# Dietary fiber, amino acid, fatty acid and tocopherol contents of the edible seaweeds *Ulva lactuca* and *Durvillaea antarctica*

J. Ortiz [a,*], N. Romero [a], P. Robert [a], J. Araya [b], J. Lopez-Hernández [c], C. Bozzo [a], E. Navarrete [a], A. Osorio [a], A. Rios [a]

[a] *Departamento de Ciencia de los Alimentos y Tecnología Química, Facultad de Ciencias Químicas y Farmacéuticas, Universidad de Chile, Casilla 233, Santiago, Chile*
[b] *Departamento de Nutrición Básica, Facultad de Medicina, Universidad de Chile, Av. Independencia 1027, Santiago, Chile*
[c] *Departamento de Química Analítica, Nutrición y Bromatología, Facultad de Farmacia, Universidad de Santiago de Compostela, 15782 Santiago de Compostela, La Coruña, España*

**Abstract**

The nutritional composition of the edible seaweeds *Durvillaea antarctica* (frond and stem) and dried *Ulva lactuca* was determined, including the soluble (SDF), insoluble (IDF) and total (TDF) dietary fiber content, amino acid and fatty acid profiles along with tocopherols and tocotrienols (pro-vitamin E). Results show that *U. lactuca* contained 60.5 ± 1.5%, and *D. antarctica* frond and stem 71.4 ± 1.5% and 56.4 ± 0.4% of TDF, respectively. Levels for the different amino acids ranged from 0.7 ± 0.1 to 1508.4 ± 9.5 (mg/100 g protein) in *U. lactuca*, from 0.2 ± 0.0 to 2019.9 ± 5.2 (mg/100 g protein) in *D. antarctica* (stem), and from 0.3 ± 0.0 to 1052.6 ± 2.9 (mg/100 g protein) in *D. antarctica* (leaves). In the three seaweeds, the most abundant fatty acid was C18:1ω9*cis* which in *U. lactuca* accounted for 27.42 ± 2.60%; in *D. antarctica* it was 25.36 ± 3.10% and 25.83 ± 2.52% in leaves and stem, respectively. In *D. antarctica*, γ-tocotrienol (651.7 ± 5.1 mg/kg), δ-tocopherol (245.9 ± 3.7 mg/kg) and α-tocopherol (179.4 ± 12.1 mg/kg) were determined in fronds, α-tocopherol (258.0 ± 7.2 mg/kg) was determined in stem. *U. lactuca*, showed a high γ-tocopherol level (963.5 ± 3.8 mg/kg).

*Keywords:* Seaweeds; Dietary fiber; Amino acids; Fatty acids; Tocopherols

## 1. Introduction

Edible seaweeds are a renewable natural resource existing in large quantities all along the Pacific Coast. Nevertheless, there has been little exploitation and exploration of seaweeds, despite potential industrial and agricultural applications. At the present time, seaweeds are used worldwide for different purposes: to obtain phycocolloids, as fodder, as a fertilizer and for direct use in human nutrition (Chapman & Chapman, 1980). Seaweeds are not a main source of energy although they are reported to be of nutritional value regarding vitamin, protein and mineral contents. (Chan, Cheung, & Ang, 1997; Norziah & Ching, 2000). It is said that 100 g of seaweed provides more than the daily requirement of Vitamin A, $B_2$ and $B_{12}$ and two thirds of the Vitamin C requirement (Chapman & Chapman, 1980), and it has been determined that seaweeds are an important source of dietary fiber, mainly soluble fiber (Lahaye, 1991), which is considered important in preventing constipation, colon cancer, cardiovascular disease and obesity, among others (Dreher, 1987; Kritchevsky, 1988; Stephen & Cummings, 1980).

* Corresponding author. Tel.: +56 2 6781663; fax: +56 2 2227900.
*E-mail address:* jortiz@uchile.cl (J. Ortiz).

Another distinctive property of sea plants, is that they are considered natural sources of hydrosoluble and liposoluble vitamins, such as thiamine and riboflavin, β-carotene and tocopherols, e.g., as well as of long-chain polyunsaturated essential fatty acids from the omega-3 family (LC-PUFAs ω3), such as eicosapentaenoic acid, C20:5ω3 (Khotimchenko, Vaskovsky, & Titlyanova, 2002), which may reduce the risk of heart disease, thrombosis and atherosclerosis (Mishra, Temelli, Ooraikul Shacklock, & Craigie, 1993). It has also been reported that the fatty acids of certain seaweeds have antiviral activity (Johns, Nichols, & Perry, 1979; Kamat et al., 1992).

There is, therefore, interest in the use of edible seaweeds in the development of low-cost, highly nutritive diets for human and animal nutrition, especially animal nutrition since sea vegetables are able to accelerate the growth of such species as big oysters, tilapia, salmon, trout, etc., all of great commercial interest (Fleming, Van Berneveld, & Hone, 1996; Hahn, 1989).

The purpose of the present investigation was to study the nutritional value of the *Ulva lactuca* and *Durvillaea antarctica* species which represent natural resources with potential economic value for use in human and animal nutrition.

## 2. Materials and methods

### 2.1. Sample collection

The *U. lactuca* seaweed was collected on November, 2003 raw and fresh from the coastal area of Northern Chile, and supplied dried and milled (flour) by *Cultivos Marinos Caldera* (Caldera, Chile). *D. antarctica* was collected raw and fresh from the central Chilean coastal area, and analyses were made separately in frond and stem (commonly known as "cochayuyo" and "ulte", respectively), since these are the two seaweed portions traditionally consumed by the population.

### 2.2. Proximal analysis

Following AOAC's methods (1996), water content (AOAC, 934.01), Ash (AOAC, 930.05), and proteins ($N \times 6.25$; AOAC, 954.01) were determined. Total carbohydrates were estimated by rounding up.

### 2.3. Lipid extraction

Lipids were extracted using a modification of Folch method according to Christie (1992). Each homogenized seaweed was extracted with 15 ml of chloroform/methanol/water (1:2:0.8), overnight in the absence of light. Three extractions were performed with ultrasonication and centrifugation. The extracts from each sample were partitioned against chloroform/ water (1:1 vol/vol) taking sample water content into account to give a final solvent ratio of chloroform/methanol/water of 1:1:0.9 by volume. NaCl (5%) was added to the aqueous phase to aid phase separation. For each sample, chloroform phases were combined and concentrated in vacuum to recover the lipids. Total lipids were gravimetrically determined on duplicate aliquots of each lipid extract.

### 2.4. Dietary fiber

Total dietary fiber and the soluble and insoluble fractions, were determined following the AOAC method, and slightly modified by Pak and Araya (1996b).

### 2.5. Amino acid analysis

Amino acids were determined by high-performance liquid chromatography (HPLC) by the method of Alaiz, Navarro, Vioque, and Vioque (1992). Algae were ground with a mortar and pestle. A 2 mg sample equivalent to 2 mg of protein was weighted in a hydrolysis tube and then 4 ml of 6.0 M hydrochloric acid was added. D, L-a-aminobutyric acid was used as internal standard. The solution was gassed with nitrogen and sealed, and then it was incubated in an oven at 110 °C for 24 h. The amino acid hydrolizate was dried in a Büchi Rotavapor (Büchi Labortechnik, meiers-eggstrasse, Switzerland) and the amino acids were dissolved in 25 ml of borate buffer (1 M, pH 9.0). Five milliliter of this solution were derivatized with 4 μl of diethyl ethoxymethylene-malonate at 50 °C for 50 min with vigorous shaking. 20 μl of this derivatized were injected directly into the HPLC. The HPLC system consisted of a Merck–Hitachi L-6200A pump (Merck, Darmstadt, Germany), a Rheodyne 7725i injector with a 20 μl sample loop, a Merck–Hitachi D-2500 chromato-integrator. The separation of derivatives was attained using a $300 \times 3.9$ mm i.d. reversed-phase column Nova–Pack $C_{18}$; particle size, 4 μm, Waters (Waters, Milford, MA, USA). Detection was accomplished using a Model L-4250 UV–vis detector (Merck–Hitachi) with variable-wavelength monitor set at 280 nm. Resolution of amino acid derivatives was routinely accomplished using a binary gradient system. The solvents used were: (A) 25 mM sodium acetate containing 0.02% of sodium azide (pH 6.0) and (B) acetonitrile. Solvent was delivered to the column at a flow-rate of 0.9 ml/min as follows: Time, 0.0–3.0 min, linear gradient from A-B (92:8) to A-B (88:12); 3.0–6.0 min, linear gradient from A-B (88:12) to A-B (86:14); 6.0–13.0 min, elution with A-B (86:14); 13.0–22.0 min, linear gradient from A-B (86:14) to (79:21); 22.0–35.0 min, linear gradient A-B (79:21) to A-B (69:31).

### 2.6. Fatty acid composition

Fatty acid composition was determined by GLC using a HP 5890 FID detector (Hewlett–Packard, Palo Alto, CA, USA), and a 50 m fused silica BPX70 capillary column 0.25 μm film, temperature programmed between 160 and 230 °C, rate 2 °C/min, with hydrogen as carrier and using reference fatty acids methyl esters (FAME) from Merck (Merck, Darmstadt, Germany) for identification. FAME were prepared according to AENOR (1991).

### 2.7. Tocopherols and tocotrienols analysis

Tocopherols and tocotrienols were determined in the lipid extracts by high-performance liquid chromatography (HPLC) with fluorescence detection, following the AOCS standard method (AOCS Ce 8-89, 1993). A LichroCART Superspher Si 60 column (25 cm × 4 mm i.d., particle size 5 μm; Merck, Darmstadt, Germany) was used. The mobile phase was propan-2-ol in hexane (0.5:99.5 v/v) at a flow-rate of 1 ml/min. The HPLC system consisted of a Merck–Hitachi L-6200A pump (Merck, Darmstadt, Germany), a Rheodyne 7725i injector with 20 μl sample loop, a Merck–Hitachi F-1050 fluorescence detector and a Merck–Hitachi D-2500 chromato-integrator. Peaks were detected at 290 and 330 nm, excitation and emission wavelengths, respectively. Tocols were identified using external standards (Merck, Darmstadt, Germany).

### 2.8. Expression of data and statistical analysis

All data presented are means ± SDs ($n = 4$).

## 3. Results and discussion

### 3.1. Protein and ash

The nutritional composition of the seaweeds under study is shown in Table 1. The mean protein content found in the present study is in agreement with values reported for various macroalgae (El-Tawil & Khalil, 1983; Murthy & Radia, 1978; Zavodnik, 1987), with such relatively high protein values (13.6–24.5 dry weight). The protein contribution of *U. lactuca* and *D. antarctica* ranged from 10.4 to 27.2 g/100 g dry weight, equivalent to the range reported by Fleurence (1999). *U. lactuca* showed a high protein content, similar to traditional high protein plant sources such as legumes and grains, especially soy and amaranth (Martínez & Añon, 1996; Norziah & Ching, 2000), thus justifying its direct use in human nutrition or for the development of balanced diets for animal nutrition. The latter has been corroborated in pisciculture and aquaculture studies. *Ulva australis* has been shown to increase the growth and development of different sea-cultivated species such as abalone (Dunstan, Barrett, Leroi, & Jeffrey, 1994; Murai, Akiyama, & Nose, 1984). Likewise, it has been demonstrated that certain sea plant protein sources meet tilapia's requirements (Jackson, Capper, & Matty, 1982). Furthermore, *U. australis* stands out for its high mineral and fiber content. In the case of *D. antarctica*, a lower protein level compared with ulva was determined, both in leaves and stem, but it may still be valuable as a protein source. The mineral content ranged from 11.0 to 15.7 g/100 g dry weight (Table 1), which is higher than the amount reported by other authors (Pak & Araya, 1992; Pak & Araya, 1996a; Pak & Araya, 1996b). The ash contents of the seaweeds were much higher than those of earth plants other than spinach and other vegetables (Rupérez, Ahrazem, & Leal, 2002) and both the stem and leaves of the plant supply high mineral contents.

### 3.2. Lipids

The literature has established that in seaweeds in general the content of lipids is less than 4% (Herbetreau, Coiffard, Derrien, & De Roeck-Holzhauer, 1997). The lipid content of the seaweeds studied in this work (Table 1) ranged from 0.3 g/100 g dry weight in *U. lactuca* to 4.3 g/100 g dry weight in *D. antarctica* (stem). In *U. lactuca* these values are significantly smaller than those determined by Wahbeh (1997) and similar to those of Pak and Araya (1996a), the differences could have been due to factors such as climate and geography of development of the seaweed.

Table 1
Nutritional composition[a] of macroalgae *Durvillaea antarctica* and *Ulva lactuca*

| Specie | Moisture | Ash (% dry weight) | Protein (% dry weight) | Lipid (% dry weight) | Carbohydrate[b] (% dry weight) | Dietary fiber (% dry weight) |
|---|---|---|---|---|---|---|
| *U. lactuca* (flour) | 12.6 ± 0.2 | 11.0 ± 0.1 | 27.2 ± 1.1 | 0.3 ± 0.0 | 61.5 ± 2.3 | 60.5 ± 0.6 |
| *D. antarctica*(leaves) | 72.3 ± 1.5 | 17.9 ± 1.2 | 10.4 ± 0.3 | 0.8 ± 0.1 | 70.9 ± 2.7 | 71.4 ± 0.5 |
| *D. antarctica*(stem) | 82.2 ± 0.7 | 25.7 ± 2.5 | 11.6 ± 0.9 | 4.3 ± 0.6 | 58.4 ± 1.2 | 56.4 ± 0.4 |

[a] Average of four analysis ± SD.
[b] Obtained by difference, includes dietary fiber.

Table 2
Composition[a] of dietary fiber in macroalgae *Durvillaea antarctica* and *Ulva lactuca*

| Specie | IDF (% dry weight) | SDF (% dry weight) | TDF (% dry weight) |
|---|---|---|---|
| *U. lactuca* | 33.3 ± 0.3 | 27.2 ± 1.2 | 60.5 ± 1.5 |
| *D. antarctica* (leaves) | 43.7 ± 0.3 | 27.7 ± 1.2 | 71.4 ± 1.5 |
| *D. antarctica* (stem) | 32.2 ± 0.7 | 24.2 ± 2.5 | 56.4 ± 0.4 |

IDF, insoluble dietary fiber; SDF, soluble dietary fiber; TDF, total dietary fiber.
[a] Average of four analyses ± SD.

### 3.3. Dietary fiber

Seaweeds are known as an excellent source of vitamins and minerals, especially sodium and iodine, due to their high polysaccharide content which could also imply a high level of soluble and insoluble dietary fiber (Lahaye, 1991). In this study it was determined that both seaweeds under investigation, *U. lactuca* and *D. antarctica,* had soluble and insoluble dietary fiber contents (Table 2) that were higher than values determined in fruits and vegetables (Pak & Araya, 1992). This high soluble fiber content suggests a favorable nutritional effect for people requiring it for any medical reason with the possible benefits of consuming either type of seaweed. It also suggests the necessity to develop seaweed-based products more attractive to consumers.

### 3.4. Amino acid composition

The amino acid composition (mg/100 g of total protein) is illustrated in Table 3. Tryptophan could not be detected after acid hydrolysis of the protein samples. All essential amino acids were present in the two species. Levels of the different amino acids ranged from 0.7 ± 0.1 to 1508.4 ± 9.5 (mg/100 g protein) in *U. lactuca*, from 0.2 ± 0.0 to 2019.9 ± 5.2 (mg/100 g protein) in *D. antarctica* (stem), and from 0.3 ± 0.0 to 1052.6 ± 2.9 in *D. antarctica* (leaves). Proteins in both types of seaweed contained a high level of amino acids, especially *U. lactuca* regarding essential amino acids; lysine, phenylalanine, methionine, leucine and valine. On the other hand, *D. antarctica* (stem) stands out as having a high level of the essential amino acids histidine and valine. In the case of *D. antarctica*, it was determined that the main limiting amino acids were isoleucine and leucine at stem level (according to OMS/ FAO standards), and mainly lysine in fronds. In *U. lactuca*, the main limiting amino acid is isoleucine, followed by leucine. The two species of algae examined may be considered a potential dietary protein for fish. It has been pointed out (Jackson et al., 1982; Ng & Wee, 1989) that certain plants could be used to provide significant proportions of the protein requirements of marine species. Given that the dietary protein requirements for optimal growth of fish range from 28% to 50% of dry diet (De Silva & Perrara, 1985; Jouncey, 1982; Kesamura, Okumura, Takeda, & Kuroki, 1982; Tacon & Cowey, 1985), and that many of the reported values are overestimates (Bowen, 1987; Millikin, 1982), we may conclude that the investigated algae could be used as partial sources of dietary protein, especially for herbivorous fish such as siganids.

Table 3
Composition[a] amino acid of macroalgae *Durvillaea antarctica* and *Ulva lactuca*

| Amino acids (mg/100 g prot.) | *D. antarctica* (leaves) | *D. antarctica* (stem) | *U. lactuca* (flour) |
|---|---|---|---|
| Asp | 745.3 ± 1.5 | 2019.9 ± 5.2 | 1487.0 ± 8.5 |
| Glu | 1052.6 ± 2.9 | 972.2 ± 2.5 | 1508.4 ± 9.5 |
| Ser | 434.4 ± 1.1 | 256.2 ± 1.5 | 833.2 ± 5.9 |
| His | 750.6 ± 2.3 | 1178.5 ± 5.5 | 133.9 ± 1.5 |
| Gly | 220.8 ± 1.7 | 293.2 ± 1.1 | 815.6 ± 5.7 |
| Thr | 255.1 ± 1.1 | 280.9 ± 1.0 | 797.8 ± 7.5 |
| Arg | 332.1 ± 1.0 | 150.4 ± 1.2 | 486.6 ± 3.5 |
| Ala | 446.4 ± 1.1 | 826.5 ± 5.5 | 1096.4 ± 10.5 |
| Pro | 0.3 ± 0.0 | 0.2 ± 0.0 | 0.7 ± 0.1 |
| Tyr | 178.2 ± 1.2 | 80.5 ± 1.1 | 435.2 ± 1.5 |
| Val | 462.9 ± 1.5 | 185.0 ± 1.5 | 339.2 ± 4.5 |
| Met | 914.7 ± 1.9 | 415.3 ± 0.9 | 671.7 ± 8.5 |
| Cys | 4.3 ± 0.1 | 97.3 ± 1.4 | 55.0 ± 6.5 |
| Ile | 350 ± 1.5 | 161.5 ± 1.1 | 550.0 ± 7.1 |
| Leu | 603.6 ± 1.9 | 274.6 ± 1.3 | 1034.5 ± 8.9 |
| Phe | 374.5 ± 1.3 | 192.6 ± 1.1 | 1245.4 ± 12.5 |
| Lys | 507.2 ± 1.1 | 193.0 ± 1.5 | 723.3 ± 8.5 |

[a] Average of four analyses ± SD.

### 3.5. Fatty acid profiles

Seaweeds have a low lipid content compared with earth vegetables such as soy, sunflower, e.g. (Darcy-Vrillon, 1993), thus being a low source of nutritional energy. Nevertheless, it is worth mentioning that the lipid fraction might contain higher levels of essential polyunsaturated fatty acids compared with traditional vegetables, which might be of interest if we consider the large amount and variety of seaweeds along the Chilean coast. The fatty acid composition of the seaweeds under study is shown in Table 4. In the tree samples studied the most abundant fatty acid was C18:1ω9*cis*, which in *U. lactuca* accounted for 27.42 ± 1.91%; in leaves of *D. antarctica* it was 25.36 ± 1.81%, and 25.83 ± 2.52% in stem of *D. antarctica.* Although our investigation showed that both seaweeds have higher total levels of PUFAs than MUFAs, the two seaweeds also contained the essential fatty acids C18:2ω6 (linoleic acid) and C18:3ω3 (linolenic acid) and the eicosanoid precursors C20:4ω6 (arachidonic acid) and C20:5ω (eicosapentaenoic acid), which have also been reported in *U. lactuca* (Wahbeh, 1997). The occurrence of the $C_{18}$PUFAs is important in human nutrition and for fish which are not able to synthesize them (Pohl & Zuheidi, 1979; Sánchez-Machado,

Table 4
Fatty acids composition[a] of macroalgae *Durvillaea antarctica* and *Ulva lactuca*

| Fatty acids | Methyl ester (%) | | |
|---|---|---|---|
| | *Ulva lactuca* (flour) | *Durvillaea antarctica* (leaves) | *Durvillaea antarctica* (stem) |
| C12:0 | 0.14 ± 0.01 | 0.22 ± 0.01 | 1.08 ± 0.02 |
| C14:0 | 1.14 ± 0.22 | 5.60 ± 0.23 | 4.23 ± 0.04 |
| C14:1 | – | 0.45 ± 0.01 | – |
| C15:0 | 0.20 ± 0.00 | 0.90 ± 0.01 | – |
| C15:1 | 1.12 ± 0.11 | 2.00 ± 0.08 | – |
| C16:0 | 14.00 ± 1.12 | 12.12 ± 1.11 | 18.33 ± 1.15 |
| C16:1 | 0.69 ± 0.11 | 2.19 ± 0.06 | – |
| C16:1ω7 | 1.87 ± 0.21 | 2.22 ± 0.02 | – |
| C16:2 | 1.03 ± 0.21 | 0.14 ± 0.00 | – |
| C17:0 | – | 0.16 ± 0.01 | – |
| C17:1 | 0.18 ± 0.11 | 0.25 ± 0.01 | – |
| C18:0 | 8.39 ± 0.12 | 3.18 ± 0.01 | 8.78 ± 1.02 |
| C18:1ω9*trans* | 0.37 ± 0.11 | 0.32 ± 0.01 | 0.32 ± 0.02 |
| C18:1ω9*cis* | 27.43 ± 1.91 | 25.36 ± 1.81 | 25.83 ± 2.52 |
| C18:1ω7*cis* | – | 0.85 ± 0.04 | 1.43 ± 0.02 |
| C18:2 | 1.72 ± 0.91 | 1.34 ± 0.12 | 8.78 ± 2.13 |
| C18:2ω6 | 8.31 ± 1.21 | 10.77 ± 0.08 | 15.65 ± 1.09 |
| C18:3ω3 | 4.38 ± 0.31 | 3.93 ± 1.12 | 1.10 ± 0.03 |
| C20:0 | 0.19 ± 0.01 | 0.67 ± 0.01 | 1.78 ± 0.02 |
| C20:1 | 4.21 ± 0.50 | 3.92 ± 0.21 | 1.63 ± 0.22 |
| C18:4ω3 | 0.41 ± 0.01 | 0.23 ± 0.11 | – |
| C20:2 | 0.24 ± 0.01 | 0.17 ± 0.00 | – |
| C20:4ω6 | 0.34 ± 0.01 | 11.23 ± 1.81 | – |
| C22:0 | 0.27 ± 0.01 | 0.40 ± 0.01 | 2.08 ± 0.02 |
| C22:1 | 0.79 ± 0.01 | 0.39 ± 0.01 | – |
| C20:5ω3 | 1.01 ± 0.01 | 4.95 ± 0.11 | 2.69 ± 0.02 |
| C24:0 | 9.45 ± 0.01 | 2.75 ± 0.06 | – |
| C22:6ω3 | 0.8 ± 0.01 | 1.66 ± 0.02 | – |
| ni | 11.32 ± 1.19 | 1.62 ± 0.02 | 5.28 ± 2.23 |
| Saturated FAs | 33.78 ± 0.12 | 25.84 ± 1.92 | 36.28 ± 2.90 |
| MUFAs | 36.66 ± 1.33 | 38.11 ± 0.12 | 29.21 ± 1.13 |
| PUFAs | 18.24 ± 1.10 | 34.42 ± 1.90 | 29.23 ± 2.20 |
| PUFAs ω6 | 8.65 ± 1.11 | 22.00 ± 0.22 | 15.65 ± 1.09 |
| PUFAs ω3 | 6.6 ± 0.91 | 10.77 ± 0.01 | 3.79 ± 0.12 |
| Ratio ω6/ω3 | 1.31 | 2.0 | 4.1 |

FAs, fatty acids; MUFAS, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids; ni, not identified.
[a] Average of four analyses ± SD.

López-Cervantes, López-Hernández, & Paseiro-Losada, 2004a). Fish can, however, elongate and desaturate dietary 18:2ω6 and 18:3ω3 fatty acids (Cowey, 1976), which occur in the investigated algae (Table 4) in relatively high levels (8.31 ± 1.21–15.65 ± 1.09% for 18:2ω6 and 1.10 ± 0.03–4.38 ± 0.31% for 18:3ω3). Studies of the fatty acid composition of 10 species of algae collected from Australia (Johns et al., 1979) reported the main saturated acid as 16:0 in green (23.9%), brown (27.9%) and red algae (33.8%). In the present study 16:0 was also the predominant saturated fatty acid (14.01–12.12%). Furthermore, the ω6/ω3 ratio, which the WHO currently recommends should be no higher than 10 in the diet as a whole, was at most 4.1, so that the seaweeds studied here may be of use for the reduction of ω6/ω3 ratio (Mahan & Escott-Stump, 2000). Variations in fatty acid contents are attributable both to environmental and genetic differences (Nelson, Phleger, & Nichols, 2002). In this study the leaves of *D. antarctica* show a greater content of MUFAS and PUFAS than the stem of *D. antarctica* (38.11 ± 0.12% v/s 29.21 ± 1.13%). The leaves *D. antarctica* are similar to ulva in MUFAS (36.66 ± 1.33–38%, 11 ± 0.12%). Ulva gave smaller values for PUFAS than the stem and leaves of D. *antartica* (18.24 ± 1.10% v/s 34.42 ± 1.90% and 29.23 ± 2.20%). Whereas in the red seaweeds, C20 PUFA has been determined as 8–12 times more abundant than C18 PUFAs, in brown seaweeds both fatty acids were more or less equally abundant (Chan et al., 1997; Herbetreau et al., 1997; Khotimchenko et al., 2002).

### 3.6. Tocopherols and tocotrienols contents

Seaweeds are an important unconventional source of vitamins (liposoluble and hydrosoluble), commonly consumed fresh or dried in many coastal areas, espe-

Table 5
Composition[a] of tocols of macroalgae *Durvillaea antarctica* and *Ulva lactuca*

| Tocols (mg/kg lipid) | *D. antarctica* (leaves) | *D. antarctica* (stem) | *U. lactuca* (flour) |
|---|---|---|---|
| α-Tocopherol | 179.4 ± 12.1 | 258.0 ± 7.2 | 9.3 ± 1.2 |
| α-Tocotrienol | nd | 2.1 ± 0.2 | 33.2 ± 5.2 |
| β-Tocopherol | 16.5 ± 1.1 | 4.5 ± 0.3 | 14.3 ± 2.2 |
| γ-Tocopherol | 19.4 ± 0.8 | 2.3 ± 0.2 | 25.8 ± 1.2 |
| γ-Tocotrienol | 651.7 ± 5.1 | nd | 963.5 ± 3.8 |
| δ-Tocopherol | 245.9 ± 3.7 | nd | 25.3 ± 2.8 |
| Total | 1112.9 ± 8.2 | 266.9 ± 10.2 | 1071.4 ± 9.2 |

nd, not detected.
[a] Average of four analyses ± SD.

cially on the Pacific coast of South America (Honya, Kinoshita, Ishikawa, Mori, & Nisizawa, 1994; Li, 1989; McHug, 1991; Osse, 1990; Sánchez-Machado, López-Cervantes, López-Hernández, & Paseiro-Losada, 2004b). Tocols comprising by α-, β-, γ-, and δ-tocopherol and its isomers α-, β-, γ- and δ-tocotrienol, are important liposoluble metabolites synthesized by plant cells, and in humans they act as Vitamin E precursors. Table 5 shows the results obtained from the determination of tocopherols and tocotrienols present in the free fat of the seaweeds *U. lactuca* y *D. antarctica*. In *D. antarctica* fronds, both types of tocols were determined, γ-tocotrienol being the predominant tocol (651.7 ± 5.1 mg/kg), followed by δ -tocopherol (245.9 ± 3.7 mg/kg) and α-tocopherol (179.4 ± 12.1 mg/kg), and β- and γ-tocopherol in lower quantity, thus giving a total tocol content of 1112.9 ± 8.2 mg/kg lipid. In *D. antarctica* stem, only the mean content of α-tocopherol (258.0 ± 7.2 mg/kg) was determined. On the other hand, *U. lactuca* showed a high level of γ-tocopherol (963.5 ± 3.8 mg/kg) and a limited level of tocopherols and tocotrienols, from which a total tocol content of 1071.4 ± 9.2 mg/kg was determined for *U. lactuca*fat. Both *D. antarctica* (leaves) fat and *U. lactuca* fat showed a high level of tocols compared with tocopherol and tocotrienol contents in traditional plant oils (Barrera-Arellano, Ruíz-Méndez, Velasco, Marquez-Ruiz, & Dobarganes, 2002; Masson & Mella, 1985). The determined levels of pro-vitamin E as well as the PUFAs content show a good nutritional complement that confirms the importance of using both types of seaweeds in normal diets for consumers.

## 4. Conclusions

The seaweeds *U. lactuca* and *D. antarctica* examined in this study have high ash contents, appreciable protein contents and dietary fiber, low total lipid contents, and relatively high levels of essential amino acids, polyunsaturated fatty acids, and tocols pro-vitamin E, which makes them a healthy food for human and animal nutrition.

## Acknowledgements

This study was funded by Dirección de Investigación y Desarrollo DID, Universidad de Chile under Proyecto DID SAL 02/14-2. We also thank Ing. Oscar Alcalde (manager director of Cultivos Caldera, Caldera, Chile) for supplying samples of seaweeds fresh and dried.

## References

AENOR. (1991). Asociación Española de Normalización. Norma UNE 55037-73. *Catálogo de Normas UNE*, Madrid.

AOAC. (1996). *Official methods of analysis of AOAC international* (16th ed.). Gaithersburg, USA.

Alaiz, M., Navarro, J., Vioque, G., & Vioque, E. (1992). Amino acid analysis by high-performance liquid chromatography after derivatization with diethyl ethoximethylenemalonate. *Journal of Chromatography, 591*, 181–186.

American Oil Chemists Society. (1993). *Official methods and recommended practices of the American Oil Chemists Society* (3rd ed.). Champaign, IL: AOCS.

Barrera-Arellano, D., Ruíz-Méndez, V., Velasco, J., Marquez-Ruiz, G., & Dobarganes, C. (2002). Loss of tocopherols and formation of degradation compounds at frying temperature in oils differing in degree of unsaturation and natural antioxidant content. *Journal Science of Food Agricultural, 82*, 1696–1702.

Bowen, S. H. (1987). Dietary protein requirement of fish. A reassessment. Canadian. *Journal Fish Aquaculture Science, 44*, 1995–2001.

Chan, J. C.-C., Cheung, P. C.-K., & Ang, P. O. Jr., (1997). Comparative studies on the effect of three drying methods on the nutritional composition of seaweeds *Sargassum hemiphyllum* (Turn) C. Ag. *Journal of Agricultural and Food Chemistry, 45*, 3056–3059.

Chapman, V. J., & Chapman, D. J. (Eds.). (1980). *Seaweeds and their uses* (3rd ed., pp. 25–42). New York: Chapman & Hall.

Christie, W. W. (1992). *Gas chromatography and lipids, a practical guide* (3rd ed.). Ayr: The Oyli Press.

Cowey, C. B. (1976). Use of synthetic diets and biochemical criteria in the assessment of nutrients of fish. *Journal of Fish Research Board Canadian, 33*, 1040–1045.

Darcy-Vrillon, B. (1993). Nutritional aspects of the developing use of marine macroalgae for the human food industry. *International Journal of Food Science and Nutrition, 44*, 23–35.

De Silva, S. S., & Perrara, W. M. K. (1985). Effects of dietary protein level on growth, food conversion and protein use in young *Tilapia niotica* at four salinities. *Transactions of the American Fisheries Society, 114*, 584–589.

Dreher, M. l. (1987). *Handbook of dietary fiber*. New York: Dekker M. and Basel Inc..

Dunstan, G. A., Barrett, S. M., Leroi, J. M., & Jeffrey, S. W. (1994). Essential polyunsaturated fatty acids from 14 species of diatom (Bacillariophyceae). *Phytochemistry, 35*, 155–161..

El-Tawil, B. A. H., & Khalil, A. N. (1983). Chemical constituents of some algal species from Abu-quir Bay, Egypt. *Journal Faculted Marine Science, 3*, 85–94.

Fleming, A. E., Van Berneveld, R. J., & Hone, P. W. (1996). The development of artificial diets for abalone: a review and future dictions Aquaculture.

Fleurence, J. (1999). Seaweed proteins: biochemical nutritional aspects and potential uses. *Trends in Food Science and Technology, 10*(1), 25–28.

Hahn, K. O. (1989). Nutrition and growth of abalone. In K. O. Hahn (Ed.), *CRC hamdbook of culture of abalone and other marine gastropods* (pp. 135–156). Boca de raton, FL: CRC Press.

Herbetreau, F., Coiffard, L. J. M., Derrien, A., & De Roeck-Holzhauer, Y. (1997). The fatty acid composition of five species of macroalgae. *Botánica Marina, 40*, 25–27.

Honya, M., Kinoshita, T., Ishikawa, M., Mori, H., & Nisizawa, K. (1994). Seasonal variation in the lipid content of cultured *Laminaria japonica*; fatty acids, sterols, β-carotene and tocopherol. *Journal Applied Phycology, 6*, 25–29.

Jackson, A. J., Capper, B. S., & Matty, A. J. (1982). Evaluation of some plant proteins in complete diets for tilapia *Sarotherodon mossanbicus*. *Aquaculture, 27*, 97–109.

Johns, R. B., Nichols, P. D., & Perry, G. J. (1979). Fatty acid composition of ten algae from Australian waters. *Phytochemistry, 18*, 799–802.

Jouncey, K. (1982). The effects of varying protein level on the growth, food conversion, protein utilization and body composition of juvenile tilapia. *Aquaculture, 27*, 43–54.

Kamat, S. Y., Wahídulla, S., D'Souza, L., Naik, C. G., Ambiye, V., & Bhakuni, D. S. (1992). Bioactivity of marine organisms, VI. Antiviral evaluation of marine algal extracts from the Indian coast. *Botanica Marina, 35*, 161–164.

Kesamura, K., Okumura, N., Takeda, H., & Kuroki, A. (1982). Studies on the nutrition of *Tilapia nilotica*; III Protein requirements of fingering *Tilapia nilotica*. Bull. Faculted (Vol. 29, pp. 285–291). Japan: Agriculture Miyazaki University.

Khotimchenko, S. V., Vaskovsky, V. E., & Titlyanova, T. V. (2002). Fatty acids of marine algae from the Pacific coast of North California. *Botánica Marina, 45*, 17–22.

Kritchevsky, D. (1988). Dietary fiber. *Annual Review Nutrition, 8*, 301–328.

Lahaye, M. (1991). Marine algae as sources of fibers: determination of soluble and insoluble dietary fiber contents in some sea vegetables. *Journal Science of Food Agricultural, 54*, 587–594.

Li, S. (1989). Cultivation and application of microalgae in People's Republic of China. *Algae Biotechnology Symposium, London*.

Mahan, K. L., & Escott-Stump, S. (2000). *Nutrición y dietoterapia, de Krause*. Madrid, Spain: Mcgraw-Hill Interamericana.

Martínez, E. N., & Añon, M. C. (1996). Composition and structural characterization of Amaranth protein isolates. Electrophoretic and colorimetric study. *Journal of Agricultural and Food Chemistry, 9*, 124–127.

Masson, L., & Mella, M. (1985). Materias grasas de consume habitual y potencial en Chile. Composición en ácidos grasos. Facultad de Ciencias Químicas y Farmacéuticas, Universidad de Chile.

McHug, D. J. (1991). Worldwide distribution of commercial resources of seaweed including. *GELIDUM Hidrobiología, 221*, 19–29.

Millikin, M. R. (1982). Qualitative and quantitative nutrient requirements of fishes: a review fish bulletin. 80, 655–696.

Mishra, V. K., Temelli, F., Ooraikul Shacklock, P. F., & Craigie, J. S. (1993). Lipids of the red algae *Palmaria palmate*. *Botánica Marina, 36*, 169–174.

Murthy, M. S., & Radia, P. (1978). Ecobiochemical studies on some economically important intertidal algae from port Okha (India). *Botanica Marine, 21*, 417–422.

Murai, T., Akiyama, T., & Nose, T. (1984). Effect of amino acid balance balance of efficiency in utilization of diet by fingerling carp. *Bulletin Japan of Society Science Fishery, 50*, 893–897.

Nelson, M. M., Phleger, C. F., & Nichols, P. D. (2002). Seasonal lipid composition in macroalgae of the northeastern Pacific Ocean. *Botánica Marina, 45*, 58–65.

Ng, W. K., & Wee, K. L. (1989). The nutritive value of cassava leaf meal in pelleted feed for Nile Tilapia. *Aquaculture, 83*, 45–58.

Norziah, M. H., & Ching, Ch. Y. (2000). Nutritional composition of edible seaweed *Gracilaria changgi*. *Food Chemistry, 68*, 69–76.

Osse, A. C. (1990). *A utilizaçao de algas marhinas como aditivo para rascoes animais*. Brasil: Instituto de Investigaçoes Pesqueiras.

Pak, N., & Araya, H. (1992). Fibra Dietética: Concepto, contenido en alimentos y consumo en Chile. *Revista Chilena de Nutrición, 20*, 124–135.

Pak, N., & Araya, H. (1996a). Macroalgas comestibles de Chile como fuente de fibra dietética: efecto en la digestibilidad aparente de proteínas fibra y energía y peso de deposiciones en ratas. *Archivos Latinoamericanos de Nutrición, 46*, 42–46.

Pak, N., & Araya, H. (1996b). Valor nutritivo y aportes de fibra dietética (soluble e insoluble) de microalgas comestibles de Chile, crudas y cocidas. *Alimentos, 21*, 63–69, pp. 67–72.

Pohl, P., & Zuheidi, F. (1979). *Fatty acids and lipids of marine algae and the control of their biosintesis by environmental factors in Marine Algae in Pharmaceutical Science*. New York: Walter de Gruyter, pp. 473–523.

Rupérez, P., Ahrazem, O., & Leal, J. A. (2002). Potencial antioxidant capacity of sulfated polysaccharides from the edibic marine brown seeweed *Fucus vesiculosus*. *Journal of Agricultural and Food Chemistry, 50*, 840–845.

Sánchez-Machado, D. I., López-Cervantes, J., López-Hernández, J., & Paseiro-Losada, P. (2004a). Fatty acids, total lipid, protein and ash contents of processed edible seaweeds. *Food Chemistry, 85*, 439–444.

Sánchez-Machado, D. I., López-Cervantes, J., López-Hernández, J., & Paseiro-Losada, P. (2004b). Simultaneous determination of thiamine and riboflavin in edible marine by high-performance liquid chromatography. *Journal of Chromatographic Science, 42*(3), 117–120.

Stephen, A. M., & Cummings, J. H. (1980). Mechanism of action of dietary fiber in the human colon. *Nature, 284*, 283–284.

Tacon, A. G. J., & Cowey, C. B. (1985). Protein and amino acid requirements. In P. Tyler & P. Calow (Eds.), *Fish energetic: new perspective* (pp. 155–183). London: Croom Helm.

Wahbeh, M. (1997). Amino acid and Fatty acid profiles of tour species of macroalgae from aqaba and their suitability for use in fish diets. *Aquaculture, 159*, 101–109.

Zavodnik, N. (1987). Seasonal variations in the rate of photosynthetic activity and chemical composition of the littoral seaweeds *Ulva rigida* and *Porphyra leucosticia* from the North Adriatic. *Botánica Marina, 30*, 71–82.