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Potential Products from Tropical Algae and Seaweeds, especially with Reference to Malaysia

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ABSTRACT Global production and utilization of algae is a multi-billion dollar industry. There is a diversity of tropical algae and seaweeds which have yet to be fully explored for commercial products. Potential products include nutraceuticals, cosmeceuticals, feed, biopharmaceuticals, phycocolloids, horticultural aids and biofuels. Native, indigenious species should be used for industrial applications as introduced species may become invasives and cause environmental and biodiversity problems. Issues to be addressed in the development of an algae/seaweed industry include: species selection, mass-production system (photobioreactor versus open systems), productivity & product yields, harvesting, and downstream processing. To make the commercialization cost-effective, the approach of 'multi-strategies coupled with multi-products' is essential.

ABSTRAK Penghasilan dan penggunaan alga merupakan industri yang bernilai berjutaan ringgit/dolar. Pelbagai sumber alga dan rumpair laut tropika masih belum digunakan dengan sepenuhnya sebagai produk komersial. Produk berpotensi termasuklah nutraseutikal, kosmeseutikal, makanan haiwan, biofarmaseutikal, fikokoloid, bahan hortikultur dan *biofuel*. Spesies-spesies tempatan dan asli harus digunakan untuk aplikasi industri, kerana ada kemungkinan spesies asing akan menjadi *invasive* dan mengakibatkan masalah-masalah sekitaran dan biodiversiti. Isu-isu yang mesti ditimbangkan dalam perkembangan industri alga/rumpair laut termasuk: pemilihan spesies, sistem pengkulturan secara besar-besaran (foto-bioreaktor lawan system terbuka), produktiviti & hasil, penuaian, serta pemprosesan *downstream*. Pendekatan 'multi-strategi bersama multi-hasil' pasti diikuti supaya proses pengkomersilan menjadi kos-efektif.

(**Keywords**: Algae, seaweeds, products, issues, commercialization)

INTRODUCTION

Algae are photosynthetic organisms, often referred to as the 'lower plants' due to their simple structures and reproductive methods. Algae range from microscopic (microalgae, phytoplankton) to macroscopic (seaweeds) species, inhabiting terrestrial, freshwater, brackishwater and marine habitats. Algae are generally classified according to various criteria, the most important being type of pigment. There is an estimated 160,000 to 1,200,000 species of algae with about 43,000 species described (Kasai et al., 2005). Global production and utilization of algae is a multi-billion dollar industry.

However more than 99% of commercial algae biomass produced worldwide are seaweeds; only about 10,000 tonnes per year is of microalgae (Benneman, Algae World Conference, Singapore, 2008). Only few microalgae species (*Chlorella, Spirulina, Dunaliella, Haematococcus, Nannochloropsis*) are commercially produced, mainly for health food supplements, pigments and aquaculture feed. However in recent years, interest in using microalgae as sources of biofuel has been tremendous, with inventors of mass-culture systems (photobioreactors) benefiting from this. Seaweeds are marine macroalgae classified into the Chlorophyta (green seaweeds), Rhodophyta (red seaweeds) and Phaeophyta (brown seaweeds).

The seaweed industry has an annual global value of US$5.5-6 billion and is used mainly for:
i) Food : US$ 5 billion; ii) phycocolloids (hydrocolloids); iii) fertilizer iv) animal feed additives; v) cosmetics , medicines. The industries use 7.5 – 8 million tonnes wet seaweed annually, harvested from wild populations or from cultivation. About 35 countries carry out cultivation; eg. China, Japan, Korea, Philippines, Indonesia, Chile, Norway. The main consumers are Japan, China, Korea (food); Denmark, France, Japan, Norway, Spain, UK, USA (industry). 94% seaweeds produced are used as food, *Laminaria japonica (kombu, Undaria pinnatifida (wakame, Porphyra (nori), Hizikia fusiformis (hiziki), Caulerpa (*sea grapes), *Monostroma (hirohana-hitoegusa)*. This brings in the highest revenue per tonne basis: *Porphyra* : US$ 16,000 per dry

tonne; *Laminaria* : US$ 2,800 per dry tonne; *Undaria* : US$ 6,900 per dry tonne

About one million tonnes wet seaweeds are used per year for production of the phycocolloids:
i) agar (US$ 132 million); 180,000 tonnes DW seaweeds yielding 30,000 tonnes agar
ii) alginate (US$ 13 million) 500,000 tonnes DW seaweeds yielding 18,000 tonnes alginic acid
iii) carrageenan (US$ 240 million); 200,000 tonnes DW seaweeds yielding 15,000 tonnes carrageenan.
Other seaweed products include seaweed meal, animal feed additives, fertilizers, liquid seaweed extracts, cosmetics and traditional medicine.

Commercialisation of the algae and seaweed resources in the Tropics has not been lucrative for the local populations as they are mainly involved in the upstream activities like cultivation, harvesting and minimal processing. The raw or semi-refined materials are exported to the developed countries for final processing with many-fold increase in profits.

In Southeast Asia, only Thailand (*Spirulina* production in Bangkok (which ceased operation lately) and Chiengmai; Myanmar (*Spirulina)*; and perhaps Vietnam and the Philippines, have large-scale algae farms and small factories. The *Spirulina* is used for health food, animal feed and exported for other uses such as colourants, cosmetic supplements.

Seaweed cultivation started in the Philippines, then spread to Malaysia, Indonesia, Thailand,Vietnam, Cambodia and to India. The tropical seaweeds in commercial production include the *Eucheuma*, *Kappaphycus* , *Caulerpa* and *Gracilaria* (Phang, 2006) (See Figure 1) . These seaweeds are produced for carrageenan, agar and as food. In Malaysia, seaweed (*Eucheuma* and *Kappaphycus*) production in Sabah increased from an average or 4,000 tonnes per year to almost 9,000 tonnes in 2007 (Sabah Dept. Fisheries, 2008).

At the current selling price of about RM4 per kg (pers comm. Dr. Gan, Omnigel), this could generate an income of RM 36 million (US10 million). There are plans to increase the seaweed production in Sabah to 125,000 tonnes per year (Sabah Dept. Fisheries, 2008). There are three factories in Sabah; two producing semi-refined carrageenan and one producing refined carrageenan. In Indonesia, *Eucheuma* and *Kappaphycus* farming is gaining popularity while some *Gracilaria* is also farmed.

Recently *Gelidium* was introduced and cultivated in Lombok for the production of pulp (for paper) and agar (You, APAC'09, Kuala Lumpur 2009). Algae and seaweeds are photosynthetic and require mainly sunlight, carbon dioxide, water and nutrients for mass production.

Sunshine and carbon dioxide are freely available in the tropics, water especially seawater is not lacking and nutrients especially that found in the abundant agroindustrial wastewaters is practically free for the taking. Therefore there is great potential for exploiting the tropical areas for production of algae and seaweeds.

ALGAE AND SEAWEED RESOURCES IN MALAYSIA

The microalgae resources are little known. Of about 43,000 species of microalgae described, 14% are maintained in the world's 20 major culture collections (Kasai et al., 2005). In Southeast Asia, collections are rare and restricted to specialty collections. In Malaysia, the University of Malaya Algae Culture Collection (UMACC) comprises more than 150 strains of both freshwater and marine species and polar species as well (Phang & Chu, 1999, 2004).

The National Institute of Environmental Studies (NIES), Japan has about 1600 strains, the Provasoli-Guillard National Centre for Culture of Marine Phytoplankton (CCMP), USA has 1837 strains and CSIRO, Tasmania has about 800 strains. These Culture Collections service the researchers as well as industries by supplying strains for research; identification; and the CCMP can also generate large volume cultures if requested.

More than 386 taxa of marine algae (seaweeds) are found in Malaysian waters; Chlorophyta: 13 families, 102 taxa; Rhodophyta: 27 families, 182 taxa; Phaeophyta: 8 families, 85 taxa; and Cyanophyta: 8 families, 17 taxa (Phang 2006, Phang et al., 2007). They are found in various habitats ranging from rocky shores, coral reefs, sandy shores, mudflats, mangroves, to estuaries.

A Seaweed and Seagrasses Herbarium has been established at the University of Malaya. It houses more than 9,000 specimens and supports the biodiversity, systematics, phylogenetics, ecology and biotechnology research in the university. It is also the main reference centre for the identification and systematics studies of Malaysian and tropical seaweeds in the country.

This herbarium supports the activities of the Consortium of Southeast Asian Seaweed Taxonomy (SEASTAX) under the auspices of the Asian-Pacific Phycological Association (APPA). Research on the taxonomy, systematics and phylogenetics of the Malaysian seaweeds have

been published by the University of Malaya Algae Research Group (see References below). The Malaysian seaweed resources have also been organized into a database as well as mapped using GIS (Du et al., 2008).

Figure 1: (a) A lipid-producing green microalgae. (b) Flat-plate photobioreactor mass-culturing *Porphyridium* for the pigment phycoerythrin in Professor Otto Pulz's laboratory in Germany. (c) *Ulva* used as a salad and has potential for producing bioethanol (d) *Kappaphycus,* a source of carrageenan. (e) *Gracilaria* an agar-producing red seaweed. (f) *Solieria*, an agar-producing red seaweed which also makes a tasty salad.

POTENTIAL UTILISATION OF TROPICAL ALGAE AND SEAWEED RESOURCES, WITH REFERENCE TO MALAYSIA

Latitudinal differences result in the evolution of variation in genera, species, or strains amongst the algae and seaweed resources. Some taxa are pantropical; viz. the ubiquitous *Chlorella*; *Caulerpa; Codium; Cladophora; Acetabularia*. In the industrial application of algae and seaweeds, it is advisable to use local, native species rather than introduce alien strains even though the latter provides a much shorter but not necessarily more efficient route.

Alien or introduced strains may not adapt to the local environment and may be more susceptible to disease and parasitism; some may even end up as threats to the local endemic flora by invading and dominating local habitats, as shown by the invasive *Caulerpa taxifolia* which was accidentally transported from the east to Europe. Native species are already adapted to ambient conditions and it only takes the identification of suitable strains for the targeted product.

While a wide range of products have already been identified and are in current commercial application, this paper will only focus on the products and processes/services that may be of potential to the tropical region especially Malaysia (Table 1). The following products are not in order of priority.

Table 1: Products from microalgae and seaweeds.

	Product/Process/Service	Microalgae	Seaweeds
1	Food/Nutraceuticals	Nutraceuticals (PUFA, carotenoids, anti-oxidants), detoxicants, colourants	Alga-oligosaccharides (soluble agar, alginate, fucoidans)
2	Feed	Feed enhancers, colourants	Seaweed meal
3	Cosmeceuticals	Anti-oxidant, suncare products, etc.	Excipients, emulsifiers, anti-cellulite, anti-aging, etc.
4	Biopharmaceuticals	Anti-viral, Anti-cancer, Algal vaccines, etc.	Photosensitisers in Photo-dynamic therapy, microbiocide (Carraguard)
5	Industrial colloids	Algal polysaccharides	Agar, agarose, carrageenan
6	Horticultural aids	Fertiliser	Fertiliser, soil conditioners, foliar sprays (growth hormones)
7	Renewable Energy (Biofuel)	Methane, Biodiesel, Hydrogen	Methane, Methanol, Ethanol
8	Climate Change Management	CO_2 Reduction/Global warming management	CO_2 Reduction/Global warming management
9	Bioremediation/Nutrient Removal	Waste bioremediation, nutrient recovery	Waste bioremediation, nutrient recovery
10	Novel useful genes	Improved strains; new products from genetic manipulation	Improved strains; new products from genetic manipulation
11	As living bioreactors for novel products and services	Algal vaccines	Vaccines

The nutraceutical and cosmeceutical, market is big and there is great potential for algae and seaweeds to capture a good share of this market. The nutraceutical industry is worth US$11.7billion. "Global demand for nutraceutical ingredients will grow 5.8 percent annually through 2010. Best prospects include probiotics, soy additives, lycopene, lutein, sterol-based additives, green tea, glucosamine and chondroitin, and coenzyme Q10. China and India will be the fastest growing markets, while the US will remain the largest" (www.freedoniagroupcom, 2008). Algae can supply lycopene, lutein, sterols. The cosmeceutical market is worth US$5.8 billion. "Demand for cosmeceuticals in the US will increase 7.4 percent annually through 2012, driven by an aging population seeking to maintain youthful appearance. Antioxidants, botanicals and enzymes are best opportunities, with injectables and skin care products having fastest growth" (www.freedoniagroupcom, 2008).

The Renewable Energy Market Opportunity (2005-2015) is as follows: Biofuels – US$ 15.7B to 52.5B; Solar power – US$11.2B to 51.1B; Wind power – US$11.8B to 48.5B. In Malaysia the transport sector takes up 38% of total energy consumption; biofuels can lighten this demand from fossil fuel. Using genetically-modified algae, a US company claimed to be able to produce 4000 gall/ac/yr of crude diesel from 40 tonnes/ac/yr biomass (presented at ISAP, Galway, 2008).

STRATEGY

Of the many potential products listed above, some may be near commercialization, while others still require sound, honest scientific work. Projections on productivity are extrapolated on small-scale studies, therefore, as an example, while it is possible to produce biodiesel from microalgae, it is as yet not economical. Issues to be addressed include: species selection, mass-production system (photobioreactor versus open systems), productivity & oil yields, harvesting, oil extraction.

These same issues apply to most other products. To make the commercialization cost-effective, the approach of 'multi-strategies coupled with multi-products' is essential. The search for useful genes through genomics research (Ho et al., 2009; Teo et al., 2009) and production of transformed seaweeds (Gan et al., 2003; Gan & Phang, 2006) with higher productivities and novel products is another important area for research. Production costs can be reduced by integrating algae/seaweed biomass production with wastewater bioremediation or even carbon sequestration, eg. aquaculture effluents (Habib et al. 2003; Phang et al. 2000; Phang et al., 1996). Combined with environmental considerations where Life-Cycle Assesments be made a necessary component of product development, we may well be on the road to having a sustainable, profitable, green Algae-Seaweed Industry in Malaysia.

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