Comparative Studies on the Effect of Three Drying Methods on the Nutritional Composition of Seaweed *Sargassum hemiphyllum* (Turn.) C. Ag.†

Jenny C.-C. Chan, Peter C.-K. Cheung,* and Put O. Ang, Jr.

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

The effect of sun-drying, oven-drying, and freeze-drying methods on the nutritional composition of the seaweed *Sargassum hemiphyllum* (Turn.) C. Ag. was investigated. Proximate and nutrient compositions (amino acids, fatty acids, minerals, and vitamin C) of the seaweed dried by the above methods were determined. The results indicated that dietary fiber and ash were the most abundant components of seaweed *S. hemiphyllum*. No significant differences in the content of crude protein and crude lipid were found among all three dried seaweed samples. Freeze-dried seaweed had the highest content of total amino acids, total polyunsaturated fatty acids, and total vitamin C when compared with sun-dried and oven-dried seaweed. However, sun-dried seaweed has the lowest values of ash, mineral, and total vitamin C contents among the three dried seaweed samples. This might be due to the leaching effect and long exposure time to air during sun-drying. Although oven-dried seaweed had the greatest nutrient losses, probably due mainly to the effect of high temperature during drying, it contained the highest mineral content. Thus, it can be concluded that the nutritional composition of seaweed *S. hemiphyllum* is greatly affected by different drying methods.

Keywords: *Seaweed; freeze-drying; oven-drying; sun-drying; nutritional composition*

INTRODUCTION

Seaweeds are traditionally consumed in the Far East, while in the West they are used almost exclusively for the phycocolloid industry (Mabeau and Fleurence, 1993). As a result of recent interests in simple living, the potentials of seaweed as a source of natural and health food became widely recognized and studies on the nutritional values of seaweeds have become more widespread. In comparison with land vegetables, seaweeds are potentially good sources of polysaccharides, minerals, and certain vitamins (Darcy-Vrillon, 1993).

Brown seaweed is one of the most abundant seaweed groups of economic importance. Within this group, plants belonging to the genus *Sargassum* are widely distributed in tropical and subtropical regions. More than 250 species have been described under this genus (Chapman and Chapman, 1980). *Sargassum hemiphyllum* (Turn.) C. Ag. is very abundant in Hong Kong (Hodgkiss and Lee, 1983). It has been used as food and medicine in both China and Japan. Furthermore, it has been collected and used as fertilizer and raw materials for the algin-processing industry in the nearby region (Ho, 1988). A number of studies on the nutritional value of *Sargassum* species has been conducted regarding the composition of their protein and amino acids (Qaism, 1991), lipid and fatty acids (Honya *et al*., 1994; Khotimchenko, 1991), dietary fibers (Suzuki *et al*., 1993; Lahaye, 1991), minerals (Mabeau *et al*., 1992; Yun *et al*., 1990), and vitamins (De Roeck-Hotlzhauer *et al*., 1991; Qasim and Barkati, 1985). However, no study has been done on the nutritional composition of *S. hemiphyllum*.

Fresh seaweeds collected from the sea are usually dried before being used in any nutritional evaluation or industrial processing. Drying is essential because crude extracts of the wet seaweed do not gel. If properly dried, seaweed samples can be stored for a number of years without appreciable loss of their gel content (FAO, 1976). Drying could be an important factor affecting the nutritional values of seaweed samples. It has been shown that high-temperature drying and cooking could greatly alter the vitamin C content in brown seaweed (Mabeau and Fleurence, 1993). Sun-drying (Carrillo *et al*., 1992), oven-drying (Hamdy and Dawes, 1988), and freeze-drying (Mabeau *et al*., 1992) are the three common drying methods employed in seaweed studies. However, each of these methods was usually used independently on separate species of seaweed. No comparison on the effect of these different drying methods on the nutritional values of samples of a single seaweed species has yet been investigated. Therefore the main objectives of this study were to identify and quantify the major classes of nutrients found in the brown seaweed *S. hemiphyllum* and to determine the effect of different drying methods on the composition of these nutrients in the seaweed samples.

MATERIALS AND METHODS

Sample Preparation. Samples of *S. hemiphyllum* were collected from Tung Ping Chau, on the northeast of Hong Kong, in December 1995. Fresh plants were thoroughly washed with water and their holdfasts and epiphytes removed. The cleaned samples were divided into three groups. One group was dried under direct sunlight for 4 days (the sun-dried group), the second group was dried in a 60 °C air oven for 15 h (the oven-dried group), and the last group was frozen in a −70 °C freezer for 24 h and then dried in a freeze-drier (Labconco, MO) for 5 days (the freeze-dried group). All samples were dried to a constant weight. The dried samples were ground in a Cyclotech mill (Tecator, Hoganas, Sweden) to pass through a 1 mm sieve and then stored in air-tight plastic bags in desiccators at room temperature for further nutritional composition analysis.

* Author to whom correspondence should be addressed [telephone, (852) 26096144; fax, (852) 26035646].

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Moisture Analysis. The moisture content of the sun-dried, oven-dried, and freeze-dried seaweed samples was determined by a LP16 infrared dryer (Mettler, Switzerland).

Crude Protein Analysis. Nitrogen content in the dried samples was determined with a CHNS/O elemental analyzer (Perkin-Elmer PE2400, Norwalk), and the percentage of protein was calculated by multiplying the percent of nitrogen found with a factor of 6.25.

Amino Acid Composition Analysis. Dried seaweed samples were hydrolyzed in 6 N HCl at 110 °C for 24 h under vacuum. Amino acid composition in the hydrolysate seaweed samples was determined by an amino acid analyzer (Beckman 6300, CA).

Extraction of Crude Lipid. Crude lipid was extracted in a Soxhlet extractor (Soxtec System HT6, Tecator, Hoganas, Sweden) with chloroform−methanol (2:1, v/v) and then purified according to the method of Folch *et al*. (1957). The purified lipid extract was evaporated to dryness in a Rapidrap nitrogen evaporator (Labconco, MO).

Fatty Acid Composition Analysis. Methyl esters of the extracted lipids were prepared with heptadecanoic acid as an internal standard. The fatty acids in the extracted lipid were methylated with boron trifluoride/methanol followed by heating in toluene at 100 °C for 30 min and extracted with hexane. The methyl esters were quantified by a gas chromatograph (Hewlett-Packard 5890 Series II) equipped with a flame ionization detector and a fused silica gel capillary column (SP-2560, 100 m × 0.25 mm i.d.). The initial temperature of the oven was 180 °C. The temperature was programmed to increase by 1 °C/min until 220 °C. The final temperature was held for 20 min. Hydrogen was used as the carrier gas. The individual methyl ester of the fatty acid was identified by comparing its retention time with that of known methyl ester standards.

Dietary Fiber Analysis. Six replicates of each sample were used to determine the content of total dietary fiber (TDF), soluble dietary fiber (SDF), and insoluble dietary fiber (IDF) by the method described in Cheung (1996) with slight modifications. In brief, replicates of samples (1 g of dry matter) were first treated with a heat stable α-amylase (EC 3.2.1.1; catalog no. A3306, Sigma Chemical Co., St. Louis, MO) for 30 min in a boiling water bath, then with an amyloglucosidase (EC 3.2.1.3, from *Aspergillus niger*; catalog no. A3513, Sigma) for 30 min at 60 °C to remove the starch, and finally with a protease (catalog no. P3910, Sigma) to solubilize the protein. After enzymatic treatment, three replicates of each sample were precipitated with 4 volumes of absolute ethanol, and the precipitate recovered by filtration was dried and weighed for TDF determination. For SDF and IDF determination, the remaining three replicates after enzymatic treatment were filtered. The insoluble material was dried and weighed, yielding the IDF; the filtrates were precipitated with 4 volumes of absolute ethanol to give SDF after filtration. The weights of TDF, SDF, and IDF were corrected for ash and residual protein content.

Determination of Ash. Ash contents were determined by overnight heating at 525 °C (AOAC, 1995).

Determination of Mineral Elements. Mineral analyses were carried out on samples digested with 65% nitric acid/98% sulfuric acid (5:1, v/v). Potassium, calcium, magnesium, zinc, nickel, iron, manganese, copper, and aluminum were determined by inductively coupled plasma−atomic emission spectroscopy (ICP-AES) (Atomic Scan 16, MA). Sodium was determined using an atomic absorption spectrophotometer (Hitachi Z-8100 Polarized Zeeman, Tokyo), and iodine content was determined according to the AOAC method (1995).

Vitamin C Analysis. A sample of 0.5 g from each drying method was stirred with 25 mL of 10% metaphosphoric acid for 15 min to a homogeneous slurry. After centrifugation, the supernatant was used for the determination of total vitamin C by the 2,4-dinitrophenylhydrazine method (The Association of Vitamin Chemists, 1966).

Statistical Analysis. All analyses were performed in triplicate. The results were analyzed by one-way ANOVA and Tukey-HSD (Wilkinson, 1988) for any significant differences.

Table 1. Proximate Composition (% of Dry Weight) of Sun-Dried, Oven-Dried, and Freeze-Dried Seaweed *S. hemiphyllum*[a]

composition	sun-dried	oven-dried	freeze-dried
crude protein (N × 6.25)	10.1 ± 0.91	9.76 ± 0.65	9.95 ± 0.26
crude lipid	3.04 ± 0.77	3.38 ± 0.22	4.42 ± 0.58
dietary fiber			
total dietary fiber	62.9 ± 0.17^{a}	56.8 ± 1.53^{b}	60.2 ± 0.22^{ab}
soluble dietary fiber	9.00 ± 0.31	9.91 ± 0.35	9.40 ± 0.27
insoluble dietary fiber	52.3 ± 0.68^{x}	45.0 ± 0.65^{y}	50.3 ± 1.16^{x}
ash	19.6 ± 0.03^{a}	21.5 ± 0.07^{b}	21.1 ± 0.12^{b}
moisture	12.4 ± 0.03^{a}	7.60 ± 0.00^{b}	9.47 ± 0.52^{c}

[a] Mean values and standard error of measurements (SEM) for three replicates. Means in rows with different superscripts (a−c) are significantly different ($p < 0.01$, ANOVA, Tukey-HSD). Means in rows with different superscripts (x, y) are significantly different ($p < 0.05$, ANOVA, Tukey-HSD).

RESULTS AND DISCUSSION

Proximate Composition. Results of the proximate composition analysis of *S. hemiphyllum* are summarized in Table 1. In general, the dietary fiber and ash were the most abundant components found in *S. hemiphyllum*, and these were in agreement with results from previous reports on brown seaweeds (Ito and Hori, 1989; Darcy-Vrillon, 1993). No significant differences were found on the content of crude protein and crude lipid among the sun-, oven-, and freeze-dried samples. The low protein content (9.76−10.1%) of *S. hemiphyllum* lies within the range of 5−15% dry weight reported for other seaweeds (Darcy-Vrillon, 1993). The crude lipid content of *S. hemiphyllum* ranged from 3.04% to 4.42%, which was slightly higher than that reported by others (Qasim, 1986; Portugal *et al*., 1983).

Except for ash and moisture, sun-dried seaweed samples showed very similar values with the freeze-dried seaweed samples in terms of its proximate composition. Sun-dried samples had the lowest level of ash content and the highest level of moisture (Table 1). Oven-dried samples exhibited the lowest values in all proximate chemical constituents except for ash (Table 1). Freshly collected *S. hemiphyllum* consists of 85−87% water (data not shown). After drying, the oven-dried seaweed contained the lowest moisture content among seaweed samples dried by the three drying methods (Table 1). Total dietary fiber in a seaweed sample includes both water-soluble and -insoluble parts. No significant differences were observed in the amount of soluble dietary fiber among all the seaweed samples examined (Table 1). However, the insoluble dietary fiber of oven-dried samples was significantly lower than that of either the sun-dried or the freeze-dried samples (Table 1). Hence, the oven-dried samples have the lowest level of total dietary fiber.

Amino Acids. The amino acid profiles of sun-, oven-, and freeze-dried samples are shown in Table 2. The total amount of aspartic acid, glutamic acid, leucine, and tyrosine accounted for half of the total amino acids present in all seaweed samples. In general, brown seaweeds are high in aspartic acid, glutamic acid, glycine, and alanine and low in tyrosine, histidine, and methionine (Ito and Hori, 1989). The amount of total amino acids of oven-dried samples was lower than that of sun- and freeze-dried samples, but the differences were not statistically significant. The damage to the amino acids seemed to be nonspecific as there were no significant differences found in the relative percentages of the individual amino acid in the three seaweed samples (Table 2). The present results showed a trend of less amino acid degradation in the freeze-dried seaweed samples than in the thermal-treated ones, though the differences were not statistically significant.

Table 2. Amino Acid Composition (% of Total Amino Acids) of Sun-Dried, Oven-Dried, and Freeze-Dried Seaweed *S. hemiphyllum*[a]

amino acid	sun-dried	oven-dried	freeze-dried
aspartic acid	9.99 ± 0.17	10.1 ± 0.21	9.88 ± 0.14
threonine	4.57 ± 0.05	4.60 ± 0.06	4.58 ± 0.03
serine	0.92 ± 0.09	0.78 ± 0.06	0.84 ± 0.11
glutamic acid	11.4 ± 0.25	11.6 ± 0.39	11.3 ± 0.07
glycine	5.24 ± 0.12	5.30 ± 0.16	5.11 ± 0.05
alanine	6.15 ± 0.04	7.18 ± 0.38	6.15 ± 0.06
cystine	1.74 ± 0.29	2.14 ± 0.13	1.46 ± 0.06
valine	5.36 ± 0.05	5.36 ± 0.04	5.34 ± 0.02
methionine	2.01 ± 0.04	2.97 ± 0.02	1.91 ± 0.22
isoleucine	4.10 ± 0.06	3.74 ± 0.31	3.77 ± 0.35
leucine	7.01 ± 0.25	6.82 ± 0.06	6.96 ± 0.02
tyrosine	22.6 ± 0.31	21.1 ± 1.34	23.0 ± 0.15
phenylalanine	4.21 ± 0.06	4.05 ± 0.19	4.19 ± 0.02
histidine	1.50 ± 0.05	1.52 ± 0.03	1.52 ± 0.04
lysine	5.03 ± 0.14	5.01 ± 0.17	4.94 ± 0.02
arginine	4.25 ± 0.03	3.74 ± 0.40	5.02 ± 0.19
proline	3.91 ± 0.02	4.02 ± 0.06	3.99 ± 0.02
total amino acids (g/100 g of dry weight)	7.05 ± 0.56	5.39 ± 0.75	7.87 ± 0.95

[a] Mean values and standard error of measurements (SEM) for three replicates.

Table 3. Fatty Acid Composition (% of Total Fatty Acids) in Sun-Dried, Oven-Dried, and Freeze-Dried Seaweed *S. hemiphyllum*[a]

fatty acid	sun-dried	oven-dried	freeze-dried
C12:0	3.28 ± 0.87	1.70 ± 0.20	1.98 ± 0.15
C14:0	3.83 ± 0.02^{ab}	4.22 ± 0.13^{a}	3.77 ± 0.08^{b}
C16:0	36.0 ± 0.38^{ab}	38.4 ± 0.70^{a}	34.3 ± 0.47^{b}
C16:1ω9	0.80 ± 0.14	0.86 ± 0.14	0.96 ± 0.02
C16:1ω7	6.28 ± 0.19^{a}	6.87 ± 0.12^{b}	6.55 ± 0.03^{ab}
C18:0	1.52 ± 0.15	1.43 ± 0.04	1.39 ± 0.03
C18:1ω9	11.0 ± 0.20^{ab}	12.0 ± 0.37^{a}	10.4 ± 0.03^{b}
C18:1ω7	0.91 ± 0.05	0.27 ± 0.01	0.93 ± 0.05
C18:2ω6	4.51 ± 0.03	4.45 ± 0.13	4.36 ± 0.12
C18:3ω3	6.84 ± 0.09^{a}	7.10 ± 0.14^{ab}	7.38 ± 0.02^{b}
C18:4ω3	5.94 ± 0.13^{a}	5.61 ± 0.15^{a}	7.00 ± 0.07^{b}
C20:4ω6	10.4 ± 0.24^{a}	9.18 ± 0.27^{b}	10.7 ± 0.16^{a}
C20:5ω6	8.64 ± 0.11^{a}	7.84 ± 0.31^{a}	10.3 ± 0.12^{b}
total saturated	44.7 ± 0.55^{ab}	45.8 ± 1.01^{a}	41.5 ± 0.38^{b}
total unsaturated	55.3 ± 0.55^{ab}	54.2 ± 1.01^{a}	58.5 ± 0.38^{b}

[a] Mean values (% of total fatty acids) and standard error of measurements (SEM) for three replicates. Means in rows with different superscripts (a, b) are significantly different ($p < 0.05$, ANOVA, Tukey-HSD).

Fatty Acids. Seaweeds are not used as a conventional energy source because of their low level of lipids. However, seaweeds contain significantly higher levels of polyunsaturated fatty acids than land vegetables (Darcy-Vrillon, 1993). The fatty acid compositions of sun-, oven-, and freeze-dried *S. hemiphyllum* are shown in Table 3. This seaweed was rich in saturated fatty acid such as palmitic acid, C16:0 (34.3−38.4%), and unsaturated fatty acids such as oleic acid, C18:1ω9 (10.4−12.0%), arachidonic acid, C20:4ω6 (9.18−10.7%), and eicosapentaenoic acid, C20:5ω6 (7.84−10.3%). Similar fatty acid profiles for other *Sargassum* species have been reported (Hamdy and Dawes, 1988; Khotimchenko, 1991). Freeze-dried seaweed samples had significantly higher levels of polyunsaturated fatty acids (such as C18:3ω3, C18:4ω3, C20:4ω6, and C20:5ω6) than the sun- and oven-dried samples (Table 3). The freeze-dried seaweed samples had a significantly lower proportion of total saturated fatty acids and a significantly higher proportion of total unsaturated fatty acids than the oven-dried samples.

Ash and Mineral Elements. Ash accounted for 19.6−21.5% of dry weight in *S. hemiphyllum* (Table 1). This was similar to that reported for other *Sargassum* species (Sautier, 1987, 1990; Portugal *et al.*, 1983). The ash content of sun-dried seaweed samples was significantly ($p < 0.01$, ANOVA) lower than that of oven- and freeze-dried samples (Table 1). In addition to the ash content, the mineral contents of sun-, oven-, and freeze-dried *S. hemiphyllum* are listed in Table 4. *S. hemiphyllum* was found to be rich in sodium, potassium, calcium, magnesium, and iron. Among the seaweed samples treated with the three drying methods, sun-dried samples generally contained the lowest amount of all minerals except calcium. The relatively lower ash and mineral contents of sun-dried seaweed samples might be due to prolonged exposure to air and the leaching effect during the drying process. No significant differences were found between the ash content of oven- and freeze-dried samples (Table 1). However, oven-dried samples had the highest amount of mineral contents such as sodium, potassium, iron, zinc, copper, manganese, and aluminum. A faster drying process, such as oven-drying, probably helped in preserving the most amount of minerals in the samples.

Table 4. Mineral Composition (mg/100 g of Dry Weight) of Sun-Dried, Oven-Dried, and Freeze-Dried Seaweed *S. hemiphyllum*[a]

mineral	sun-dried	oven-dried	freeze-dried
sodium	951 ± 26.1	1010 ± 27.5	946 ± 43.0
potassium	4470 ± 118^{a}	6620 ± 100^{b}	5690 ± 47.1^{c}
calcium	2240 ± 10.1^{a}	2100 ± 13.1^{b}	2090 ± 48.2^{b}
magnesium	989 ± 4.84	989 ± 11.8	1010 ± 11.1
iron	2.08 ± 0.05^{a}	2.60 ± 0.07^{b}	1.94 ± 0.17^{a}
zinc	0.16 ± 0.01	0.18 ± 0.01	0.14 ± 0.01
copper	traces	0.03 ± 0.01	traces
manganese	0.17 ± 0.00	0.20 ± 0.03	0.19 ± 0.02
aluminum	2.90 ± 0.48^{a}	5.49 ± 0.20^{b}	3.99 ± 0.62^{ab}
nickel	traces	traces	traces
iodine	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00

[a] Mean values and standard error of measurements (SEM) for three replicates. Means in rows with different superscripts (a−c) are significantly different ($p < 0.05$, ANOVA, Tukey-HSD).

Vitamin C. Brown seaweeds generally contain more vitamin C than red and green seaweeds (Mabeau and Fleurence, 1993; Qasim and Barkati, 1985). Vitamin C content of *S. hemiphyllum* ranged from 51.9 to 153 mg/100 g on a dry matter basis. These results were in agreement within the range of 22−541 mg/100 g of dry weight reported for other *Sargassum* species (Qasim and Barkati, 1985). Tukey-HSD test showed that the vitamin C content of *S. hemiphyllum* was strongly dependent on the drying process. The vitamin C content of freeze-dried samples (153 ± 12.0 mg/100 g) was significantly ($p < 0.01$, ANOVA) higher than that of oven- and sun-dried samples (97.7 ± 12.1 and 51.9 ± 3.47 mg/100 g, respectively). High temperature during drying has been shown to greatly alter the vitamin C content of seaweed samples (Mabeau and Fleurence, 1993). However, the vitamin C content of sun-dried samples reported here was significantly ($p < 0.01$, ANOVA) lower than that of oven-dried samples. The relatively lower level of vitamin C content in sun-dried samples was probably due to prolonged exposure to air and the leaching effect during the sun-drying process. It is likely that contents of other vitamins obtained from sun-, oven-, and freeze-dried samples would show a similar pattern as that obtained for vitamin C.

CONCLUSION

S. hemiphyllum exhibited a particularly low content of fat (1−3%), but polyunsaturated fatty acids accounted for 54.2−58.5% of the total fatty acids, and hence this is an ideal low-fat food. Besides, the high contents of polysaccharides (56.8−62.9% of the dry weight) and micronutrients such as minerals (19.6−21.5% of the dry weight) and vitamin C (51.9−153 mg/100 g) showed that *S. hemipyllum* could be a potential rich source of nutrients.

Different drying methods have significant effects on the amount of nutritional composition extracted from *S. hemiphyllum*. Freeze-drying provided seaweeds with the best nutritional quantity. However, the equipment and operating costs for freeze-drying are higher and its drying capacity is smaller than those for sun- and oven-drying. For economic reasons, sun-drying is widely used in both seaweed studies and the phycocolloid industry. But sun-drying is strongly dependent on the weather and the length of the day and is more labor intensive than the other two methods. In this study, sun-dried samples generally had a very similar nutritional quality as the freeze-dried samples. But the significantly lower levels of ash, mineral, and vitamin C contents in the former suggested that micronutrients are very sensitive to conditions during the drying process. Of the three methods studied, it is most difficult to control conditions during sun-drying. Its slower drying rate likely increased the leaching effect and prolonged the exposure time of seaweed to air. Both of these could cause significant micronutrient losses from the samples. Although the fast drying rate in oven-drying preserved the ash and mineral contents, the use of high temperatures during drying caused the greatest nutrient losses among all the samples treated.

In choosing the most appropriate drying method for seaweed, one needs to consider the environmental and economic factors, as well as the way the seaweed will eventually be used. Specifically, whether the seaweed will be used as food, medicine, animal feed and fertilizer, or a source of specific nutrients will determine how it should be dried.

Overall, freeze-drying appears to be the most appropriate drying method in retaining the nutritional composition of seaweeds. A study on the seasonal variation of the nutritional composition of *S. hemiphyllum* in Hong Kong is currently underway with samples pretreated by freeze-drying. The present study is only based on *S. hemiphyllum*, a brown seaweed. Further studies are necessary for other classes of seaweed such as red and green seaweeds which have their distinguished cell wall polysaccharides and chemical composition, so they may not respond similarly to the different drying methods.

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