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FUNCTIONAL FOODS

Functional foods constitute a rapidly growing focus for research, product development and consumer interest as well as regulatory efforts in recent years. Such products contain bioactives that offer considerable opportunities for reducing mounting health care costs for ailments such as heart disease, diabetes, cancer, immune and inflammatory disorders, mental and depression related diseases, together with the aging process and obesity. Although the association between health and diet and food, including functional foods, was originally anecdotal and based on epidemiological data, modern nutrition and food science focus on health promotion, and have now reached a molecular level. Thus, health promotion, disease risk reduction and performance improvement through diet and lifestyle have entered a new and sophisticated level in terms of delivery, absorption and metabolism which are also influenced by genetic factors. Molecular nutrition and food science are now shaping the future direction for recommending personalized diets for optimum maintenance of health, improving life quality and increasing lifespan while reducing the burden on the health care (Shahidi, 2004, 2008).

Although there is no universally accepted term for functional foods and nutraceuticals, the following definitions might represent a general understanding and expectation for this type of products as defined by Health Canada. “A functional food is similar in appearance to, or may be, a conventional food that is consumed as part of a usual diet, and is demonstrated to have physiological benefits and/or reduce the risk of chronic disease beyond basic nutritional function, i.e., they contain bioactive compounds.” Meanwhile, "a nutraceutical is a product isolated or purified from foods that is generally sold in medicinal forms not usually associated with foods. A nutraceutical is demonstrated to have a physiological benefit or provide protection against chronic disease." A new term has now emerged in Canada in which nutraceuticals are categorized under natural health products (NHP) which also include dietary supplements, among others (Geoffrey, 2006; Simon *et al.,* 2008). Thus, natural health products may be defined as "products usually sold in dosage form for the purpose of diagnosing, treating or reducing disease risk, restoring or correcting function or maintaining or promoting health." (Agriculture and Agri-Food Canada; Health Canada).

Functional foods may include vitamin- and mineral-enriched products, products containing added fibre, pre-, pro-, and synbiotics, and omega-3 fatty acids/oils, among others. Enrichment may also be achieved via agricultural practices such as plant breeding or by processing, special livestock feeding or by employing biotechnological means. Thus, fortified beverages with calcium or omega-3 oils, muffins with beta-glucan, yogurts with probiotics and drinks with herb blends as well as omega-3 eggs, meat and canola oil high in carotenoids or wheat with enhanced lutein level or rice with other carotenoids are considered as examples of functional foods. Examples of natural health products include beta-glucan isolated from oats, antioxidants from blueberries, sterols and stanols from wood pulp, omega-3 fatty acids and oils from marine and algal sources. In addition, products such as essential fatty acids, enzymes, carotenoids and probiotics from animal and micro-organisms as well as marine-based products such as glucosamine, chitosan and fish oils or vitamins and minerals are categorized as NHP. A recent report by the Food and Agriculture Organization of the United Nations (FAO, 2007) also provides information about the status of functional foods

Regulatory Issues

The term "functional food" first appeared in *Nature* in 1993 in an article titled "Japan Explores the Boundary between Food and Medicine" (Swinbanks and O'Brien, 1993) while the term "nutraceutical" was coined by Stephen DeFelice in 1989, from "nutrition" and "pharmaceutical" to reference "food" or "part of a food" that provides health benefits (DeFelice, 2002). The 1984 initiative of the Ministry of Education, Science and Culture (MESC) of Japan served as a basis to explore the interface between food and medical sciences. However, regulatory issues for functional foods and nutraceuticals depend to a large extent on the country in which they are marketed and the nature of ingredients and the way they are categorized for rendering their effects (Hasler, 2005).

As it might be expected, Japan has led the way for establishing strict procedures for approval and marketing of functional foods under "food for specified health use" or "FOSHU" which was conceptualized in 1991. Under FOSHU, there are several categories and these are for gut health or for metabolic syndrome and lifestyle-related diseases. The categories so specified are products for gastrointestinal conditions, dental caries and mineral absorption and those for bone health and strength, blood pressure, blood glucose, blood cholesterol and blood triacylglycerol (triglyceride; TAG).

In the United States of America (USA), there is no legal status for functional foods or nutraceuticals but health claims with respect to structure-function are allowed to appear on the label for food and dietary supplements in accordance with the 1990 Nutrition and Labelling Education Act (NLEA) which required the US Food and Drug Administration (FDA) to promulgate new regulations and this was done in 1993. In 1994, the Dietary Supplement Health and Education Act (DSHEA) was passed by the US Congress which allowed structure-function claims and related nutritional support claims for dietary supplements which exempted ~~them~~ dietary supplements from the requirements of the food additives of the US Food, Drug and Cosmetic (US FD & C) Act of the 1938. The 1997 FDA Modernization Act (FDAMA) provided a second way an alternative option for the use of health claims to be authorized. This is based on an "authoritative statement" from a scientific body in the US Government or National Academy of Science in order to expedite the process. Finally, FDA's 2003 Consumer Health Information for Better Nutrition Initiative allowed for the use of qualified health claims when scientific evidence was not well enough established to meet the scientific statement required by FDA to issue an authorized regulation. Although several health claims are allowed in the United States, only 5 are currently allowed in Canada; with wording such as "a healthy diet low in saturated and trans fats may reduce the risk of heart disease". For more extensive details on functional foods and the USA regulatory status, the Institute of Food Technologists (IFT), published an IFT Expert Report on "Functional Foods: Opportunties and Challenges" which contains insight from extensive deliberations of an multidisciplinary panel.

In the European Union, nutrition and health claims are governed by Regulation 1924/2006 (EC No 1924/2006) (http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32006R1924R(01):EN:NOT) which was adopted in December 2006 in order to provide harmonized rules for making such claims. The process for evaluation and compilation of health claims is in progress and permitted health claims shall be adopted by no later than January 31, 2010 (Blanchfield, http://www.worldfoodscience.org/cms/?pid=1004310 (q.v).In Australia and New Zealand health claims for foods are not allowed. However, if specifically prescribed by the Food Standards Code, such claims are permitted. The Codex Alimentarius does not have a definition for health claim, but notes that a high level of quality of the scientific justification for the claimed effects is obligatory for using any health claim (http://www.nceff.com.au/pdf/Codex.pdf).

Functional Food And Their Bioactive Components

The beneficial health effects of functional foods are due to the presence of a myriad of bioactives that render their effects via a number of mechanisms at different levels. The diseases of concern include coronary heart disease, certain types of cancer, type 2 diabetes, brain health and mental disorders, immune response, inflammation, obesity, arthritis, in association with oxidative stress and metabolic syndrome. The substances that may influence such diseases often originate from plant sources, but some are also derived from animals and micro-organisms.

Examples include carotenoids such as alpha- and beta-carotene, lutein, astaxanthin, lycopene and fucoxanthin; dietary fibre, beta-glucan, soluble fibre, long-chain omega-3 fatty acids, phenolics such as phenolic acids, phenyl propanoids, catechins, anthocyanidins, flavones, flavonones, proanthocyanidins and lignans; sterols and stanols, pre-, pro-, and synbiotics and soy isoflavones and proteins as well as biologically active peptides from different sources (Table 1).

Table 1. Examples of Functional Food Ingredients

Functional Components	Source	Potential Benefits
Carotenoids and Xanthophylls		
Alpha- and Beta-carotene	Carrots, fruits, vegetables	Neutralize damage of free radicals to cells
Lutein	Green vegetables	Reduce the risk of macular degeneration
Lycopene	Tomato products (ketchup, sauces), watermelon	Reduce the risk of prostate cancer
Dietary Fibre		
Insoluble Fibre	Wheat bran	Reduce risk of breast or colon cancer
Beta-Glucan	Oats, barley	Reduce risk of cardiovascular disease. Protect against heart disease and some cancers; lower LDL and total cholesterol
Fatty Acids		
Long chain omega-3 PUFA (EPA/DHA)	Salmon and other fish oils	Reduce risk of CVD, eye function and mental disorders
Conjugated linoleic acid (CLA)	Cheese, meat products	Decrease risk of certain cancers, anti-obesity
Gamma-linolenic acid (GLA)	Evening primrose oil, borage oil, black currant oil	Skin irritations, menstrual discomfort
Phenolics/Polyphenolics		
Flavan-3-ols (anthocyanidins)	Fruits	Neutralize free radicals, thus reducing the risk of cancer
Catechins	Green tea	
Flavonones	Citrus fruits	
Flavones	Fruits/vegetables	
Lignans	Flax, sesame rye, vegetables	Prevention of cancer, renal failure
Tannins (proanthocyanidines)	Cranberries, cocoa, chocolate	Reduce risk of cardiovascular disease (CVD)
Plant Sterols/Stanols		
Sterol and Stanol Esters	Corn, soy, wheat, wood oils	Lower blood cholesterol levels by inhibiting cholesterol absorption
Prebiotics/Probiotics/Symbiotics		
Fructo-oligosaccharides (FOS)	Jerusalem artichokes, shallots, onion powder	Improve quality of intestinal microflora; GI health
Lactobacillus	Yogurt, other diary products	
Soy Proteins and Phytoestrogens		
Soy Protein	Soy protein isolate, concentrate and/or hydrolyzate	Blood pressure, heart health
Isoflavones (e.g. Daidzein and Genistein)	Soy and soy-based foods	Protect against heart disease and some cancers; lower LDL cholesterol, reduce menopausal symptoms and hot flashes

Adapted from: International Food Information Council.

The following provides some examples of functional foods/functional food ingredients that are currently available in the market in order to provide information necessary to appreciate their potential health benefits that are related to their bioactive constituents.

Dietary Fibre. Fibre occurs in the insoluble or soluble form and is the endogenous component of plant materials in the diet that is resistant to digestion by enzymes produced. in the human digestive system. These include cellulose, hemicellulose, pectin and lignin that are present in a variety of foods such as cereals, especially oats, psillium, and barley, as well as legumes such as beans, together with fruits and vegetables, among others. Soluble fibre in oat bran served as a basis for the first health claim allowed under the U.S. NLEA with supportive evidence being provided by a public corporation (the Quaker Oats Company; now owned by Pepsico). The claim is allowed to appear on packaging and notes that the consumption of approximately 25 g/day of oat-containing foods may help reducing the risk of heart disease. This claim was allowed on the basis of many epidemiological and cohort studies that demonstrated daily intakes of some 25-50 g of fibre resulted in reduced risk cardiovascular disease via lowering the level of LDL cholesterol. This effect is thought to be rendered by the binding and diluting action of soluble fibres on bile acids, hence lowering of intestinal pH, which inhibits the conversion of primary bile acids to secondary bile acids, thus reducing the absorption of fat and cholesterol and increasing faecal discharge due to their insoluble fibre counterparts. Furthermore, fibre is fermented in the colon by intestinal microflora and produces short-chain fatty acids (SCFA); these SCFA are responsible for possible lowering of serum cholesterol and decreased risk of cancer. In addition, certain types of fibre may improve glycemic control, insulin resistance and blood lipid profile (Health-Evidence.ca http://health-evidence.ca/documents/16184/Brunner 2005 Summary Statement-English.pdf).

Whole Woods, Phenolic Compounds And Antioxidants. Of more recent interest has been food phenolics and their role as antioxidants when offered in foods. Phenolic compounds are secondary metabolites that are ubiquitously distributed in plants and are represented by simple phenols, benzoic acid and cinnamic acid derivatives, flavonoids, stilbenes, and proanthocyanidins, among others. Phenolic compounds are present in all parts of plants, vegetables and fruits, although at different levels depending on their maturity state, but are concentrated in the bran and hulls of cereals, legumes and oilseeds and skin and seeds of fruits and nuts (Shahidi *et al.,* 2007). Thus, phenolic and polyphenolic compounds may be consumed as such, as part of a normal diet. The daily dietary intake of phenolics on the average is about one gram. However, the concentration of phenolics in foods may be enhanced purposely by inducing stress to the plants or by agricultural and biotechnological means. The phenolics involved render their health benefits by a variety of mechanisms although they are recognized most prominently for their antioxidant potential. Thus an assortment of drinks and fruit juices have been offered to the market under claims related to their antioxidant activity and the terms antioxidant and ORAC (oxygen radical antioxidant capacity) are now being recognized by an increasing number of consumers.

The mechanism by which phenolic compounds exert their beneficial effects may be related, but not limited, to their antioxidant activity. Other mechanisms are related to their effect on cell differentiation, increasing activity of certain enzymes that detoxify carcinogens, blocking the formation of dangerous N-nitrosamines, altering the colonic milieu and/or estrogen metabolism, maintaining DNA repair and affecting DNA methylation, increasing apoptosis of cancer cells and decreasing cell proliferation, as well as preserving the integrity of intracellular matrices. Such effects may be rendered individually or collectively, perhaps in a synergistic manner with other bioactives, in different sites and to different extent, hence promoting health and decreasing risk for diseases.

Examples of functional foods containing phenolic antioxidants are green, black and oolong teas, berry and pomegranate juices, and certain formulated multi-grain breads and cereals containing brans, specifically oat bran, among others. The latter category is also important because of the presence of dietary fibre components. Extracts of grapeseed, blueberry, cranberry and green tea are now available in health food and drug stores; their main constituents are polyphenols or include polyphenols (Shahidi and Naczk, 2004; Naczk and Shahidi, 2006).

Soy Proteins And Soy Products. The proteins in soy have been associated with a reduction in the risk of coronary heart disease as permitted under the U.S. NLEA because they may reduce the risk of coronary heart disease by lowering blood cholesterol levels. This may be partly due to amino acid profile that could influence the level of circulating triacylglycerols and LDL cholesterol by over 10% when consumed at about 47 g/day. As

noted under phenolics, soy also contains isoflavones which possess estrogen-like activity and hence are important in lowering of cholesterol as well as reducing the risk of post-menopausal cardiovascular diseases, among others. The circulating genestein in the blood from the consumption of soy protein or soy isoflavones inhibits the activity of tyrosine kinase, an enzyme that is involved in plaque formation in the arteries.

Meanwhile, protein hydrolysates from soybean and other sources may have beneficial health effects via a number of mechanisms that include antioxidant effect as well as an ACE (angiotensin converting enzyme) inhibitory activity (Kim *et al.,* 2001). These hydrolysates may be prepared and used in foods for special effects, but are also formed in the digestive system which might render effects as observed for soy and soy-based products, among others.

Soy isoflavones are amongst phenolics present in this legume and are present mainly as deidzein and genistein. Their content in different soy-based product is different depending on the processing technologies employed. They are also available in pill form. The beneficial health effects of soy isoflavones are thought to be related to a reduction of breast cancer risk observed in populations using large amounts of soy products as well as living benefits for menopausal systems, among others.

Omega-3 And Other Specialty Oils. Omega-3 fatty acids, mainly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are obtained mainly from oils of fish or marine mammals. Their importance was first recognized over 30 years ago when epidemiological data indicated that Greenland Eskimos, despite their consumption of a diet with nearly twice the cholesterol content of their Danish counterpart, and an intake of the same level of fat, suffered an incidence of myocardial infarction (MI) which was a fraction of that of the Danes. A close scrutiny of the data available indicated that the ratio of dietary intake of omega-3 to omega-6 in the said Eskimo population was nearly 10 times that of the Danes in Greenland and this was directly related to the reduction in their incidence of MI. This observation has gained further support from other population studies as well as intervention trials. What is proven to date is that omega-3 fatty acids render their cardiovascular protection via reducing the incidences of arrhythmias as well as by lowering the level of serum triacylglycerols (TAG). However, there are many other mechanisms by which such an effect may be rendered. Thus intake of fish oils for protection from cardiovascular diseases has been recommended and this has a main effect in reducing health care costs (Shahidi and Miraliakbari, 2004, 2005).

A large number of foods have now been formulated in which omega-3 fatty acids are added for fortification purposes and these include dairy products, juices, breads, pastas and bars, among others. In addition, fish oils are used in the encapsulated form for health purposes. Meanwhile, concentrates of omega-3 fatty acids in the alkyl ester or triacylglycerol forms are also available.

Flaxseed has recently been promoted for its omega-3 fatty acids, namely, linolenic acid, as well as its lignan and fibre and protein hydrolysates. However, the omega-3 linolenic acid from flax might only convert to long-chain omega-3 fatty acids at 2-5% and for applications or uses where the latter are required, this fact must be taken into consideration.

Other beneficial oils include those containing gamma-linolenic acids for skin disorders and pre-menstrual pains and oils or products containing conjugated linoleic acid (CLA) isomers that are considered as having a potential in alleviating certain diseases and also for possible weight gain reduction. Meanwhile, medium-chain fatty acid-containing oils and foods, mainly from some tropical plant sources, are important as a quick source of energy.

Finally, modified oils devoid of sn-2 fatty acids are found to be important in possible weight reduction because they cannot be used for re-synthesizing new TAG molecules that could possibly be deposited as subcutaneous fat or in the arteries. Meanwhile, structured lipids produced by placing specific fatty acids in selected positions in the TAG molecules have been produced and these may serve as important lipid sources as functional food ingredients and for therapeutic and medical applications (e.g. Shahidi, 2007).

Phytosterols And Phytostanols. Phytosterols and phytostanols are structurally very similar to cholesterol except that they possess different side chains and the latter is devoid of a double bond; these affect the absorption of cholesterol in the body and hence may reduce the total and LDL cholesterols by approximately 10%; products such as spreads, margarines and yogurts, among others, are available in the marketplace in some countries. While beneficial effects of phytosterols/phytostanols in reducing the risk of cardiovascular

disease has been acknowledged, oxidation of phytosterols may render harmful effects and their overuse may also be responsible for potentially undesirable effects (Dutta, 2004). They were originally incorporated in fat spreads, but their subsequent incorporation in a wide variety of products (including cheese, yogurts, fruit juices and drinks), has created a situation in which some consumers may unwittingly exceed the EU recommended limit of 3g per day.

Probiotics, Prebiotics And Synbiotics. Probiotics are bacteria-containing foods, such as milk and other dairy products especially yogurt and kefir, as well as fermented vegetables, that are capable of altering the floral composition of the gut in favour of beneficial micro-organisms. Several strains of bacteria have been studied and used as probiotics. *Lactobacillus* and *Bifidobacterium*, commonly found in yogurts, are often used to treat gastrointestinal problems by improving the ability of the digestive system to prevent invasion by pathogens. Multi-strain probiotics are also now available in the capsule form. These bacteria, once in the large intestine, are thought to ferment indigestible carbohydrates to enhance the production of short-chain fatty acids, hence decreasing the concentration of circulatory cholesterol by inhibiting cholesterol synthesis in the liver or by moving cholesterol from plasma to the liver. Presence of SCFA of 2 to 4 carbon atoms is effective in reducing the incidence of colon cancer, and symptoms of irritable bowel syndrome (IBS) as they enhance proliferation in normal cells while decreasing that in the transformed cells.

Prebiotics is the term used to define indigestible food components that selectively stimulate the growth and/or the activity of the beneficial bacteria in the colon and hence improve health of the digestive system. Examples include inulin as well as oligosaccharides of galactose and xylose, among others. Meanwhile, synbiotics are products that contain both pre- and probiotics with a synergistic effect. Thus a product containing a prebiotic such as oligofructose and a probiotic like *bifidobacteria* would fulfill the definition (Fotiadis *et al*., 2008 http://www/wjgnet.com/1007-9327/14/6453.asp).

Sensory Aspects And Delivery Of Functional Food Ingredients

Functional food ingredients may be added to foods as such, if not endogenously present or in the protected form. The latter might become necessary due to solubility and stability problems that pose a challenge for certain ingredients and for some specific applications. As an example, fish oils containing omega-3 fatty acids are prone to oxidation and hence may lead to the formation of off-flavours in foods. In addition, their use in aqueous systems requires emulsifiers, among others. Microencapsulated products are thus used in a number of applications and some are produced by a coacervation process. The latter microcapsules remain in the insoluble form until they are broken down in the GI tract, hence the contents are delivered in the intact form. In the emulsified products, nanoparticles may be produced and used as a vehicle for delivery (Chen *et al*., 2006). Of course issues such as efficacy and toxicity factors must be considered as challenges that one may face due to the increase in surface area, thus leading to altered properties that require careful consideration.

Health Effects

The earlier sections of this bulletin have provided specific examples of different classes of food bioactives that could promote health. Risk factors for cardiovascular diseases (CVD) include hypertension, high blood cholesterol and lipid as well as their oxidation. Although the body protects itself from such oxidative damages, dietary factors such as omega-3 fatty acids and antioxidants and phytosterols affect this process.

Although genetic predisposition may be a significant risk factor in cancers, physical exercise and diet are factors that the individual can control to modify the risk. On the dietary factors, the consensus view of experts (World Cancer Research Fund International, 2007) is to limit consumption of energy-dense foods, red meat, alcohol and salt; avoid cured, smoked or salted meats and mouldy grains or pulses. An integrated approach to the evidence shows that most diets that are protective against cancer are mainly made up of foods of plant origin (especially non-starchy vegetables, pulses and fruits). The dietary fibre and bioactive substances present may play an important part. The expert panel did not recommend dietary supplements for cancer prevention, on the basis that the evidence shows that high-dose dietary supplements can be protective or can cause cancer. Other possible benefits of functional foods are related to their effects on inflammation, arthritis, brain health, ageing process, diabetes and the metabolic syndrome. Readers may refer to other specific sources for further information (Camire *et al.,* 2003; Mine *et al.,* 2009).

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An IUFoST Scientific Information Bulletin is not an exhaustive dissertation or review, but a brief outline of the scientific principles involved in the topic and, for each, provision of key reliable on-line and other sources of further information.

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