Functional Foods: Dietary Fibers, Prebiotics, Probiotics, and Synbiotics

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Topic Highlights

- Dietary fiber (DF) and whole grain functional foods
- Prebiotic, probiotic, and synbiotic functional foods
- Metabolic syndrome-related diseases and cancers
- Lactose intolerance

Learning Objectives

- To achieve understanding of the definitions of DFs, whole grain foods, prebiotics, probiotics, and synbiotics
- To achieve understanding of DF and prebiotic grain sources
- To impart principles of DFs, prebiotics, probiotics, and synbiotics with respect to the processing of functional foods
- To explain linkages of the intake of DFs, prebiotics, probiotics, and synbiotics to health

Introduction

Functional foods processed from DFs are linked to various health benefits. Soluble fibers and β-glucans in particular are known to modulate hyperlipidemia, hyperinsulinemia, hyperglycemia, and obesity, which are risk factors for chronic diseases including cardiovascular diseases (CVDs), diabetes mellitus, and cancers. Soluble fibers are rapidly fermented by gut microbiota. Adequate intake (AI) of insoluble fibers is also linked to the reduction of colon cancers and improved gastrointestinal health (GIH), reduced CVD, and obesity. Cereal grain fibers and legume cotyledons are included in bread, extruded products, cakes, cookies, and fermented and other ready-to-eat breakfast cereal (RTE) products. Consumption of whole grain foods is encouraged for AI of DF. Health-promoting effects of DF are imparted by nonstarch carbohydrates, resistant starches, and closely associated/attached compounds. Those DFs that selectively promote growth and/or activities of probiotics and promote host health are prebiotics. Arabinoxylans, fructans, inulin, resistant starches, β-glucans, and α-galactooligosaccharides are fermented by probiotics to short-chain fatty acids (SCFAs): butyrate, propionate, and acetate that are absorbed in the colon to furnish additional energy for the host. Prebiotics are also known to improve the absorption of calcium and magnesium and to suppress colon cancers and absorption of triglycerides and cholesterol. Cellulose and water-insoluble arabinoxylans are major contributors to laxative effects and fecal bulking. Barley, wheat, rye, oats, triticale, maize, einkorn, chickpea, and lentils are notable sources of prebiotics. Intake of prebiotics is also achieved through consumption of whole grains like teff, millets, sorghums, and brown rice. Dietary intake of probiotic bacteria mainly from the genera of *Lactobacillus* and *Bifidobacterium* is linked to improved immune capacity and GI health and to suppressing various diseases including colon cancers, allergy, asthma, celiac disease, HIV infection, inflammatory bowel diseases, hypertension, gastrointestinal pathogen infections, peptic ulcer, diarrhea, obesity, necrotizing enterocolitis, rheumatoid arthritis, and liver diseases. In this article, the nature and sources of DFs, prebiotics, probiotics, and synbiotics for functional foods are described with emphasis on grains.

Dietary Fibers and Whole Grains

Dietary Fibers

DFs are a structurally diverse group of compounds. Various regulatory bodies and professional societies – American Association of Cereal Chemists International (AACCI), Institute of Medicine (IOM), Food Standards Australia and New Zealand (FSANZ), FAO/WHO *Codex Alimentarius Commission*, European Food Safety Authority, and Health Canada – have offered definitions for DF primarily based on the physiological roles and analytical methods used to isolate and quantify them. According to *Codex*, DFs are carbohydrate polymers with 10 or more monomeric units (decision on whether to include carbohydrates of 3–9 monomeric units should be left up to national authorities), which are not hydrolyzed by the endogenous enzymes in the small intestine of humans and comprise the following:

(1) Edible carbohydrate polymers naturally occurring in the food as consumed. When derived from a plant origin, DF may include fractions of lignin and/or other compounds – protein fractions, phenolic compounds, waxes, saponins, phytates, cutin, vitamins, phytosterols, minerals, etc. – when such compounds are associated with the polysaccharides in the plant cell walls and extracted together.
(2) Carbohydrate polymers, which have been obtained from food raw materials by physical, enzymatic, or chemical means and which have been shown to have a beneficial physiological effect to health as demonstrated by generally accepted scientific evidence to competent authorities.
(3) Synthetic carbohydrate polymers, which have been shown to have a beneficial physiological effect to health as demonstrated by generally accepted scientific evidence to competent authorities.
(4) The *Codex* definition is expected to be used in all jurisdictions. Currently, there is wider consensus that the AACCI definition is reconciling with *Codex* definition. AACCI defines DF as edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. DFs include polysaccharides, oligosaccharides, lignin, and associated plant substances. DFs promote beneficial physiological effects including laxation and/or blood cholesterol and glucose attenuations. DFs thus comprise the following:

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i. Nonstarch polysaccharides and resistant oligosaccharides: cellulose, β-glucans, hemicellulose (arabinoxylans and arabinogalactans), polyfructoses (inulin and oligofructans), galactooligosaccharides, gums, mucilages, and pectins
ii. Analogous carbohydrates (indigestible dextrins/resistant maltodextrins from corn and other sources and resistant potato dextrins), synthesized carbohydrate compounds (polydextrose, methylcellulose, and hydroxypropyl methylcellulose), and resistant starches
iii. Lignins
iv. Substances associated with the nonstarch polysaccharides and lignin complex in plants (waxes, phytates, cutins, saponins, suberin, polyphenols, tannins, vitamins, minerals, alkylresorcinols, carotenoids, betaine, etc.)

The classification of DFs as soluble (gums, oligosaccharides, pectins, water-soluble arabinoxylans, β-glucans, galactomannans, psyllium fibers, and alginates) and insoluble (cellulose, lignins, and water-insoluble arabinoxylans) also continues to be in use. DFs for human nutrition are largely derived from cereal grains 44%, vegetables 21%, fruits 13%, and legumes 10%. The outer pericarp of cereal grains, endosperm cell walls, seed coat and cotyledons of legumes, psyllium husks, and fruit and vegetable skins are rich sources of DF. Diets rich in bran (pericarp, aleurone layer, and testa) and germ are known to have high antioxidant activities than diets based on refined white flours largely due to associated DF–phenolics, tocols, and carotenoid antioxidants. Functional foods containing DFs are currently widely available in the form of breads; extruded products like pasta, cakes, and cookies; and fermented and other RTE products. Although incorporation of DF to some levels has produced products comparable to those processed from refined flours, increased DF contents have been associated with reduced consumer acceptance (color, texture, and taste). Currently, improvements being researched include the use of enzymes and other physicochemical means to modify fiber structures and incorporation of fibers from fruits and vegetable skins.

The beneficial physiological effects conferred by AI of DF include attenuation of blood cholesterol and blood sugars, suppression of CVD diseases (coronary heart disease, stroke, and hypertension), weight control, improved insulin sensitivity and suppression of type 2 diabetes mellitus, improvement of GIH, improved laxation, suppression of cancers such as colon and breast cancers, improved immunity, and contribution to the overall longevity. The physiological roles of DF can vary depending on nature of the compound. Properties of DF such as viscosity, molecular weight, molecular size, solubility, water-holding capacity, and fermentation characteristics by gut microbiota are known to play a role in the physiological effects of DF-based functional foods. Increased intake of soluble fibers is known to suppress hyperglycemia and to improve insulin sensitivity in nondiabetic and diabetic individuals. Cardiovascular protective roles of DF are imparted by attenuation of blood cholesterol levels specifically by interfering and limiting cholesterol fractions transported by LDL. The viscous characteristics of fiber are implicated to have a dominant role in this regard. Energy load reduction and weight control are imparted by (1) displacing available energy and nutrients from the diet; (2) increasing chewing, limiting intake, and promoting secretion of saliva and gastric juice resulting in an expansion of the stomach and increased satiety; and (3) reducing absorption efficiency of the small intestine. Diets with high DF contents are known to have slow nutrient digestion and gastric emptying rates. This action leads toward attenuation of blood glucose and helps in the control of type 2 diabetes mellitus. Some DFs are fermented (prebiotic) completely or partially by the symbiotic microorganisms of the large intestine to SCFA-like butyrate, which is the preferred energy source for mucosa cells. Inulin and oligofructans are not used by potential pathogenic bacteria but are the preferred substrate for beneficial *Bifidobacteria* and thus help to maintain and restore the balance of healthful gut microbiota. Beta-glucans and the presence of magnesium in whole grains and/or bran-rich DF are known to lead to improved insulin sensitivity to suppress type 2 diabetes and other metabolic syndrome diseases. Psyllium (or ispaghula; *Plantago ispaghula* or *Plantago ovata*) fibers and oat and barley β-glucans are used in functional foods targeted at lower cholesterol and blood sugars for improved cardiovascular health, control of type 2 diabetes, and weight reduction and maintenance. Cereal grain DFs are generally recognized to be more potent than fruits and vegetable fibers in the many beneficial physiological roles of the DF functional foods. Excessive DF intake through functional foods or other regular diets may lead to deleterious effects because it contributes to reduced absorption of some vitamins, minerals, proteins, and energy. It may also lead to diarrhea, flatulence, bloating, and abdominal discomfort. Children less than 1 year old and older people, in particular, are advised not to consume higher than recommended DF levels. The recommended AI for total DF is 19–25 g day^{-1} for children aged 1–8 years, 31–38 g day^{-1} for boys aged 9–18 years, 38–30 g day^{-1} for males greater than 19 years old, 26 g day^{-1} for girls aged 9–13 years, 25–21 g day^{-1} for females greater than 19 years old, 28 g day^{-1} at pregnancy, and 29 g day^{-1} during lactation.

Whole Grains

Whole grains are defined by AACCI in 1999 as "consisting of the intact, ground, cracked or flaked caryopsis, whose principal anatomical components – the starchy endosperm, germ, and bran – are present in the same relative proportions as they exist in the intact caryopsis." Thus, whole grains are good sources of various nutrients, starch, proteins, lipids, DF, vitamins (thiamine, riboflavin, niacin, pantothenic acid, vitamin B6, folate, and vitamin E), minerals, and phytochemicals such as various phenolic compounds, phytosterols, tocols, lignans, and carotenoids. AI of whole grain foods has been associated with GIH and reduced risk of various metabolic syndrome-related diseases (obesity, diabetes, hypertension, and dyslipidemia) and various cancers. For example, consumption of two to three servings per day (about 48 g) of whole grains is preventive of the risks of CVD, type 2 diabetes mellitus, overweight, and obesity. Whole grain intake results in greater intake of diverse nutrients. Although whole grain has been defined, it remains challenging for researchers, industry, regulatory authorities, and consumers to clearly identify what constitutes whole grain foods. Following a review of evidence from various epidemiological, interventions, animals, and human clinical studies on relationship of whole grain intake and the many benefits on health and wellness, an expert panel of whole grain working committee in 2014 has recommended that '8 g of whole grain per 30 g serving (27 g per 100 g), without a fiber requirement, be considered a minimum content of whole grains that is nutritionally meaningful and that a food providing at least 8 g of whole grains per 30 g serving be defined as a whole-grain food.' This definition also reconciles with the one offered by AACCI that 'whole grain food product must contain 8 g or more of whole grain per 30 g of product.' Sources of whole grain functional foods include whole wheat and rye flours, barley and whole barley flour, whole grain maize meal, grits and popcorn, teff, sorghum, oat groats, whole grain millets, brown rice, quinoa, amaranth, buckwheat, and wild rice. Thus, whole grain foods (whole grain snacks and extruded, fermented, and baked foods) can be regarded as functional foods rich in DF and phytochemicals. Many African traditional diets and other indigenous foods around the globe are based on whole grains being consumed as boiled, cooked, fermented, and baked as in *injera* from grain teff in Ethiopia. Such diets can be described as functional foods and they have been serving communities since folklore.

Probiotics, Prebiotics, and Synbiotics

Human organs particularly the gastrointestinal tract (GIT) are known to be host for vast numbers of microbes ($\sim 10^{15}$ bacterial cells), which are designated as microbiota, microflora, or normal flora. These microbiota are today extensively exploited for GIT health and beyond under probiotic and synbiotic functional foods. Consumption of such diets is actually not new because a range of naturally occurring prebiotics and probiotics primarily from the genera *Lactobacillus*, *Bifidobacterium*, and *Saccharomyces* are consumed throughout the world in the indigenous fermented foods since folklore. Probiotics and prebiotics are also available commercially in the form of dietary supplements and clinical therapeutics to be delivered orally or nonorally.

Probiotics

The word probiotics is derived from the Greek term 'pro bios' meaning 'for life.' The widely accepted definition of probiotics given by FAO/WHO (2001) as "Live microorganisms which when administered in adequate amounts confer a health benefits on the host" was recommended in August 2014 by International Scientific Association for Probiotics and Prebiotics (ISAPP) to be used with minor rewording as "Live microorganisms that, when administered in adequate amounts, confer a health benefit on the host." Major bacterial strains commonly used in probiotics are lactic acid bacteria (LAB) from the genera of *Lactobacillus* and *Bifidobacterium* (Table 1). Other LAB reported are from *Pediococcus*, *Lactococcus*, *Leuconostoc*, *Streptococcus*, and *Weissella*. Certain yeast and fungal strains are also recognized for probiotic effects. The ISAPP restricted the term probiotic to be used only on products that deliver live, safe microorganisms with suitable viable counts ($\geq 10^6$ colony-forming units per gram of a product) of well-defined strains with a reasonable expectation of delivering benefits for well-being of the host. Ability to survive, proliferate, and colonize the gut is also a criterion although some cultures lack such ability like traditional yogurt starter cultures (*S. salivarius* subsp. *thermophilus* and *L. delbrueckii* subsp. *bulgaricus*), which are recognized as probiotics because of their production of β-galactosidase that helps lactose digestion in maldigesters. ISAPP has divided live cultures into two: (1) probiotic (nonoral probiotic foods, probiotic drugs, probiotic medical foods, nonoral probiotics, defined microbial consortia, probiotic dietary supplement, probiotic infant formula, and probiotic animal feed) and (2) not probiotic (fermented foods with undefined microbial content and undefined consortia including fecal microbiota transplant).

The various beneficial functions of probiotics are (1) structural and histological such as the development of healthy structure and morphology of the gut; (2) metabolic such as in the synthesis of B vitamins, vitamin K, amino acids, SCFA, antioxidants, and bacteriocins and in the biotransformation of bile, which help to modulate glucose and cholesterol homeostasis; and (3) protective from colonization by pathogens such as through production of antimicrobial compounds, by competing for nutrients and attachment sites on gut lining. The various health benefits documented for probiotic diets include suppression of (1) obesity and type 2 diabetes through modulating glucose metabolism; (2) allergic inflammation and atopic dermatitis; (3) liver disease; (4) hypercholesterolemia and CVD

Table 1 Microbial species used as probiotics

Species	*Strain*
Lactobacilli	*L. acidophilus*, *L. bulgaricus*, *L. casei*, *L. delbrueckii* ssp. *bulgaricus*, *L. fermentum*, *L. johnsonii*, *L. crispatus*, *L. salivarius*, *L. bifidus*, *L. reuteri*, *L. plantarum*, *L. helveticus*, *L. casei* subsp. *rhamnosus*, *L. gallinarum*, *L. brevis*, *L. gasseri*, *L. cellobiosus*, *L. vitulinus*, *L. collinoides*, *L. cremoris*, *L. ruminis*, *L. dextranicum*, *L. lactis*, *L. rhamnosus*, *L. curvatus*, *L. faecium*, *L. paracasei*
Bifidobacteria	*B. bifidum*, *B. adolescentis*, *B. brevis*, *B. longum*, *B. animalis*, *B. infantis*, *B. thermophilum*, *B. breve*, *B. essencis*, *and B. lactis*
Bacillus	*B. coagulans* (GanedenBC30), *B. lactis* DR10, *B. licheniformis*, *B. subtilis* R0179, *B. subtilis (natto)* OUV23481
Pediococcus	*P. acidilactici*, *P. pentosaceus*, *P. halophilus*
Lactococcus	*L. lactis* subspp. *lactis* and *cremoris*
Leuconostoc	*L. mesenteroides* subsp. *dextranium*, *paramesenteroides*, or *lactis*
Streptococcus	*S. diacetilactis*, *S. cremoris*, *S. lactis*, *salivarius* subsp. *thermophilus*, *S. faecium*, *S. equinus*
Weissella	*W. cibaria* and *confusa*
Yeast	*Saccharomyces cerevisiae*, *S. cerevisiae* var. *boulardii*
Fungi	*Aspergillus oryzae*, *Scytalidium acidophilum*

through modulating cholesterol, LDL-cholesterol, and triglyceride metabolisms; (5) various cancers such as colon, bladder, and cervical cancers; (6) inflammatory bowel disease; (7) diarrhea; (8) lactose intolerance; (9) renal diseases; (10) hormonal immune response failure; and (11) ingestion of toxic compounds. Although probiotics containing dairy products are dominant, probiotic-fermented cereals and soy beverages, flakes, baked goods, soups, and traditional fermented cereals are also available. Microencapsulation of probiotics is currently being researched to enable incorporation into various grain products. Fermented grain products containing probiotics have the following advantages: the possibility of grain components to be prebiotic sources, multimedia characteristics of the grain products, and their lactose- and cholesterol-free natures.

Prebiotics

The current consensus definition given is "A dietary prebiotic is a selectively fermented ingredient that results in specific changes, in the composition and/or activity of the gastrointestinal microbiota, thus conferring benefit(s) upon host health." Compounds recognized as prebiotics include inulin-type fructans (inulin fructooligosaccharides, and oligofructose), lactulose, galactooligosaccharides, isomaltooligosaccharides, lactosucrose, xylooligosaccharides, glucooligosaccharides, sugar alcohols, resistant starches, and modified starches. Resistant starches, fructans, arabinoxylans, arabinoxylan oligosaccharides, and β-glucans are reported in various grains such as in wheat, rye, maize, barley, oat, and maize.

Prebiotic food products are available in the market as beverages (soy milk, smoothies, and juice), bakery products (snack bars, biscuits/cookies, waffles, and pancakes), breakfast cereal (extruded cereals and instant oatmeal), confectionery (chocolate and gummy candy), dairy products (yogurt, ice cream, and frozen yogurt), desserts (pudding and jelly/jello), fruit products (fruit preparations), and infant and toddler foods and in specialty liquid nutrient supplements. Inulin-type fructans are popular prebiotics. Even though fructans are present in grains, good sources are from Jerusalem artichoke, chicory, garlic, and onion.

Prebiotics are fermented to SCFA acetate, propionate, and butyrate. Other bacterial end products include lactate, ethanol, succinate, formate, valerate, caproate, isobutyrate, 2-methyl butyrate, and isovalerate. Bacterial fermentation takes place in the cecum and colon, where SCFAs are absorbed, stimulating absorption of vitamins, water, and minerals (calcium and magnesium). The SCFAs have been known to have a protective effect on the intestinal epithelium. The colonic bacteria prefer butyrate as their sole source of energy and are also metabolized by the colonic epithelium where it regulates cell growth and differentiation. Butyrate is known to induce secretion of mucin, antimicrobial peptides, and other factors, which reinforces the defense barrier in the colon. Butyrate limitation leads to inflammation characteristics of the ulcerative colitis. Acetate and propionate are found in portal blood and are eventually metabolized by the liver (propionate) or peripheral tissues, particularly muscle (acetate). Acetate and propionate might also play a role as modulators of glucose metabolism. Absorption of such SCFAs is implicated to result in low glycemic responses and to ameliorate insulin sensitivity.

Synbiotics are a combination of probiotics and prebiotics when administered together. There is synergy between probiotics and prebiotics resulting in more effectiveness than using either one because it favors competitive advantage for probiotic rapid adaptation in the GIT. Synbiotics are currently available as combinations of bifidobacteria and fructo-oligosaccharides (FOS), lactobacillus GG and inulins; bifidobacteria, lactobacilli and FOS or inulins.

Functional Foods for Lactose Intolerance

Lactose intolerance is the inability to utilize lactose from milk because of limited lactase enzyme production in the small intestine in some individuals. Infants can produce adequate lactase enabling them to utilize lactose of milk, which is the sole carbon source for the newborn. The ability to generate lactase enzymes diminishes with age. For individuals with limited lactase production, lactose will be transferred to the large intestine intact where it is hydrolyzed and fermented. The hydrolyzed products cause secretion of water into the intestinal lumen to balance the osmolarity pressures. This accumulation of water produces dehydration and electrolyte imbalance on the systemic side and watery stools on the intraintestinal sides. The fermentation of the sugar adds gaseous components (carbon dioxide, hydrogen, and methane) leading to bloating, cramping, and flatulence. The limited calcium supply through inadequate milk intake may lead to osteoporosis. Probiotics containing *Lactobacillus* strains are known to recover the lactose tolerance. The various nondairy probiotic functional foods and drinks developed include the following:

(1) Soy-based (nonfermented soy-based frozen desserts, fermented soymilk drink, and soy-based stirred yogurt-like drinks).
(2) Cereal-based puddings; rice-based yogurt; oat-based drink; oat-based products; yosa, an oat-bran pudding; mahewu, a fermented maize beverage; maize-based beverage; probiotic beverages fermented from wheat, rye, millet, maize, teff, sorghum, and other cereals; malt-based drinks; boza fermented from cereals, maize, and sorghum; millet malt-fermented probiotic beverages; and millet or sorghum flour-fermented probiotic beverage.
(3) Fruit- and vegetable-based drinks; fermented banana pulp and fermented banana juice; beet-based drink; tomato-based drink; many dried fruits; green coconut water; peanut milk; cranberry, pineapple, and orange juices; ginger juice; grape and passion fruit juices; cabbage juice; carrot juice; noni juice; onion puree; probiotic banana puree; nonfermented fruit juice beverages; and blackcurrant juice.
(4) Others (starch-saccharified probiotic drink, probiotic cassava-flour product, meat products, and dosa (rice and Bengal gram)).

Conclusions

Various DFs are available from whole grains, which are also sources of other nutrients and phytochemicals. The health-promoting effects of DF (GIH, cancer prevention, and suppression of metabolic syndrome-related diseases) are widely acknowledged. Functional foods containing DF are available as baked, extruded, fermented foods and beverages. Many components of DF have prebiotic effects. The health-promoting effects of prebiotics are known by their selective growth promotion of probiotics, fermentation to SCFA, prevention of various cancers, and enhancement of mineral absorption. They also suppress CVD, obesity, and diabetes. Prebiotic functional foods are available as beverages, whole grains, fermented cereal foods, bakery products, and RTE, infant, and toddler foods and in specialty liquid nutrient supplements. Probiotics (specific strains of *Lactobacillus* and *Bifidobacterium*) are known to have various healthful effects (enhancement of gut immunity, anti-inflammation, prevention of pathogenic infection, and suppression of irritable bowel syndrome (IBS), cancers, CVD, diabetes, rheumatoid arthritis, liver diseases, lactose intolerance, and diarrhea). Currently, nondairy probiotic functional foods and drinks such as soy-based foods, fermented cereals, and extruded and baked foods are on the rise. Microencapsulation is one option to incorporate probiotics in grain products. A combination of prebiotics and probiotics as synbiotics has synergetic health-promoting effects. Many traditional fermented grain foods with live or active cultures if fully characterized have huge potential to be used as probiotic functional diets. Development of grains with desirable DF profiles of prebiotic potential and improved phytonutrients can advance prebiotic, probiotic, and DF functional foods. The bioactives used in DF, whole grains, and prebiotic functional foods are concentrated in the outer portions of the grains, which may be contaminated by toxicants that can pose food safety challenges. Good agricultural practices, good manufacturing practices, hazard analysis critical control points, and adequate grain drying, cleaning, scouring, and/or removal of very small portion of outermost layers of grains during milling can suppress such food safety challenges and also preserve functional ingredients.

Exercises for Revision

- Provide definitions of DFs, whole grain foods, prebiotics, probiotics, and synbiotics.
- List up to seven different compounds regarded to be DFs.
- List up to four different compounds regarded to be prebiotics.
- Provide genera of microbial species widely used as probiotics.
- Provide essential characteristics of probiotics.
- Provide at least two health beneficial effects of DFs, whole grain foods, prebiotics, probiotics, and synbiotics.
- List up to four indigenous fermented foods consumed in your communities believed to have the effects of prebiotics, probiotics, and synbiotics.
- List potential safe diets for lactose-intolerant individuals.

Exercises for Readers to Explore the Topic Further

- What innovations in grain-processing technology can you envisage to preserve grain bioactive ingredients used to deliver optimum DFs, prebiotics, and probiotics?
- How would you provide further characterization of specific DF components from grains for their health benefits and prebiotic effects?
- Suggest further improvements that may be made to traditional fermented grain foods to promote their probiotic value.

Explore possibilities for developing grains using conventional breeding or through genetic manipulation to provide desirable DF profiles for prebiotic potential, like inulin-type fructans and β-glucans.

See also: **The Basics**: Grain, Morphology of Internal Structure (00010); **Food Grains and Well-being**: Nutrition, Soy-Based Foods (00066); **Food Grains and the Consumer**: Grains and Health (00067); **Food Grains and Well-being**: Functional Foods–Overview (00071); **Food Grains and the Consumer**: Cultural Differences in Processing and Consumption (00073); Fortification of Grain-based Foods (00074); Genetically Modified Grains and the Consumer (00075); Labeling of Grain-Based Foods (00076); Grains and Health – Misinformation and Misconceptions (00078); **Food Grains: Intolerance, Allergy and Diseases**: Celiac Disease (00083); **Carbohydrates**: Cereals: Chemistry of Non-starch Polysaccharides (00090); Beta glucans and health (00096); Resistant Starch and health (00097); Glycemic index (00098); **Bioactives and Toxins**: Bioactives in Wheat Bran (00109); Bioactives-antioxidants (00110); **Non-wheat Foods**: Soybean, Soy-Based Fermented Foods (00129); **Beverages from Grains**: Fermentation, Foods and Nonalcoholic Beverages (00136).

Further Reading

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