Marine functional foods and functional ingredients

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Dermot Hurst

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Foras na Mara

"to undertake, to co-ordinate, to promote and to assist in marine research and development and to provide such services related to marine research and development that, in the opinion of the institute, will promote economic development and create employment and protect the marine environment"
Marine Institute Act 1991

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Images / photographs by: David Branigan - Oceansport, Andrew Downes and Model Works.
For more information on the images please contact the Communications Section of the Marine Institute.

Steering Group Members

Dr. Pamela Byrne, Department of Agriculture and Food
Dr. Ronan Gormley, Teagasc
Prof. Liam Donnelly, Teagasc
Mr. Don McSwiney, Enterprise Ireland
Mr. Tom Scanlon, BIM
Ms. Helen Brophy, BIM
Dr. Dermot Hurst, Marine Institute

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Galway,
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1. Background

The Marine Institute, in conjunction with Enterprise Ireland, Bord Iascaigh Mhara (BIM), Teagasc and the Department of Agriculture and Food is developing a national research programme in Marine Functional Foods and Ingredients. *Sea Change: A Marine Knowledge, Research and Innovation Strategy for Ireland 2007 to 2013* (in press) identified the need for such a Programme. The government's *Strategy for Science, Technology and Innovation* identified a lead role for the Marine Institute in defining the Programme.

This briefing document was prepared to assist in defining a national research programme in marine origin functional food and ingredients. A '*functional food*' is one that provides a health benefit in addition to meeting the basic nutritional need of the consumer. The marine environment is recognised as a source of bio-active compounds including Omega-3 oils, essential minerals and vitamins, antioxidants, peptides, proteins and enzymes; all of which have potential use in food products.

Sea Change: A Marine Knowledge, Research and Innovation Strategy for Ireland 2007 to 2013 identified key requirements and set goals for a Marine Functional Foods Research Programme, they include;

- Creating a strong, interdisciplinary research capability, able to exploit marine biodiversity as a source of materials for use in functional foods;
- Developing capabilities to process marine-based materials for use by the functional ingredients sector;
- Supporting the creation of new research capacity in areas that underpin research in marine functional ingredients and foods; and
- Establishing new research capabilities in marine functional foods: linking indigenous and multi-national food and pharmaceutical industries with researchers at state and third-level research institutions.

The anticipated research outputs from the Programme during 2007 to 2013 include;

- Active participation by state and third-level research institutions and industry in nationally and internationally funded programmes;
- The discovery of marine based functional food materials;

- New processing methods to extract functional materials from marine materials; and
- A knowledge base that supports food companies to produce novel and innovative marine-based functional food ingredients and products.

This briefing paper gives insights into the issues surrounding marine functional foods and highlights opportunities for researchers in the marine sciences and food sciences areas to engage in collaborative research. It will be used as the basis for further consultation with the research community and firms in the marine and food sectors and to assist in exploring and prioritising research themes.

2. Introduction

The creation and exploitation of knowledge is already driving Ireland's new economy. The combination of attracting research intensive inward investment and supporting Irish firms to increase their commitment to research and innovation, supports national science and technology policy. One area in which this developmental approach is already working is at the food-health interface. Enterprise Ireland has singled out *functional foods* as a growth opportunity; and in doing so highlighted the potential of the dairy and marine sectors as sources of "*functional ingredients*".[1] The potential of the food-health area provides opportunities for scientists in the food and marine areas to extend the range and application of their research skills.

There is a thriving food sector in Ireland. Some Irish firms are leading players in the global food ingredients and consumer foods markets. Significant investments in food research by the Department of Agriculture and Food and other national agencies has enabled Ireland to build an international reputation in *functional food* research. The outputs from collaborative multi-disciplinary research has resulted in scientific discovery and the capability to manage complex research programmes.

Ireland's marine sector is experiencing change as the affect of sustained investments in research by the Marine Institute and other agencies such as Science Foundation Ireland, the Higher Education Authority and the Irish Research Council for Science, Engineering and Technology (IRCSET) begins to yield results. In growing its capacity to engage in strategic research, the marine sector is making an increasingly important contribution to the national economy.

Ireland's location and extensive marine resources represent a development opportunity. It will be possible for Ireland to harness scientific expertise in food, nutrition, health, biological and marine sciences and to target them towards the exploitation of Ireland's unique food production and marine environment to yield bioactive components and new marine based functional ingredients. Establishing a new programme of research to bring these skills and research competencies together is expected to yield new functional materials and seafood products and contribute to building essential research capacity.

The international markets for functional food and functional ingredients are expanding rapidly, driven by consumer concerns over health; the quest for healthy diets; a rising awareness of the role of food in targeting disease; and research leading to the development of new functional ingredients.

[1] Food Production Daily (2003) *Adding value to Ireland's food industry*, 4th June, 2003, www.foodproductiondaily.com/news/ng.asp?id=29955

This paper provides insights into the demand and potential of functional foods and the potential of the marine environment as a source of high value-added functional ingredients. It does so in light of plans to set-up a national research programme to target the use of marine origin ingredients as functional food components. In addition to identifying the drivers of research and describing market opportunities in functional ingredients, the paper describes why functional ingredients are important from a health perspective and identifies marine origin materials with known functional properties.

3. Functional Foods – An Overview

What is a Functional Food?

A 'functional food' provides a health benefit in addition to meeting a basic nutritional need. The American Institute of Medicine define functional foods as "food or food ingredients that may provide a health benefit beyond the traditional nutrients it contains".[2] The underlying concept of a functional food is that of a food, or food component(s), having the ability to contribute beneficially to human body functions by way of improving the state of well-being and reducing the risk of disease.[3] These definitions recognise the role of food not only in human development, growth and body maintenance, but also in maintaining the quality of human life.

In 1999, a European Community (EC) Concerted Action on Functional Foods Science in Europe (FUFOSE) tightened the definition of "functional food". It declared a food as "functional" if – "it is satisfactorily demonstrated to affect beneficially one or more target functions in the body, beyond adequate nutritional effects, in a way that is relevant to either and an improved state of health and well-being and/or reduction in risk of disease".[4] Functional foods must remain foods; and they must demonstrate their effects from amounts that can normally be consumed in the diet. They are not pills or capsules, but part of a normal food pattern. Unlike dietary supplements, which are taken in pill or liquid form, functional foods also have to meet the taste requirements and preferences of consumers.

In essence, therefore, a functional food can be:

- A natural food in which one or more of its components are naturally enhanced through growing conditions;
- A food to which a component(s) is added in order to provide benefits;
- A food from which a component(s) is removed in order to reduce any adverse health effect;
- A food in which a chemical modification of one or more of its components occurred in order to improve health; or
- A food in which the bioavailability of its components were changed or modified to improve the absorption of a beneficial component.

[2] U.S. Institute of Medicine (IOM), J. ADA 1995, 95:493-496
[3] Ashwell, M. (2002) *Concepts of Functional Food*, International Life Sciences Institute, ILSI Press, Washington
[4] Bellisle, F. (1998) *Functional Food Science in Europe – Theme Papers*, http://europe.ilsi.org/publications/ecprojects/functionalfoodsthemepapers.htm

Functional foods fill the space between conventional food and dietary supplements. Some common examples of functional foods include, light or low calorie products; food with low-salt levels; cholesterol-lowering spreads and beverages; foods that are specifically low-glycemic; and products that carry an antioxidant claim such as some teas and juices. Potentially exploiting a marine sourced material is a number of spreads, breads and beverages that contain Omega-3 fats. Conventional foods consumed in their natural state (e.g. fruit, vegetables, and grains) or novel foods that incorporate functional components to provide greater health benefits also fit within the definition of functional foods.

The Concept of Functional Food

Consumer demand and scientific discovery contribute to the proliferation of functional consumer foods and functional food ingredients.[5] The variety and availability of these products are increasing. Suppliers now offer foods and ingredients that claim to lower cholesterol and hypertension, and ingredients that enhance mental health and energy levels. There are now functional foods targeted at skin, gut, heart, joint, eye and cognitive or mental health.

In the past, foods were recognised as being nutritious based on the content of essential nutrients; a combination of fat, protein, carbohydrate, minerals and vitamins being present to support normal metabolic activity and bodily function. Now, biologically active components that impart health benefits or desirable physiological effects in foods are sought. These materials are known as nutricines - components of food considered for their beneficial effect upon health, rather than their direct contribution to nutrition. Examples of important nutricines include antioxidants, non-digestible carbohydrates, natural acids, enzymes and lecithins.[6]

Functional attributes of many traditional foods are being discovered. At the same time, new food products are being developed with beneficial components. Currently, the majority of functional foods are of plant origin.[7] These include carotenoids, flavonoids, non-digestible oligosaccharides, organic acids, phospholipids and polyphenols. Research is showing foods of animal origin as also having several useful nutricines such as, lutein in eggs; various carotenoids; and long chain polyunsaturated fatty acids (PUFAs) in fish; and conjugated linoleic acid (CLA) in milk.[8,9]

[5] Lewis, H. (2006) *Global market review of functional foods forecasts to 2010*, Aroq Ltd, UK, (justfood.com Report)
[6] Adams, C.A. (1999) *Nutricines – Food Components in Health and Nutrition*, Nottingham University Press, Nottingham
[7] Amadò, R., Abt, B., Bravo, L., Goñi, I. & Saura-Calixto, F. (2002) (Eds) *Bioactive compounds in plant foods. Health effects and perspectives for the food industry*, Cost Action 916, European Commission, Directorate General for Research, Brussels, Belgium
[8] For extensive coverage recent research on PUFAs in fish see Proceedings of the 2nd Joint Trans-Atlantic Fisheries Technology Conference, Quebec City, October 29th – 1st November, 2006
[9] Roche, H.M., Noone, A. & Gibney, M. (2001) *Conjugated linoleic acid: A novel therapeutic nutrient?* Nut Res Rev. 14: 173-187.

Functional Food Related Terminology

Across the functional food area, particularly in relation to the promotion and marketing of foods and food ingredients, a number of terms frequently crop up. These are used casually, and can be confusing for the consumer and food scientist. The more commonly used terms are described below.

Nutraceuticals

Though often used interchangeably, there is a difference between functional foods and nutraceuticals. According to Stephen DeFelice who created the term; nutraceuticals are "foods (or part of a food) that provide medical and health benefits, including the prevention and/or treatment of a disease."[10]

Probiotics

These are live microbial food supplements (bacteria) that are thought to beneficially affect the host by improving its intestinal balance. They are administered orally and the bacteria should be capable of reaching the intestine alive. For this to occur, the bacteria must be resistant against stomach acid bile, be capable of growing under anaerobic conditions and be non-toxic. Probiotics are foods that provide the gut with 'good' bacteria.

Prebiotics

Prebiotics are nutrients and constituents of food that gut flora feed upon, thus increasing their numbers. They are non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improve host health.[11] Prebiotics are targeted to act on the flora in the large intestine, though no specific bacterial group is singled out. Often, however, it is assumed that a prebiotic should increase the number and/or activity of bifidobacteria and lactic acid bacteria, as these groups of bacteria are claimed to have several beneficial effects on the host.

Synbiotics

Synbiotics refers to combination nutritional supplements comprised of probiotics and prebiotics. In essence, they are used in an attempt to improve the survival of probiotic organisms and stimulate growth. Some may protect against intestinal pathogens and ameliorate the severity of inflammatory bowel diseases. Others may be helpful in limiting antibiotic associated diarrhoea, as well as infectious and viral diarrhoea. A number of

[10] Brower, V. (1998) *Nutraceuticals: poised for a healthy slice of the healthcare market?* Nat Biotechnology. 16: 728-731

[11] Gibson, G. R. & Roberfroid, M. B. (1995) *Dietary modulation of the human colonic microbiotica: introducing the concept of prebiotics*, J of Nutr. 125: 1401-1412

symbiotic supplements are currently available; including combinations of bifidobacteria and fructo-oligosaccharides.[12]

Dietary supplements

Dietary supplements are products taken by mouth. They contain a 'dietary ingredient' intended to supplement the diet. The 'dietary ingredients' in these products include vitamins, minerals, herbs or other botanicals, amino acids, and substances such as enzymes, organ tissues, glandulars and metabolites. Dietary supplements can also be extracts or concentrates and are found in many forms such as tablets, capsules, softgels, gelcaps, liquids, or powders. In some countries it is illegal to make any specific claim for dietary supplements to act as a treatment, prevention or cure for a specific disease or condition.[13]

Fortified foods

These are foods that are modified (fortified) by the addition of nutrients (vitamins and minerals) to replace some of the nutritional value lost during its processing or storage, or to enhance the nutritional value of the food product by adding nutrients that are not normally contained in that food item.

Dietetic foods

Examples of dietetics include, infant feed formulae and baby foods; weight reduction foods; foods for sports people; and foods that have specific medicinal uses. Whereas functional foods target the general population, dietetic foods are intended to meet the nutritional requirements of persons with specific disease or other medical conditions. An EU Directive defines what constitutes dietetic foods.[14] It sets out the requirements for composition, marketing, labelling and food safety aspects of dietetic foods.

Health enhancing foods

This term describes foods to which consumers are drawn in an attempt to counter the negative aspects of some other foods. Shifting preferences away from foods high in fat, sugar and salt, towards foods that alleviate diet related health concerns of consumers, indicates an acceptance on the part of the consumer that some foods can enhance health. These include natural or manufactured foods or food ingredients that confer specific health-enhancing benefits beyond their basic nutritional functions.[15] For example, fish, fruit and vegetables in their natural state are health enhancing foods. When processed into juices, for example,

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[12] www.pdrhealth.com/drug_info/nmdrugprofiles/nutsupdrugs/syn_0327.shtml
[13] U. S. Food and Drug Administration, www.cfsan.fda.gov//~dms/ds-oview.html
[14] EU Framework Directive 89/398/EEC plus amendments 96/84/EC and 1999/41/EC
[15] Bogue, J. & Sorenson, D. (2005) *An Exploratory Study of Consumers' Attitudes Towards Health Enhancing Foods*, Agribusiness Discussion Paper No 36, University College, Cork

health benefiting properties may even be enhanced, resulting in them being called health enhancing consumer foods.

4. Marine Functional Ingredients

Marine functional ingredients include; materials extracted from fish and shellfish; and extracts from marine plants and other marine organisms and marine bacteria. Some species of fish are inherently functional.[16] Although the functional properties of some marine origin components are known, others remain to be evaluated and new sources yet to be discovered. The marine environment is a major potential source of functional materials, including Omega-3 oils, essential minerals and vitamins, antioxidants, peptides and enzymes.[17]

The consumption of fish can have a considerable impact in dietary control of coronary heart disease (CHD). Consuming long-chain fatty acids as found in some fish species is strongly associated with protection from CHD. Other marine origin dietary components are known to contribute to reducing the risk of some cancers and improving immune system function.[18] There are also reports that indicate potential for fish and other marine foods to reduce inflammatory bowel disease, improve bone health and counter psychiatric disorders.[19]

Some of the strongest scientific evidence underpinning the health claims for marine origin functional materials relates to marine oils, specifically fish origin Omega-3 polyunsaturated fatty acids (PUFAs). Coupled with this scientific evidence, consumer awareness regarding the health benefits of fish oil in the diet is increasing. Internationally, an increase in demand for fish oil and a proliferation of fish oil fortified products is reported.[20]

The nutritional benefits of whole fish and fish products as functional foods and the potential of fish as a source of bioactive components are well known. Fish and other marine organisms are identified as sources of calcium (from fish bones and shells), anti-hypertensive proteins (peptides and protein hydrolysates), antioxidants (from fish skins), selenium, chitin (and its derivatives), Omega-3 PUFAs, taurine and other bioactive components.[16]

Fish farming and aquaculture can play an important role in a functional foods context; they can target the production of species high in functional compounds.[21] They offer scope to produce fish, shellfish and seaweed from which functional materials can be extracted. It is also possible to increase the levels of bioactive compounds in whole fish by dedicated feeding regimes. It may even be possible to develop functional feeds for aquaculture that benefit not only the fish, but also the consumer.

[16] Gormley, R. (2006) *Fish as a functional food*, In Proceedings of the Functional Food Network Conference, Turku, Finland, March 8 – 10
[17] www.seafoodplus.org/fileadmin/files/news/2004-01-22SFRTD1launchBrussels.pdf
[18] Borresen, T. (2006) *Future priorities of research for health, safe and nutritious seafood based on result from SEAFOODplus*, In Proceedings of the 2nd Joint Trans-Atlantic Fisheries Technology Conference, Quebec City, October 29th – 1st November, 2006
[19] Mazza, M., Pomponi, M., Janiri, L., Bria, P. & Mazza, S. (2006) *Omega-3 fatty acids and antioxidants in neurological and psychiatric diseases: An overview*, Prog Neuropsychopharmacol Biol Psychiatry. Aug 25
[20] Frost and Sullivan Market Report (2004) *European Omega-3 and Omega-6 PUFA Ingredients Market*, July 2004
[21] Bell, G. (2006) *Sustainable aquafeeds for the provision of safe and nutritious aquaculture*, In Proceedings of the 2nd Joint Trans-Atlantic Fisheries Technology Conference, Quebec City, October 29th – 1st November, 2006

Examples of Functional Materials from the Marine

The source of marine functional ingredients is expanding rapidly; with species of fish and algae each being targeted for exploration.[22] Some of the main sources of marine origin functional materials are described below. They include materials extracted from marine organisms, fish and fish waste products.

Fish waste

It is estimated that 18 - 30 million tonnes of fish waste is dumped around the world annually.[23] Traditionally, the major outlet for fish waste was fishmeal and oil extraction. Until 2000, the United Kingdom imported 290,000 tonne per annum of fishmeal and oil. Limits placed by the EU on the use of fishmeal in animal feeds may have reduced these imports.[24] Irish fish wastes are small in comparison to those of the UK. In addition, they are distributed at many locations around the coastline. A Marine Institute funded study of Irish fish waste assessed the level of waste from finfish and shellfish at approximately 64,000 tonnes in 2000.[25]

Fish waste remains a source of bioactive materials. It is known that fish bones are a good source of calcium. In Iceland and Norway, fish livers are brought ashore for processing into fish oils. Fish waste is also a source of proteins, vitamins and antioxidants, minerals, amino acids and peptides.[26]

Fish protein hydrolysates

Enzymes are used to break down fish proteins into amino acids to yield a highly functional food ingredient. As well as having functional properties, this powdered form of protein is attractive to the food processing sector. Current uses include milk replacement in young animal feeding; fermented fish sauces; the production of fish peptone broth as a microbiological growth media; and as food binding and gelling agents.

Bioactive proteins and peptides

Fish and other foods are known to contain anti-hypertensive peptides known as angiotensin I converting enzyme (ACE) inhibitors. These bioactive components are found in the muscle flesh of various species. Protease inhibitors of the serpin family can also be found in seafood.

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[22] For an extensive review of active research on fish and algae see Proceedings of the 2nd Joint Trans-Atlantic Fisheries Technology Conference, Quebec City, October 29th – 1st November, 2006

[23] Elvevoll, E. (2004) *Fish waste and functional foods*, Total Food, Norwich, England, www.totalfood2004.com/elvevoll_files/frame.htm

[24] Archer, M. (2001) *Fish waste production in the United Kingdom*, Sea fish report No SR537, The Sea Fish Industry Authority

[25] Marine Institute (2003) *Disposal and reutilisation of fish and fish processing waste (including aquaculture)*, NDP Desk Study, DK/01/003, Marine Institute, Oranmore, 2003

[26] Office of the Commissioner for Aquaculture Development (2002) *Market outlook in the international fish and seafood sector*, OCAD, Ottawa, Canada, 2002

Antioxidants

Sources of marine origin antioxidants include species of eel, *Anguilla japonica* and *Conger myriaster*, halibut skin, cod liver oil, green lipped mussels, and marine algae.[27] These marine origin functional ingredients may also be of interest to the pharmaceutical sector.

Selenium

Many European consumers may be deficient in selenium due to selenium depletion in European soils. Recent evidence suggests that organic selenium may be anti-carcinogenic. Fish farming has the potential to deliver fish rich in organic selenium and this is being addressed in the ongoing EU integrated SEAFOODplus project.[28] Selenium was found to be retained in the flesh of African catfish, when fed a selenium rich diet (organic selenium and selenium enriched garlic).

Omega-3 PUFAs

Commonly found in cold-water fish, these necessary oils must be obtained through diet since the human body can't metabolise them. The options to incorporate PUFAs into food are many. Encapsulated fish oils are increasingly common in beverages. They are also used in breads and confectionary products and incorporated into various dietary supplements. Some fish can retain PUFAs in their flesh. The opportunity to increase the PUFA content of fish flesh via a non marine oil rich diet could increase the level of PUFAs in fish. Salmon, sardines, mackerel, cod and herrings are sources of PUFAs. Some species of marine algae also contain high levels of PUFAs.

Taurine

Fish is a good source of taurine. Its content in different species is being studied by researchers at the Teagasc Ashtown Food Research Centre (AFRC) as part of the EU Framework SEAFOODplus project.[28] Taurine is present in cod, mackerel, farmed and wild salmon, albacore tuna, ray, siki shark, whiting and several other species. Taurine, hypotaurine, and thiotaurine have been identified and assayed in several deep sea organisms including bivalves and tubeworms living close to hydrothermal vent sites.[29] The potential for taurine to reduce blood pressure, improve cardiac performance and reduce blood cholesterol levels is the subject of on going research.[28]

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[27] Gormley, R. (2006) *Fish as a functional food*, In Proceedings of the Functional Food Network Conference, Turku, Finland, March 8 – 10

[28] SEAFOODplus, www.seafoodplus.org/Project_4_4_CONSUMERPR.59.0.html

[29] Chaimbault, P., Alberic, P., Elfakir, C. & Lafosse, M. (2004) *Development of an LC-MS-MS method for the quantification of taurine derivatives in marine invertebrates*, Anal Biochem. Sep, 15; 332(2) 215-25

Chitin

This is a naturally occurring non-toxic, biodegradable polymer extracted from crab, shrimp, lobster, prawn, squid and cuttlefish. The processing of shells and bones from these species results in the production of chitosan. Chitosan has functional food properties and can be used as gelling agents, emulsifiers and as a food preservative. Its ability to absorb fat creates a new potential for use an anti-cholesterol agent.[30] Chitosan is also used in the medical sector, as a wound dressing.

Carotenoids

Originally of interest for their use as a food colouring agent, and still used as such, these compounds are what give some fish and shellfish their reddish pink colour. The two main carotenoids, astaxanthin and canthaxanthin, are extracted from crab and shrimp processing. New uses for both these compounds have been identified. Their highly antioxidative properties make them candidates as functional food ingredients.[31] Astaxanthin may have a use as an anti-aging compound, whilst canthaxanthin could contribute to treatments for Alzheimer's and Parkinson's disease, high cholesterol, strokes and cancer.

Polysaccharides

These are naturally occurring sugar molecules found in various algae and in other marine species such as molluscs and even jellyfish. In their gum form, polysaccharides are well know in the food industry as gelling agents. The potential of this group of polymers as functional ingredients is reflected in the level of research into their use as anti-microbial, antiviral and anti-fungal treatments.[32]

Enzymes

Fish derived enzymes are not as common as those from other sources, but nonetheless are valuable commodities. They are particularly effective in working at low temperatures. They have a use in food processing, where cod-derived pepsin is used to control flavour development in some cheeses. Trypsin can be used to recover carotenoids and flavourings from fish waste and fish. An increase in demand for marine sourced enzymes is likely as biotechnology activity continues to expand.[33]

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[30] Bokura, H. & Kobayashi, S. (2003) *Chitosan decreases total cholesterol in women: a randomized, double-blind, placebo-controlled trial*, Eur J Clin Nutr. May, 57(5) 721-5

[31] Chew, B.P., Park J.S., Wong, M.W. & Wong, T.S. (1999) *A comparison of the anticancer activities of dietary beta-carotene, canthaxanthin and astaxanthin in mice in vivo*, Anticancer Res. May-Jun, 19(3A) 1849-53

[32] Marine Natural Products and Antagonistic Properties of Marine Organisms for Human Health, www.pharmaasia.com/article.asp?articleid=5858

[33] Frost and Sullivan *Market Report (2005) European Protein Ingredients Market,* July 2005

5. Diet, Nutrition and Chronic Diseases

The development of functional foods is driven largely by concerns over health.[34] There is conclusive scientific evidence about the relationship between diet and health. Together with lifestyle factors, diet is shown as a determinant of chronic non-communicable diseases and conditions such as obesity, heart disease, type 2 diabetes, hypertension, cancer and osteoporosis.[35]

According to *The World Health Report,* a few major risk factors account for a significant proportion of all deaths and diseases in most countries.[36] Six of the top seven risk factors linked to premature death relate to diet and physical activity. Unhealthy diets and failing to adopt an active lifestyle are the leading causes of avoidable illness and premature death in Europe. In the industrialised world, dietary factors are estimated to account for 30 percent of all cancers.[37]

A healthy diet is recognised as a major contributor in the prevention of cardio-vascular disease and some other non-communicable diseases. Aspects of human health that potentially could be improved through diet and are targets for functional foods include, early development and growth, regulation of basic metabolic processes, defence against oxidative stress, cardiovascular physiology, gastrointestinal physiology, cognitive and mental performance, physical performance and fitness.[38]

Early development and growth

Growth is determined by genetic, nutritional and environmental factors and is usually associated with increases in physical parameters – length, mass, etc.[38] These developments are indicative of the progressive changes that occur in tissues and organs at all stages of the growth cycle. Some periods of growth, such as those taking place during pregnancy and in early life, are more important than others and can determine developmental and behavioural aspects of adult life. Diet in early life also appears to have effects on sensory and cognitive abilities.

Early stage development is known to be influenced by the consumption of polyunsaturated fatty acids, iron, zinc and iodine.[39] The beneficial effects on immune response, from antioxidants, vitamins, trace element, fatty acids, arginine, nucleotides, probiotics and altered allergenic components of infant foods, are also suggested as targets for new functional materials. The possibility of combining calcium with other bone growth constituents such as proteins, phosphorous, magnesium and zinc as well as vitamins D and K need to be confirmed.

[34] Lewis, H. (2006) *Global market review of functional foods forecasts to 2010*, Aroq Ltd, UK, (justfood.com Report)
[35] European Commission (2005) *Promoting Healthy Diets and Physical Activity: A European dimension for the prevention of overweight, obesity and chronic diseases*, EC Green Paper COM(2005) 637 final, Brussels
[36] World Health Organisation (2002) *The World Health Report: 2002 Reducing risks, promoting health life*, WHO, Geneva
[37] World Health Organisation (2003) *Diet, Nutrition and the Prevention of Chronic Disease*, Report of a Joint WHO/FAO Expert Consultation, WHO, Geneva
[38] Ashwell, M. (2002) *Concepts of Functional Food*, International Life Sciences Institute, ILSI Press, Washington
[39] Branca, F. (2002) *Micronutrients, Growth and Development: Factors Affecting Nutrient Intake in Children*, European Nutrition Summaries update, Issue 1, 2002

The metabolic process

Basic metabolic and physiological processes are influenced by diet. Some chronic diseases are partly related to total energy intake, levels of physical activity and poor eating habits. For example, obesity, an excessive accumulation of body fat, whether internal or subcutaneous, is associated with type 2 diabetes and other diseases. Specific proteins in the body control the chemical reactions of metabolism and each chemical reaction is co-ordinated with other body functions.

Diabetes mellitus is associated with increased plasma-glucose concentrations - the hormone insulin controls glucose levels. Type 2 diabetes occurs when the body cannot respond normally to insulin and a resistance is developed. Once prevalent only in obese and/or older people, it is increasingly common in younger people.[40]

The development of functional foods that can influence the absorption rate of glucose into the bloodstream and/or optimise the rate of carbohydrate release, offers potential in helping to optimise metabolism. Various starches, dietary fibre and organic acids are known to influence glucose uptake, whilst hydrogenated carbohydrates or trehalose help to improve the glycemic response to foods.

Defence against oxidative stress

Oxygen, so essential to life, is paradoxically also involved in toxic reactions that threaten human well-being. The formation and activity of reactive oxygen species (ROS), which act as oxidants, is seen as one such harmful effect. It is believed that such oxidants are major contributors to ageing and diseases found in the aged, including heart disease, cancer, cataracts, and diseases of the immune and nervous systems. The body has a number of natural defences that act as antioxidants and nutrition plays a key role in maintaining them. Antioxidants limit cell damage. Poor or insufficient nutrition can limit the effectiveness of these defences. When natural antioxidants are unable cope with the load, as may occur when there is a high exposure to oxidants, oxidative stress occurs.

The principle micronutrient (vitamin) antioxidants are vitamin E, beta-carotene, and vitamin C. Vitamin C (ascorbic acid) is a water soluble vitamin present in citrus fruits and juices, green peppers, cabbage, spinach, broccoli, kale, cantaloupe, kiwi and strawberries. Beta-carotene is a precursor to vitamin A (retinol) and is present in liver, egg yolk, milk, butter, spinach, carrots, squash, broccoli, yams, tomato, cantaloupe, peaches and grains. Vitamin E is a fat soluble vitamin present in nuts, seeds, whole grains (esp. wheat germ and apricots) and in vegetable

[40] Sloan, E. (2006) *Top 10 Functional food trends*, Food Technology, 0406, www.ift.org

and fish oils. Additionally, selenium, a trace metal that is required for proper function of one of the body's antioxidant enzyme systems, is sometimes included in this category. As the body cannot produce these micronutrients, they must be supplied in the diet.

The cardiovascular system

Major diseases of the cardiovascular system include coronary heart disease (CHD), peripheral artery disease and stroke. CHD is particularly prevalent in most industrialised countries. The key symptoms of CHD, resulting from arteries supplying blood to the heart being narrowed by atherosclerosis, include angina, heart attack and sudden cardiac death.[41]

Maintaining the integrity of the coronary artery by controlling blood pressure and inflammation, maintaining appropriate levels of lipoproteins, and reducing the likelihood of blood clot formation are well known defences against cardiovascular system diseases (CVD). By developing insights to the risk factors for CVD, it is possible to clarify the potential role for functional foods to reduce them.

Several factors, including obesity, smoking and genetics, contribute to high blood pressure. Dietary components such as potassium, calcium and certain fatty acids may have a beneficial effect on reducing blood pressure.[41]

Where any damage to the endothelial cells (the cells that line arteries) or dysfunction of the endothelium as occurs, for example, through smoking, the risk of CVD increases. Oxidised low-density lipoprotein (LDL) has been found in damaged arterial walls and could also contribute to CDV. Similarly, elevated concentrations of LDL, high levels of other lipoproteins, triacylglycerol and low levels of HDL cholesterol concentration, are strong CVD risk factors. Reducing stroke potential by controlling blood clot formation and minimising calcification of arteries by maintaining levels of vitamin K may also reduce the risk CVD.[41]

Functional foods may have a major role in promoting optimal heart health and in reducing the risks factors associated with CVD. It is known that levels of blood lipids can be influenced by dietary fatty acids. Diets low in saturated fatty acids and trans-fatty acids could reduce the risk of CVD. Concentrations of LDL cholesterol can be reduced by intakes of oleic, linoleic and alpha linolenic acids and foods enriched in these unsaturated fatty acids could also reduce the risk of CVD.[42] Some fish oils contain long-chain highly polyunsaturated fatty acids derived from alpha linolenic acids. These oils are already being incorporated into foods. Diets rich in antioxidants can inhibit LDL oxidation and soluble fibre can reduce LDL cholesterol

[41] Ashwell, M. (2002) *Concepts of Functional Food*, International Life Sciences Institute, ILSI Press, Washington
[42] Psota, T. L., Gebauer, S. K. & Kris-Etherton, P. (2006) *Dietary Omega-3 fatty acid intake and cardiovascular risk*, American Journal of Cardiology, 2006, Aug 21, 98(4A):3i-18i

concentration. Soy protein, plant sterol and stanol esters are incorporated into new functional food to reduce LDL cholesterol.

Gastrointestinal function

The large intestine is a highly metabolically active organ. It contains a complex microbial ecosystem composed mostly of anaerobic bacteria. These micro-flora play a major role in salvaging energy and controlling the growth of harmful bacteria. They are thought to contribute to the development of the immune system in early-stage growth. It is known that the consumption of probiotics, prebiotics and synbiotics can help to maintain a balance in gut flora.[43] These dietary strategies provide opportunities on which to base new functional foods. Already, there are attempts to build on the known beneficial properties of such bacteria (e.g. bifidobacteria and lactobacilli) by incorporating them into yoghurts and drinks. Some of these products target improving the growth of the beneficial bacteria, whilst others provide components to maintain gut-flora health.

Claims regarding probiotics include their ability to counter lactose intolerance, stimulate the immune system and reduce the severity of gastrointestinal infections. A current topic for Irish based researchers is the potential to use probiotics to limit colorectal cancer.[44] Prebiotics are thought to contribute to immune system activation, and increase the absorption of minerals such as calcium. Additionally, lesions, which are indicators of carcinomas, may be reduced through the consumption of probiotics. The major food application for probiotics to date is in dairy foods. However, prebiotics offer functional food producers more scope. New products in this area include spreads, baked products, salad dressings and meats.[45]

Cognitive and mental performance

Some foods and food components are known to bring about changes in mood and mental state. They can create both long-term and short-term feelings of well-being. Some are known to alter sensations, perceptions, memory and attention span. It is these properties that have been maximised in creating foods with the sensory appeal for consumers. Key attributes of appeal include palatability - achieved by increasing fat or sugar content - colour and flavour. The effects of components that stimulate such responses can be immediate; as in the case of foods that are known to influence appetite, satiety or attention; or more long-term, as with foods that bring about change in memory and mental processes.[46]

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[43] Macfarlane, S., Macfarlane, G.T. & Cummings, J.H. (2006) *Review article: prebiotics in the gastrointestinal tract*, Aliment Pharmacol Ther. 2006, Sep 1;24 (5) 701-14

[44] This work is part of the UCC/Teagasc/APC research programme

[45] Sloan, E. (2006) *Top 10 Functional food trends*, Food Technology, 0406, www.ift.org

[46] Young, G. & Conquer, J. (2005) *Omega-3 fatty acids and neuropsychiatric disorders*, Reprod Nutr Dev. 2005, Jan-Feb, 45(1):1-28

The ability of foods to bring about different mental reactions and responses has led to the search for food components that produce desired health effects. It is known that high carbohydrate meals can produce feelings of drowsiness and that the amino acid tryptophan can cause fatigue. Sweet foods such as sucrose may relieve stress and the activation of endogenous opioids could reduce perceptions of pain. Identifying and building components such as these, and others, into foods creates the potential to alter the consumers' response to food. It may be possible therefore, to produce functional food products, which cause more healthy foods – less sugar and fat, and more fibre, to be consumed. Some specific components being evaluated for their effects on mood and cognitive performance include choline, caffeine and some of the amino acids.

Just as mental performance is a target for functional foods, so too is physical performance. Athletes experience a range of physical and mental stresses during, and after, training and competition. Countering these adverse reactions calls for specific nutritional measures. It is an area offering considerable potential for functional food development and already there are many sports performance beverages available in what is identified as a major market growth area. New challenges in developing beverages include designing foods around novel components to provide hydration, energy intake and micronutrients to support training and competition.[47]

[47] Ashwell, M. (2002) *Concepts of Functional Food*, International Life Sciences Institute, ILSI Press, Washington

6. Functional Foods and Ingredient Market Review

Food companies have quickly exploited consumer recognition of the link between food and health. Consumers' growing demand for foods with health benefits is creating new product opportunities. The result is a huge market for 'healthy' foods in developed countries.

One of the reasons for the large growth in the functional foods market is the trend towards ageing populations in all western countries and the increased incidence of diet-related illness in this population. The second is that obesity is a world problem: there are an estimated one billion people considered as obese or overweight from eating too much of the wrong kind of food and too little exercise.[48] A considerable shift in consumer preferences in relation to the nutritional quality of food has resulted from the public and private (company) sector "healthy eating" promotion initiatives. Consumers are now far more likely to consider not only the sensory characteristics of food, but also food products that have good nutritional properties.[49]

Market Segmentation

In recent years, a functional food market with formal market structures and segmentation has developed. This market comprises functional food and beverage products, functional food ingredients, nutraceuticals and dietary supplements.[50] Further market segmentation exists across the sector, with functional foods being developed for different ages groups, e.g. from infants to aged; and gender, there are "for women only" and "formulated for women's health" functional foods. Gender specific products accounted for $4 billion sales in the USA in 2004.[51] There are now functional food products that target sports oriented people and even functional foods for animals.[50] Markets are also segmented on the basis of a desired health outcome; e.g. to reduce body mass, cholesterol, blood pressure and symptoms of arthritis; increased bone density and improved cognitive capacity and many others. A further basis for segmentation is the food product itself, with an array of functional beverages, snack food, breakfast cereals, spreads, salad dressing, bread, confectionery, milk, soup, yoghurts and deserts available.

Market Development

The new functional foods market is characterised by high growth rates across all sectors. In 2005, the global functional food market reached $73.5 billion. Rapid annual growth rates of up to 14 percent are expected to continue well into 2010. Post 2010, functional foods will probably account for five percent of the global food sector in the developed world and continue to show high growth rates.[52]

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[48] Popkin, B. (2006) *The Nutrition Transition in High and Low-Income Countries: What are the Policy Lessons?* Proceedings of the International Association of Agricultural Economists Conference, Canberra, June 2006

[49] Frost and Sullivan Market Report (2005) *Opportunities in the Microencapsulated Food Ingredients Market*, October, 2005

[50] Sloan, E. (2006) *Top 10 Functional food trends*, Food Technology, 0406, www.ift.org

[51] Natural Products Industry Insider - Functional Foods for Women's Health, www.naturalproductsinsider.com/articles/681ffocus.html

[52] Lewis, H. (2006) *Global market review of functional foods forecasts to 2010*, Aroq Ltd, UK, (justfood.com Report)

Analysts indicate opportunities for growth in the functional ingredients sector (the US market alone is valued at $30 billion), driven by the demand for functional foods. The variety of functional ingredients is expanding, but the functional ingredients area is currently dominated by demand for probiotics, antioxidants and PUFAs.[53]

A recent report by the US based market analyst The Freedonia Group predicted the health foods industry, already worth nearly $200 billion, will continue to grow, helped by contributions from functional ingredients such as soy and Omega-3 fish oils.[54]

Structural changes in the market appear likely if, as suggested by Freedonia, China outstrips the US's prime market position in the production of ingredients. Behind further likely market change and solid growth of some areas of the ingredients sector, is recent "strong clinical evidence" about health benefits of certain ingredients, principally, soy proteins, lutein, lycopene, Omega-3s, probiotics and sterol esters, calcium and magnesium, garlic, green tea, chondroitin and glucosamine, and coenzyme Q10.

According to the Freedonia Group Report "China and India will emerge as the fastest-expanding functional food/nutraceutical markets as strong economic growth allows them to upgrade and diversify food, beverage and drug production capabilities." It goes on to state "the United States will remain the largest global consumer of nutraceutical ingredients due to the broad, increasing range of nutritional preparations and natural medicines produced domestically."

Functional Materials

These form the basis for processed functional foods, dietary and nutritional supplements, nutraceuticals, probiotics, prebiotics and other functional health enhancing food products. The developments in this sector drive activity in the identification, extraction and processing of materials. These developments include the use of microencapsulation to facilitate handling and distribution of functional materials and also to provide targeted nutrition in processed food products by fortification with oils, vitamins and minerals. Insights into the market dynamics of a range of functional components, some of which could be extracted from the marine, are given below.

[53] Frost and Sullivan Market Report (2005) *Opportunities in the Miroencapsulated Food Ingredients Market*, October 2005
[54] Anon (2006) *China to outsell US Nutraceutical ingredients within a few years*, Functional Foods and Nutrition, www.ffnmag.com/ASP/articleDisplay.asp?strArticleId=1095&str

Polyunsaturated fatty acids (PUFAs)

The world market for PUFAs was valued at $700 million in 2004; with the European market accounting for nearly $200 million.[55] Analysts view PUFAs as a fast growing sector, able to sustain growth rates in excess of 8 percent per annum well past 2010. The PUFA market, comprising Omega-3 and Omega-6 includes fish oils, algal oils, flax oil, vegetable oils, nuts and seeds. Marine oil is by far the most developed sector; particularly cod liver oil, which holds maximum potential as a nutritional supplement and functional ingredient and accounts for the greatest market share by value, ahead of algae and flax oils. Although there is generally a high level of market acceptance of PUFAs in all markets, concerns about their stability, especially shelf-life oxidation and taste, remain for both marine and plant origin oils. Despite these concerns, and the associated challenges of dealing with them, oils, especially Omega-3 oils, have the highest growth potential of all functional ingredients. This growth is attributed to the broad spectrum of health issues that such oils can influence and to a rising consumer awareness of the beneficial effects of PUFAs. With some participants in the market experiencing growth rates of 20 percent or more and consumer awareness of the benefits from PUFAs improving every year, the market for PUFAs looks promising.

Antioxidants

The world market value of all commercially used carotenoids was $887 million in 2004.[56] It is expected to grow by an average of 2.9 percent annually, to just over $1 billion by 2010. The market value of beta-carotene was $242 million in 2004. This group of antioxidants have pro-vitamin A properties, but the major use in the food sector remains primarily a colouring. Its use as a functional food ingredient, however, is reported to be growing.

There are claims that lutein, a naturally occurring antioxidant found in dark leafy vegetables, fruit, corn and egg yolks, has specific health benefits for eyes, skin and the cardiovascular system. The strong link between lutein and alleviation of macular degeneration contributed to market growth. This is reflected in a total market value of $139 million in 2004, from just $64 million in 1999. An annual growth of around 6 percent per annum is forecast to 2009.[56]

Coenzyme Q10 (CoQ10) has been suggested as a potential treatment for many conditions. Some research supports the use of coenzyme CoQ10 for congestive heart failure, after heart attacks, high blood pressure, heart complications associated with diabetes and Alzheimer's disease; although it is not well-established what constitutes safe and effective doses. CoQ10 is a fat-soluble, vitamin-like substance found in every human cell. CoQ10 is naturally present in a variety of foods. Organ meats such as heart, liver and kidney as well soybean oil, sardines,

[55] Frost and Sullivan Market Report (2004) *European Omega-3 and Omega-6 PUFA Ingredients Market*, July 2004
[56] BCC Market Research Report, (2005) *The Global Market for Carotenoids*, June, 2005

mackerel and peanuts are particularly high in CoQ10. In 2005, the US market for CoQ10 was $212 million and accounted for nearly 10 percent of the US dietary supplements market. On the back of continued interest in the range of beneficial claims associated with CoQ10, market growth of around 8 percent per annum is expected to continue past 2010.[57]

Lycopene is a proven antioxidant. It is an open-chain unsaturated carotenoid that imparts red colour to tomatoes, guava, rosehip, watermelon and pink grapefruit. There are suggestions that lycopene is associated with reduced risk of macular degenerative disease, serum lipid oxidation and cancers of the lung, bladder, cervix and skin. In line with the general growth of carotenoids, the market for lycopene is expected to grow and be valued at $26 million by 2010.[57]

Phytosterols

Phytosterols are cholesterol-like molecules found in all plant foods, with the highest concentrations occurring in vegetable oils. Also known as plant sterols, they are known to contribute to cholesterol-lowering activity. The number of new products containing phytosterols has been on the rise since 2000. Many foods and beverages such as yoghurt, milk, sausages, cold cuts, bakery products, spicy sauces, margarine and spreads now incorporate phytosterols. In a recent report, market analysts Frost and Sullivan valued the US phytosterol market at $103.9m in 2005 and estimated it will reach $196.7m by 2012. The same report valued the European phytosterols market at $184.6 million in 2005 and estimated sales to reach $395.2 million by 2012.[58]

Probiotics and prebiotics

The sale of probiotics in the USA reached $764 million in 2005 and is expected to rise at an average annual rate of 7.1 percent, reaching $1.1 billion by 2010. Probiotics used in the manufacture of dietary supplements are projected to top $291.4 million in 2010. Food applications dominate the market for probiotics and in 2005, sales reached $498 million. Sales are expected to continue to rise at around 7 percent per annum and reach $700 by 2010. Yogurts, kefir and cultured drinks represent major product categories and growth areas.

The European probiotics market is already worth in excess of €520 million. The fastest-growing sector of that market is the UK. Information on the European prebiotic market is scant; however, it is thought to have been worth about €87 million in 2003, and expected to

[57] Frost and Sullivan Market Report (2003) *European and United States Food Antioxidants Markets*, January 2003
[58] Frost and Sullivan Market Report (2006) *Strategic Analysis of the European Phytosterols Market, 2002 to 2005*, April 2006

grow to €179.7 million by 2010.[59] The European prebiotic market is currently dominated by fructan (inulin and fructooligosaccharides) and galactooligosaccharide. Finished products containing prebiotic ingredients include bread, chocolate, yoghurt and dietary supplements. Inulin can replace fat or be used to improve texture and mouth feel of food products.

Chitin

Chitin is one of the world's most abundant natural polymers. Found in the exoskeleton of shellfish such as crab, lobster and shrimp, the polysaccharide is finding increased use as a dietary supplement. Its potential to bind fats in the stomach is linked to weight loss and to reducing the levels of cholesterol. Chitosan, a fibre derived from chitin, is also gaining in use in the food and medical sectors. Worldwide sales of chitin and chitosan were estimated to exceed $2 billion by 2004.[60]

Polyphenolics

Polyphenols are natural flavonoids found in seaweed, grapes, cocoa and other plants. They have been identified as having a potent antioxidant activity and are already being incorporated into some teas and other beverages. The two major classes of molecules in seaweed that are identified as having sales growth potential are polysaccharides and polyphenolics.

Fish protein

This is a concentrate made from inedible fish and the trimmings from human consumption grade fish. It is used for its nutritional benefit and sold across different markets. When used for human consumption it is described as surimi. Fish protein markets, whilst generating revenues in Europe of €458.6 million in 2004 are reported to be falling. Since 2001, and largely as a result of bans on the sales of fish proteins into the animal (ruminant) feed sector, fish protein sales have fallen by 30 percent. About one-third of the total fish in the world is used to produce fish proteins and fish oils; amounting to 30 million tonnes in 2004.[61]

Global Trends

New functional food products

According to US food company executives, functional food product profitability and general market growth will continue to rise over the next five to 10 years.[62] At the same time, the number of functional food products is set to increase; and hence demand for functional ingredients also rise.

[59] Frost and Sullivan Market Report (2003) *European Probiotic and Prebiotic Functional Dairy Foods Markets*, May 2003
[60] Frost and Sullivan Market Report (2005) *Strategic Analysis of the European Dietary Supplements Markets*, May 2005
[61] Frost and Sullivan Market Report (2005) *European Protein Ingredients Market*, July 2005
[62] Reference to a Reuters/Business Insight Report (2005) quoted in Allen, S., *The Market for Functional Foods*, Pulse Point, January 2005

The best-selling functional food products are energy and sports drinks. The largest functional food sector is the beverage sector, followed by breads and cereals. Energy bars and snacks are the third largest sector.[63] Together, the three categories make up 50 percent of all functional food products sold in the USA. Annual growth rates for functional beverages remain in double figures. The pattern of sales for functional beverages in the EU is the same as that in the US. That is where the similarity ends. Unlike the US market, European sales of dairy based probiotic products, mostly yoghurt drinks and spreads containing plant stanols, are well positioned.

Interestingly, it is reported that none of the leading USA based products sold in any of the above three categories make use of novel bioactive components.[64] Instead, they incorporate well-known ingredients: vitamins, minerals, soy and fibre to provide the functionality. However, the major food ingredients firms are working to further develop the market for bioactive ingredients in response to the consumer demand for functional foods.[65] For many firms, marketing a functional food to address particular medical conditions has not yet proven to be a particularly successful strategy.

Regulatory environment

Functional food/ingredient regulations are not harmonised and vary from country to country. Getting a new functional food product into the market is a complicated process and can take a long time. Claims about functionality have to be supported by scientific evidence.

Japan took a lead on the regulatory front and created a set of dedicated regulations for functional foods; including the creation of different categories of approval covering functions, medical claims and qualified claims. As might be expected, given its leadership in functional foods, the Japanese regulatory system is highly developed and by 2005, 537 approved functional food products or ingredients had been listed.[66]

Pending EU regulations will allow for the classification of nutrient function, enhanced function and reduction of disease claims. The European Food Safety Authority is responsible for drafting these regulations and their formal adoption by the EU Parliament was scheduled for July 2006.

The United States Food and Drug Administration (FDA) places responsibility on the producer to fit health claims within a set of defined relationships. Manufacturers have to identify each product as a nutrient, or a food. As scientific evidence emerges regarding relationships

[63] Sloan, E.(2006) *Top 10 Functional food trends*, Food Technology, 0406, www.ift.org
[64] Allen, S. (2005) *The Market for Functional Foods*, Pulse Point, January 2005
[65] Wrick, K. (2005) *Development Opportunities for Functional Foods*, Food Product Design, July 2003
[66] Lewis, H. (2006) *Global market review of functional foods forecasts to 2010*, Aroq Ltd, UK, (justfood.com Report)

between ingredients and nutrition, the FDA is expanding the list of approved claims.[67]

Canada is reported as lagging behind other markets due to earlier restrictions on the sale of functional foods. Canada's approval process is considered complicated and lengthy. However, under a national development plan designed to improve health care, functional food sales are set to rise and clear regulations for certification are likely to be introduced.[67]

Established under the joint Australian and New Zealand Food Regulation Ministerial Council, Food Standards Australia and New Zealand (FSANZ) manage a two-level system for food claims. Low-level claims that don't involve disease or reference biomarkers are not subject to any control. Any high-level claim concerning functionality and effect on health has to be approved by FSANZ.[67]

According to many analysts, China is showing huge growth potential as a functional food market, with sales of functional foods topping €200 million in 2005.[67] However, attractive as the market appears, the regulatory environment is seen as a major deterrent to new entrants.

Consumer trends

A recent Institute of Food Technology commissioned report gives insights into the demands for functional food products and highlights associated market trends.[68] It identifies the core themes for new consumer foods as low calorie; the provision of multiple benefits; and foods that reduce diet-related health risks for children. The report ranks functional food trends based on the focus of new products launched during 2005. Foods that specifically target children and aim to provide them with "healthier options" head the list. By providing greater variety, making it easier to eat a healthy diet, food companies responded to the health problems facing the "at-risk" category of children in the US. In doing so, they provided fortification whilst retaining the taste. Other groups were also targeted by offerings of fortified products including sports people, pregnant and lactating women and the aged. The emerging new function food products in the USA market are summarised in Table 1.

[67] Lewis, H. (2006) *Global market review of functional foods forecasts to 2010*, Aroq Ltd, UK, (justfood.com Report)
[68] Sloan, E. (2006) *Top 10 Functional food trends*, Food Technology, 0406, www.ift.org

Table 1 *Top 10 Functional food trends in the USA 2006*

MARKET AREA	KEY ISSUES
Children and others at risk	Targeting reduction of obesity related illness – reformulating products to be more nutrient, have less fat, and fewer calories, less sugar and sodium and by the introduction of more natural food ingredients – low fat dairy, soy products and cereals.
Limit on calorie intake	With increasing numbers of adults now looking after their weight and health they are turning to light and lower calorie products of smaller sized portions.
Introduction of phytochemicals	Interest in phytochemicals as a source of antioxidants and in antioxidants generally is rising. Food that contains added antioxidants is capturing market share from the food supplements product sales.
Provision of multiple benefits	Food that targets not only the immediate health concern – e.g. a desire to loose weight, but also some future health condition.
Incorporated healthy fats	Awareness of Omega-3s is rising and reflecting this is the launch of new low fat and Omega-3 containing products in the USA market.
More products dedicated to the aged	With ageing populations and rising incidence of age related disease products targeting this segment of what is seen as relatively untapped are rising. Heart connector foods are estimated to represent a$71 billion opportunity and pain/muscular/joints $40 billion; gastrointestinal $21 billion.
Low-glycemic	Products filling this space are expected to have a major impact on the market in 2006 and could become the most lasting, far-reaching market of all time in the food sector. Health benefits from low-glycemic foods could well outstrip the common perception of them as weight-loss aids and extend into appetite control, blood sugar level management and even mood control.
Organic foods	Growth in the organic food sector remains high, with converted consumers broadening their purchasing into more product categories. Increasing numbers of consumers are buying organic produce for their children; local food suppliers also benefit from the organic purchasing preferences of consumers.
Sports performance enhancing	Coping with the desire to maintain energy levels, raise them and trying to stay healthy are the reasons stated for buying energy food and beverages. These desires span young and old age groups and drive growth in the energy/health beverages market. Attempts in include PUFAs in dairy based health drinks have commenced.
Healthy deserts/treats/snacks	Foods with less sugar, fat and calories are beginning to replace more traditional "indulgent" foods. Healthy options in ice-creams, deserts, soft drinks, beers and wine, snack foods are finding there ways not only into main stream food retail, but also local convenience stores.

Source: *Sloan, A. E., Top 10 Functional Food Trends, Food Technology, April, 2006*

Meeting the health concerns of consumers cannot be done in isolation from more traditional food properties and consumer needs. The very same attributes that sell traditional foods - taste, texture, convenience, quality and the use of premium food ingredients - have an equal importance in healthier food products. However, some functional food ingredients, e.g. marine oils, present food scientists with major challenges in respect of masking the taste and smell of fish and oil.

Drivers of Functional Food Product Innovation

Health policy and government intervention

The decline in human health resulting from poor eating habits is responsible for the increase in both the value and volume growth of functional foods. Subsequent responses by industry and those involved in research into food and health cannot alone address these global health issues. The promotion of healthy eating practice and changes to lifestyles, often led by national governments and state health departments, is just as important. Canada, Australia and New Zealand have each initiated actions on the health-nutrition front in recent times. A ten-year programme in Canada costing C$41 billion includes specific research on functional foods. Australia has directed €2 million towards similar research. Ireland completed a major review of diet and health in 2005 that resulted in new policy requirements surrounding obesity and called for new initiatives to combat diet and lifestyle related illness and disease.[69] The Marine Institute led *National Knowledge, Research and Innovation Strategy - Sea Change*, identified the development of marine origin functional food and ingredients as a priority opportunity for Irish firms and calls for more research on marine origin functional materials.

Awareness and education

National governments and international agencies are concerned about the decline in human health standards. As a result, a number of countries have initiated specific health awareness and education initiatives. There are also concerns about the rising health costs of looking after a rapidly ageing population in the western world. The combined affect of this high-level concern is two-fold. Firstly, it is stimulating research activity; and secondly, it is raising awareness amongst consumers of the need to consider dietary health and adopt healthy lifestyles.

[69] Department of Health & Children (2005) *OBESITY – The Report of the National Task Force on Obesity*, Health Promotion Unit, Dublin, 2005

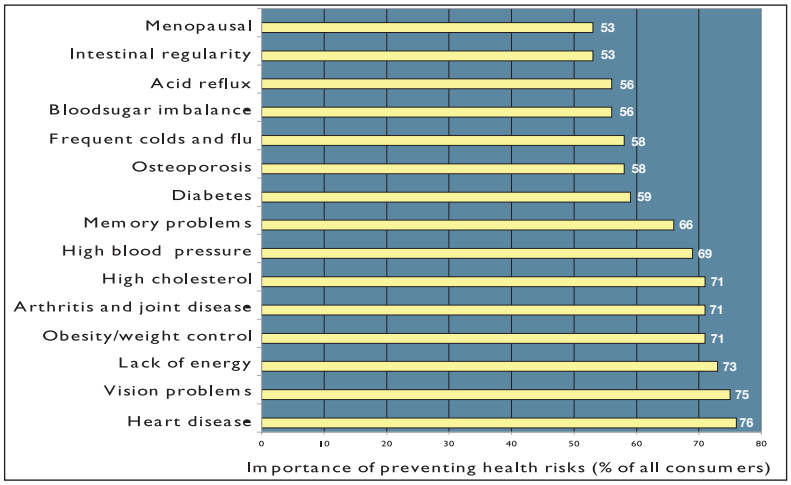
Lifestyle

Consumers are beginning to realise the difference between healthy and unhealthy foods. People are also being encouraged to adopt an overall healthier lifestyle, combining balanced diets with regular exercise. Reported growth in the sales of functional food products is closely linked to consumers' increasing interest in healthier lifestyles. The adages "you are what you eat" and "prevention is better than cure" appear to have some relevance as far as consumers are concerned. They partly explain the response to, and desire for, foods that prevent or alleviate diet-related illnesses. The desire to minimise the adverse effects of a "traditional" western diet on their health: changing eating habits to more "healthy" food products is now just as important as reducing weight.

Consumer health concerns

Consumers are beginning to be more concerned about health and are taking steps to attempt to prevent the onset of disease.[70] For the consumer intent on making positive health impacts through diet, the major health concerns they have relate largely to disease of the heart and problems with sight. These and other consumer health concerns indicate possible new directions for those seeking to develop functional foods and ingredients. The top health issues from a USA consumer perspective are listed in Figure 1. The health concerns of European customers are likely to be different to those of US consumers.

Figure 1 *Top health issues of consumers in the USA*



Source: Sloan, A. E., Top 10 Functional Food Trends, Food Technology, April, 2006

[70] Sloan, E. (2006) *Top 10 Functional food trends*, Food Technology, 0406, www.ift.org

Ingredients sector

Developing product responses to the consumer demand for healthier foods is a challenge for all food companies. Value-added food firms rely heavily on the ingredients sector to develop the bioactive materials that deliver food functionality. The availability of functional components is a limitation in providing functional food products. Securing access to highly desirable and effective functional ingredients is behind the development of value added products. The ingredients sector, rather than the consumer foods sector, is responsible for innovative functional food products.

Scientific research

Research remains a major driver of developments in the functional food sector. At a time when regulations concerning 'claims' associated with food products are changing, research outputs are highly important in securing market positions for functional food products and functional ingredients. Research activities include discovery of new materials; validation of their functional role; identification of nutritional properties of known materials; materials processing and extraction; development of bioassays; clinical trials and consumer studies. The food ingredients sector needs solid scientific support to be able to substantiate food-health claims.

Market Success Factors

The spread of functional food product opportunities are almost infinite, when looked at against a background of the rising health concerns and the steps already taken by food firms to develop new functional food products. Behind the food product innovation is a solid base of research, involving various disciplines, that isolated, validated and developed functional materials on which these new products are based.

There are many forces which drive the purchasing decision and hence influence the market success of functional foods. These are summarised in Table 2 and are relevant both to food ingredients and to functional consumer foods. These factors are not arranged in any hierarchy and are shown to reflect the array of attributes that researchers and others involved in the commercialisation of functional food ingredients and products in the USA take into account.

Table 2 *Functional food market success factors*

Functional food success factors
Taste, only just, is positioned ahead of the health benefits
Health benefits are clearly and concisely communicated via marketing and product packaging
Food product benefits are supported by solid scientific evidence
There is a combination of short-term health benefits and long-term disease prevention, control or reduction
Health claims are endorsed by independent recognised authorities
Products deliver nutrients with scientifically proven efficacy and bioavailability
Products provide consumers with interesting, unique and appealing flavours and convenience
Products have nutritional and health benefits of interest to the consumer
Development involved communications with the scientific and health professionals
Producers acknowledged the regulatory environment and the differences between national regulations
Producers developed novel distribution channels to build new markets
Research created ingredients and products that target specific health concerns – obesity, cardiovascular
Consistent product communications which highlight, food, health and lifestyle were used

Source: Just-food Global report 2006

Examples of Marine Materials in Recently Launched Functional Foods

Marine materials do not yet occupy a major position as a functional food ingredient. The major exception is Omega-3 fish oil, which appears to be slowly gaining in acceptance and use. Although the marine environment offers great potential as a source of novel ingredients, it remains relatively untapped and under developed. Table 3 gives some examples of products launched during 2005 to 2006 that included marine ingredients as the functional component. Taken from a total of 40 new and noteworthy functional food products, the five new marine-based products represent 12 percent of all launches reported by analysts Just-food.[71]

[71] Lewis, H. (2006) *Global market review of functional foods forecasts to 2010*, Aroq Ltd, UK, (justfood.com Report)

Table 3 *Marine material based functional foods, 2005 to 2006*

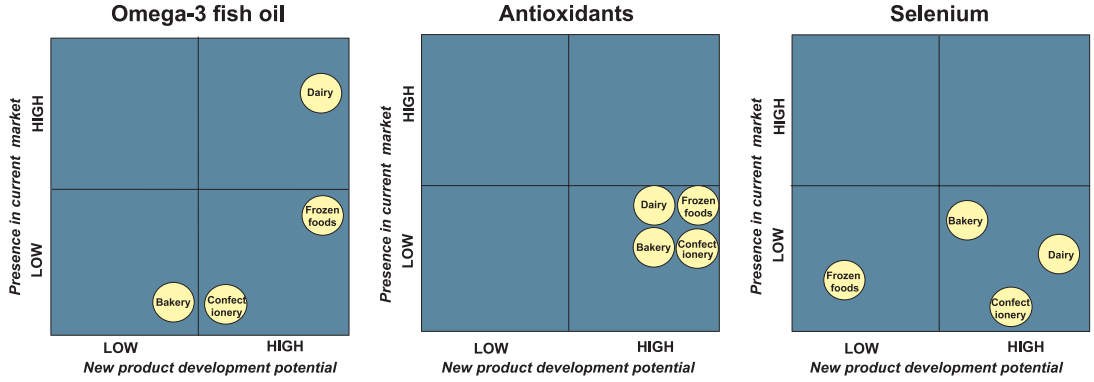
Product	Manufacturer	Marine component	Food segment	Country
Kernerug	Kohberg A/S	Omega-3 fish oil	Bakery	Denmark
XXXtreme	Fox's	Taurine[72]	Confectionery	UK
OMU drinkable yoghurt	Canton American	Omega-3 fish oil	Dairy	China
Fisherman's basket	Findus	Omega-3 fish oil	Frozen foods	Australia
Tender calamari rings	Sealord Group	Omega-3 fish oil	Frozen foods	New Zealand

Source: Just-food Global report 2006

Marine Related Ingredients - Growth Opportunities

In the 2006 Just-food Report, analysts identified market opportunities for functional foods and ingredients in bakery, cereals, confectionery, dairy and frozen foods.[73] In doing so, they identified market potential of specific functional ingredients. Marine origin materials featured as offering high potential as fundamental components in new value-added consumer foods. Selenium, a raft of antioxidants and Omega-3 fish oils have identified roles to play in future food products. The market positioning and new product development (NDP) potential of these components are highlighted in Figure 2 and point to the incorporation of fish-oils in dairy products as offering the highest growth potential overall. Antioxidants also offer high potential as components in value added foods, but do not appear to have the same level of market penetration as fish oils.

Figure 2 *Marine origin ingredient potential*



[72] Available from fish, it is unknown if fish is the source of the Taurine
[73] Lewis, H. (2006) *Global market review of functional foods forecasts to 2010*, Aroq Ltd, UK, (justfood.com Report)

7. International Marine Related Functional Food Research

Ireland, having established the core scientific expertise and demonstrated an international standing in functional food research, is well positioned to accelerate its activity in what is largely a new and underdeveloped research area – Marine Functional Foods. Other countries are already engaged in the identification and development of functional food components from the marine environment and have targeted public monies at the activity. It is also very clear from various market studies, and indeed the Irish experience, that food ingredients firms and value added food firms are also engaged in supporting discovery-oriented research.

The identification and exploitation of marine bio-materials (bioactive and other compounds from marine organisms and the wider marine environment), the development of value-added marine food (such as modified fish and seaweed production), and the utilisation of non-food products from the marine (such as micro-organisms) offer possibilities for new enterprise activity. A wide range of pre-commercial research is required to stimulate and enable commercial activity. Some examples of international research effort concentrating on the marine as a source of ingredients are given below.

Nordic Countries

Since the 1990s, Iceland's Fisheries Laboratories have been engaged in a range of projects that exploring the functional properties of fish and other marine organisms. Norway through research at the Norwegian University of Science and Technology and the Norwegian Institute of Fisheries and Aquaculture Research, similarly maintains a long tradition in exploring the potential of marine origin ingredients in functional foods.

The Proceedings of the Joint Trans-Atlantic Fisheries Technology Conference gives some insight to the areas of marine related functional food research conducted by the Nordic countries.[74] The titles of some relevant research papers delivered at the 2003 Conference are listed in Table 4.

[74] Trans Atlantic Fisheries Technology Conference (TAFT 2003), Iceland, June 11–14, 2003, http://vefur.rf.is/TAFT2003/

Table 4 *Nordic country marine functional food research*

Theme: Innovative handling and processing of fish and shellfish	
	Country
Minimal processing technologies in the food industry	SE
Radio-frequency heating of minimally processed fish products - Possible quality improvements by rapid heating	NO
Possibilities of new processing and distribution of sea-frozen cod *(Gadus morhua)* fillets packaged under modified atmosphere	IS
Effect of pre-rigor filleting and other process parameters on smoked salmon quality	IS
Theme: Development of fish products for health and well-being	
	Country
Development of new functional fish products to promote health and well being	NO
Theme: Consumer perceptions to fish consumption	
	Country
Antecedents of seafood consumption behaviour	NO
Brining of cod fillets: influence on sensory properties	NO
Brining of cod: Enhancing consumers' preference	NO
Consumer perception of wild and farmed cod under different information conditions: Two in-home consumer studies	NO
Consumer survey: Cod fillets packaged in air and modified atmosphere (MAP)	IS
European consumer preference for smoked salmon	IS
Theme: Functional properties of fish components	
	Country
Haemoglobin-mediated oxidation of washed cod mince phospholipids: Effects of pH and haemoglobin source	SE
Protein solubility of herring proteins as affected by freezing and frozen storage	IS
Oxidation of cod liver oil - use of naturally occurring anti-oxidants	NO
Hydrolysis of cod *(Gadus morhua)* by-products: Influence of initial inactivation, amount of added water and centrifugation conditions	NO
Matrix metalloproteinases in fish muscle	NO
Seasonal changes in trypsin- and chymotrypsin-like activity in viscera from cod species	NO

Table 4 *Nordic country marine functional food research (continued...)*

Theme: Novel compounds derived from marine origin	
	Country
Deep-sea species - A source for human consumption and novel compounds with beneficial health effects	NO
Variation in lipid composition in different by-product from species of the gadidae family	NO
Enzymes and bioactive peptides from fish waste related to fish silage, fish feed and fish sauce production	NO
Bitterness in fish protein hydrolysates: Origin and methods for removal	NO
Volatile flavour compounds in seafood flavorants	NO
Utilization of fish by-products in Iceland	IS
Recent developments in deacetylation of chitin and possible applications in food formulations	IS

Research collaboration between Nordic countries led to the creation of MARIFUNC - a research network dedicated to marine ingredient research.[75] Involving researchers from Norway, Denmark, Iceland, Sweden and Finland working in collaboration MARIFUNC plans reflect the potential to utilise nutrients and other bioactive substances isolated from fish, and the use of fish, as ingredients for functional foods. The project commenced in July, 2006 with an initial budget of €553,000. Its initial focus is reported as directed towards research in health claims for marine functional foods; consumer acceptance of marine functional foods; innovative consumer driven marine functional foods product and ingredients development and networking, cooperation and international positioning.

The EU

The SEAFOODplus project supported by the EU Sixth Framework Programme is a major marine oriented functional food research project.[76] It involves partners from 16 countries, including Ireland, working on 20 marine foods-related research projects. The Programme objective is "to make it possible to reduce health problems, to prevent major diseases and to increase well-being among European consumers by using the opportunity to apply the benefits obtained through consumption of health promoting and safe seafood products of high eating quality." Areas of research include; seafood and human nutrition; consumer behaviour and well-being; seafood safety; seafood from aquaculture; and traceability. The individual projects for each of the five RTDI pillars of the SEAFOODplus project are listed in Table 5.

[75] Nordic Network for Marine Functional Food (MARIFUNC), www.marifunc.org
[76] www.seafoodplus.org

Table 5 *SEAFOOD plus projects*

Pillar 1 Seafood and human nutrition
Gastro-intestinal health with special emphasis on reduction of risk of colon cancer and inflammatory bowel disease
Health of young European families and fish consumption
Metabolism of n-3 fatty acids and heart disease
Pillar 2 Seafood and consumer behaviour and well-being
Seafood Consumption: Explaining attitudes, preferences and eating habits across consumer segments in Europe
Improved seafood sensory quality for the consumer
SEAFOOD Information and Communication: Assessment of consumer needs for seafood information and the development of effective seafood communication
Consumer evaluation and willingness to buy convenience and tailor-made seafood products
Pillar 3 Seafood safety
Development of standard reference methods for hepatitis A virus and Norovirus in bivalve molluscan shellfish
Reduction of risk in shellfish harvesting areas
3 Seafood: Enhanced assessment of bacterial associated contamination
Biogenic amines in seafoods - assessment and management of consumer exposure
Pillar 4 Seafood from source to consumer
High added-value functional seafood products for human health from seafood by-products by innovative mild processing
Hurdle technology (including minimal processing) to ensure quality and safety of convenience seafood
Preventing seafood lipid oxidation and texture softening to maintain healthy components and quality of seafood
Consumer driven development of innovative tailor-made seafood products (with functional components from plant or marine origin) to improve health of consumers
Pillar 5 Seafood from aquaculture
Physiology and genetics of seafood quality traits
Ethical quality traits in farmed fish: The role of husbandry practices and aquaculture production systems

Functional Foodnet (FFNet), is a Specific Support Actions (SSA) project financed by the EU 6th Framework Programme.[77] It seeks to strengthen the innovative capacity of the food industry in the area of functional and healthier foods; marine functional food is just one of a number of related strands in this project. The four principle goals of the FFNet programme are:

- Technology and information transfer on scientific research, on markets and on the legal considerations for functional food production and health claims in the EU;
- Proactive networking to establish new collaborations and business relationships amongst non-competing companies;
- Forming a collaborative platform of key European food and ingredient companies, scientists, health professionals, marketing and innovation specialists; and
- Establishing trans-European product-specific working groups.

Japan

Japan is the recognised home of functional foods. The whole concept of functional foods was born there in the late 1980s, largely in response to clearly identified public health needs - that Japanese needed more calcium and fibre in their diets. Since then, Japan has invested heavily in science to identify and exploit other functional food ingredients. The typical Japanese diet is rich in fish. It is no coincidence therefore, that there is a deep tradition in the use of natural products from marine resources for the production of functional ingredients and nutraceuticals in Japan.

Fatty fish and fish oils are rich sources of Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA). Japanese scientists are exploring the functional benefits of fish oils (DHA) in cognitive health, behavioural disorders and as anti-cancer treatment.[78,79] (EPA) encapsulated products with over 92 percent of purity are used in pharmaceutical products for atherosclerosis and for hyperlipidemia.[80] Many advanced scientific studies on the isolation and utilisation of bioactive natural products for pharmaceutical applications, including anti-microbial anti-mould, anti-virus and anti-tumour compounds, have been carried out.[81]

[77] www.functionalfoodnet.eu

[78] Shirai, N. & Suzuki, H. (2006) *DHA and its Derivatives as Potential Anti-Cancer Drugs and other Therapeutics*, In Proceedings of the 7th International Conference on Nutraceuticals and Functional Foods, November 5 – 8, 2006, Reno, NV

[79] Hosokawa, M., Sashima, T., Maeda, H. & Miyashita, K. (2006) *Effect of a Simultaneous Supplmentation with Fish Oil and Green Tea Extract-Using Japanese Processed Foods on Intelligence in the Elderly*, In Proceedings of the 7th International Conference on Nutraceuticals and Functional Foods, November 5 – 8, 2006, Reno, NV

[80] Seaton, T. (2006) *The Omega 3 Explosion*, Nutraceuticals World www.nutraceuticalsworld.com/articles/2006/03/the-omega-3-explosion.php

[81] Ohshima, T. (2004) *Food technology – Value added utilisation of marine products – Success story in Japan*, In Advanced Topics for Fisheries and Marine Science – course content, Tokyo University of Marine Science and Technology, www.soi.wide.ad.jp/class/20040015

Peptides are pre-assembled, short chains of amino acids with a wide array of potential applications - from skin disorders to anti-hypertension. Japanese research is active in seeking marine origin peptides. Research into the chemical nature and biological properties peptides of sea urchin egg jelly, peptides of marine worms and marine vertebrates is underway.[82] Products incorporating peptides from sardines and bonito to aid the treatment of hypertension are available.[83] Research into the use of marine origin peptides to treat the symptoms of diabetes, lower levels of cholesterol and increase mineral absorption is also underway.[84]

Korea

Market growth opportunities and recognition of the ability of functional ingredients to induce beneficial physical effects in humans drives Korean functional food research. The Korean Food Research Institute initiated a project to target the marine environment as a source of novel materials, seeking to identify and commercialise bioactive compounds.[85] This project started in 2002 and is engaged in research to define methods to support the efficient use of marine bio-resources. It is looking at methods for the isolation and purification of functional materials. The research project approach is quite specific; it targets the production of chondroitin as a potential component in anti-arthritis functional foods and will screen marine plants for polyphenolic sources to be used in the rapidly expanding antioxidants market.

New Zealand

New Zealand has set ambitious targets in a focused research programme to transform its seafood industry into a supplier of high value functional marine ingredients. Directed and managed by New Zealand's Crop and Food Research Institute, the programme has two goals.[86] Firstly, it sets out to develop new knowledge about the superior or differentiated biochemical, chemical and physicochemical properties of the under-utilised collagen, protein, enzyme, lipid and carbohydrate components from marine sources. In doing so, it targets maximising fishing bycatch and seafood processing waste as a source of materials. Secondly, it plans to use and apply this new knowledge to underpin and develop new processes for extracting or separating ingredients from fishery discards, for purifying and preserving these ingredients, and for using them in novel food and other applications. The long-term programme goal is to generate results that will help create both significant wealth from a new marine ingredients sector and a more sustainable future for New Zealand's fishing sector.

[82] Bhakuni, D. S. & Rawat, D.S. (2005) *Bioactive Marine Peptides*, Springer, Netherlands, 2005
[83] Report by Nippon Supplement Inc. (2006) *Katsuobushi Oligopeptide - A functional food with anti-hypertensive activity*, www.nippon-sapuri.com/english/home.html
[84] Gutierrez, M.A. (2004) *What has been done by research and development in Japan to document health properties of marine by-products?* Report by TINE Biomarin, Bergen, Norway, January 2004
[85] www.kfri.re.kr/newekfri/index_06.htm
[86] www.crop.cri.nz

8. Irish Functional Food Research Activity

Compared to the research effort that continues to target dairy-based functional food development, the potential of the Irish marine sector to provide functional ingredients is yet to be developed. Action to close the knowledge gap and expand research activity in this area requires not only the refocusing of some resources, but also the creation of new capacity within the Irish research and innovation system.

Clear national planning priorities and the allocation of significant financial resources has helped to create a foundation of institutional based research skills in functional foods. This is a platform on which to build new research capabilities in marine origin functional ingredients. *Sea Change: A Marine Knowledge, Research and Innovation Strategy for Ireland 2007 to 2013* provides the framework for new research initiatives in marine origin functional foods and ingredients.

Ireland has an international reputation in dairy research and was able to use this expertise to identify opportunities to derive value-added materials from fresh milk. With a solid international reputation in marine sciences Ireland has an opportunity to similarly develop opportunities for marine origin value-added products. Recent investments in biotechnology research and marine sciences, particularly the marine life sciences, provide core skills to support research in marine origin materials as a source of functional food ingredients.

Important as the development of scientific skills is, there is also a need to further develop research management skills in order to integrate research activities and manage priorities. It is also necessary to strengthen links between the food and nutritional scientists and the marine life scientists. Mechanisms that strengthen links between the institutional research community and industry are also needed.

Irish and Internationally Funded Projects

The Department of Agriculture and Food FIRM (Food Industry Research Measure) Programme and its predecessor the Non-Commissioned Food Research Programme provided significant funds for food research. Together these initiatives have provided approximately €100 million to develop Irish research capabilities and increase our national capacity to engage in food related research. The support provided has enabled a wide range of functional food related research to be completed. It is generally recognised that this early funding positioned Ireland on the international stage as far as functional food research is concerned. Successive national research funding rounds, including initiatives such as the

Higher Education Authority PRTLI and Science Foundation Ireland continue to add further research capabilities and expand Ireland's research capacity in functional food.

National funding has positioned Irish researchers to engage in international research in areas related to functional foods. Irish research scientists have participated in international functional food projects with a marine dimension to them.[87] Support from EU 5th and 6th Research Framework Programmes also supported Irish scientists to engage in functional food research. A summary of the functional food projects supported by Irish agencies and by EU funding that included a marine dimension is given in Table 6. Functional food projects that received support from the Department of Agriculture and Food FIRM Programme and EU funds are shown in Table 7 and Table 8 respectively.

Table 6 *Marine functional food projects - Irish and EU funded*

Project title	Leader	Source of funds
Utilisation and stabilisation of by-products from cod species	UCC	Ireland
Novel Functional beverages based on Polysaccharide additives of algal origin	NUIG	Ireland
SEAFOOD Plus	Teagasc (Irish leader)	EU
FFNet (Functional Food Net)	Teagasc (Irish leader)	EU

Source FIRM-Relay www.relayresearch.ie

[87] Irish researchers are known to be working in SEAFOODplus and other projects involving international partners (www.seafoodplus.org)

Table 7 *Nationally funded functional food projects 2000 to 2006*

Project title	Leader
Beverages to promote optimum skeletal joint function	UCD
Development of a new generation of fermented (non-alcoholic) functional cereal beverages	UCC
Functional beverages containing health-promoting prebiotic milk oligosaccharides	Teagasc
Development of bioactive oligosaccharide-enriched ingredients derived from whey	Teagasc
Biopolymer films: from structure to mechanical properties	Teagasc
FUNLAC: Lacticin-based Ingredients for biopreservative and functional food applications	Teagasc
Development of novel probiotic and symbiotic (probiotic & prebiotic) products	UCC
Bioavailability of health promoting ingredients from functional meat and dairy foods: cost-effective in vitro assessment	UCC
Nutritional and metabolic effects of phytosterols: functional benefits of plant sterols and stanols as ingredients in functional foods	UCC
Designer biocultures for promotion of human and animal health	Teagasc
Stabilization of probiotic cultures by encapsulation and entrapment for use in functional foods	Teagasc
Live 5: Probiotics for Salmonella reduction in the food chain	Teagasc
Development of novel functional ingredients for use in the manufacture of convenience foods including meat	UCC
Evaluation of nutritional effects of phytosterols and oxyphytosterols in the food supply	UCC
The health benefits of conjugated linoleic acid (CLA) on coronary heart disease (CHD)	UCC
Potential benefits of conjugated linoleic acid (CLA) to bone health	UCC
Functional foods enriched in the health promoting fatty acid-conjugated linoleic acid (CLA)	Teagasc
Probiotic functional foods using probiotic bifidobacteria	UCC
Probiotic functional foods using probiotic lactobacilli bacteria	UCC

Source FIRM-Relay www.relayresearch.ie

Table 8 *EU Funded Functional Food Projects*

Project title	Irish partner
Nutritional enhancement of probiotics and prebiotics: technology aspects on microbial viability, stability, functionality and on prebiotic function.	Teagasc
Informall - Communication about food allergies - information for consumers, regulators and industry	
Plant food allergies: field to table strategies for reducing their incidence in Europe (SAFE)	
Folate: from food to functionality and optimal health	
Garlic and health: The development of high quality garlic and its influence on biomarkers of atherosclerosis and cancer in humans for disease prevention	
Design of foods with improved functionality and superior health effects using cereal beta-glucans	
The role of lipids in neurodegeneration and their preventive potential in diet	
Increase in nutritional value of food raw materials by addition, activity, or in situ production of microbial nutraceuticals	UCC
The effect of olive oil consumption on oxidative damage in European populations	
European research on functional effects of dietary antioxidants	UCC
Barley beta-d-glucan and wheat arabinoxylan soluble fibre technologies for health promoting bread products	
Hypotensive peptides from milk proteins	UL
Flavonoids in fruits and vegetables : their impact on food quality, nutrition and human health	
BIOCLA: Production of CLA enriched dairy products by natural means	Teagasc
Diet, genomics and the metabolic syndrome: an integrated nutrition, agro-food, social and economic analysis	UCD
Health Grain - Exploiting bioactivity of european cereal grains for improved nutrition and health benefits	
Increasing fruit consumption through a trans disciplinary approach leading to high quality produce from environmentally safe, sustainable methods (ISAFRUIT)	
Stable isotope applications to monitor starch digestion and fermentation for the development of functional foods	

Source: FIRM-Relay www.relayresearch.ie

It is clear that the majority of Irish involvement in functional food research to date is outside the marine area. However, the tables 6, 7 and 8 illustrate the wealth of Irish research experience that is directly relevant to supporting marine functional food research.

Three institutions, Teagasc, University College, Cork (UCC) and University College, Dublin (UCD), performed the majority of Irish functional food research in the projects identified above. The University of Limerick and the National University of Ireland, Galway are also involved in functional food research, as are other institutions. Significant resources, both human and physical, necessary for functional food research exist at UCC, UCD and Teagasc.

Enterprise Ireland, in collaboration with leading players in the Irish food ingredients sector, is funding the development of a 'virtual' functional food research centre. This initiative will focus on the exploitation of dairy origin materials in functional foods. The research will target specific diseases. According to Enterprise Ireland formal announcements regarding partners and projects will be made in early 2006.[88]

[88] This initiative was announced at the Functional Food Forum meeting in Portlaoise, June 2006

9. Ireland's Marine Resource

Irish waters contain some of Europe's most productive fishing grounds and are home to a wide variety of plant life, shellfish, mammals and micro-organisms. Although much is known about commercial fisheries resources, much remains to be discovered about the full potential of Ireland's total marine resource. Recent seabed mapping by the Irish National Seabed Survey (INSS) provides physical characteristics of the marine habitat. Detailed mapping of 87 percent of Ireland's 90 million hectare marine environment has been completed. INFOMAR, the successor to the INSS, will map and provide survey details of inner coastal areas of Ireland. Seabed mapping provides the first essential step for scientific fisheries management and in monitoring environmental change. Commercial fishing activities generate revenue and sustain rural communities in coastal areas and in 2004, Irish waters produced 1.5 million tonnes of fish valued at €186 million.

Ireland actively manages its fish resource under the EU Common Fisheries Policy. This is a limited approach to fishery management; placing catch limits on species but falling short of recognising the potential direct and indirect impact of fishing on the ecosystem. Fish stocks are renewable resources with limited levels of production and can only replace or produce a given biomass each year through reproduction and growth. Fisheries without a management system typically overexploit fish stocks to the point that their production capacity is limited. The EU Council of Fisheries Ministers agree the EU's total allowable catch (TAC) for species and allocate catch quotas to member states.

Ireland's aquaculture activities are outside the scope of any fish quota regime and therefore represent an opportunity to maximise the sector's output as a source of raw materials from which bioactive components can be extracted. Together with marine micro-organisms, aquaculture offers development potential. However, further research is needed to be able to target species as sources of functional components.

Internationally, the seaweed industry provides a wide variety of products with an estimated combined value of $ 5.5-6 billion per annum from 2000: including wild harvested as well as aquaculture output totals 7.5-8 million tonnes annually. Food products for human consumption account $ 5 billion of this total. Hydrocolloids, including agar, alginate and carrageenan extracted from various red and brown seaweeds generate nearly $1 billion, while smaller, miscellaneous uses, such as in fertilisers and animal feed additives, make up the rest.[89]

[89] McHugh, J.A. (2003) *A guide to the seaweed industry*, FAO Fisheries Technical Paper 441, Rome, 2003

Fish Stocks

Ireland's share of fishery stocks as defined by the Common Fisheries Policy changes over time. The Irish quotas for 6 out of 15 key economically important species were reduced between 2005 and 2006. The only species for which quotas either increased, or remained static for 2006, included nephoros, monkfish, hake, haddock, sole, mackerel and horse mackerel.[90] Importantly, in light of their potential as a source of functional ingredients the quota for both mackerel and horse mackerel increased to 47,894 tonnes and 33,546 tonnes respectively. Blue whiting and herring also contribute significantly to total landings; although their quotas were reduced in 2006.

Table 9 *Summary of Irish fish quota comparison between 2005 and 2006 quotas*

	2005 volume (tonnes)		2006 volume (tonnes)		
Stock	**TAC**	**Ireland**	**TAC**	**Ireland**	**Change to Irish Quota**
Nephros	32,244	7,380	39,173	8,167	11%
Monk	29,768	2,370	31,142	2,474	4%
Hake	23,888	1,318	24,617	1,358	3%
Haddock	19,822	3,213	19,927	3,222	0%
Sole	2,743	550	2,692	548	0%
Mergrim	22,143	3,562	21,180	3,402	-4%
Saithe	20,618	2,062	17,535	1,957	-5%
Plaice	3,692	1,774	3,410	1,658	-7%
Whiting	23,714	6,780	21,737	6,202	-9%
Cod	28,570	2,719	26,941	2,443	-10%
Pollock	17,563	1,377	15,750	1,231	-11%
Mackerel	217,477	46,149	225,837	47,894	4%
Horse mackerel	173,869	33,053	176,214	33,546	1%
Herring	150,777	37,602	126,590	35,334	-6%
Blue whiting	474,333	75,893	222,109	43,010	-43%
Totals	**1,241,221**	**225,802**	**974,854**	**192,446**	**15%**

Source: Marine Institute Stock Book November, 2005

[90] Marine Institute (2005) *The Stock Book – Annual Review of Fish Stocks in 2005 with Management Advice for 2006*, Marine Institute, Galway, November 2005

In Irish waters stocks of cod, which is traditionally looked upon a source of Omega-3 oils, have been overfished and in some cases are in danger of collapse. Against this background, alternative oil bearing species have to be considered. The main 'oily' fish species (excluding wild salmon and trout) are migratory and include mackerel, horse mackerel, herring and blue whiting.

Marine Plants and Algae

Because of the many claims that have been made for the effectiveness of seaweeds on human health, principally associated with its consumption, marine algae (seaweed is classified as an algae not a plant) offer potential as functional ingredients. Seaweeds are a source of food and consumed either fresh or dried. They are rich in minerals and enzymes and are attractive to the pharmaceutical, cosmetic and biotechnological industries as well as the food sector. Seaweeds are also used as an agricultural fertiliser.[91]

Seaweeds, often referred to as micro-algae are classified into three broad groups based on their pigmentation: brown, red and green. Brown seaweeds contain more bioactive components than either red or green seaweed. Species around the Irish coast that are known to be used as 'sea vegetables' and therefore fit for human consumption, include brown, red and green seaweeds as indicated in Table 10.

Table 10 *Human consumption of Irish seaweeds*

Brown seaweeds	Red seaweeds	Green seaweeds
Alaria esculenta (Atlantic Wakame)	***Palmaria palmata*** (Dulse or Dillisk)	***Ulva lactuca*** (Sea Lettuce)
Laminaria digitata (Kombu)	***Chondrus crispus*** (Carrageen)	***Enteromorpha sp.*** (Green Stringy weed)
Laminaria hyperborea (Kombu)	***Porphyra sp.***	
Laminaria saccharina (Sweet Kombu)		
Himanthalia elongata (Sea Spaghetti)		

Source: www.irishseaweed.com

[91] Guiry, M., *Seaweed Site,* www.seaweed.ie

A rich diversity of seaweed exists around the Irish coast with over 500 different species identified since the 18th Century.[92] It is not surprising therefore that a long tradition in the use of seaweed exists in Ireland. Seaweeds were once widely used as an agricultural fertiliser, cattle fodder, as human food, in the manufacture of soap and as a pottery glaze. Today wild stocks of seaweed in Ireland yield approximately 36,000 tonnes annually.[93] World output stands at close to 8 million tonnes.[94] The extent of the Irish seaweed resource has not been fully determined.

Aquaculture

Aquaculture is a controllable marine materials resource. The Irish aquaculture sector produces a variety of fish, shellfish and seaweeds for human consumption and is an important contributor to the national economy. With much activity based in relatively under-developed coastal areas, the aquaculture sector plays an important role in sustaining rural communities.

Modern Irish aquaculture began its development in the 1970s but remains relatively under developed. To date the sector has concentrated on the production of shellfish, the main species being mussels, oysters (both native and Pacific), clams and scallops; salmon and rainbow trout and more recently cod. Attempts to farm turbot ceased in the 1990s. There is also a small-scale production of freshwater perch.[95]

The potential for Ireland to develop seaweed aquaculture was highlighted by the Marine Institute in its strategic review of seaweed aquaculture.[93] To date activity in the sector is limited to the issue of licences and to a small number of pilot projects. A number of seaweed species have been identified as particularly suitable for cultivation in Ireland, including *Alaria esculenta, Palmaria palmata, Asparagopsis armata, Chondrus crispus* and *Laminaria saccharina*.

A summary of Ireland's aquaculture output for 2003 and 2004 is shown in Table 11.

[92] www.irishseaweed.com/nutritionalanalysis/brief_history_of_seaweed_uses_in.htm
[93] Werner, A., Clarke, D. & Krann, S. (2004) *Strategic Review of the Feasibility of Seaweed Aquaculture in Ireland*, Marine Institute, Galway 2004
[94] McHugh, J.A. (2003) *A guide to the seaweed industry*, FAO Fisheries Technical Paper 441, Rome, 2003
[95] Parsons, A. (2004) *Status of Irish Aquaculture 2004*, Marine Institute, Bord Iascaigh Mhara & Taighde Mara Teo, Galway.

Table 11 *Irish aquaculture production 2003 and 3004*

	Volume (tonnes)		Value (€,000)	
Species	**2003**	**2004**	**2003**	**2004**
Shellfish				
Rope mussel	9,313	8,755	7,568	6,871
Bottom mussel	29,976	28,560	21,653	21,014
Gigas oyster	4,830	5,103	9,902	12,204
Native oyster	325	390	1,324	1,636
Clam	154	181	795	711
Scallop	80	103	380	437
Total shellfish	***44,678***	***43,092***	***41,782***	***43,600***
Finfish				
Salmon ova/smolts	-	-	2,000	2,337
Salmon	16,347	14,067	54,198	51,289
Sea reared trout	370	282	1,200	860
Freshwater trout	1,018	889	2,318	2,116
Other finfish	40	25	350	300
Total finfish	***17,838***	***15,263***	***60,066***	***56,902***
Total aquaculture	**62,516**	**58,355**	**101,848**	**100,502**

Source: Status of Irish Aquaculture 2004, Marine Institute, Bord Iascaigh Mhara and Taighde Mara Teo

Marine micro-organisms

Over the past decade, marine micro-organisms have become recognized as an important and untapped resource for novel bioactive compounds. Various reports indicate the diversity of micro organisms living in the sea and highlight chemical compounds that have been discovered. Of the billions of species of marine micro organisms, only a few thousand have been isolated and described. Yet the collective molecule-making skills of marine microbes produce a vast diversity of natural chemical products. These could yield new pharmaceuticals, fine chemicals, pollution remediation agents, industrial enzymes, flavouring agents, and other products.

The oceans cover greater than 70 percent of the earth's surface and, taking this into account by volume, represent more than 95 percent of the biosphere. Given this fact, the expanse of Ireland's marine territories present themselves as unexplored areas of opportunity for the discovery of bioactive compounds. The Marine Institute has commenced a pilot biodiscovery project that targets sponges as a potential source of pharmacological compounds for cancer treatment. Against this background, and with knowledge of the increasing international interest in the use of micro-organisms in the production of food and in food products, efforts to isolate unique micro organisms from Ireland's waters are justified. However, there is limited knowledge of the physiological requirements of most marine micro organisms and of their potential in the food sector.

The sequencing of marine genomes and the techniques of functional genomics (including transcriptome, proteome, and metabolome analyses) open up new possibilities for the screening of new metabolites of biotechnological interest and those offering potential in the food sector. Although the sequencing of microbial marine genomes has been somewhat limited to date, selected genome sequences of marine bacteria and algae have already been published.[96]

[96] Schweder, T., Lindequist, U. & Lalk, M. (2005) *Screening for New Metabolites from Marine*, Adv Biochem Eng Biotechnol. 96:1-48

10. Themes for Future Irish Marine Functional Food Research

Internationally, there are examples of various approaches being used to set the research agenda for functional foods. Some focus research effort on particular organisms or groups of organisms; others on finding bioactive materials that target specific diseases. Research can target specific consumer categories - different age groups, women or even ethnic origins. It is also possible to build research competencies around known functional materials and bioactive ingredients or by targeting primary economic sectors such as agriculture and the marine as possible sources of new bioactive ingredients. A bio-prospecting approach, seeking to discover bioactive materials from the marine environment can prove to be open-ended; hence some target area is a more strategic approach. Alternatively, a broader, more science-based approach to defining a research programme could be considered; one in which broad themes related to marine functional foods allow a scientific agenda to be developed around research competencies.

The initial concept and broad content of a dedicated research programme in marine functional foods originated in *Sea Change: A Marine Knowledge, Research and Innovation Strategy for Ireland 2007 to 2013*. Recent contributions from Ireland's research community - food sciences and marine science, and the likely long-term beneficiaries – the seafood processors, consumer food companies and food ingredients firms helped to further highlight priorities and provide an overall thematic structure to a research programme.

Programme

Sea Change: A Marine Knowledge, Research and Innovation Strategy for Ireland 2007 to 2013 sets broad objectives for a marine functional foods research programme. It sets goals to use materials from the marine environment as functional ingredients, in functional foods, and in value-added seafood products; and for ensuring Ireland develops the necessary long-term capacity and research capabilities. These are outlined below.

Research Goals

- To isolate, identify, characterise and determine the bioavailability of functional materials;
- Understand their mechanism of action and how they promote health and reduce the risk of chronic diseases; and
- Develop them, through new processes, into ingredients that add value to food and non-food products.

Capacity and Capability Enhancement

- Build research teams to engage in long-term research activity that places Ireland on the international stage and allows it to be recognised recognised as a leader in marine functional foods research;
- Ensure Ireland recruits and maintains high quality postgraduates and other research staff with specialist scientific skills that benefit the Irish marine food and food ingredients sector;
- Encourage the formation of strong national scientific collaboration to generate specialist knowledge in areas of science relevant to marine functional ingredients;
- Enable Irish research institutions to compete for leadership roles in future international research programmes, e.g. 7th Framework Programme;
- Contribute to raising the levels of research performance and the utilisation of research knowledge in the marine foods sector; and
- Maximise the contribution of research funds from other sources to support functional food research.

Research Themes

It is important to concentrate what could well be limited financial support for research upon areas where Ireland has a natural advantage regarding the availability of potentially useful functional materials, or an abundance of species that can be exploited, whilst maintaining stocks at replacement levels. This approach suggests four areas to target research – aquaculture, seaweed, marine micro-organisms and abundant fish species.

Supporting the delivery of the programme goals are a range of possible research themes. These themes do not attempt to set a research agenda or describe a particular research project, but rather provide scope for researchers to address issues of current major commercial and scientific interest.

Extracts obtained from seafood processing discards

These materials have many un-explored and under-exploited properties. Fish enzymes, protein and mineral extracts, and biomolecules extracted from fish collagen or lipid sources promise a wide range of unique biological, chemical or physical functionalities. Research would help to develop seafood composition, seafood biochemistry and bioprocessing skills and the processes needed to exploit innovations in this area. By international standards, Ireland has a small and highly dispersed fish waste sector; it may not be economically feasible to exploit Irish waste materials.

Marine origin functional ingredients

This research theme would include generating the essential new knowledge required to identify high-value marine ingredients that exist within Ireland's marine environment and which possess properties of relevance to the functional food sector; including the identification of new processes for extracting and purifying compounds for use as ingredients. It would target the identification of functional materials such as anti-hypersensitive proteins (peptides and protein hydrolysates), antioxidants, selenium, taurine, polysaccharides, polyphenolics and other bioactive components in marine species.

Applications for novel marine ingredients

Functional ingredients are found in foods, cosmetics, pet food, animal feeds, dietary supplements, bioactive packaging and a range of other industrial products. The primary focus of this theme is to research and demonstrate new concept products based on marine origin materials, in advance of their commercial exploitation. It would aim to identify non-food

applications for marine materials. This research theme is closely linked to the Marine Institute supported pilot programme in Bio discovery that targeted marine sponges as potential sources of bioactive materials.

Marine origin consumer foods

This theme aims to support the seafood sector to capture and maximise the natural value of Ireland's seafood. It would involve research to increase our understanding of post-harvest physiology and biochemistry of key commercial seafood species; improve processing and the identification/assessment of the role of underutilised fish species as new consumer foods; and improve the preservation of fish and extend shelf-life. Seeking ways to improve the utilisation of fish could impact on the sector's competitiveness as well as generate new fish products.

Marine functional food

Opportunities exist, for example though aquaculture, to increase the levels of bioactive materials in seafood. This theme is designed to enable approaches such as this to be explored to improve or enhance the inherent functionality which is present in certain species of fish and shellfish. This theme could also include research into the use of functional feed in aquaculture; including probiotics, thereby improving the survival of farmed fish.

Nutrition and health

Health and nutrition sciences are the fundamental pillars of functional food research activity. They combine to explore the impact and efficacy of potential materials on disease and in maintaining well-being. Research in areas such as the nutritional properties of marine materials, bio availability of ingredients in marine materials, the absorption mechanisms of ingredients by the body; and methods that lead to the justification of claims associated with functional marine materials all fall within this broad theme.

Safety of marine origin materials

The marine environment is potentially a source of dangerous pathogens. Fish remains a potential source of chemical contaminants. Persistent organochlorine compounds, e.g. PCBs, dioxins and insecticides such as DDT/DDE, accumulate in the marine food chain. Cadmium, lead, mercury and arsenic can also accumulate in the marine environment. In extracting functional ingredients from the marine environment, ensuring they remain free from these compounds and from harmful bacteria, viruses and toxins is essential. This research theme spans a broad area from the harvesting of materials to processing and incorporation of marine ingredients into food products.

Consumer and market analysis

The consumer is a key driver of growth in the functional food sector. However, it is also recognised that consumers can associate functional ingredients, through for example taste, (as can occur in the use of fish oils) with something unpleasant to consume. Such a reaction could have a negative impact on the development of fish oil based products. The scientific research agenda can be influenced by new consumer and market knowledge concerning the market acceptance and market requirements of and for functional foods and ingredients of marine origin. Outputs from this research theme would include contributions to the scientific research agenda, consumer attitudes to marine products, new product ideas and identification of factors that could be explored in designing new products and communicating the benefits of a marine diet to consumers.

Marine ecology

Issues of security of supply need to be addressed in building new market opportunities around ingredients from the marine environment. A thorough understanding of the abundance and distribution of marine organisms is essential if materials are to be harvested sustainably. Research under this theme will also support the identification of species from which functional materials could be obtained. Finally, the potential impact of harvesting on biodiversity and the impact marine climate change on the availability of marine plants, animals and micro-organisms - the basis of functional ingredients - will require new research.

Regulatory affairs

Regulations concerning functional foods and ingredients are not harmonised. The regulatory systems differ from country to country and as yet the EC has not finalised its position on regulations. Those involved in developing functional foods can expect to face scientific and commercial challenges in getting products to market. An understanding of the impact of an evolving regulatory environment on the sector is required. It is highly likely that the regulatory environment will itself drive research in new areas relating to products and manufacturing processes; including rapid testing, clinical trials, labelling, food safety and quality management. Against a background of the health challenges facing countries in the developed world, research concerning the impact or influence of claims and labels on consumer health could emerge as a research topic.

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HEADQUARTERS

MARINE INSTITUTE
Rinville,
Oranmore,
Co. Galway
Tel: +353 91 387200
Fax: +353 91 387201
Email: institute.mail@marine.ie

MARINE INSTITUTE REGIONAL OFFICES

MARINE INSTITUTE
80 Harcourt Street
Dublin 2
Tel: +353 1 4766500
Fax: +353 1 4784988

MARINE INSTITUTE
Furnace
Newport
Co. Mayo
Tel: +353 98 42300
Fax: +353 98 42340