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UNUSUAL FOODS FOR HUMAN CONSUMPTION

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Seaweeds and their Value in Foodstuffs

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Seaweeds belong to a group of plants known as the algae which are the lowest and simplest of all the plants in the plant kingdom. In the primary classification they are divided into four groups, the brown algae or Phaeophyceae, the red algae or Rhodophyceae, the green algae or Chlorophyceae and the blue-green algae or Myxophyceae. From the industrial point of view the brown and red algae are the most important, partly because of the nature of the materials they contain and partly because they occur in sufficient quantity to possess an economic value.

From time immemorial man has utilized seaweeds for food. In the Chinese *Book of Poetry* written in the time of Confucius (between 800 and 600 B.C.) there is a poem that mentions a housewife who cooks seaweeds. At that time seaweed was considered a food of great delicacy and even a worthy sacrificial offering to the ancestors. Several kinds of alga were used by the ancient Chinese as food, and the brown alga *Laminaria saccharina* is frequently mentioned. Later, references to seaweed were not so favourable. Virgil and Horace, for example, both used the term *vilior algâ* meaning more vile or worthless than seaweed.

In the East, however, seaweeds still form an important constituent of food supplies and are not used merely as appetizers or stabilizers of confections as they are in the West. Seaweed is used in Japan to a far greater extent than in any other country and is still said to provide about 25% of the daily diet. The brown seaweeds, for example, are incorporated in the flour and are used in almost every household as noodles, toasted and served with rice or in soup. Two species, *L. japonica* and *L. angustata*, because of their high contents of mannitol and glutamic acid are used for sweetening and flavouring.

In the West, seaweeds have never really been accepted in our diet and have only been eaten in times of scarcity and where the standard of living has been low. In this country, Porphyra is still eaten ; grilled on toast it looks like spinach and tastes like oysters and is made into laverbread, the national dish of South Wales.

The extensive use of the phycocolloids in various food industries has raised the

question of their nutritive value. The question is an open one and has always afforded a good deal of speculation, *e.g.* it has been suggested that there may be present in the intestinal tract of the Japanese people a specialized bacterial flora, giving the seaweeds a greater nutritive value, and as seaweeds are given to the children there would be adequate time for a modified flora to be set up. In digestibility trials with ruminants it has been found that when seaweed is first introduced into the diet it is completely undigested, appearing unaltered in the faeces (Lapicque, 1919). After a few days, however, no seaweed as such is found in the faeces. This also suggests that the bacterial flora plays an important part in the digestion of seaweed. In view of this and the fact that seaweed contains vitamins and trace elements it is not advisable to assess the food value of seaweeds entirely in terms of digestibility coefficients.

Brown algae

As the bulk of the seaweed around our shores is of the brown variety, work at the Institute of Seaweed Research has been confined almost entirely to the brown algae. Surveys carried out by the Institute have shown the presence of about 180,000 tons in the littoral zone (between high and low water) which could be economically harvested, while in the sublittoral zone (the region below low water) about 10,000,000 tons of weed are available. An extensive study of the brown

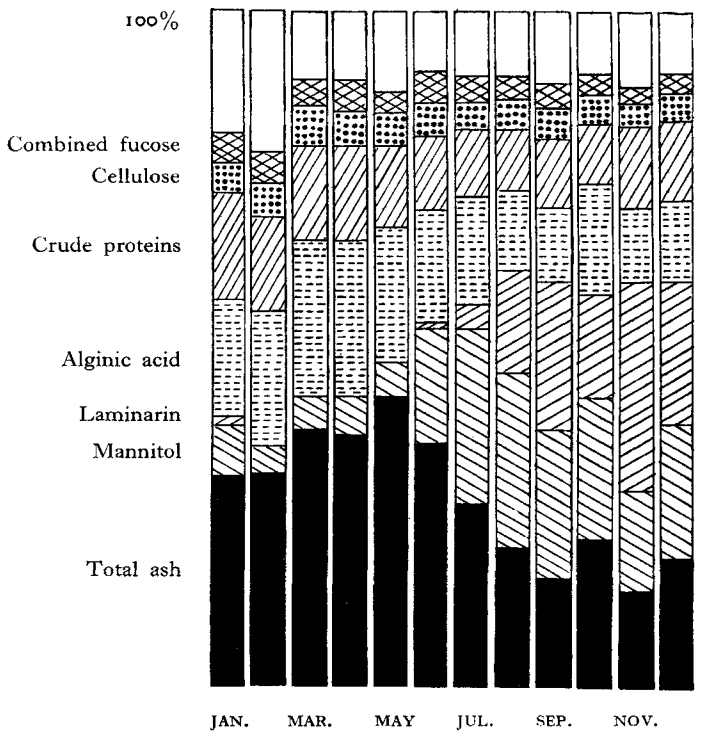

Fig. 1. Seasonal variation in chemical composition in *Laminaria cloustoni* fronds, 1946.

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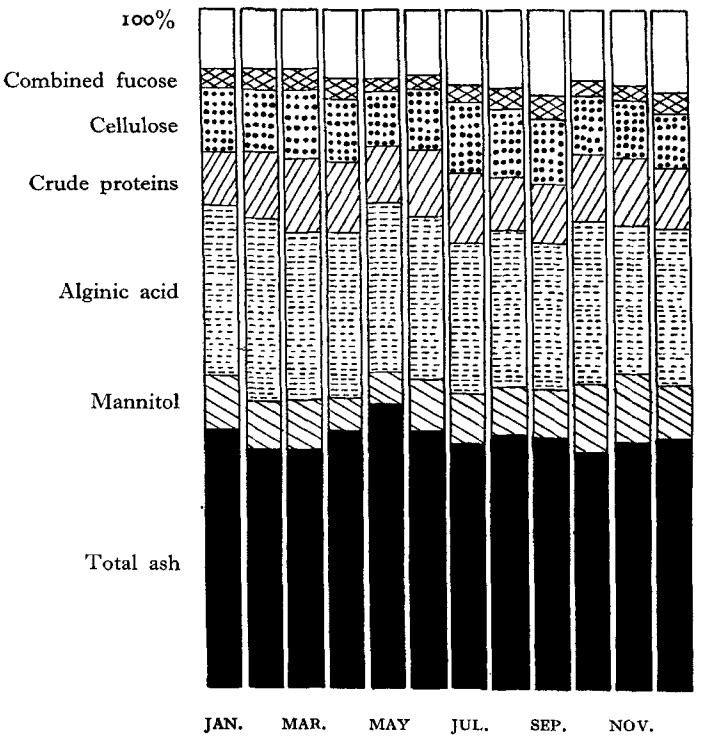

Fig. 2. Seasonal variation in chemical composition of *Laminaria cloustoni*, stipes, 1946.

algae over a period of 4 years (Black 1948 *a–d*, 1949, 1950) has shown that they undergo marked seasonal variations in chemical composition. Figs. 1 and 2 give the variation in chemical constituents over a period of 1 year for the common sublittoral weed, *Laminaria cloustoni*. The results show a marked seasonal variation in the frond (leaf) with very little variation in the stipe (stalk) and indicate that it would be inadvisable to harvest the weed from March to June when laminarin (see p.35) is absent.

In common with land plants, seaweeds contain carbohydrates, fats, proteins, vitamins and a high percentage of mineral matter. In view of the fact that seaweeds are unattractive and unpalatable to human beings in this country, the feeding of seaweed to livestock has been investigated, and trials have been carried out at the recognized colleges under the auspices of the Institute of Seaweed Research. No work of a similar nature has been carried out with human beings. It is therefore difficult to assess the nutritive value of seaweeds for man and only an attempt will be made to assess the value of their constituents.

Carbohydrates

Mannitol. In the absence of free sugars the hexahydric alcohol mannitol appears to be the primary product of photosynthesis of the brown algae and it varies from 5% to as much as 37% of the dry matter, depending on the species, habitat, season of the year and depth of immersion of the weed : mannitol, or manna sugar, is a colourless, odourless, crystalline powder with half the sweetness of sucrose,

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Small amounts of mannitol are readily utilized, though it is less readily converted to glycogen than sorbitol. In comparatively large doses (30–50 g) it has a mild laxative effect but its ingestion does not significantly increase the sugar content of the blood. The fate of mannitol in man and animals has been studied by a number of workers and their work has been reviewed by Todd, Myers & West (1939) and Blatherwick, Bradshaw, Ewing, Larson & Sawyer (1940). Later work by Ellis & Krantz (1941) showed that in man the daily ingestion of 10 g mannitol for 1 month produced no change in the blood and no kidney damage. It has been suggested, therefore, that it be used as a sweetening agent in diabetic foods. It is at present used as an edible dusting powder for chewing gum and anticaking agent in pharmaceutical preparations.

Laminarin. In place of the starch of the land plants, the brown algae contain laminarin which increases to as much as 36% of the dry matter (Black, 1948 *a–d*, 1949, 1950). Laminarin is a glucan composed of about 20 β-D-glucopyranose units linked through carbon atoms 1 and 3. It is completely hydrolysed by dilute acid (Black, Dewar & Woodward, 1953) and less readily by certain enzymes (Kylin, 1915; Gruzewska, 1921 ; Dillon & O'Colla, 1950, 1951 ; Peat, Thomas & Whelan, 1952) to D-glucose. No actual digestibility tests have been carried out with this polysaccharide but it has been shown in experiments at the Hannah Dairy Research Institute (unpublished work) to be readily utilized in the bovine rumen and completely assimilated by pigs (Sheehy, Brophy, Dillon & O'Muineachian, 1942) and sheep (unpublished work at the Rowett Research Institute). Work by Dr G. Blaine (unpublished) has shown that it behaves like glucose on intravenous injection. This constituent contributes, therefore, greatly to the nutritive value of seaweed.

Alginic acid. This cell-wall constituent of the brown algae is made up of a straight chain of β-D-mannopyruronic-acid residues linked through the 1 : 4 positions. Nilson & Lemon (1942) investigated the relative nutritive values of algin (sodium alginate) and gelatin for male albino rats and concluded that algin had considerable nutritive value.

Recent work by Feldman, Urbach, Naegele, Regan & Doerner (1952) has shown that alginic acid is well tolerated by human beings when ingested in amounts of 45 g daily, but that it is mildly laxative. It also increased faecal excretion of sodium and potassium about one-fifth as much as the commonly used clinical dosages of cation exchange resins. The alginates are very extensively used in the food industry chiefly as emulsifiers and stabilizers (Moncrieff, 1952).

Fucoidin. No metabolic studies have as yet been carried out with this cell-wall constituent which is considered to be a polyfucose monosulphate. From its chemical structure one might expect it to resemble agar or carragheenin. Saiki (1906) made a thorough investigation of the utilization by man of the latter two and found the digestibility to be very imperfect.

Cellulose. The cellulose has been shown to be fundamentally similar to the cellulose of the land plants (Percival & Ross, 1949). In the brown algae it is exceedingly low, varying from 1 to 9% (dry basis). In view of such low figures one might assume that seaweeds could not provide bulk, but the low digestibility

and unavailability of the alginates would compensate for this and influence beneficially the functioning of the intestinal tract.

Proteins

The protein of algae in common with that of most other plants is less assimilable than animal protein. Work by Channing & Young (1952) and Ericson & Sjöström (1952) has shown that the amino-acid composition is similar to that of the proteins of land plants. The brown seaweeds examined contained the same seventeen amino-acids, but nothing is known of the type of proteins present. Recent work in Russia by Kovalev, Osmolovskaya & Lovyagina (1948) on the use of the brown algae as a possible source of human food has shown the assimilation of proteins to be between 32 and 80%.

Fats

The brown algae contain a varying amount of fat, from less than 1% in the sublittoral weeds to 8–9% in the most exposed weed, *Pelvetia canaliculata*. Takahashi, Shirahama & Tase (1933, 1935) have studied the fats of the algae indigenous to Japan and have identified the following acids : capric, caproic, caprylic, linolenic, oleic, myristic, palmitic and stearic.

Major mineral and trace elements

A characteristic feature of seaweeds is their high mineral content, the ash of the dry matter varying from 10% to as high as 50%. It can be said that seaweeds contain all the elements (Black & Mitchell, 1952) that have so far been shown to play an important part in the physiological processes of man. In a balanced diet, therefore, they would appear to be an excellent mineral supplement.

The occurrence of iodine is a question of major importance. It has been observed that the iodine content of the air in Central Europe has fallen considerably since kelp burning ceased, depriving man and animals of a supply of iodine that must hitherto have had some biological effect. The brown algae contain on the dry basis 0·03–1·5% iodine depending on the species and the season of the year, in a form considered more valuable than that in iodine salts. Part of the iodine has been shown to be present as 3 : 5-diiodotyrosine, the precursor of thyroxine.

Vitamins

Seaweeds are a very important source of vitamins, and from the limited information available they appear to be similar to green vegetables in their vitamin content. The brown algae do not appear to contain vitamin A, but contain its precursor, β-carotene (40 p.p.m. dry basis). In addition they contain a high percentage of fucoxanthin, which may also be a precursor of vitamin A, thiamine and riboflavin, and recent work by Ericson (1952) has shown the presence of cobalamin, folic acid, folinic acid and other growth-promoting substances. By a microbiological-assay method he found 0·5–1·0 μg cobalamin/g dry weight in the samples examined. This is remarkably high when one considers that whole plants were analysed and

that the cobalamin may be concentrated in one part of the plant. The content of cobalamin of some algae appears to be comparable with that of liver, and this is the first evidence of cobalamin occurring in any quantity in a plant material.

The ascorbic-acid content of seaweeds is comparable with that of many vegetables and fruits, and with the Eskimos of west Greenland seaweed at one time assumed the role of an essential food supplying half their vitamin C requirements. Lunde & Lie (1938) examined various species and found 5–140 mg ascorbic acid /100 g wet weed, the amount depending on the season and the species.

It has also been claimed that the brown seaweeds contain vitamins D, F, K and tocopherol (Kirby, 1951). Fucosterol has been shown (Black & Cornhill, 1951) to be present in the brown seaweeds in amounts varying from 0·1–0·3% and this sterol may be a precursor of vitamin D.

Red algae

For centuries the red algae have been used in small quantities in the food industries. No detailed survey has as yet been carried out to assess our red weed resources. A survey was carried out during the Second World War by Marshall, Newton & Orr (1949) but it was concerned only with the littoral zone. Only a very brief review of their utilization in foodstuffs will be given here. *Porphyra laciniata*, *e.g.*, used to be eaten as a vegetable with vinegar and pepper under the name of 'laver' in Wales, 'sloke' in Ireland and 'slack' in Scotland.

The two most important red algal polysaccharides, both of which have been known for many years, are agar and carragheenin. Carragheenin was first extracted by Schmidt (1844) from *Chondrus crispus* and the term carragheenin now generally refers to the extract obtained from *Chondrus crispus* and *Gigartina stellata* and these two species either individually or together are known as carragheen or Irish moss.

Agar was originally the Malay name for certain East Indian red algae, but it is now almost exclusively used for the dried gelatinous extract (Tseng, 1946). None of the true agar-bearing species, *e.g.* Gelidium, or Gracilaria, are, however, present in sufficient quantity in this country for large scale collection.

Agar has been and still is used as a food article in a great variety of ways in China and Japan. Up to the early part of this century China annually imported over a million pounds of agar entirely for food, using it frequently as a substitute for the expensive 'bird's nests'. In Japan, agar is still served in numerous ways as an article of food, such as agar-rice and agar cakes. Agar was first introduced into this country in the middle of the last century and was used chiefly as a gelatin substitute. Because of its low digestibility it is often used in certain bakery products as a source of roughage.

Agar and carragheenin find important uses in confectionery, in making jellies and marshmallows, in meat canning and in medicinal and pharmaceutical preparations.

Chemically, there is little similarity between the brown and red algae, the metabolism of the former being founded on a mannose basis whereas that of the latter is on a galactose basis. Mannitol is absent from the red algae and its place

is taken by dulcitol or sorbitol, and a galactan ethereal sulphate is common to most red species.

Saiki (1906) made a thorough investigation of the utilization of agar and carragheenin by animals and man and found that, as with algin, utilization was very imperfect. Swartz (1946) found that carragheenin was entirely unaffected by common micro-organisms and only little affected by the digestive enzymes. The coefficient of digestibility by man was only 6%. The only recent work on the nutritive value of these phycocolloids is that of Nilson & Lemon (1942) who used albino rats as test animals.

Green algae

In conclusion, reference should perhaps be made to recent work in the U.S.A., Germany, Sweden and Israel on the possibility of culturing unicellular freshwater green algae as a possible source of food. This work, recently reviewed by Woodward (1952), has met with success and has reached the pilot scale. It is possible, *e.g.* by adjusting the culture conditions of chlorella, to obtain a material with a lipid content as high as 85% (dry basis). It is not yet known whether such a product would be acceptable as a human food, but the utilization of solar energy, in this way, to achieve photosynthesis under controlled conditions offers great possibilities.

Conclusion

Seaweeds, therefore, despite the many contradictions in the literature, do appear to have some nutritive value while at the same time providing vitamins and the elements essential for health, but as they are unpalatable and unacceptable to the people in the Western Hemisphere it appears more logical to feed them to animals destined for human consumption.

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Mushrooms and Toadstools

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I must confess that I have only a layman's knowledge of nutrition : I have probably been invited to join in this symposium because it is almost only in this country that fungi are regarded as an unusual food. For the most part we are content with the cultivated mushroom where purchase is felt to ensure security. Country people gather the field mushroom ; to a townsman the eating of it is a bold adventure. The easily recognized blewits (*Tricholoma personatum*) is eaten in the midlands and north and is sold in the markets ; the morel (*Morchella esculenta*) is used in the north for flavouring soups and gravies.

The modern British attitude towards fungi is difficult to understand. One factor is doubtless the comparative lack of forests, where most of the larger species have their habitats : another the fact that until recently there was an abundance of other food : a third appears to be tradition.

The evidence from former times is somewhat contradictory. Nothing is known about the views of early Britons. The Romans were fond of fungi and would certainly not have disregarded those they knew when they landed here. Though there is much praise of them in both Greek and Roman writings, great stress is laid on the accidents they caused, and it was known that they were convenient for administering poison. Dioscorides in *De materia medica* classified fungi into those edible and those poisonous. At the revival of learning the chief aim of the herbalists was to elucidate Dioscorides. They accepted his grouping but added accounts of the ' funest accidents ' which the ancients had reported presumably as news. Our two chief herbals give conflicting accounts about English usage.