WASTE TREATMENT BY ALGAL CULTIVATION

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ALGAL BIOMASS AND ITS COMMERCIAL UTILISATION

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ABSTRACT

Algal biomass is a source of high value products worth over A$100 x 10^6 per annum. Red and brown seaweeds yield the phycocolloids, which are used as gelling, viscosity and clarifying agents in the food, cosmetic and pharmaceutical industries. Microalgal products in the health food market include *Spirulina* and *Chlorella* powder and tablets. The blue phycocyanin pigment extracted from *Spirulina* is used as a food colouring, and β-carotene extracted from *Dunaliella salina*, is sold as a yellow food colouring, and for its provitamin A and anti-oxidant properties in nutritional supplements. Development of new intensive culture systems is expected to widen the range of commercial algal products in the future.

KEYWORDS

algal products, β-carotene, *Dunaliella*, *Spirulina*, *Chlorella*, commercial, phycocolloids, paddle-ponds.

INTRODUCTION

Algal biomass is used commercially as a source of products which have a market worth more than A$100 x 10^6 per annum worldwide. Algal products include high value specialised chemicals, fine chemicals, vitamins, health foods, human food products and aquaculture larval feed products. This paper addresses the algal products presently on the market; it is offered as a source of product ideas to those who produce algal biomass as a byproduct of wastewater treatment. The basic algal process and some of the products are illustrated diagrammatically in Table 1.

Table 1. Diagrammatic illustration of algal processes and the potential products.

RESOURCE	FEEDSTOCK	PROCESS	PRODUCT
SUNLIGHT CO_2 WATER NUTRIENTS	MICROALGAL BIOMASS	Extraction	β-Carotene Pigments Glycerol Fatty Acids Sterols Amino Acids Vitamins Pharmaceuticals Antibiotics Polysaccharides
		Aerobic fermentation	Ethanol
		Anaerobic fermentation	Methane Organic Acids Hydrogen
		Catalytic processing	Paraffins Olefins Aromatics
		Direct application	Waste Treatment Soil Conditioners Aquaculture Feeds

ALGAL PRODUCTS

Seaweed Products

A brief history of algal products has been recently published by Borowitzka and Borowitzka (1990). Seaweeds have been used as a human food and animal fodder since ancient times (Chapman and Chapman, 1980). The seaweed chemical industry commenced in the late 17th Century in France with the production of soda ash (sodium carbonate) and potash (mixed potassium salts, mainly potassium carbonate) from the brown seaweeds *Fucus*, *Ascophyllum* and *Laminaria*. These algae were harvested from natural populations. Production of these chemicals grew in the 18th century, spreading to the Channel Islands, Orkneys, Ireland, Sweden and Norway. Iodine was a commercial by-product of the ashing process from 1813.

Late in the 19th Century, an industry started in Japan using *Laminaria*, *Ecklonia* and *Sargassum*. Shortages of potash and iodine during the first world war led to establishment of the kelp industry in the United States, harvesting *Macrocystis pyrifera* and *M. integrifolia* and *Nereocystis luetkiana*. Ammonia, acetone and fertiliser products were also manufactured (Chapman and Chapman, 1980).

Cheaper alternative courses of the chemicals and products led to a decline in these industries, and today the main products of the seaweed industry are phycocolloid gelling and viscosity agents including agar and carrageenan.

Agar is used as a gelling agent in microbiological media and as a gelling agent and clarifier in foods; over 10,000 t per year is produced, mostly from the red seaweed *Gracilaria* in Chile and China. Agar is an algal galactan, containing the disaccharide agarobiose (agarose) as its repeating unit.

Carrageenans exhibit a range of different viscosity and gelling properties, depending on the sulphate esterification of their constituent D-galactopyranose units (Hosford and McCandless, 1975; McCandless, 1981). Over 10,000 t per year of carrageenans are extracted from the red seaweeds *Chondrus*, *Gigartina*, *Iridea*, *Eucheuma* and *Hypnea*, which are farmed and harvested mostly in the Philippines and Chile. Carrageenans are used as gelling and clarifying agents in food products, in cosmetics, and coatings including paints, inks and paper treatments.

Alginic acid, the salts of which are called alginates, is extracted from brown algae including *Macrocystis*, *Laminaria*, and *Ascophyllum*, which are grown and processed in China, the United States, Chile and Japan. Alginic acid is a polymer of D-mannuronic and L-glucuronic acids, and the alginates are used as gelling and viscosity agents in the food and biomedical industries.

All commercial algal phycocolloids are derived from marine seaweeds. The seaweeds are farmed and harvested often in very labour intensive processes, although some mechanisation of fertilisation and harvesting has been achieved.

Experimental production of polysaccharides from the red micro-alga *Porphyridium* has yielded extracellular polysaccharides which have properties similar to some carrageenans, and to the bacterial product, xanthan, for use in applications in foods and in oil recovery from oil wells (Savins, 1978; Ramus, 1980; Vonshak *et al.*, 1985). Potential commercial by-products of *Porphyridium* culture are the essential fatty acid arachidonic acid (20:4ω6) and the red phycobilin pigment, phycoerythrin which is used as a fluorescent marker in molecular biology and as a food colouring.

Microalgal Products

There is less history of human consumption of microalgae than the seaweeds, probably because of the practical difficulty of collection of useful quantities. The blue-green alga, *Spirulina platensis* grows naturally in alkaline lakes with greater than 70 $g.L^{-1}$ salts, and was eaten as a food by the Aztecs in Mexico (Ciferri, 1983) and the natives of Lake Chad in Africa (Léonard and Compère, 1967). There is now a world production of about 1,000 t per year, most of which is sold as a dried powder of tablets as a dietary supplement. Animal feed grade *Spirulina* powder is used as a pigment source in feeds for koi carp and other ornamental fish.

Spirulina production uses paddle-wheel stirred, annular shaped shallow ponds. The growth medium has a high pH and bicarbonate concentration and N, P and trace element nutrients. Harvesting is by filtration. Dainippon Ink and Chemicals Inc., which runs large *Spirulina* farms in California and Thailand, also extracts the blue phycobilin pigment, phycocyanin for use as a food colour in Japan (1-2 tonnes per year). *Spirulina* is also known as a source of gamma linolenic acid, an essential fatty acid with claimed health benefits (summarised by Richmond, 1988). Another filamentous blue-green alga, *Nostoc punctiforme*, is eaten in China and Mongolia (Johnson, 1970).

Chlorella, a unicellular green alga, has been grown, and sold as powder or tablets into the health food/dietary supplement markets of Asia, especially Japan, and elsewhere, since the 1950's. Approximately 5,000 t per year is sold; it is produced in algal farms in Taiwan, Thailand and Japan.

Our only algal industry in Australia is β-carotene production using the green unicellular alga, *Dunaliella salina*. Two Australian companies, Western Biotechnology Ltd. and Betatene Ltd. produce more than half of the world's algal β-carotene. β-Carotene has been manufactured by chemical synthesis since the 1950's, but a niche market exists for several tonnes per year of "natural" algal β-carotene. β-Carotene is provitamin A, a natural antioxidant recently implicated in fighting some cancers, cardiovascular diseases, and aging-related diseases (Borowitzka and Borowitzka, 1988).

A wide range of growth systems are used in commercial *Dunaliella salina* production. Betatene, situated in Whyalla, South Africa, uses a large area of shallow fertilised ponds, totalling 300 ha in a very extensive culture system. Western Biotechnology's culture system is more intensive, using ten shallow 5 ha ponds, fertilised and harvested every 2-4 weeks (Borowitzka, 1990). Microbio (Calipatria, California, U.S.) and N.B.T. (Israel, near Eilat) both use concrete annular paddle-wheel stirred ponds with plastic liners. Carbon dioxide and nutrients are added to achieve fast growth rates in both paddle-pond culture systems.

A plant based on a closed tubular reactor culture system (Photobioreactor Ltd., U.K. and Spain) has not reached commercial production.

The harvesting and processing systems also vary between the companies. Centrifugation to separate the *D. salina* biomass is an option with an intensively grown, dense culture as raw material; the more extensive culture systems use flocculation/flotation and adhesion binding harvest systems, both derived from processes used in wastewater treatment. The β-carotene is extracted from the harvested biomass using hot vegetable oil, rather than volatile solvents, to preserve the 'natural' aspect of the product.

Most of the algae growing in high rate oxidation ponds or similar systems used for wastewater treatment at present, do not produce high value products such as β-carotene, however the algal biomass still has a range of uses. The main use to date has been as feed for fish (Sandbank and Hepher, 1978, 1980) and poultry (Lipstein and Hurwitz, 1980; Yannai *et al.*, 1980) and several types of integrated wastewater treatment systems together with fish or shellfish farming have been examined (Ryther *et al.*, 1975; Mann and Ryther, 1977; De Pauw and Persoone, 1988). The use of waste-grown microalgae as animal feed or in aquaculture is probably the most likely application in the short term, and requires the least process development.

Other potential applications are for the production of relatively low value products such as lipids and fatty acids (Borowitzka, 1988a, c) and possibly also polysaccharides (Borowitzka, 1988b; Arad, 1990). The wastewater treatment system could possibly also be integrated with a plant to produce liquid fuels (pseudo-vegetable oils) or the biomass could be fermented to methane (Neenan *et al.*, 1986; Oswald, 1988). If the algae are grown in a 'clean' culture system, and are used for tertiary treatment of wastewaters, then the range of potential products is much greater.

CONCLUSIONS

Because the technology of culture, harvesting and downstream processing of microalgal products is relatively new and experimental, only high value products have been commercialised. For example, algal β-carotene sells for over A$1,000 per kg and phycocyanin over A$600 per kg. Dried *Spirulina* and *Chlorella* powder sell for between US$15-25 per kg.

Production costs will fall as the industry develops, and this should make additional algal products worthy of commercial consideration.

An increasing application is in the growing aquaculture industry, for which specific microalgae are cultured to provide larval feeds. At present this algal production is usually integrated into the aquaculture farm. The range of fine chemicals may be extended as algae are rich sources of a wide range of pigments, essential fatty acids and unusual lipids. Antibiotic, antineoplastic and other pharmaceutical activities have also been reported (Reichelt and Borowitzka, 1984) and screening continues intensively in Japan and the U.S. (Bloor and England, 1991; Patterson _et al_., 1991)

The range of potential algal products will be extended in the future as intensive and closed reactor culture systems are further developed. Closed systems have higher capital costs than ponds, but allow control of contaminants, and of environmental parameters such as temperature, CO_2 and O_2 concentration and light intensity. Variations in all of these factors can reduce the productivity of open pond cultures. Chiefly because of the problems of contaminating competitive or predator organisms, successful open pond algal monocultures are limited to algae which tolerate environmental extremes, such as *Dunaliella salina* (high salinity) and *Spirulina* (high pH); growth medium suited to these algae excludes most potential competitors. On the other hand, *Chlorella* is a very fast growing alga which is simply able to out-compete most contaminants.

Some genetic manipulations of algae are commencing, including mutation and cell fusion studies. Vectors are available and have permitted considerable work with blue-green algal genomes (Craig *et al.* 1988).

Although lagging behind bacterial and yeast genetics, algal genetics can be expected to boost yields and reduce costs of algal products in the future.

The future of algal biotechnology, therefore, probably lies with an increasing range of high value products, grown using improved strains in increasingly highly controlled reactors. Pond systems will be improved and costs reduced for the several species amenable to pond culture.

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