	3.26 ± 0.01[2]	2.77 ± 0.01[3]	2.96 ± 0.01[6]	2.77 ± 0.01[6]	2.62 ± 0.01[6]	1.56 ± 0.01[3]	1.21 ± 0.01[5]	0.77 ± 0.00[2]

content in brown seaweeds is generally the lowest (5–15%), with slightly higher values in some kelps (i.e., *Undaria pinnatifida*, 11–24%; Burtin 2003). The values found in *E. arborea* (annual average 9.44 %) are characteristic of brown algae. Ash was the second highest fraction in *E. arborea* (annual average 24.77 %), after carbohydrates. This value is in agreement with the high concentration of minerals described below. Generally, ash content is low in red algae. Green algae range from low to medium concentrations, and the highest concentrations are found in brown algae. The ash content in *E. arborea* (19–29%) was at a lower range for brown algae. Lipids content in macroalgae is generally low. Lipid content of *M. pyrifera* (0.56–0.75%; Castro-González et al. 1994) is similar to the values found for *E. arborea* (0.45–0.66). Fiber represents the residual material after separation of soluble components in diluted acid and alkali (cellulose, lignin, minerals, and others). High fiber indicates low nutritional value; only ruminants digest fiber (De León 1983). However, dietary fiber is useful to prevent fiber deficiency (Pak and Araya 1996). The crude fiber content in red algae is generally low (1–6%) and high in green algae (4.6–28.1%; Huerta-Muzquiz et al. 1999; Carrillo-Domínguez et al. 2002, Table 6). The content in *E. arborea* (4.3–6.4%, annual average 5.2%) was lower than fiber described for the tropical alga *Sargassum* sp. (12.7%; Gojon-Báez et al. 1998). Carbohydrates are the largest component in many algae (41–74.7%). In *E. arborea*, the average carbohydrates content was 49%. Most of the carbohydrates in algae are phycocolloids, such as agar (in red algae) and alginate (in brown algae). The carbohydrates like the starch, mannitol, and laminaran can be easily metabolized by human and animals due to the type of alpha glycosidic bond 1–4 and 1–6, as well as beta 1–3 that these contain. Other carbohydrates like agar and carrageenan with α 1–3 and β 1–4 or alginic acid with α and β 1–4 bonds, cannot be metabolized by humans, only by those animal species that possess specific enzymes (Percival and McDowell 1967; Klasing 1998). Gross energy is the total amount of energy supplied by food and is an important quantitative measurement of calorific value (Lamare and Wing 2001). The average calorific content of macroalgae from New Zealand was not significantly different among algal groups, ranging from 10.3 to 11.1 kJ g^{-1} (Lamare and Wing 2001). *E. arborea*'s energy values ranged 8.74–10.84 kJ g^{-1}, similar to *M. pyrifera* (9.6 kJ g^{-1}; Gojon-Báez et al. 1998). Gross energy followed the same seasonal variation as carbohydrate content with its maximum in the summer. McQuaid (1985) suggested that seasonal reductions in calorific content in algae may be related to a reduction in

Table 5 Monthly variation of fatty acids in *Eisenia arborea*

Month	TFA	ARA[1]	ALA[2]	LA[2]	EPA[2]	DHA[3]
MAR	33.92[1]	20.39 ± 2.84[1]	4.71 ± 0.12[1]	5.41 ± 0.86[1]	3.24 ± 0.57[1]	0.17 ± 0.11[1]
APR	55.16[2]	33.02 ± 6.20[2]	8.25 ± 1.27[2]	8.23 ± 2.17[2]	5.66 ± 1.15[2]	0.25 ± 0.06[1]
MAY	65.52[3]	37.54 ± 0.98[2]	10.75 ± 0.28[2]	9.81 ± 0.26[2]	7.09 ± 0.18[2]	0.33 ± 0.01[1]
JUN	49.62[2]	27.71 ± 6.17[2]	8.00 ± 1.70[2]	7.94 ± 1.58[2]	5.43 ± 1.36[2]	0.54 ± 0.01[2]
JUL	56.07[2]	31.32 ± 5.78[2]	9.77 ± 1.08[2]	8.07 ± 1.50[2]	6.63 ± 1.07[2]	0.28 ± 0.13[1]
AUG	53.82[2]	30.46 ± 3.14[2]	8.47 ± 0.63[2]	8.45 ± 1.83[2]	6.31 ± 0.67[2]	0.24 ± 0.09[1]
SEP	51.57[2]	29.60 ± 0.49[2]	7.16 ± 0.18[2]	8.82 ± 2.16[2]	5.99 ± 0.27[2]	0.22 ± 0.06[1]
OCT	21.37[1]	11.99 ± 3.09[1]	3.26 ± 0.78[1]	3.58 ± 0.45[3]	2.34 ± 0.57[1]	0.20 ± 0.04[1]
NOV	27.44[1]	14.34 ± 1.48[1]	4.07 ± 0.19[1]	6.07 ± 0.22[1]	2.80 ± 0.01[1]	0.16 ± 0.07[1]
DEC	29.56[1]	14.99 ± 0.39[1]	5.37 ± 0.06[1]	5.51 ± 0.19[1]	3.48 ± 0.03[1]	0.21 ± 0.01[1]

Values are means (mg per 100 g, dw)±SD, n=3. Different superscripts indicate significant differences among amino acids, and months

TFA total fatty acids, *ARA* arachidonic acid, *ALA* alpha linolenic acid, *LA* linoleic acid, *EPA* eicosapentanoic acid, *DHA* docosahexanoic acid

Table 6 Comparison of the main chemical components in *Eisenia arborea* with other seaweeds

Group	Species	(%)	Source
Protein			
R	*Palmaria palmata* (Linnaeus) Kuntze	35–47	Burtin 2003
R	*Porphyra tenera* Kjellman	35–47	Burtin 2003
G	*Ulva lactuca* Linnaeus	14.0	Huerta-Muzquiz et al. 1999
G	*Caulerpa* spp	8.5–28.1	Huerta-Muzquiz et al. 1999
G	*Enteromorpha* spp	9.4	Aguilera-Morales et al. 2005
B	*Undaria pinnatifida* (Harvey) Suringar	11–24	Burtin 2003
B	*Nereocystis luetkeana* (K. Mertens) Postels & Ruprecht	15.3	Barta et al. 1981
B	*Macrocystis pyrifera* (L.) C. Agardh	5–12	Rodríguez-Montesinos and Hernández-Carmona 1991
B	*Eisenia arborea* Areschoug	5–11	This study
Ash			
R	*Porphyra* sp	8–16	Nisizawa et al. 1987
R	*Laurencia johnstonii* Setchell et Gardner	38.3	Carrillo-Domínguez et al. 2002
G	*Ulva* spp	13–46	Huerta-Muzquiz et al. 1999; Carrillo-Domínguez et al. 2002
G	*Caulerpa* spp	13–25	Huerta-Muzquiz et al. 1999
G	*Codium isthmocladum* Vickers	8.2	Huerta-Muzquiz et al. 1999
B	*Sargassum sinicola*	38.3	Carrillo-Domínguez et al. 2002
B	*Hydroclathrus clathratus* (Bory) Howe	63.7	Carrillo-Domínguez et al. 2002
B	*Macrocystis pyrifera*	31–41	Rodríguez-Montesinos and Hernández Carmona 1991; Castro-González et al. 1994
B	*Eisenia arborea*	19–29	This study
Lipids			
R	*Palmaria palmata*	0.3–0.8	Morgan et al. 1980
R	*Laurencia jhonstonii*	2.5	Carrillo-Domínguez et al. 2002
G	*Caulerpa* spp	1.8–3	Huerta-Muzquiz et al. 1999
G	*Ulva* spp	0.54	Carrillo-Domínguez et al. 2002
B	*Sargassum polyceratium* Montagne	5.98	Huerta-Muzquiz et al. 1999
B	*Macrocystis pyrifera*	0.56–0.75	Castro-González et al. 1994
B	*Eisenia arborea*	0.45–0.66	This study
Fiber			
R	*Spyridia filamentosa* (Wulfen)Harvey	1–3.8	Huerta-Muzquiz et al. 1999; Carrillo-Domínguez et al. 2002
R	*Laurencia jhonstonii*	6.14	Carrillo-Domínguez et al. 2002
G	*Enteromorpha intestinalis*	4.66	Carrillo-Domínguez et al. 2002
G	*Caulerpa* spp	8.5–28.1	Huerta-Muzquiz et al. 1999
B	*Macrocystis pyrifera*	4.4–8.8	Rodríguez-Montesinos and Hernández Carmona 1991; Castro-González et al. 1994
B	*Sargassum* sp	12.7	Gojon-Báez et al. 1998
B	*Eisenia arborea*	4.3–6.4	This study
Carbohydrates			
R	*Porphyra yezoensis* Ueda	44	Indergaard and Minsaas 1991
R	*Eucheuma isiforme* (C.Agardh) J.Agardh	74.7	Huerta-Muzquiz et al. 1999
G	*Ulva* sp	42	Arasaki and Arasaki 1983
G	*Codium isthmocladum*	73.1	Huerta-Muzquiz et al. 1999
B	*Ascophyllum nodosum*	52	Anderson et al. 2006
B	*Macrocystis pyrifera*	46	Castro et al. 1994
B	*Sargassum* spp	41	Gojon-Báez et al. 1998
B	*Eisenia arborea*	43–54	This study

G green alga, *R* red alga, *B* brown alga

Table 7 Comparison of minerals in *Eisenia arborea* with other brown seaweeds

	Seaweeds[a]	*Macrocystis pyrifera*[b]	*Sargassum* spp[b]	*Ascophyllum nodosum*[c]	*Eisenia arborea*[d]
K	41,400	52,600	24,400	20,000	47,455
Na	30,000	34,200	24,500	24,000	23,228
Mg	7,300	52,800	138,300	5,000	16,156
Ca	14,300	14,000	32,700	10,000	11,731
Fe	300				6,153
Cu	15			4–15	9
Zn	90			35–100	10

For comparison all data were calculated as μg g^{-1} (dw)

[a] Lobban and Harrison 1994

[b] Gojon-Báez et al. 1998

[c] Anderson et al. 2006

[d] This study

carbohydrate content during rapid growth and an associated increase in carbon. Lamare and Wing (2001) suggested that the calorific value of the seaweed may be a useful indicator of their nutritional value. An initial assessment of this calorific value could be made through an examination of the carbohydrate content of the species. The minerals analyzed are some of the essential elements required by algae (DeBoer 1981) and were expected in higher quantities. The mineral contents of *E. arborea* were similar to those reported by other authors (Table 7). Among macro elements, potassium was the most concentrated followed by sodium, magnesium, and calcium. The only abundant trace element was iron. Copper and zinc occurred in minor concentrations. Seaweeds are one of the most important vegetable sources of macro and trace elements. According to Burtin (2003), calcium content may be as high as 7% of the dry weight in macroalgae and up to 25% to 34% in the calcareous algae such as the Corallinales that produce calcified cell walls. Seaweed consumption may therefore be beneficial for expectant mothers, adolescents, and the elderly; all exposed to a risk of calcium or other macro and microelement deficiency.

The six vitamins that are reported as some of the more abundant in algae (Allen et al. 2001; Burtin 2003; Cremades-Ugarte 2007; A, D_3, E, C, B_1, and B_2) were determined. There are few published data on vitamins in macroalgae. Vitamin A in *E. arborea* had an annual average of 5.8 IU. Values for other macroalgae (mentioned as genera by the author) are: *Laminaria* (4.3 IU), *Palmaria* (266 IU), and *Porphyra* (384 IU; Cremades-Ugarte 2007). Vitamin C concentration (dw) ranges from 50–300 mg 100 g^{-1} in green and brown seaweeds, and 10–80 mg 100 g^{-1} in red algae (Burtin 2003). The average annual concentration in *E. arborea* was 34.4 mg 100 g^{-1} of alga. This value is close to the value described for mandarins (37.7 mg 100 g^{-1}; Lee and Kader 2000). Vitamin C is of interest because it strengthens the immune defense system, activates the intestinal absorption of iron, controls the formation of conjunctive tissue and the protidic matrix of bony tissue, and also acts in trapping free radicals and regenerates vitamin E (Burtin 2003). Vitamin E had an annual average of 8.3 mg.100 g^{-1} in *E. arborea,* below the 20–60 mg/g (dw) of tocopherols reported for *Ascophyllum* and *Fucus*. Gamma and alpha tocopherols increase the production of nitric oxide and nitric oxide synthase activity (cNOS) and also play an important role in the prevention of cardiovascular diseases (Solibami and Kamat 1985). *E. arborea* also contains vitamins D_3, B_2, and B_1 in minor concentrations. Allen et al. (2001) found that extracts from the brown seaweed *A. nodosum*, increased the antioxidant activity in both plants and animals.

The concentrations of amino acids in *E. arborea* were similar to those found by other authors (Castro-González et al. 1994; Fleurence et al. 1999; Jimenez-Escrig and Goñi-Cambrodón 1999; Aguilera-Morales et al. 2005; Casas-Valdez et al. 2006). In general, seaweed proteins (data in mg per 100 g of protein) contain high concentrations of alanine (4.4–9.9), glutamic acid (6.5–24), and aspartic acid (6.1–12), which together may reach 25–30% of the total. The last three amino acids are related to the metabolism of tricarboxylic acid (Fattorusso and Piattelli 1980), and are used by algae as a source of nitrogen for growth (Stewart 1979). The low concentration of methionine, histidine, and cysteine, has been also described by the authors mentioned above. Four of the amino acids in higher concentration in *E. arborea* were also among the four amino acids in higher concentrations in *M. pyrifera* (Castro-González et al. 1994). In general, the values detected in *E. arborea* are in the range of essential amino acids for nutrition of poultry (Scott et al. 1982), fish (NRC 1993), pigs (NRC 1998), monogastric animals (Viana-Ramos et al. 2000; NRC 2001), and humans (Torun 1999; Muñoz de Chávez et al. 2002). When

fresh, the taste of the center (medulla) of *E. arborea* is sweet. The sweet taste of other algae like nori is attributed to the amounts of alanine, glutamic acid, and glycine (Nisizawa et al. 1987), and this could be the case for *E. arborea*, although mannitol could also enhance the sweet taste.

Total fatty acids in *E. arborea* were low (21–65 mg 100 g^{-1}, dw) compared to levels found in algae from Canada and China, the latter ranging from 2,000–7,000 mg 100 g^{-1} (dw) (Colombo et al. 2006). The highest concentration in *E. arborea* was arachidonic acid (11–37 mg 100 g^{-1}). Fatty acids have beneficial effects in humans, reducing cardiovascular and inflammatory diseases (Dyerberg et al. 1978).

E. arborea could be used for animal or human nutrition due to the lack of anti-nutritional factors such as saponins or cyanogenic glycosides. It does, however, contain alginic acid and other polysaccharides that are indigestible by humans (Mori et al. 1981). In Europe, an inclusion of 3% of *Ascophyllum nodosum* as animal feed is allowed (Indergaard and Minsaas 1991). Part of the nutritive value of seaweed meal comes from proteins, but their proteins are bound to phenols forming insoluble compounds that cannot be decomposed by microbial stomach processes or enzymes. Therefore, proteins cannot be digested. To compensate for this, it is necessary to add 4 g of protein/kg of seaweed meal (Indergaard and Minsaas 1991). As fodder supplement, with high vitamins, minerals and trace elements, seaweed meal is a good candidate. The use of seaweed meal has demonstrated improved results on hens, pigs, and cattle (see review in Indergaard and Minsaas 1991). Also, the extract of *A. nodosum* optimized the immunocompetence of lambs (Saker et al. 2004), and *Gracilaria cervicornis* was used to feed shrimp with no adverse effects (Marinho-Soriano et al. 2007).

Studies on the brown algae *M. pyrifera* and *Sargassum* spp. as fodder supplement in ruminants (Gojon-Báez et al. 1998) and chickens (Carrillo et al. 1990) showed promising results. Other studies with Mexican algae concluded that they all have a low protein content and low energy value, but are high in minerals, trace elements, and carbohydrate content (Carrillo-Domínguez et al. 2002). The use of *Sargassum* as feedstuff for goats showed no negative effects (Casas-Valdez et al. 2006). Another use attributed to the genus *Eisenia* is for the antioxidant activity of phlorotannins isolated from *Eisenia bicyclis* (Kjellman) Setchell (Nakamura et al. 1996). Some other promising areas are for their use as antitumor activity, anticoagulant activity, and antihyperlipidemic (Jiménez-Escrig and Goñi-Cambrodón 1999).

In conclusion, the chemical composition of *E. arborea* suggests that is a good candidate to test its beneficial nutritional effects if consumed by animals or humans. In terms of amino acids, seaweed protein is similar to that of egg whites and some legumes. The marine macroalgae are low in fats, and have a significant content of vitamins and minerals. However, it is also important to determine the maximum percentage that can be added to the diets and maintain a balance of all nutritional requirements.

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References

Aguilar-Rosas R, Aguilar-Rosas LE, Ramos-Jardón NA (1990) Análisis biogeográfico del orden Laminariales (Phaeophyta) en las costas de la península de Baja California, México. Invest Marinas CICIMAR 5:107–121

Aguilera-Morales M, Casas-Valdez M, Carrillo-Domínguez S, González-Acosta B, Pérez-Gil F (2005) Chemical composition and microbiological assays of marine algae *Enteromorpha* spp as a potential food source. J Food Composition Anal 18:79–88. doi:10.1016/j.jfca.2003.12.012

Allen VG, Pond KR, Saker KE, Fontenot JP, Bagley CP, Ivy RL et al (2001) Tasco: influence of a brown seaweed on antioxidants in forages and livestock. A review. J Anim Sci 79:21–31

Anderson MJ, Blanton JR, Gleghorn J, Kim SW, Johnson JW (2006) *Ascophyllum nodosum* supplementation strategies that improve overall carcass merit of implanted English crossbred cattle. Asian-Aust J Anim Sci 19:1514–1521

AOAC (1990) Official methods of analysis, 15th edn. Association of Official Agricultural Chemists, Washington, DC

Arasaki S, Arasaki T (1983) Vegetables from the sea. Japan, Tokyo

Arvizu DL, Rodríguez YE, Hernández G, Murillo JI (2007) Chemical constituents of *Eisenia arborea* Areschoug from Baja California Sur, Mexico. Invest Marinas 35(2):63–69

Barta ES, Branen AL, Leung HK (1981) Nutritional analysis of Puget Sound bull kelp (*Nereocystis luetkeana*). J Food Sci 46:494–497. doi:10.1111/j.1365-2621.1981.tb04894.x

Burtin P (2003) Nutritional value of seaweeds. Electron J Environ Agr Food Chem 2:248–503

Carrillo DS, Casas VMM, Castro GMI, Pérez-Gil RF, García VR (1990) Empleo del alga marina *Macrocystis pyrifera* en dieta para pollos de carne. Invest Agraria Produccion Sanidad Animales 5:137–142

Carrillo-Domínguez S, Casas-Valdez MM, Ramos-Ramos F, Pérez-Gil F, Sánchez- Rodríguez I (2002) Algas marinas de Baja California Sur, México: Valor nutrimental. Arch Latinoam Nutr 52(4):400–405

Casas-Valdez MM, Hernández-Contreras H, Marín-Álvarez A, Águila-Ramírez RN, Hernández-Guerrero CJ, Sánchez-Rodríguez I, Carrillo-Domínguez S (2006) El alga marina *Sargassum* (Sargassaceae): una alternativa tropical para la alimentación de ganado caprino. Rev Biol Trop 54:83–92

Castro-González MI, Carrillo-Domínguez S, Pérez-Gil F (1994) Chemical composition of *Macrocystis pyrifera* (Giant Sargazo) collected in summer and winter and its possible use in animal feeding. Cienc Mar 20:33–40

Colombo ML, Rise P, Giavarini F, De Angelis L, Galli C, Bolis CL (2006) Marine macroalgae as source of polyunsaturated fatty acids. Plant Foods Hum Nutr 61:67–72. doi:10.1007/s11130-006-0015-7

Cremades-Ugarte J (2007). Algas Marinas: usos y biotecnología. http://uvifan.scai.uma.es/Algasmarinas.htm. Accessed 18 September 2007.

De León HS (1983) Manual de análisis de alimentos. México. Escuela Nacional de Ciencias Biológicas—IPN

DeBoer JA (1981) Nutrients. In: Lobban CS, Wynne MJ (eds) The Biology of seaweeds. Blackwell, Oxford, pp 356–391

Domínguez AX (1979) Métodos de investigación fitoquímica. LIMUSA, México

Druehl LD (1970) The pattern of Laminarales distribution in the northeast Pacific. J Phycol 9:237–247

Dyerberg J, Bang HO, Stoffersen E, Moncada S, Vane J (1978) Eicosapentanoic acid and prevention of thrombosis and atherosclerosis. Lancet 2:117–119. doi:10.1016/S0140-6736(78)91505-2

Edwards MS, Hernández-Carmona G (2005) Delayed recovery of giant kelp near its southern range limit in the North Pacific following El Niño. Mar Biol (Berl) 147:273–279. doi:10.1007/s00227-004-1548-7

Fattorusso E, Piattelli M (1980) Amino acids from marine algae. In: Scheuer PJ (ed) Marine natural products. Chemical and biological perspectives. Academic, USA, pp 95–134

Fleurence J, Chenard E, Lucon M (1999) Determination of the nutritional value of proteins obtained from *Ulva armorica*. J Appl Phycol 11:231–239. doi:10.1023/A:1008067308100

Folch J, Lees M, Sloane-Stanley G (1957) A simple method for the isolation and purification of total lipids. J Biol Chem 226:497–504

Gaylord B, Denny M (1997) Flow and flexibility. I. Effects of size, shape and stiffness in determining wave forces on the stipitate kelps *Eisenia arborea* and *Pterygophora californica*. J Exp Biol 200:3141–3164

Glombitza KW, Gerstberger G (1985) Phlorotannins with dibenzodioxin structural elements from brown alga *Eisenia arborea*. Phytochemistry 24:543–551. doi:10.1016/S0031-9422(00)80764-5

Gojon-Báez HH, Siqueiros-Beltrones DA, Hernández-Contreras H (1998) *In situ* ruminal digestibility and degradability of *Macrocystis pyrifera* and *Sargassum* spp in bovine livestock. Cienc Mar 24:463–481

Hernández-Carmona G (1985) Variación estacional del contenido de alginatos en tres especies de feofitas de Baja California Sur. Invest Marinas CICIMAR 2:29–45

Hernández-Carmona G, García O, Robledo D, Foster M (2000) Restoration techniques for *Macrocystis pyrifera* (Phaeophyceae) populations at the southern limit of their distribution in Mexico. Bot Mar 43:273–284. doi:10.1515/BOT.2000.029

Huerta-Múzquiz L, Mendoza-González C, Mateo-Cid LE, Dreckmann-Stay K, Seales RB, Chávez G, et al (1999). Algas marinas bentónicas de la Península de Yucatán y uso potencial de especies selectas. Informe Técnico Conabio-M039, México

Indergaard M, Minsaas J (1991) Animal and human nutrition. In: Guiry MD, Blunden G (eds) Seaweed resources in Europe: uses and potential. Wiley, Chichester, pp 21–64

Jiménez-Escrig A, Goñi-Cambrodón I (1999) Evaluación nutricional y efectos fisiológicos de macroalgas marinas comestibles. Arch Latinoam Nutr 49:114–120

Klasing KC (1998) Comparative avian nutrition. CAB, London

Lamare MD, Wing SR (2001) Calorific content of New Zealand marine macrophytes. N Z J Mar Freshw Res 35:355–341

Lee SK, Kader AA (2000) Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol Technol 20:207–220. doi:10.1016/S0925-5214(00)00133-2

Lobban CS, Harrison PJ (1994) Seaweed ecology and physiology. Cambridge University Press, New York

Manley S, Goodwin K, North WJ (1992) Laboratory production of bromoform, methylene bromide and methyl iodide by macroalgae and distribution in nearshore southern California waters. Limnol Oceanogr 37:1652–1659

Marinho-Soriano E, Camara MR, Carbajal TM, Carneiro MAA (2007) Preliminary evaluation of the seaweed *Gracilaria cervicornis* (Rhodophyta) as a partial substitute for the industrial feeds used in shrimp (*Litopenaeus vannamei*) framing. Aquacult Res 38:182–187

Matson PG, Edwards MS (2007) Effects of ocean temperature on the southern range limits of two understory kelps, *Pterygophora californica* and *Eisenia arborea*, at multiple life-stages. Mar Biol (Berl) 151(5):1941–1949. doi:10.1007/s00227-007-0630-3

McQuaid CD (1985) Seasonal variation in the ash-free calorific value of nine intertidal algae. Bot Mar 28:545–548

Millipore Waters Chromatography (1993) Manual No. WATO52874. Method Waters AccQ-TAG Chemistry Package, Millipore Corporation 34 Maple Street Milford, MA 01757

Monroe EE, Wall E, Rolland ML (1952) Detection and estimation of steroidal sapogenins in plant tissue. Anal Chem 8:1337–1341

Morgan KC, Wright JLC, Simpson FJ (1980) Review of chemical constituents of the red alga *Palmaria palmata* (dulse). Econ Bot 34:27–50

Mori B, Kusima K, Iwasaki T, Okiya H (1981) Dietary fiber content of seaweeds. Nippon Nogeikagaku Kaishi 55:787–791

Muñoz CM, Ledesma SJA, Chavez VA, Pérez-Gil RF, Mendoza ME, Calvo C et al (2002) Los Alimentos y sus Nutrientes. Tablas de Valor Nutritivo de Alimentos. McGraw-Hill, Mexico

Nakamura T, Nagayakama K, Udrida K, Tanaka R (1996) Antioxidant activity of phlorotannins isolated from the brown *Eisenia bicyclis*. Fish Sci 62:923–926

Nisizawa K, Noda H, Kikuchi R, Watanabe T (1987) The main seaweed foods in Japan Hydrobiologia, 151/152, 5-29

NRC (1993) Nutrient requirements of fish. National Research Council. National Academy Press, Washington DC

NRC (1998) Nutrient requirements of swine, 9th edn. National Academy Press, Washington, DC

NRC (2001) Nutriment requirements of beef cattle 7th revised. National Academy Press, Washington, DC

Pak N, Araya H (1996) Macroalgas marinas comestibles de Chile como fuente de fibra dietética: Efecto de la digestibilidad aparente de proteínas, fibra y energía y peso de deposiciones de ratas. Arch Latinoam Nutr 46:42–46

Parr M (1987) Handbook of analytical methods for oxygen bombs 207 Parr ASTM Inc

Percival E, McDowell RH (1967) Chemistry and enzymology of marine algal polysaccharides. Academic, London

Ponce-Díaz G, Lluch-Cota SE, Bautista-Romero JJ, Lluch-Cota D (2003) Multiscale characterization of the sea temperature in an area of abalone banks (*Haliotis* spp) at Bahía Asunción, Baja California Sur, Mexico. Cienc Mar 29:291–303

Ragan MA, Glombitza KW (1986) Phlorotannins, brown algal polyphenols. Prog Phycological Res 4:129–241

Rodríguez-Montesinos YE, Hernández-Carmona G (1991) Seasonal and geographic variation of *Macrocystis pyrifera* chemical composition at the western coast of Baja California. Cienc Mar 17:91–107

Rougereau A, Person O, Rougereau G (1997) Determination of vitamins. In: Multon JL, Stadelman WJ, Dieter L, Watkins BA (eds) Analysis of food constituents. Wiley, New York, pp 280–292

Saker KE, Fike JH, Veit H, Ward DL (2004) Brown seaweed- (TascoTM) treated conserved forage enhances antioxidant status and immune function in heat-stressed wether lambs. J Anim Physiol Anim Nutr (Berl) 88:122–130. doi:10.1111/j.1439-0396.2003.00468.x

Scott LM, Nesheim MC, Young AJ (1982) Nutrition of the chicken, 3rd edn. Scott, New York

Serviere-Zaragoza E, Gómez-López D, Ponce-Díaz G (2002) Gross chemical composition of three common macroalgae and a sea grass

on the Pacific coast of Baja California, Mexico. Hidrobiologia 12:113–118

Solibami VJ, Kamat SY (1985) Distribution of tocopherol (Vitamin E) in marine algae from Goa, west coast of India. Indian J Mar Sci 14:228–229

Spalding H, Foster MS, Heine JN (2003) Composition, distribution and abundance of deep-water (>30 m) macroalgae in Central California. J Phycol 39:273–284

Stewart WD (1979) Algal physiology and biochemistry. University of California Press, USA

Torun B (1999) Protein Quality and Sources. In: Sadler MJ, Strain JJ, Caballero B (eds) Encyclopedia of human nutrition III. Academic, USA, pp 1654–1661

Van Alstyne KL, McCarthy JJ, Hustead CL, Kearns LJ (1999) Phlorotannin allocation among tissues of northeastern Pacific kelps and rockweeds. J Phycol 35:483–492. doi:10.1046/j.1529-8817.1999.3530483.x

Viana-Ramos M, Oliveira-Monteiro AC, Azevedo-Moreira R, Fontenele-Urano AF (2000) Amino acid composition of some Brazilian seaweed species. J Food Biochem 24:33–39. doi:10.1111/j.1745-4514.2000.tb00041.x