Omega-3 oils down under—An update

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The health benefits of omega-3 (n-3) fatty acids are diverse, and nutritional studies continue to demonstrate important benefits from consumption of omega-3 oils. The two main omega-3 long-chain ($\geq C_{20}$) polyunsaturated fatty acids (LC-PUFA) present in fish oil—20:5ω-3, eicosapentaenoic acid (EPA), and 22:6ω-3, docosahexaenoic acid (DHA)—are beneficial against many human disorders; these oils are often termed the "good oils." It is well accepted that these fish-derived LC-PUFA decrease the incidence of coronary heart disease (CHD). From this evidence, it is generally recognized that eating fish two or three times per week results in measurable benefits with respect to parameters examined in CHD studies.

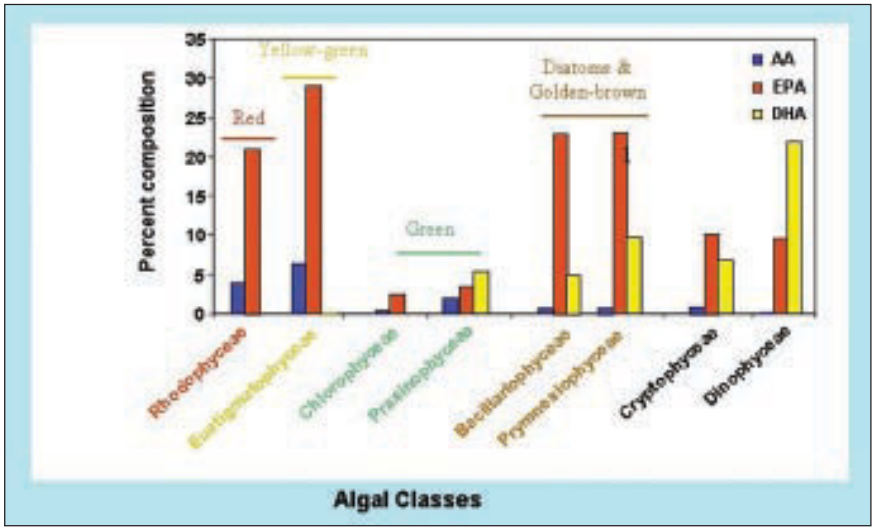

Figure 1. Distribution of long-chain polyunsaturated fatty acids (LC-PUFA) in microalgae. AA, arachidonic acid (20:6ω-3); EPA, eicosapentaenoic acid (20:5ω-3); and DHA, docosahexaenoic acid (22:6ω-3).

Table 1
Distribution of selected PUFA and LC-PUFA in microalgae and other groups, and areas of application

Group	Genus/Species	PUFA	Application
Eustigmatophytes Diatoms	*Nannochloropsis* *Chaetoceros*	EPA	Aquaculture
Dinoflagellates Thraustochytrids	*Crypthecodinium cohnii* *Schizochytrium*	DHA	Aquaculture, health supplements, infant formula
Red algae Thraustochytrids Fungi	*Porphyridium* Undescribed species *Mortierella*	AA	Aquaculture, infant formula Pharmaceutical industry (precursor to prostaglandins)
Blue-green algae	*Spirulina*	GLA	Health supplements

Abbreviations: GLA, γ-linolenic acid (18:3ω-6); EPA, eicosapentaenoic acid (20:5ω-3); DHA, docosahexaenoic acid (22:6ω-3); AA, arachidonic acid (20:4ω-6).

Omega-3 LC-PUFA also are effective in the treatment of other disorders such as rheumatoid arthritis and hypertension. The biochemical effects of plant- and fish-derived oils in some forms of cancer therapy have been examined, and the results have been promising, although further research and trials are required. Other studies indicate that omega-3 LC-PUFA are beneficial in infant nutrition and development and against mental disorders, e.g., schizophrenia, attention deficit hyperactivity disorder, and Alzheimer's disease.

Research at Australia's CSIRO (Commonweath Scientific & Research Organisation) over the past decade has examined the content and composition of omega-3 LC-PUFA oils from a range of edible seafoods. This includes assessment of farmed Australian seafoods. Two guides—"Seafood, the Good Food I" and "Seafood, the Good Food II"—have been published, with findings incorporated into the "Australian Seafood Handbook" and other publications (netlink:www.marine.csiro.au/cmr_pubs). These books provide the public, nutritionists, and other groups with information on levels of the "good oils" in Australian seafoods. We have also examined by-product oils. High-quality tuna oil products rich in DHA are now manufactured in Australia by NuMega Ingredients Pty. Ltd. of Brisbane, Queensland (netlink: www.nu-mega.com), with salmon and blue grenadier (termed hoki in New Zealand) oils presently under development.

Against a background of an increasing understanding of the many health benefits of the omega-3 oils, there is a need for new sources of these oils. Ransom Myers and Boris Worm at Canada's Dalhousie University at Halifax in Nova Scotia reported in 2003 (in the journal *Nature*) that large predatory fish biomass today is estimated to be only 10% of preindustrial levels. Global fish stocks will not meet future human nutritional needs. Australian research by Bob Kearney and colleagues at the Fisheries Research and Development Corporation at Deakin, Australian Capital Territory, has shown that stocks of up to 60 species (e.g., eastern gemfish, snapper in the states of New South Wales and Western Australia, southern bluefin tuna, and trevally) are under pressure from environmental degradation and

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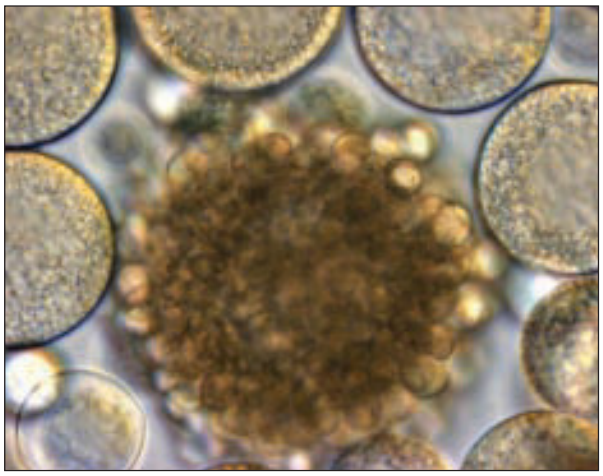

Figure 2. Thraustochytrids, a source of single-cell oils, show great morphological diversity, from single cells to clusters of cells, complex reticulate forms, and motile stages.

overfishing. Since mercury accumulation may be a problem for pregnant women consuming some species of larger, long-lived fish from certain regions (netlink: www.foodstandards.gov.au), additional nonseafood sources of omega-3 LC-PUFA may be nutritionally advantageous.

Proposed land-plant oils with LC-PUFA

Some land plants produce 18:3ω-3, α-linolenic acid (ALA), the simplest member of the omega-3 fatty acid family. But land plants do not have the extra enzymes to synthesize the omega-3 LC-PUFA, i.e., EPA and DHA, that are derived from ALA. It is not widely known that marine fish do not actually produce the essential omega-3 LC-PUFA. Rather, the LC-PUFA are biosynthesized by single-cell microbes (microalgae, select bacteria, and other microheterotrophs) and passed up the food chain. These groups of microbes contain the enzymes needed to make large amounts of the omega-3 LC-PUFA oils, particularly EPA and DHA.

Using gene technology, a multidisciplinary research team under the leadership of AOCS member Allan Green within the CSIRO Food Futures Flagship Program (netlink: www.csiro.au) launched in March 2004 aims to transfer the genes from marine microorganisms into oilseed and crop plants to enable them to produce omega-3 LC-PUFA oils containing EPA and DHA. Initially, transfer of the appropriate genes to model plants will be performed to characterize gene activities. Candidate crop plants for commercial applications could include canola and linseed.

If the project is successful, farmers in the future could be growing oilseed and crop plants that contain omega-3 LC-PUFA. The technology to develop plant-based omega-3 crops has great potential to provide farmers with a new premium market for their produce. The novel omega-3 technology also could improve the economic and environmental sustainability of the rapidly growing aquaculture industry by providing plant-derived aquaculture feeds to replace the current unsustainable use of fishmeal and fish oil-based feeds.

Table 2
Fatty acid composition (% of total) of new Australian thraustochytrid strains[a]

	Strain				Australian oils	
Fatty acid	A	C	H	O	Tuna oil	Salmon oil
16:0	18.0	16.4	13.5	22.1	19.4	16.2
20:4ω-6 (AA)	4.0	10.5	13.4	0.7	2.4	1.1
20:5ω-3 (EPA)	15.8	7.7	5.2	4.1	6.5	10.0
22:5ω-6 [DPA(6)]	16.6	9.3	12.7	3.4	<1	<0.5
22:6ω-3 DHA	28.2	21.6	19.2	61.0	26.8	14.7

[a]Results for representative samples of Australian-produced tuna and salmon oils are shown for comparison. DPA(6), docosapentaenoic acid (22:5ω-6); for other abbreviations see Table 1.

Differences that may exist in the nutritional properties of oils may be due to the position of the LC-PUFA within the triglyceride molecule (termed regiospecificity); therefore, we aim to assess these properties during the project to maximize potential health benefits. The project team will seek novel lipases from insect and other sources, determine and optimize regiospecificity of LC-PUFA-containing oils presently produced and those being designed, and perform laboratory and farm-based feeding trials with a range of animals.

Single-cell oils (SCO)

Over the past decade, our group has profiled the oil composition of a range of Australian microalgae and other microorganisms housed in the CSIRO Collection of Living Microalgae based in Hobart, Tasmania (netlink: www.marine.csiro.au/microalgae). The current main research focus is application of these microalgae in aquaculture.

Considerable diversity in LC-PUFA profiles occurs across the classes of phototrophic algae (Table 1, Figure 1). Green algae either do not contain or have only very low levels of EPA and DHA; diatoms contain elevated EPA, as do eustigmatophytes; dinoflagellates contain DHA and other C_{18} PUFA; red algae can contain elevated proportions of 20:4ω-6, arachidonic acid (AA). This diversity in LC-PUFA is potentially valuable, and there is interest in the production of these light-requiring algae in photobioreactors for high-purity LC-PUFA. The use of photobioreactors to produce SCO sources of LC-PUFA is still considered to be expensive, although further research and development can bring production costs down. Research into optimizing microalgal production in photobioreactors is occurring in CSIRO and includes collaboration with the University of Florence in Italy.

New strains of Australian thraustochytrids have been isolated recently (Figure 2). Thraustochytrids are single-cell organisms that produce a high oil and LC-PUFA content. Although they were initially thought to be primitive fungi, they have been reassigned to the subclass Thraustochytridae (Chromista, Heterokonta), which aligns them more closely with diatoms and brown algae. Under culture, thraustochytrids can achieve considerably higher biomass yield (>20 g/L) than other microalgae. In addition, thraustochytrids can be grown in fermenters on an organic carbon source and therefore are a highly attractive, renewable, and contaminant-free source of omega-3 oils.

Fatty acid profiles for selected Australian thraustochytrids are shown in Table 2, together with profiles of selected fish oils. Strain O contains very high levels of DHA (61%). High DHA-containing thraustochytrids often contain high proportions of 22:5ω-6, docosapentaenoic acid [DPA(6)], as is observed for strains A, C, and H. DPA(6) is a minor component in strain O under the culture conditions employed. Further work is required to assess how the proportion of these two LC-PUFA varies with culture conditions.

Strain A contains both DHA (28%) and EPA (16%) as the main LC-PUFA. The relative levels of these two PUFA are similar to those occurring in salmon and tuna oils, which are increasingly sought for nutritional applications due to their DHA/EPA ratio being >1 (Table 2), a preferred ratio resulting from the fact that DHA and EPA perform different roles in human health. Strains C and H differed from the other strains, with AA (10–13%) being present as a major LC-PUFA. As both DHA and AA are added separately to infant formula, oil from these strains may be attractive in that they may be able to provide both PUFA simultaneously. A number of other LC-PUFA were found to be present in the thraustochytrids including DPA(3) (docosapentaenoic acid, 22:5ω-3) and 22:4ω-6 and other components.

Potential applications of the LC-PUFA-producing thraustochytrids include incorporation in live feed as a source of essential LC-PUFA for rearing larvae in aquaculture, and as components in aquaculture feeds used for raising juvenile and adult finfish and crustaceans (prawns and lobsters). Just as the LC-PUFA are beneficial for human nutrition and well-being, they are key ingredients for cultured marine and freshwater species.

Increasingly, fish-derived LC-PUFA oils are being incorporated into food products and in infant formula. It will be possible to incorporate SCO oils, and in some instances the microorganisms themselves, without first separating the oil. Indeed, other components of microorganisms, such as antioxidants, vitamins, and protein, can offer a highly nutritious, whole-cell package. This is already fundamental to the use of microalgae as feeds in aquaculture. It is the basis of most of the handful of microalgae for which a niche has been established in the health supplement market, e.g., *Dunaliella* for β-carotene (produced by Cognis Australia Pty. Ltd. of Broadmeadows, Victoria, Australia), *Haematococcus* for astaxanthin, and *Chlorella* for immune system function and for general health and well-being (all these are green algae), as is the "super food" *Spirulina* (a blue-green alga, also known as a cyanobacterium). Other than the thraustochytrids, the only microalga marketed for LC-PUFA is the dinoflagellate *Crypthecodinium cohnii* used for infant nutrition and health supplements (Martek Biosciences Corporation, Columbia, Maryland), suggesting the opportunity for new microorganism-based "super foods" containing omega-3 oils.

CSIRO Marine Research, Hobart, members of the Omega-3 Project team (left to right from top): Peter Nichols, Stanley Robert, Mina Brock, Susan Blackburn, Peter Mansour, Bronwyn Innes, and Dion Frampton.

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Further reading

Blackburn, S., D. Frampton, I. Jameson, M. Brown, M. Mansour, A. Negri, N. Parker, S. Robert, C. Bolch, P. Nichols, and J. Volkman, The CSIRO Collection of Living Microalgae: An Australian Perspective on Microalgal Biodiversity and Applications, in *Algae 2002 Japan: Proceedings of the NIES Culture Collection Symposium*, in press.

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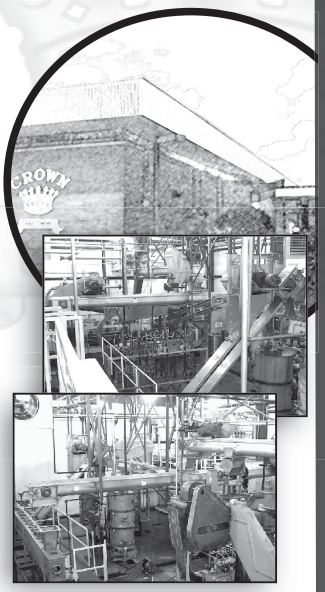

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