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Nutritional evaluation of some subtropical red and green seaweeds Part I — proximate composition, amino acid profiles and some physico-chemical properties

K.H. Wong, Peter C.K. Cheung *

Department of Biology, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong

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Abstract

The proximate composition, amino acid profile and some physico-chemical properties of two subtropical red seaweeds (*Hypnea charoides* and *Hypnea japonica*) and one green seaweed (*Ulva lactuca*) were investigated. The total dietary fiber [ranged from 50.3 to 55.4% dry weight (DW)] and ash (ranged from 21.3 to 22.8% DW) were the two most abundant components in these seaweeds but their crude lipid contents were very low (ranged from 1.42 to 1.64% DW). Although the crude protein content of the red seaweeds was significantly ($p < 0.05$, ANOVA, Tukey-HSD) higher than that of the green, the three seaweed proteins contained all essential amino acids, the levels of which were comparable to those of the FAO/WHO requirement. Moreover, the swelling capacity (SWC), water-holding capacity (WHC) and oil-holding capacity (OHC) of the seaweeds had a high positive correlation ($r = 0.99$–1.00) with their total amount of fiber and protein. Among the three seaweeds, the two red seaweeds exhibited significantly ($p < 0.05$, ANOVA, Tukey-HSD) better physico-chemical properties, which were similar to some commercial fiber-rich food ingredients.

Keywords: Proximate composition; Amino acid profile; Physico-chemical properties; Seaweeds

1. Introduction

In the Far East and Asian Pacific, people have a long tradition of consuming seaweeds as part of their diet while, in the Western countries, the principal uses of seaweeds are as sources of phycocolloids, thickening and gelling agents for various industrial applications including uses in foods (Abbott, 1996; Darcy-Vrillon, 1993; Mabeau & Fleurence, 1993). Recently, in France, seaweeds have been authorized as vegetables and condiments (Mabeau, 1989). Therefore, seaweeds have become a valuable vegetable (fresh or dried) and an important food ingredient in the human diet.

The nutritional properties of seaweeds are not completely known yet, and they are usually estimated from their chemical composition alone (Darcy-Vrillon, 1993; Mabeau & Fleurence, 1993). Compared to land plants, the chemical composition of seaweeds has been poorly investigated and most of the available information only deals with traditional Japanese seaweeds (Fujiwara-Arasaki, Mino & Kuroda, 1984; Nisizawa, Noda, Kikuchi & Watanabe, 1987; Watanabe & Nisizawa, 1984). The chemical composition of seaweeds varies with species, habitats, maturity and environmental conditions (Ito & Hori, 1989). Nevertheless, in general, seaweeds are rich in non-starch polysaccharides, minerals and vitamins (Darcy-Vrillon, 1993; Mabeau & Fleurence, 1993). As seaweed polysaccharides cannot be entirely digested by human intestinal enzymes, they are regarded as a new source of dietary fiber and food ingredients (Lahaye, 1991; Mabeau, Cavaloc, Fleurence & Lahaye, 1992; Mabeau & Fleurence, 1993). Together with their low lipid content, seaweeds only provide a very low amount of energy (Jurkovic, Kolb & Colic, 1995). Consumption of seaweeds can increase the intake of dietary fiber and lower the occurrence of some chronic diseases (diabetes, obesity, heart diseases, cancers, etc.), which are associated with low fiber diets of the Western countries (Southgate, 1990).

Dietary fiber can be divided into soluble and insoluble fractions. The viscosity of soluble dietary fiber is responsible for slower digestion and absorption of nutrients, and lower levels of blood cholesterol and glucose. In contrast, insoluble dietary fiber is characterized by its

* Corresponding author. Tel.: +852-2609-6144; fax: +852-2603-5646.

E-mail address: petercheung@cuhk.edu.hk (P.C.K. Cheung).

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ability to increase fecal bulk and decrease intestinal transit time (Baghurst, Baghurst & Record, 1996; Potty, 1996). Therefore, the physiological effects of dietary fiber are correlated with their particular physico-chemical properties (Roehring, 1988). As dietary fiber is the major component of the seaweeds, determining the physico-chemical properties of seaweed dietary fiber can give us some understanding of the physiological effects of consuming seaweeds and their potential applications as texturizing and bulking agents in making low-calorie foods.

Although the seaweed floras in Hong Kong are fairly rich, they are relatively under-utilized (Hodgkiss & Lee, 1983). In general, most Hong Kong seaweeds are mainly used as animal feeds or fertilizers by the coastal villagers (Hodgkiss & Lee, 1983). Two red seaweeds (*Hypnea charoides* and *Hypnea japonica*) and one green seaweed (*Ulva lactuca*) are very abundant in Hong Kong (Hodgkiss & Lee, 1983). The aim of the present study in this part was to determine the chemical composition and amino acid profiles of these three subtropical seaweeds in order to provide more comprehensive nutrient information about them. Furthermore, some physico-chemical properties of these seaweeds were also investigated in order to evaluate their potential use as food ingredients.

2. Materials and methods

2.1. Sample preparation

All samples of seaweed were collected from A Ma Wan (AMW) and Lung Lok Shui (LLS) at Tung Ping Chau, in the northeast of Hong Kong. *H. charoides* and *H. japonica* (red seaweeds) were collected from both LLS and AMW in December 1997 while *U. lactuca* (green seaweeds) was only collected from AMW in December 1997. Fresh plants were thoroughly washed with distilled water and their holdfasts and epiphytes were removed. All cleaned seaweeds were then frozen in a −70°C freezer for 24 h and then dried in a freeze-drier (Labconco, MO) for 5 days. All samples were dried to constant weight. The dried samples were pulverized by using a cyclotech mill (Tecator, Hoganas, Sweden) to pass through a screen with an aperture of 0.5 mm. The milled seaweed samples were then stored in air-tight plastic bags in desiccators at room temperature (25°C) prior to further nutrient composition analysis.

2.2. Proximate composition

2.2.1. Crude protein analysis

The crude protein content was calculated by multiplying the nitrogen content, which was determined by a CHNS/O Analyzer (Perkin-Elmer 2400, Connecticut, USA) by a factor of 6.25.

2.2.2. Determination of ash

The ash contents were estimated by heating the seaweeds overnight in a furnace at 525°C (AOAC, 1995).

2.2.3. Total dietary fiber analysis

The content of total dietary fiber (TDF) in seaweeds was determined according to the AOAC enzymatic-gravimetric method (AOAC, 1995). In brief, aliquots of samples (1 g of dry matter) were first treated with two amylases, a heat-stable α-amylase (EC 3.2.1.1 from *Bacillus licheniformis*, catalog no. A33306, Sigma Chemical Co., St. Louis, MO) for 30 min in a boiling water bath and a fungal amyloglucosidase (EC 3.2.1.3 from *Aspergillus niger*, catalog no. A3513, Sigma) for 30 min at 60°C to remove starch and then a bacterial protease (from Subtilisin Carlsberg, catalog no. P3910, Sigma) to solubilize protein. The amylase enzymes used had been tested to be free of β-glucanase. The enzyme-treated mixture containing the buffer solution and non-digestible materials was precipitated with four volumes of absolute ethanol. Then the ethanol-insoluble residue was filtered with a Fiber-Tec System (Tecator 1023, Hoganas, Sweden). The residue recovered was washed, oven-dried and weighed to give the gravimetric yield of the seaweed fiber material or TDF. The weight of TDF was corrected for ash and residual protein content and a blank.

2.2.4. Extraction of crude lipids

Crude lipids were extracted from the seaweed powder in a Soxhlet extractor (Soxtec System HT6, Tecator, Hoganas, Sweden) with chloroform:methanol (2:1, v/v). The contents of crude lipids were determined gravimetrically after oven-drying (80°C) the extract overnight.

2.2.5. Moisture analysis

Moisture content determined by an infrared moisture analyzer (Mettler LJ 16, Greifensee, Switzerland) at 120°C was expressed as percentage by weight of sample.

2.3. Amino acid analysis

Two milligrams of seaweed samples were hydrolyzed with 0.5 ml 6 M HCl (catalog no. H0636, Sigma) in a sealed ampoule containing 8 μl phenol (for protection of tyrosine) and 0.25 μl mol norleucine (catalogue no. N8513, Sigma) as an internal standard for 24 h at 110°C under vacuum. The acid hydrolysate was evaporated to dryness using a Speedvac concentrator (Savant Instrument, Farmingdale, NY) and the dry residue was redissolved in 0.5 ml of citrate buffer (Beckman A303084, CA). The sample was filtered through a 0.45 μm nylon filter before being analyzed with an automated Amino

Acid Analyzer (Beckman 6300, CA). Sulphur-containing amino acids, cystine and methionine were determined after a pre-hydrolysis oxidation with performic acids (Gehrke, Wall, Absheer, Kaiser & Zumwalt, 1985). The contents of different amino acids recovered are presented as mg g^{-1} protein and are compared with the FAO/WHO (1991) reference pattern. The essential amino acid (EAA) score was calculated by the method of FAO/WHO as shown below:

$$\text{Essential amino acid score} = \frac{\text{mg of EAA in 1 g of test protein}}{\text{mg of EAA in 1 g of egg protein}} \times 100$$

2.4. Physico-chemical properties

2.4.1. Swelling capacity (SWC)

SWC of seaweed samples was analyzed by the bed volume technique after equilibrating in excess solvent (Kuniak & Marchessault, 1972). To 200 mg of seaweed samples in a 50 ml measuring cylinder, 20 ml of de-ionized water were added and the mixtures were then vigorously stirred. The measuring cylinder was left to stand for 24 h at 25 and 37°C. Swelling volume was measured and expressed as milliliters of swollen sample per g of sample (DW).

2.4.2. Water-holding capacity (WHC)

WHC of seaweed samples were measured by the modified centrifugation method described by Suzuki, Ohsugi, Yoshie, Shirai and Hirano (1996). Twenty ml of de-ionized water were added to each centrifuged tube containing 200 mg of seaweed samples. Then the tubes were shaken in a shaking culture bath for 24 h at 25 and 37°C. After centrifuging at 14,000×*g* for 30 min, the supernatant was discarded and the moisture content of pellet was determined after dehydration in an oven for 2 h at 120°C. The WHC of seaweed was expressed as the weight of grams of water held by 1 g of sample (DW).

2.4.3. Oil-holding capacity (OHC)

OHC of seaweed samples were determined by the method of Caprez, Arrigoni, Amado and Neukom (1986) with slight modifications. About 3 g of seaweed samples were placed in each centrifuge tube, to which 10.5 g of corn oil were added. The tubes were left for 30 min at room temperature (25°C) with agitation. After that, the mixture was centrifuged at 2500 × *g* for 30 min. The oil supernatant was then removed and measured. The OHC of seaweed samples were expressed as the number of grams of oil held by 1 g of sample (DW). Density of the oil was found to be 0.92 g/ml.

2.5. Statistical analysis

All analyses were performed in triplicate. Except for the amino acid profiles, all data are presented as mean values ± S.D. and the mean values were analyzed by one-way ANOVA and Tukey-HSD at $p < 0.05$ (Wilkinson, 1988) to detect significant differences among groups. Moreover, the results of SWC and WHC were further evaluated by the Student's *t*-test ($p < 0.05$) to determine the significance of differences between the mean values obtained from two different temperatures. The assumptions of the parametric statistics were satisfied.

3. Results and discussion

3.1. Proximate composition

Table 1 shows the proximate composition of the red and green seaweed samples. The crude protein content (7.06–19.0% DW) of the three seaweeds was within the range for red and green seaweeds (10–47% DW) as reported by Fleurence (1999). However, the crude protein of the *U. lactuca* (7.06% DW) was found to be lower than that of other *Ulva* species (10–26% DW) (Fleurence, 1999). The crude protein content of the two red seaweeds (*H. charoides* and *H. japonica*) was significantly ($p < 0.05$, ANOVA, Tukey-HSD) higher than that of the green seaweed (Table 1). This observation agreed with previous reports (Darcy-Vrillon, 1993; Fleurence, 1999; Mabeau & Fleuence, 1993). Furthermore, the crude protein content of *H. charoides* and *U. lactuca* was notably higher than the same species found in the Philippines (6.60–10.5 and 4.20% DW, respectively) (Portugal, Ladines, Ardena, Resurreccion, Medina & Matibag, 1983). Variations in the protein content of seaweeds can be due to different species and seasonal periods (Fleurence, 1999).

All seaweeds had ash contents (21.3–22.8% DW), which were consistent with previous results (Mabeau et al., 1992; Mabeau & Fleurence, 1993). The ash contents of all the seaweeds were similar. Also, in this study, the ash content of the *Hypnea* and *Ulva* species were comparable to that of some seaweed species of the same genus: *H. charoides* (23.5–34.9% DW), *H. pannosa* (15.3% DW), *U. lactuca* (24.6% DW) and *U. pertusa* (24.7% DW) (Behairy & El-Sayed, 1983; Portugal et al., 1983).

As shown in Table 1, the total dietary fiber, which was the most abundant component in these seaweeds (50.3–55.4% DW), was higher than the levels found in most higher plants. This observation was in accordance with previous results (Darcy-Vrillon, 1993; Ito & Hori, 1989; Mabeau & Fleurence, 1993). Moreover, the TDF of the *U. lactuca* was comparable to that of *U. pertusa*

Table 1
Proximate composition (g/100 g DW[a]) of *H. japonica*, *H. charoides* and *U. lactuca*[b]

Composition	*H. japonica*	*H. charoides*	*U. lactuca*
Crude protein ($N\times6.25$)	19.0±0.36a	18.4±0.30a	7.06±0.06b
Ash	22.1±0.72a	22.8±2.23a	21.3±2.78a
TDF[c]	53.2±0.56ab	50.3±2.78a	55.4±2.00b
Crude lipid	1.42±0.35a	1.48±0.15a	1.64±0.10a
Carbohydrate[d]	4.28±1.52a	7.02±4.06b	14.6±4.94c
Moisture[e]	9.95±0.27a	10.9±0.62a	10.6±1.14a

[a] Sample dry weight.
[b] Data are mean values of three determinations ± S.D. Means in rows with different letters (a–c) are significantly different ($p < 0.05$, ANOVA, Tukey-HSD).
[c] TDF = total dietary fiber.
[d] Calculated by difference (= 100− crude protein− crude lipid− TDF− ash).
[e] Moisture content is expressed as percentage of freeze-dried sample.

(52.1% DW) (Yoshie, Suzuki, Shirai & Hirano, 1997) and to the same species (38.1 and 40.0% DW) reported earlier (Lahaye, 1991; Lahaye & Jegou, 1993). Seaweeds contain large amounts of dietary fiber which are particularly rich in the soluble fraction (Darcy-Vrillon, 1993; Lahaye, 1991; Mabeau & Fleurence, 1993). The chemical nature and physico-chemical properties of some common seaweed dietary fibers such as alginates, carrageenans and agars are quite well known, but most seaweed dietary fibers in particular the insoluble types and their physiological effects have still not received much attention (Mabeau & Fleurence, 1993).

In general, the lipid contents of these subtropical seaweeds were low (1.42–1.64% DW) but within the range (1.00–3.00% DW) reported previously (Mabeau & Fleurence, 1993). Although the crude lipid content of *H. charoides* (1.48% DW) was lower than that of previous data (2.20–2.70% DW) (Portugal et al., 1983), the crude lipid content of the *U. lactuca* (1.64% DW) was comparable to *Ulva* species from the Philippines (1.60–1.80% DW) (Portugal et al., 1983). As all the seaweed samples were treated by the same drying method (freeze-drying), no significant differences in moisture content were obtained.

3.2. Amino acid composition

The amino acid profiles and the essential amino acid scores of seaweed samples are presented in Table 2. The amino acid analyzed represented both the free and combined amino acids. The seaweed samples contained all the essential amino acids (in different proportions, excluding tryptophan), which accounted for 42.1–48.4% of the total amino acid content [Level of total EAAs (mg/g of protein)/sum of all measured amino acids (mg/g protein) × 100%]. Similar results have been obtained from other subtropical seaweeds (Behairy & El-Sayed, 1983; Qasim, 1991). Furthermore, the levels of all their essential amino acids were comparable to those of the FAO/WHO (1991) requirement pattern. Leucine was the common limiting amino acid of *H. charoides* and *U. lactuca* while the limiting amino acids of *H. japonica* were tyrosine and phenylalanine. Although the sulphur-containing amino acids (methionine and cystine) of some *Hypnea* species have been reported to be the limiting amino acids (Portugal et al., 1983), the methionine and cystine levels of the *Hypnea* species in this study were above the FAO/WHO requirement (EAA score ranged from 1.90 to 1.95). With respect to the total EAA in the FAO/WHO requirement pattern, all red and green seaweeds seemed to be able to contribute adequate levels of total EAA.

All seaweed samples exhibited similar non-essential amino acid patterns, in which aspartic and glutamic acid constituted a substantial amount of the total amino acids (20.8–22.9% of total AA). Similar results were reported previously (Behairy & El-Sayed, 1983; Fleurence, 1999; Mabeau et al., 1992). According to Mabeau et al. (1992), the high levels of aspartic and glutamic acids were responsible for the special flavor and taste of the seaweeds.

Qasim (1991) reported that there were some pronounced differences between the amino acid profiles of Rhodophyceae (red seaweeds) and Chlorophyceae (green seaweeds). Previous results revealed that the sulfur-containing amino acids of the red seaweeds were higher than that of green seaweeds (Qasim, 1991). In this study, the amino acid profiles of the seaweeds further confirmed this observation [red seaweeds (*Hypnea* species): 5.11–5.23% of total AA; green seaweed (*U. lactuca*): 3.25% of the total AA]. Moreover, the total amino acid content (16.2–17.3 g/100 g DW) of the red seaweeds was more than 2 times that of the green seaweeds (6.30 g/100 g DW). This result also agrees with previous data reported by Qasim (1991). In this study, the total amino acid content (6.30–17.3 g/100 g DW) of each seaweed sample was comparable to its corresponding crude protein content (7.06–19.0 g/100 g DW) (Table 1). This

Table 2
Amino acid profiles (mg g^{-1} protein)[a] of *H. japonica*, *H. charoides* and *U. lactuca*

Amino acids	*H. japonica*	*H. charoides*	*U. lactuca*	FAO/WHO (1991) requirement pattern
Aspartic acid	98.4	88.6	98.7	
Threonine	45.9 (1.35)	51.3 (1.51)	50.6 (1.49)	34
Serine	47.5	44.9	55.4	
Glutamic acid	110	98.4	87.3	
Proline	45.4	47.9	44.6	
Glycine	54.2	50.6	67.4	
Alanine	57.4	52.3	73.9	
Valine	56.3 (1.61)	61.4 (1.75)	55.0 (1.57)	35
Methionine	18.5 (1.90)[b]	16.8 (1.95)[b]	15.7 (1.16)[b]	25[b]
Cystine	29.1	28.1	13.3	
Isoleucine	44.8 (1.60)	48.5 (1.73)	38.2 (1.36)	28
Leucine	97.9 (1.48)	72.3 (1.10)	67.1 (1.02)	66
Tyrosine	27.9 (1.03)[c]	26.0 (1.30)[c]	35.0 (1.11)[c]	63[c]
Phenylalanine	37.2	56.0	35.0	
Histidine	6.89	6.58	4.82	
Lysine	66.3 (1.14)	64.9 (1.12)	65.8 (1.13)	58
Arginine	66.8	63.6	84.4	
Tryptophan	ND[d]	ND	ND	11
Total EAA[e]	424	425	376	320
Total amino acids (g/100 g DW[f])	17.3	16.2	6.30	—

[a] Values are the average of three determinations. Figures in parentheses are the essential amino acids score.
[b] Cystine + methionine.
[c] Tyrosine + phenylalanine.
[d] Not determined.
[e] Total essential amino acids (mg/g protein) excludes tryptophan.
[f] Sample dry weight.

implied that the amounts of non-protein nitrogenous materials in these seaweeds were insignificant.

3.3. Physico-chemical properties

Seaweeds are rich in dietary fiber (> 50% DW), particularly in the soluble form (Darcy-Vrillon, 1993; Mabeau & Fleuence, 1993). Fleury and Lahaye (1991) reported that the physico-chemical properties of seaweed powder could be assumed to reflect those of the fiber present. Furthermore, since seaweed proteins are closely related to the cell wall polysaccharides (Fleurence, Le Coeur, Mabeau, Maurice & Landrein, 1995; Jordan & Vilter, 1991), they may also play a role in the physico-chemical properties such as water-holding (Chou & Morr, 1979). In this study, the total content of protein and TDF in the seaweed samples were up to 62.5–72.2% DW (Table 1), so the physico-chemical properties of the red and green seaweeds might be mainly determined by these two chemical components.

SWC, WHC and OHC of the red and green seaweed samples are shown in Table 3. At 25°C, the SWC and WHC of the seaweed samples ranged from 11.2 to 22.1 ml/g DW and 8.68–11.8 g/g DW, respectively with the SWC and WHC of *H. japonica* being the highest ($p < 0.05$, ANOVA, Tukey-HSD). The WHC of the three seaweed samples at 25°C were not only similar to that of *U. lactuca* (7.50 g/g DW) and *E. compressa* (9.50 g/g DW) (Lahaye & Jegou, 1993), but also comparable to that of some agricultural by-products (dietary fiber concentrates) (6.30–13.2 g/g DW) reported previously (Grigelmo-Miguel, Gorinstein & Martin-Belloso, 1999; Grigelmo-Miguel & Martin-Belloso, 1997, 1999). Furthermore, both SWC and WHC of the red and green seaweed samples were also comparable to the SWC (9.90–24.0 ml/g DW) and WHC (6.60–9.00 g/g DW) of some commercial dietary fiber-rich supplements (Goñi & Martin-Carrón, 1998). Among the three seaweed samples, the remarkably high SWC and WHC values of the *H. charoides* and *H. japonica* suggested that the red seaweeds could be potentially used as a functional ingredient to reduce calories, avoid syneresis and modify the viscosity and texture of formulated food.

In this study, the SWC and WHC of the three seaweed samples at 37°C ranged from 13.0 to 24.1 ml/g DW and 9.71 to 14.0 g/g DW, respectively (Table 3). The SWC of *U. lactuca* was comparable to that of *L. digitata* (15.6 ml/g DW) at 37°C (Fleury & Lahaye, 1991), while the SWC of the *H. charoides* and *H. japonica* were in agreement with that of Japanese seaweeds such as nori, hijiki, kombu and aonori (about 20.0 ml/g DW) determined at the same temperature (Suzuki et al., 1996).

Table 3
The swelling, water and oil holding capacity of *H. japonica*, *H. charoides* and *U. lactuca*[a]

Seaweeds	SWC[b] (ml/g DW[c])		WHC[d] (g/g DW)		OHC[e] (g/g DW)
	25°C	37°C	25°C	37°C	
H. japonica	22.1±0.57ax	24.1±0.38ay	11.8±0.05ax	14.0±0.36ay	0.95±0.04a
H. charoides	19.6±0.45bx	20.7±0.60by	10.9±0.30bx	12.4±0.31by	0.82±0.01b
U. lactuca	11.2±0.40cx	13.0± 0.70cy	8.68±0.50cx	9.71±0.11cy	0.65±0.03c

[a] Data are mean values of three determinations ± S.D. Means in each column with different letters (a–c) are significantly different ($p < 0.05$, ANOVA, Tukey-HSD). For each parameter of SWC and WHC, means in two adjacent columns with different letters (x,y) are also significantly different ($p < 0.05$, Student's *t*-test).
[b] SWC = swelling capacity.
[c] Sample dry weight.
[d] WHC = water-holding capacity.
[e] OHC = oil-holding capacity.

At 37°C, although the WHC of all seaweed samples were lower than that of wakame (19.0–44.0 g/g DW) (Suzuki et al., 1996) and *L. digitata* (18.7 g/g DW) (Fleury & Lahaye, 1991), their WHC values were comparable to that of hijiki and kombu (about 10.0–12.0 g/g DW) (Suzuki et al., 1996) determined at the same temperature. Furthermore, a very high correlation was also obtained between the total amount of protein and TDF and the SWC ($r = 0.99$ at 25°C; $r = 1.00$ at 37°C) as well as the WHC ($r = 1.00$ for both 25 and 37°C). This indicated that both SWC and WHC of the red and green seaweeds depended very much on the amount of protein and TDF present.

According to Robertson and Eastwood (1981), water exists in fiber in three forms: it is bound to the hydrophilic polysaccharides; it is held within the fiber matrix or it is trapped within the cell wall lumen. WHC, determined by the centrifugation method used in this study, represented all three types of water associated with the fiber (Fleury & Lahaye, 1991). Apart from the different water-holding ability in fiber, the differences in SWC and WHC among the seaweed samples might be attributed to the different protein conformations and the variations in the number and nature of the water binding sites on the protein molecules (Chou & Morr, 1979). In addition to chemical compositions, some physical properties, such as structure, particle size, porosity, pH, temperature, ionic strength, types of ions in solutions and density are important to the understanding of the different behaviors of samples during hydration (Auffret, Ralet, Guillon, Barry & Thibault, 1994; Fleury & Lahaye, 1991; Robertson & Eastwood, 1981).

In this study, the effects of temperature on SWC and WHC were also investigated. In agreement with the observations of Arrigoni, Caprez, Amado and Neukom (1986) and Caprez et al. (1986), both SWC and WHC of all seaweed samples increased significantly ($p < 0.05$, ANOVA, Tukey-HSD) with temperature (Table 3). Such increase was probably related to the increase in the solubility of fibers and proteins (Fleury & Lahaye, 1991). Furthermore, a very high correlation between the SWC and WHC was obtained at each temperature (25°C, $r = 1.00$ and 37°C, $r = 1.00$). Similar relationships ($r = 0.96$) amongst Japanese seaweeds such as kombu, wakame and nori had been reported previously (Suzuki et al., 1996). The two hydration properties, SWC and WHC, which are mainly determined by the food content (like dietary fiber) (Sosulski & Cadden, 1982) have been shown to be closely related (López, Ros, Rincõn, Periago, Martínez & Ortuñe, 1996).

Table 3 also shows the OHC of the red and green seaweed samples. OHC is another important property of food ingredients used in formulated food. In this study, the OHC of the seaweed samples ranged from 0.65 to 0.95 g/g DW, with the OHC of *H. japonica* being the highest ($p < 0.05$, ANOVA, Tukey-HSD). Among the seaweed samples, the considerably high OHC of the *H. charoides* and *H. japonica* were comparable to the high OHC values of orange (0.86–1.28 g/g DW) and peach (1.02–1.11 g/g DW) dietary fiber concentrates reported in recent work (Grigeimo-Miguel et al., 1999; Grigeimo-Miguel & Martin-Belloso, 1999). This suggested that the red seaweeds would be able to stabilize food emulsions with a high percentage of fat.

Basically, the mechanism of OHC is mainly due to the physical entrapment of oil by capillary attraction (Kinsella, 1976). Moreover, the hydrophobicity of proteins also plays a major role in fat absorption (Voutsinas & Nakai, 1983). Therefore, among the seaweed samples, the variations in OHC may be partially due to the different proportions of polar side chains of the amino acids on the surfaces of their protein molecules (Chau & Cheung, 1998). Furthermore, Fleury and Lahaye (1991) reported that the OHC of seaweed are also related to the particle size, overall charge density and hydrophilic nature of the individual particles. Similarly, the correlation between OHC and total amount of protein and TDF was very high ($r = 1.00$). This implied that the OHC of

the red and green seaweed powder might also depend on the total content of protein and TDF present.

4. Conclusions

With respect to the high protein level and balanced amino acid profile, the two red seaweeds studied here appeared to be an interesting potential source of plant food proteins. However, the nutritional values of the seaweeds obtained here were based on chemical analyses only. Biological evaluation using human and animal feeding studies would be required to establish the nutritional value of these seaweeds, particularly the in vivo protein digestibility and bioavailability of the essential amino acids. Also, *H. charoides* and *H. japonica* had physico-chemical properties that were comparable to those of some commercial fiber-rich products, indicating that they could be used as functional ingredients in formulated food. Moreover, the three physico-chemical properties, SWC, WHC and OHC, had a high positive correlation with the total amount of TDF and protein in the seaweeds.

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