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# Total dietary fiber content in Hawaiian marine algae

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## Abstract

In the Hawaiian Islands, many species of marine macroalgae are eaten by people, as well as by many marine herbivores, notably Hawaiian green sea turtles. The total dietary fiber (TDF) content, which may affect the palatability, digestibility, and nutritional value of seaweed, was determined for 26 species (15 Rhodophyta, 5 Phaeophyta, and 6 Chlorophyta) using an enzymatic-gravimetric procedure. The highest TDF (dry weight) values were found in the following three native Hawaiian species: *Ahnfeltiopsis concinna* 59.8%, *Gayralia oxysperma* 55.8%, and *Sargassum obtusifollium* 53.7%. *Codium reediae* contained the lowest amount of TDF (23.5% dry weight). Thirteen species contained more TDF than wheat bran.

**Keywords:** dietary fiber; edible seaweed; Hawaii; nutritional composition.

## Introduction

In addition to vitamins and minerals, seaweeds are also potentially good sources of fiber (Chapman and Chapman 1980, Arasaki and Arasaki 1983, Ito and Hori 1989, Lahaye 1991). The total dietary fiber composition per gram dry weight of marine algae is generally higher than in land plants (Darcy-Vrillon 1993). Dietary fiber "is the remnants of the edible part of the plant and analogous carbohydrate that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the human large intestine. It includes polysaccharides, oligosaccharides, lignin, and associated plant substances" (Prosky 2000, p. 292). Dietary fiber and crude fiber (the organic matter in the dried residue after digestion of the sample with dilute acid and dilute alkali) are terms that reflect different methodologies used to estimate the contents of foods. Both have been used in previous studies on marine algae (Burkholder et al. 1971, Portugal et al. 1983, Lahaye 1991, Naidu et al. 1993, Fan et al. 1993, Suzuki et al. 1993, Lee et al. 1996, Robledo and Freile Pelegrin 1997, Norziah and Ching 2000). Seaweeds are known to contain a variety of soluble and insoluble fibers, including agar, carrageenans, xylans, alginates, fucans, laminarans, sulfated rhamnoxyloglucurons, celluloses, and mannans (Darcy-Vrillon 1993). Dietary fiber from edible seaweeds show physicochemical properties (water retention capacity, binding capacity, cation exchange capacity, fermentability, etc.) that may have beneficial effects on body weight, cholesterol metabolisim, and blood lipid levels (Lahaye and Jegou 1993, Suzuki et al. 1996, Jiménez-Escrig and Sánchez-Muniz 2000, Wong and Cheung 2000).

Fresh seaweeds, both wild and cultivated, are commonly eaten as food in the Hawaiian Islands (Abbott 1978). In 2001, the commercial harvest of wild seaweed in the Hawaiian Islands was approximately 6666 kg valued at US$ 38,849 (Department of Land and Natural Resources 2002). Previous studies on the nutritional composition of Hawaiian marine algae (Reed 1907, Miller 1927, Harry 1934, McDermid and Stuercke 2003, 2004) provided no information on total dietary fiber. However, crude fiber values were reported for Hawaiian *Ahnfeltiopsis*, *Ulva* and *Gracilaria* (Reed 1907), and Schwartz (1911) extracted hemicelluloses from eight species of Hawaiian seaweeds. The purpose of this study was to determine the total dietary fiber content using modern, quantitative Association of Official Analytical Chemists (AOAC) methods in a variety of Hawaiian seaweeds consumed by humans and marine herbivores.

## Materials and methods

### Collection

Approximately 1 kg fresh weight (consisting of at least 20 different thalli from the population) of 26 species of marine algae were collected from 13 different intertidal or subtidal sites on the islands of Maui, O'ahu, Hawai'i, and Midway Atoll at times of high biomass or optimal harvesting (low tides and/or low surf) (Table 1). The specimens were placed in food-grade plastic bags, and transported to the laboratory in insulated containers. The list of species includes members of the Chlorophyta, Phaeophyta, and Rhodophyta. Species were chosen based on current and historical popularity as edible species in human diets in the Hawaiian Islands (Abbott 1978, 1996), e.g., *Codium reediae*, *Asparagopsis taxiformis* and *Gracilaria coronopifolia*. In addition, some species commonly consumed by green sea turtles (*Chelonia mydas* L.) were also selected for analysis (Russell and Balazs 2000), e.g., *Ulva fasciata* and *Pterocladiella capillacea*. Samples were identified to genus and species based on examination of morphological and anatomical characteristics, and using taxonomic references (Abbott 1999, Abbott and Huisman 2004). Voucher specimens were selected, photographed, and prepared as dried herbarium specimens deposited in the Bishop Museum Herbarium in Honolulu (BISH). Wheat (*Triticum aestivum* L.)

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**Table 1** Hawaiian seaweed species and wheat bran analyzed for total dietary fiber (TDF).

| Species | TDF (%) | Location, Island | Date collected |
|---|---|---|---|
| Chlorophyta | | | |
| *Caulerpa lentillifera* J. Agardh | 24.0 | Waikaloa Resort, Hawai'i | 11/x/02 |
| *Codium hawaiiense* Silva *et* Chacana | 35.4 | Corsair Wreck, Midway | 21/ix/02 |
| *Codium reediae* Silva | 23.5 | RHSF, Hawai'i | 12/iii/02 |
| *Enteromorpha flexuosa* (Wulfen) J. Agardh | 47.5 | North Shore, O'ahu | 31/i/02 |
| *Gayralia oxyspermum* (Kützing) Vinogradova | 55.8 | Leleiwi, Hawai'i | 25/x/01 |
| *Ulva fasciata* Delile | 50.1 | North Shore, O'ahu | 30/i/02 |
| Phaeophyta | | | |
| *Dictyopteris plagiogramma* (Montagne) Vickers | 40.8 | Kailua, O'ahu | 05/viii/03 |
| *Dictyota acutiloba* J. Agardh | 34.8 | Hale'iwa, O'ahu | 31/i/02 |
| *Dictyota sandvicensis* Kützing | 34.6 | Hale'iwa, O'ahu | 31/i/02 |
| *Sargassum echinocarpum* J. Agardh | 47.9 | Onekahakaha, Hawai'i | 01/iii/02 |
| *Sargassum obtusifolium* J. Agardh | 53.7 | Onekahakaha, Hawai'i | 01/iii/02 |
| Rhodophyta | | | |
| *Ahnfeltiopsis concinna* (J. Agardh) Silva *et* DeCew | 59.8 | Onekahakaha, Hawai'i | 16/x/01 |
| *Asparagopsis taxiformis* (Delile) Trevisan | 44.0 | Leleiwi, Hawai'i | 25/v/02 |
| *Chondrus ocellatus* Holmes | 52.9 | Leleiwi, Hawai'i | 03/i/02 |
| *Eucheuma denticulatum* (Burman) Collins *et* Harvey | 45.3 | Kāne'ohe Bay, O'ahu | 13/ii/02 |
| *Gracilaria coronopifolia* J. Agardh | 27.0 | RHSF, Hawai'i | 20/xi/01 |
| *Gracilaria parvispora* Abbott | 26.4 | RHSF, Hawai'i | 23/x/01 |
| *Gracilaria salicornia* (C. Agardh) Dawson | 35.8 | Kāne'ohe Bay, O'ahu | 13/ii/02 |
| *Gracilaria tikvahiae* McLachlan | 28.4 | RHSF, Hawai'i | 06/xi/01 |
| *Grateloupia filicina* (Lamouroux) C. Agardh | 51.2 | Kahului Harbor, Maui | 29/vii/03 |
| *Halymenia formosa* Harvey *ex* Kützing | 32.4 | Mahai'ula Bay, Hawai'i | 09/iii/02 |
| *Laurencia dotyi* Saito | 47.9 | Wai'anae, O'ahu | 05/vi/02 |
| *Laurencia mcdermidiae* Abbott | 41.6 | Wai'anae, O'ahu | 05/vi/02 |
| *Laurencia nidifica* J. Agardh | 37.4 | Wai'anae, O'ahu | 05/vi/02 |
| *Porphyra vietnamensis* Tanaka *et* Pham | 43.5 | Onekahakaha, Hawai'i | 28/ii/02 |
| *Pterocladiella capillacea* (Gmelin) Santelices *et* Hommersand | 43.5 | Punulu'u, Hawai'i | 02/i/02 |
| Wheat bran | 42.7 | | |

All TDF values reported as a percent of dry weight of plant material.
RHSF=Royal Hawaiian Sea Farms.

bran was processed and analyzed simultaneously with the samples to serve as an internal comparison to the seaweeds.

### Sample preparation

Within 6 h of collection, thalli were cleaned of any epiphytic algae or invertebrates, sand or debris, and rinsed three times in filtered seawater. Samples were spun in a salad spinner for 30 s to remove excess water, and were placed on aluminum foil trays, and dried to a constant weight at 60°C in an air oven. The dried samples were then ground into a fine powder (to pass through a 1-mm sieve) using a coffee grinder or analytical mill (IKA™ A11, Wilmington, USA). Dry, ground material was stored in airtight labeled glass jars in a refrigerator at 4°C until TDF analysis.

### Total dietary fiber analysis

An enzymatic-gravimetric procedure for TDF analysis was used (Prosky et al. 1988, Lahaye 1991, AOAC 1995) using a total dietary assay kit (catalog number TDF-100A, Sigma Chemical Co., St. Louis, USA). The TDF analyses were carried out on all species within a 2-month period from September to October 2003 to ensure full enzymatic activity. Dried ground samples to be tested for TDF were run in quadruplicate along with duplicate blanks, all weighed on a Mettler (Columbus, USA) balance with readability to 0.1 mg. Samples and blanks were incubated with heat stable $\alpha$-amylase at pH 6.0 for 15 min at 95°C, and then digested first with protease (at pH 7.5, 30 min, 60°C) and then with amyloglucosidase (at pH 4.5, 30 min, 60°C) to remove the protein and starch. Ethanol was added to precipitate the soluble dietary fiber, and the next day, the residue was filtered and washed with ethanol and acetone. The residue was dried overnight at 105°C. After drying, the residue was weighed. Half of the residues of the samples and blanks were analyzed for nitrogen, and the others ashed (5 h at 525°C). Nitrogen concentration in residues was assessed with a Leco-FP528 auto combustion analyzer (Waters Agricultural Laboratories, Camilla, USA). Protein content in the residues was determined by multiplying the nitrogen content by a factor of 6.25. The weight of TDF was calculated as the average residue weight less the average weight of the protein and average weight of the ash in the residue, less the TDF of the blank. All TDF values were reported as percent relative to the dry weight of the plant material.

## Results

Total dietary fiber content in 26 species of Hawaiian marine macroalgae was determined (Table 1). TDF values ranged from 23.5 to 59.8%, with 13 species containing more TDF than wheat bran (42.7% TDF). Nine of the 15 Rhodophyta species had TDF concentrations over 40%. TDF values in Hawaiian Chlorophyta species tested ranged from 23.5% in *Codium reediae* to 55.8% in *Gayralia oxysperma*. Of the Phaeophyta, only *Sargassum echinocarpum* and *S. obtusifolium* contained higher TDF than wheat bran. Within genus, variation in TDF content was less than 1% in *Dictyota acutiloba* and *D. sandvicensis*, whereas congeneric species of *Codium*, *Gracilaria*, *Laurencia* and *Sargassum* differed greatly in TDF.

## Discussion

In general, TDF values for Hawaiian seaweeds are similar to those previously reported for other macroalgal species, ranging from 32.7–74.6% (Lahaye 1991, Chan et al. 1997, Wong and Cheung 2000, Rupérez and Saura-Calixto 2001). Many edible Hawaiian seaweeds are comparable in TDF content to other well-known non-marine sources of dietary fiber, such as wheat bran (43.9%), high fiber cereal (32.2%) and oats (11.3%) (Prosky et al. 1988). Based on our results, *Ahnfeltiopsis concinna*, *Gayralia oxysperma* and *Sargassum obtusifollium* may be potential sources of fiber-rich products.

Crude fiber values reported in previous studies are substantially lower than TDF values due to the differences in extraction methods, and show no consistent pattern, which precludes simple conversion or direct comparison between the two fiber measurements. For instance, *Ulva lactuca* L. shows a 6-fold difference between its values of 6.3% crude fiber (Portugal et al. 1983) and 38.1% TDF (Lahaye 1991); whereas in *Sargassum hemiphyllum* (Turner) C. Ag. the crude fiber (18.6%, Portugal et al. 1983) is only 3 times lower than the TDF (56.8–62.9%, Chan et al. 1997). Crude fiber and TDF values reported for Hawaiian seaweeds display even more erratic variation. Reed (1907) determined the crude fiber values of three species of Hawaiian seaweeds: *Ahnfeltiopsis concinna* (2.66%), *Gracilaria coronopifolia* (2.98%) and *Ulva fasciata* (0.19%). The TDF values reported in our study for these same three species are 9 to 253 times higher than Reed's crude fiber values.

Suzuki et al. (1993) documented definite seasonal variation in fiber content in *Hizikia fusiformis* (Harvey) Okamura in Japan. The TDF content ranged from 36 to 54% during their nine-month observations. The insoluble fiber fraction was greater and more variable than the soluble fiber fraction. The extent to which environmental conditions or algal phenology affect TDF content in tropical seaweeds is not known.

Basic information on chemical composition of seaweeds traditionally used as food in the Hawaiian Islands is of special interest. The high TDF content of certain Hawaiian seaweeds may have been beneficial in human nutrition prior to European contact, as well as today. A person might eat as much as ½ cup fresh *Gracilaria*, *Grateloupia*, *Dictyopteris* or *Codium* (equivalent to about 20 g dry weight) with a meal of fish and poi (paste made from roasted, peeled roots of taro) or in a bowl of stew (Abbott, personal communication), and the seaweed could provide approximately 5–10 g of TDF depending on the species.

In addition, fiber content may influence the palatability, digestibility and nutritional quality of Hawaiian seaweeds in the diets of other organisms, such as green sea turtles, reef fish, shore crabs, and other herbivorous invertebrates. Cellulose is digested in the hindgut of green turtles through bacterial fermentation (Bjorndal 1979). Endosymbiotic microbes in the intestines of some herbivorous surgeonfish and labroids (Fishelson et al. 1985, Clements 1991, Pollak and Montgomery 1994) may act in the digestion of fiber-rich algae.

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