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Whole Grains and Pulses: A Comparison of the Nutritional and Health Benefits

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ABSTRACT: Nutrition plays an important role in the prevention and management of disease. Whole grain cereals contain a host of nutrients and bioactive substances that have health-promoting effects. Epidemiological evidence shows a consistent inverse association between whole grain intake and the risk of chronic disease. Despite a concerted effort by scientists, educators, and policy makers to promote the consumption of whole grains, it remains dismally short of the recommended intakes. Pulses (dried beans and peas) differ from whole grains in their structural and physicochemical properties and have varying amounts of fiber, resistant starch, vitamins, minerals, and other bioactive components; nevertheless, these food groups complement each other. Observational as well as intervention trials show that pulse consumption has beneficial effects on the prevention and management of chronic disease. The nutritional and phytochemical components of pulses coupled with those of whole grains suggest a potential synergistic effect that could provide significant health benefits.

KEYWORDS: *whole grains, legumes, pulses, obesity, diabetes, cardiovascular disease*

INTRODUCTION

Nutrition makes a substantial contribution to the etiology, prevention, and progression of disease.[1−3] Diets high in fruits, vegetables, whole grains, and proteins from plant sources and low in meat and meat products such as the Mediterranean dietary patterns have been shown to have long-term beneficial effects on health.[4−6] It is not by mere coincidence that longevity is also characterized by similar dietary patterns,[7] although the impact of other lifestyle factors cannot be ignored. High levels of dietary fiber, antioxidants, unsaturated fatty acids, and foods low in energy density are some of the protective components of the diet.[8] It is also likely that the bioactive components of the diet work in concert to promote health.

Epidemiological evidence consistently demonstrates that whole grains lower the risk of chronic diseases such as cardiovascular disease,[9] diabetes,[10] the metabolic syndrome,[11] and certain cancers.[12] Whole grain consumption may also play a positive role in weight management.[13] Similarly, the consumption of pulses (dried seeds from the legume family such as beans, peas, lentils, and chickpeas) has been shown to have beneficial effects on the prevention and management of obesity[14] and related disorders including coronary heart disease,[15] diabetes,[16] and the metabolic syndrome.[17] Whole grains and pulses are an abundant source of macronutrients, micronutrients, and phytonutrients that contribute to their health benefits.[18,19] These food groups differ in their structural and physicochemical properties and have varying amounts of fiber, resistant starch, vitamins, minerals, and other bioactive components. However, they complement each other. Thus, traditional foods such as the combinations of red beans and rice, burritos with refried beans, and hummus with pita bread provide an improved protein quality compared to the individual foods because of their complementary amino acid profiles.

Dietary advice to increase whole grain consumption has been promoted for decades, yet the daily consumption of whole grains falls far short of the recommendation.[20] On the other hand, refined grain intake exceeds the recommendation.[21] The U.S. Dietary Guidelines[22] as well as the Dietary Approaches to Stop Hypertension (DASH) Eating Plan of the National Heart, Lung, and Blood Institute[23] recommend consumption of pulses. They are an important component of the Mediterranean diet, which is associated with good health.[24] The nutritional and phytochemical components of pulses coupled with those of whole grains suggest a potential synergistic effect. Furthermore, the nutritional value of traditionally preferred enriched grain products can be enhanced if eaten along with pulses and may serve to provide some of the whole grain benefits that are seemingly unattainable due to its low consumption. This review will explore the nutritional value and health benefits of whole grain and legume consumption with a particular focus on pulses.

COMPOSITION OF WHOLE GRAINS

Cereals are defined as the fruit or seed of plants that belong to the Gramineae family of grasses and include wheat, rice, barley, corn, rye, oats, millets, sorghum, tef, triticale, canary seed, Job's tears, Fonio, and wild rice. Amaranth, buckwheat, and quinoa function as cereals. However, they are seeds from non-Gramineae families and are referred to as pseudocereals.[25] The seed is composed of the endosperm, the bran, which is the outer layer of the whole grain, and the germ, which is located at the base of the grain.[26] Whole-grain products are derived from cereals.[25] According to the American Association of Cereal Chemists International (AACCI) "whole grains shall consist of the intact, ground, cracked or flaked caryopsis, whose principal

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anatomical components the starchy endosperm, germ, and bran are present in the same relative proportions as they exist in the intact caryopsis". In April 2013, the AACCI further characterized a whole-grain product as being one that must contain 8 g or more of whole grain per 30 g of product.[27] The U.S. Food and Drug Administration (FDA) adopted the AACCI definition of whole grain; however, to qualify for the FDA whole-grain health claim at least 51% of the total weight of the product must be whole grain. The main whole-grain cereals consumed across the world are wheat, rice, and corn, followed by oats, rye, barley, triticale, millet, and sorghum.[18]

Carbohydrates. Starch is the main storage polysaccharide of cereal grains and is an important source of energy in the human diet. The endosperm of cereal grains contains mostly starch. In wheat, for example, starch comprises approximately 80−85% of the grain.[18] Starch is composed of amylose, a linear glucan with few branches, and amylopectin, which is a larger and more highly branched molecule. The ratios and molecular weights of the starch polymers vary widely among the cereals and help account for wide variations in functionality. Amylose comprises approximately 15−30% of total starch, and its content varies from one cereal to another.[28]

Dietary fiber includes macromolecules that resist digestion by human endogenous enzymes and is essentially composed of plant cell wall components.[19] These macromolecules are nonstarch polysaccharides, or structural carbohydrates.[29] Dietary fiber as defined by the AACCI is the edible part of plants and analogous carbohydrates that is resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances.[27] Thus, the AACCI definition also includes resistant starch, which is starch that resists digestion in the small intestine, but is later fermented by the colonic microflora. There are several definitions of dietary fiber; some include resistant starch, whereas others do not include starch polysaccharides.[30] For labeling, dietary fiber is defined by a number of analytical methods that are accepted by the Association of Official Analytical Chemists International (AOAC). Thus, labeling and defining dietary fiber in the United States rely on analytical methods rather than an accurate definition that includes its role in health.[31]

Dietary fiber may be soluble or insoluble on the basis of its solubility in water and buffer solutions. Soluble fibers are easily fermented by the microflora of the large intestine. They consist of pectins, gums, inulin-type fructans, and some hemicelluloses. Insoluble fiber is poorly fermented, but it contributes to fecal bulk, thereby promoting laxation, and includes cellulose, some hemicelluloses, lignin, and arabinoxylan.[19]

Whole grains are an abundant source of dietary fiber and other bioactive components, with the bran and germ fractions containing higher proportions than the endosperm. For example, approximately 63% of the fiber component of wheat is found in the bran and germ.[18] During the refining process the bran and germ fractions are removed. Thus, most refined cereal products have lost the protective components.[18] Whole grains contain approximately 80% more dietary fiber than refined cereal products.[32] A product that contains the original components of a whole grain recombined to deliver the relative proportion that naturally occurs in the grain kernel is referred to as a reconstituted whole-grain product. The bulk of the whole-grain food products available on store shelves would be considered reconstituted whole-grain products.[32] In the United States, approximately 90% of the whole grains consumed are provided by ready-to-eat-cereals (28.7%), yeast breads (25.3%), hot cereals (13.75%), popcorn (12.4%), and crackers (6.4%).[33]

In a summary of the American Society for Nutrition Symposium on the health benefits of whole grains, Jonalagadda et al. determined that observational studies have consistently shown an association between whole-grain consumption and disease risk reduction; however, the evidence from interventional studies offered less support.[32] In an evaluation of studies using foods that conformed to the AACCI definition of whole grains, no effect of whole-grain consumption on cardiovascular disease (CVD) risk reduction was found. When the analysis was expanded to studies that included bran, germ, and fiber along with whole grains, the results of 14 observational studies suggested a protective effect of whole-grain consumption on CVD risk. In the expanded analysis, intervention studies for the most part supported a beneficial effect.[26] Similar associations have been determined for cereal fiber and whole grains on risk factors for obesity, diabetes, and CVD,[34] suggesting that the fiber component of whole grain may be the determining factor in the physiological responses. However, the mechanisms involved in eliciting the positive effect have not been clearly elucidated. The possibility of the synergistic actions of the other bioactive components cannot be excluded.[18]

It has been suggested that dietary fiber may be protective against colorectal cancer on the basis of the finding of a low incidence of colorectal cancer in rural, black Africans, whose diet contained large amounts of unprocessed food plants, especially cereals.[35] However, incontrovertible evidence from human studies of a protective role for dietary fiber in colorectal cancer is unavailable at this time. Large randomized controlled trials found no effect of supplementation of wheat bran[36] or dietary fiber[37] on the recurrence of colorectal adenomas.

In the large multicenter European Prospective Investigation into Cancer and Nutrition (EPIC) observational study, dietary fiber from foods was inversely related to incidence of large bowel cancer.[38] However, another large-scale epidemiological study showed no correlation between fiber intake and the risk of colorectal cancer.[39] Furthermore, in a pooled analysis of 13 prospective cohort studies it was found that high dietary fiber intake was not associated with a reduced risk of colorectal cancer when adjusted for other risk factors, but the study did find an increased risk among people with a low intake of dietary fiber (<10 g/day).[40] In a large prospective cohort of men and women in the NIH-AARP Diet and Health Study[41] that assessed dietary intake through self-administered food frequency questionnaires, although no association was found between fiber intake and colorectal cancer, a statistically significant inverse association between whole-grain consumption and colorectal cancer was observed. The authors suggested that whole-grain components other than fiber such as vitamins, minerals, phenols, and phytoestrogens may have an effect on colorectal carcinogenesis.

Starch is generally considered to be completely digestible; however, starches can contain significant amounts of resistant starch depending on the nature of the starch and the processing. The digestibility of starch and thereby the resistant starch content are influenced by several factors that affect its accessibility to enzymes such as the structure of the starch granule and whether it is disrupted or intact. Greater hydrolysis is achieved with hydration and heat treatments that cause gelatinization. The polymers in starches with high amylose content can reassociate on cooling in a process called retrogradation, which is then poorly digested by amylases. Interactions with other food components such as the formation of lipid complexes may also reduce the rate of amylosis.[42]

In addition, grains also contain significant amounts of oligosaccharides such as oligofructose and inulin. These carbohydrates, which have a low level of polymerization, are nonviscous but have some effects similar to those of soluble fiber in the gastrointestinal tract.[43] Further dietary fiber, oligosaccharides, and resistant starch entering the large bowel can alter the gut microbiome and confer protective effects on health. The fiber and resistant starches are fermented to short-chain fatty acids (SCFAs), which may play an important role in the prevention and treatment of chronic disease. The molecular mechanisms by which SCFAs induce their effects are being actively investigated. Nevertheless, they have been shown to play an important role in the prevention and treatment of the metabolic syndrome, bowel disorders, and certain cancers.[44]

Proteins. A large proportion of the world supply of dietary protein, approximately 65%, is met by plant proteins with cereal grains (47%) and pulses, nuts, and oil seeds (8%) accounting for most of it.[45] In Western diets, protein from plant sources constitutes a lower proportion of protein intake compared to developing nations. The digestibility, amino acid composition, and presence of factors that influence digestibility are the major differences between plant and animal protein sources. However, contrary to popular belief, protein from plant sources can meet human protein needs. Whole grains are rich sources of protein, albeit low in the amino acid lysine. Diets that comprise plant sources of protein abundant in lysine such as pulses can complement whole-grain components. A lower protein to energy ratio may be the outcome compared to diets high in animal protein and more closely resembles the recommended intakes for protein.[46] Moreover, high intakes of animal protein are associated with obesity.[47] Plant sources of protein being lower in fat provide less energy.

Vitamins and Minerals. Whole-grain cereals are significant sources of the B-vitamins thiamin, niacin, pantothenic acid, and biotin. Wheat germ is rich in pyridoxine. However, whole-grain cereal products are not a particularly good source of folate. Moreover, the bioavailability in whole grains varies greatly and is far less than 100%. Of the B-vitamins, thiamin and pyridoxine have the greatest bioavailability.[18] Thiamin diphosphate functions as a coenzyme necessary for the oxidative decarboxylation of pyruvate, α-ketoglutarate, and the branched-chain amino acids. These reactions are necessary for generating energy. As a coenzyme it is involved in the synthesis of pentoses and NADPH. In addition, thiamin has a non-coenzyme role in membrane and nerve conduction.[48] Pyridoxal phosphate, the coenzyme form of vitamin B_6, is necessary for amino acid, lipid, and homocysteine metabolism as well as the synthesis of heme. It plays a role in the synthesis of serotonin from tryptophan and other neurotransmitters. A pyridoxine-dependent enzyme is also involved in homocysteine metabolism.[48]

Vitamin E functions as an antioxidant protecting the integrity of cellular membranes by preventing the oxidation of polyunsaturated lipids by free radicals.[49] In vivo studies among animals[50] and in human aortic endothelial cells[51] have shown that vitamin E prevents oxidative stress. The vitamin E content of whole-grain cereals is variable. Corn and rye are the richest sources, whereas wheat, barley, and oats have lesser amounts.[49] Vitamin E may also function to maintain selenium in the reduced state. Selenium is a cofactor for gluthathione peroxidase, an enzyme that protects against oxidative damage to tissues; however, the selenium content of cereals depends upon the soil in which the grain is grown.[52]

Whole grains and pulses are among the richest sources of magnesium, which may in part explain their favorable effects on insulin sensitivity and diabetes. In cardiac and vascular smooth muscle, magnesium has a role in the regulation of contractile proteins and sarcoplasmic reticular membrane transport of calcium ions (Ca^{2+}). It is a cofactor in ATPase activities and is involved in the metabolic regulation of energy-dependent cytoplasmic and mitochondrial pathways. Magnesium is found associated with calcium and phosphate in hydroxyapatite, the major component of bone. Additionally, magnesium is found on the surface of bone in an amorphous form that is thought to maintain serum levels through an exchangeable pool.[48] Intracellular magnesium concentration has also been shown to be effective in increasing insulin secretion and the rate at which glucose is cleared from the blood. It offsets calcium-related excitation−contraction coupling and decreases smooth cell responsiveness to depolarizing stimuli. Thus, magnesium may play a key role in modulating insulin-mediated glucose uptake and vascular tone.[53] However, calcium from whole-grain cereals may not contribute significantly to bone health because the calcium to potassium ratio in cereals is below the recommendation for effective calcium use by the body. More than 85% of the potassium content of cereals is supplied by phytic acid, which has a high affinity for hydroxyapatite. Thus, grain consumption may have a role in dental health through the cariostatic effect of phytic acid.[18]

Other minerals such as iron, zinc, copper, and manganese are cofactors of antioxidant enzymes and have other regulatory and metabolic functions. The physiological functions of zinc include bone formation, skin integrity, carbohydrate metabolism, and taste acuity.[48,54] Iron has an important role in respiration and energy metabolism, immune function, and cognitive development. Plant foods are primarily sources of nonheme iron. The absorption of nonheme iron is approximately 2−3%, which can be enhanced to 8% if it is ingested along with a source of vitamin C and meat, fish, or poultry.[48] Furthermore, whole grains have a high concentration of phytic acid, and chelation of minerals may reduce their bioavailability.

Phytonutrients. Phytochemicals are non-nutrient bioactive compounds in fruits, vegetables, grains, and other plant foods that may reduce the risk of chronic disease.[55] Phenolics are phytochemicals that form part of the plant defense mechanism and include phenolic acid, which contributes approximately two-thirds of the phenolics in our diets, the remaining being supplied by flavonoids.[55] The phenolic compounds in grains include derivatives of benzoic and cinnamic acids, anthocyanidins, quinones, flavonols, chalones, amino phenolic compounds, tocotrienols, tocopherols, and carotenoids.[56] Whole grains are a major source of phenolic acids such as ferulic, vanillic, caffeic, syringic, sinapic, and *p*-coumaric acids.[49] Whole grains have been associated with antioxidant activity, which may be attributed to their phytochemical content.

Phenolic acids are mostly found esterified or bound to plant cell wall polymers. These complexes can evade digestion to reach the colon intact, where they may be digested by organisms in the microbiome, thereby releasing the bound phenolic compounds to exert their physiological effects. Thus, unlike fruits and vegetables where the antioxidant polyphenols are either free or in the form of soluble conjugates and available

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in the small intestine, in whole grains their site of action may be the colon.[49] This may in part be the reason why whole grains have been associated with reduced risk of colon cancer.

The antioxidant capacity of breads, ready-to-eat breakfast cereals, and uncooked cereals ranges from 13.18 to 24.79 Trolox equivalents (TE)/g, which is higher than that of most vegetables but far less than that of dry beans, which ranges from 80.4 to 149.21/g.[57] In vivo, the antioxidant potential may be higher than that derived from in vitro assays because fiber-associated compounds are generally not included.[49] The bound fractions make a significant contribution and are generally much higher than the free and soluble fractions.[58,59]

Carotenoids are a group of pigments synthesized by plants and select species of algae and fungi.[60] Approximately 90% of the carotenoids in the human diet consist of β-carotene, α-carotene, lycopene, cryptoxanthin, and lutein.[61] One of the characteristic features of carotenoids is a long series of alternating double and single bonds. Carotenoids scavenge free radicals and become free radicals themselves, but they can remain stable compounds because the free radical can be delocalized among the alternating single and double bonds. Thus, carotenoids make good antioxidants.[62] Despite a vast amount of research, a disease-preventing role is hard to ascribe to carotenoids,[60,63] which may be because the experimental designs have used an all or none approach more conducive to trials of drug efficacy, whereas the populations may not have been completely naïve to carotenoids. Carotenoids are ubiquitous components of food and may have small effects that aggregate over decades, working in synergy with other dietary components and lifestyle factors.[60]

Phytic acid present in whole grains chelates minerals such as zinc, iron, calcium, and magnesium, which reduces their bioavailability. On the positive side, phytic acid has been shown to reduce oxidative damage by suppressing iron-catalyzed oxidative reactions.[18] Phytic acid may also reduce oxidative damage to the intestinal epithelium associated with oxygen radicals produced by colonic bacteria.[52] However, the antioxidant effect of phytic acid from whole grains has not been evaluated.

Lignins are components of whole-grain cereals that may comprise 3−7% of the bran fraction. Structurally, lignins are related to lignans but differ from them by their polymeric nature and distribution in plants. Lignans are phytoestrogens present in whole grains such as corn, oats, wheat, and rye. Rats can metabolize lignins and lignans from cereal sources to mammalian lignans.[64] Lignans and their metabolites, the mammalian lignans enterodiol and enterolactone, have antioxidant potential due to their polyphenolic structure.[49] Lignins, because of their polymeric nature and their embedding in the cell wall, are usually considered inert in the digestive tract.[64] Lignans have been shown to be protective against certain cancers;[65] hence, if lignins are metabolized to lignans in humans as they are in rats, whole-grain cereal consumption might confer added anticancer effects.[18]

Plant sterols and stanols are found in grains, as well as pulses. These compounds are structurally similar to cholesterol. The mechanisms by which they are clinically beneficial include reduction in cholesterol absorption and transintestinal cholesterol synthesis, both of which result in increased fecal neutral sterol excretion to explain the low-density lipoprotein (LDL) cholesterol lowering effect of plant sterols and stanols.[66] The vast amount of evidence to support a cholesterol-lowering effect led to the recommendation for the inclusion of plant sterols and stanols in the diet because humans are unable to synthesize these compounds. However, the recommended level of 2 g/day is difficult to meet and the average consumption in the Western diet ranges from 0.2 to 0.4 g/day.[67] Thus, whole-grain consumption may help to meet the recommendation and potentially confer a cardioprotective effect.

■ COMPOSITION OF PULSES

Legumes are plants belonging to the Leguminosae family. They are second to cereals in providing food crops for the world.[68] Legumes include alfalfa, clover, lupin, green beans and peas, peanuts, soybeans, dry beans, broad beans, dry peas, chickpeas, and lentils. Pulses are annual leguminous crops yielding from 1 to 12 grains or seeds within a pod. The Food and Agriculture Organization (FAO) limits its definition of pulses to crops harvested solely for dry grain, thereby excluding crops harvested green for food such as green peas and green beans, and classifies these as vegetable crops. Also excluded are those crops used mainly for oil extraction, such as soybean and peanuts, and leguminous crops such as seeds of clover and alfalfa that are used exclusively for sowing purposes. Pulses contain approximately 55−65% of their total weight as carbohydrates, mainly starches.[69] The protein content of pulses ranges from about 20% (dry weight) in peas and beans to 38−40% in lupin.[68] A serving of pulses (half cup of cooked dried pulses) contains 2−4 g of fiber and 7−8 g of protein. Most beans are very low in fat, generally containing <5% of energy as fat except for chickpeas, lupin seeds, and soybeans, which contain from <15 to 47% fat.[70] Pulses contain substantial amounts of the B-vitamins and minerals important for human health, such as iron, calcium, and potassium, as well as phytochemicals: bioactive compounds, including enzyme inhibitors, lectins, oligosaccharides, and phenolic compounds.[71]

Carbohydrates. Starch digestibility affects the glycemic response and compared to cereal foods such as whole-grain breads, spaghetti, rice, breakfast cereals, and oatmeal, legumes elicit the lowest postprandial glucose responses.[72,73] The digestibility of starch from legumes is much lower than that ofcereal starch.[74−77] The rate at which legume starches are digested is approximately 45% lower than that of cereal starches.[75] Starch digestion is slowed in the small intestine if access to pancreatic amylase is hindered by the presence of other plant materials. Pulses have a rigid cell wall, which inhibits swelling and dispersion of the starch. Moreover, the crystallinity of starch in pulses as determined by the ordered arrangements of adjacent double-helix amylopectin is the B and C type, which is more resistant to digestion than the A type found in cereals.[19] Pulses contain 30−40% of amylose starch, which is 5−10% more amylose starch than cereals.[78] Higher amylose than amylopectin starch content correlates with higher resistant starch content.[19] Although it is difficult to quantify resistant starch because of a lack of standardized methods of analysis,[79] cooked pulses are prone to retrograde more quickly than cereals, which slows the process of digestion. Moreover, pulses are high in protein, and protein−starch interactions further hinder digestibility. Additionally, the presence of high amounts of dietary fiber in pulses may greatly lower the rate and extent of starch digestibility.[19]

Pulses are high in fiber even without including the resistant starch fraction, ranging from 4 to 19 g and averaging approximately 13 g per cup of mature dry seeds, cooked (boiled without salt).[80] Along with cereals, pulses are a primary source of phytates in the human diet. Phytates may reduce the rate of starch digestion and delay the postprandial glycemic response.[81] Furthermore, α-amylase inhibitors found in pulses, particularly dry beans, in amounts ranging from 2 to 4 g/kg may also reduce starch availability.[82] Bean extracts containing α-amylase inhibitors have been shown to reduce starch digestion in vitro and cause weight loss in humans,[83] but the lack of consistent results[83−86] and the fact that residual phytohemagglutinin present in beans may cause adverse gastrointestinal events[87] warrant further investigation. Thus, pulses are known as slow-release carbohydrates because of their reduced digestibility.

The oligosaccharides raffinose, stachyose, and verbascose are present in pulses in amounts ranging from 1 to 12% of the dry weight of pulses. Humans lack α-galactosidases in the upper regions of the gastrointestinal tract; hence, the oligosaccharides enter the lower gut, where they are fermented by bacteria to produce carbon dioxide and hydrogen.[88] The flatulence and bloating associated with pulse consumption has been attributed to these nondigestible but rapidly fermentable oligosaccharides. The discomfort of possible gastrointestinal disturbances may deter pulse consumption,[89] although evidence suggests that flatulence or other gastrointestinal symptoms associated with the consumption of pulses may progress into tolerance.[90,91]

The amount and type of dietary fiber have major influences on the composition of intestinal microbiota and thereby the production of SCFAs.[44] However, it is likely that the diet-induced effects depend on pre-existent gut microbial composition, in interaction with the host phenotype. Changes in the diet such as increased nondigestible food ingredients can also result in shifts in microbiota distribution.[92] Nevertheless, the high oligosaccharide and resistant starch components of pulses are potentially good sources of substrates for SCFA production.

Humans share a mutual relationship with their gut microbiota marked by symbiosis, wherein one partner benefits without harming the other, or commensalism, wherein partners coexist without detriment but without any noticeable benefit.[93] The mucosal immune system selectively and actively tolerates the gut microbiota during steady-state conditions and will mount an inflammatory response once there is a threat of disease or infection. Once microbiota are under immune attack, a more pathogenic profile will emerge and the peaceful coexistence will cease. Commensal bacteria maintain a stable environment by inducing and modulating host innate immunity.[94] Thus, manipulations of the gut microbiome through the diet are therapeutic interventions that are not unthinkable; however, it is only long-term diets that appear to effect the desired changes.[95] Because α-galactosides, more commonly known as oligosaccharides, comprise 25−65% of the sugar fraction of legumes,[96] their prebiotic potential is worthy of exploration.

Proteins. Pulses accumulate large amounts of proteins during their development and are among the richest sources of dietary proteins. The proteins in pulses are largely storage proteins with globulins forming the largest component. Pulse storage proteins are relatively low in sulfur-containing amino acids, methionine and cysteine, as well as the aromatic amino acid tryptophan. However, they contain significant amounts of lysine, which is the limiting amino acid in cereals, making the two plant sources of proteins nutritionally complementary. The degree of complementation may also depend on the content of the second limiting amino acid, namely, threonine in cereals and tryptophan in pulses.[68] Meat consumption in the United States averages 212 g/day. High meat consumption is associated with higher intakes of energy and fat compared to lower meat intake and a greater likelihood of obesity.[47] High red meat intake is associated with less desirable levels of the biomarkers of inflammation and glucose metabolism (C-reactive protein, fasting insulin, and HbA1C), and a high body mass index (BMI) accounts for a significant proportion of this association.[97] Therefore, although protein needs in the United States are largely met by meat consumption, substitution with plant proteins provides a healthier option.

Pulse seeds contain several comparatively minor proteins called antinutrients, including enzymes, enzyme inhibitors, and lectins. The inhibition of various digestive enzymes, including trypsin, chymotrypsin, and amylase, reduces the bioavailability of nutrients, but their effect is usually manifest only if the seed or the flour is consumed uncooked, because cooking normally denatures the antinutrients.[68] The term antinutrient appears to be a misnomer as their extracts have beneficial effects on human health and the nutraceutical potential is worth noting.

Lectins account for 2.4−5% of the protein content of kidney beans. They directly inhibit HIV reverse transcriptase, an enzyme critical for replication of the human immunodeficiency virus, and β-glucosidase, which is required for processing of viral proteins.[82] Thus, lectins from kidney beans form an important component of antiretroviral therapy. Including raw kidney beans in the diet of obese rats reduces lipid accumulation, which may be due to reduced insulin levels caused by lectins.[98] Lectins can resist gastric digestion, yet they can be absorbed into the bloodstream while remaining biologically active, and these properties may contribute to their antitumor effects. Lectins may bind to cell membranes or receptors to cause cytotoxicity, apoptosis, and inhibition of tumor growth. They may also penetrate the cell to cause agglutination of cancer cells.[99] Lectins may have a role in weight management by increasing the shedding of brush border membranes to interfere with gastric secretion and nutrient absorption, but reports of lectin toxicity are conflicting.[100] Thus, further research on a safe and effective dose is needed before its therapeutic role in the treatment of obesity is promoted.

Protease inhibitors of the Bowman−Birk inhibitor family, from peas, have been shown to have antiproliferative effects in human colon cancer cells. These inhibitors also inhibit protease-mediated inflammation. However, the beneficial effects require the protein to be in the biologically active form. Although cooking deactivates these proteins, denaturation may not always be complete; thus, regular consumption may contribute to the beneficial effect.[68] Angiotensin-1 converting enzyme (ACE) raises blood pressure when it converts angiotensin-1 to a potent vasoconstrictor angiotensin-2, and ACE inhibitor drugs are used to treat hypertension. Chickpeas and peas contain ACE inhibitor peptides. In vitro digestion studies indicate that pea protein and red lentil isolates have antihypertensive activity.[101,102] Therefore, pulses and their extracts may possess the potential for anticarcinogenic, anti-inflammatory, and antihypertensive effects, but further research is needed.

Vitamins and Minerals. Pulses are also a good source of B-vitamins, namely, riboflavin, thiamin, niacin, pyridoxine, and folic acid. These vitamins have important functions in energy metabolism and fatty acid metabolic pathways. Niacin is a coenzyme in energy metabolism and fatty acid metabolic pathways. It is involved in the modification of chromosomal

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Table 1. Energy, Macronutrient, and Fiber Contents of Common Legumes and Cereals[a]

	serving size	energy (kcal)	carbohydrate (g)	protein (g)	fat (g)	fiber[b] (g)
legumes						
pinto beans	1/2 cup	122	22.42	7.70	0.56	7.7
great northern beans	1/2 cup	104	18.66	7.37	0.40	6.2
navy beans	1/2 cup	127	23.71	7.49	0.56	9.6
black beans	1/2 cup	114	20.39	7.62	0.46	7.5
cowpeas (blackeyes, crowder, southern)	1/2 cup	99	17.75	6.61	0.45	5.6
kidney beans	1/2 cup	112	20.18	7.67	0.44	5.7
chickpeas	1/2 cup	134	22.48	7.27	2.12	6.2
split peas	1/2 cup	116	20.68	8.17	0.38	8.1
lentils	1/2 cup	115	19.93	8.93	0.38	7.8
lupin	1/2 cup	99	8.20	12.92	2.42	2.3
whole-grain products						
bread, whole wheat	1 slice	81	13.67	3.98	1.12	1.9
English muffin, whole wheat	1/2 muffin	67	13.33	2.90	0.69	2.2
bread pita, whole wheat	1, 4 in. diameter	74	15.40	2.74	0.73	2.1
crackers, whole wheat	6 crackers	118	19.20	2.92	3.90	2.8
oats, regular or quick, cooked with water	1/2 cup	83	14.04	2.97	1.78	2.0
ready-to-eat cereal, All Bran	1/2 cup	81	23.01	4.07	1.52	9.1
rice, brown, medium grain, cooked	1/2 cup	109	22.92	2.26	0.81	1.8
spaghetti, whole wheat, cooked	1/2 cup	87	18.58	3.73	0.38	3.2
popcorn, air popped	3.5 cups	108	21.78	3.62	1.29	4.1
refined grain products						
bread, white	1 slice	74	13.74	2.56	0.89	0.8
bread, rye	1 slice	83	15.46	2.72	1.06	1.9
barley, pearled, cooked	1/2 cup	97	22.15	1.77	0.35	3.0
pseudocereals						
amaranth, cooked	1/2 cup	125	22.99	4.67	1.94	2.60
quinoa, cooked	1/2 cup	111	19.70	4.07	1.78	2.60
buckwheat, cooked	1/2 cup	77	16.75	2.84	0.52	2.30

[a]Values are for one serving of mature dry legume seeds, cooked (boiled without salt), and one serving of cereals. Source: U.S. Department of Agriculture (USDA), Agricultural Research Service, 2012. USDA National nutrient database for Standard Reference26. Nutrient Data Laboratory Home Page, http://www.ars.usda.gov/ba/bhnrc/ndl. [b]Does not include all of the resistant starch fraction.

proteins that function in the nucleus in DNA repair and regulation as well as cell differentiation. Niacin is also required for mobilization of calcium from intracellular stores.[48] In societies where the chief dietary staple consists of cereals such as corn or sorghum, niacin deficiency is likely to occur because it is covalently bound to complex carbohydrates, although chemical treatment with bases such as limewater can improve availability.[48]

Beans are an excellent source of folate, and two or more servings of some pulses can provide approximately 400 μg, which represents 100% of the daily requirements.[71] Global DNA hypomethylation and targeted hypermethylation are considered deviant patterns of DNA methylation found in many human diseases, such as cancer, imprinting disorders, and developmental disabilities.[103−105] Reductions in global DNA methylation may be precipitated by a low folate status.[106]

Minerals are essential micronutrients in human health. Iron is essential for respiration and energy metabolism. Zinc is a component of numerous metalloenzymes having catalytic activity or structural integrity that are zinc-dependent.[48] Although the bioavailability of iron from pulses is relatively low, approximately 20−25% of zinc is bioavailable.[107] Zinc deficiency has been associated with cardiovascular and renal diseases.[108] Calcium is an important component of the structure of bones and teeth. It is involved in blood clotting, enzyme regulation, nerve transmission, and muscle contraction.[48] Calcium bioavailability from pulses is half that of milk; nevertheless, approximately 20% of the calcium content of beans is bioavailable.[109]

Pulses are high in potassium and low in sodium. The effects of potassium on blood pressure are intertwined with sodium. The kidneys are genetically predisposed to conserve sodium and excrete potassium. This adaptation is linked to prehistoric humans who consumed a diet rich in potassium and low in sodium. The linkage of modern diets rich in sodium and low in potassium to the pathogenesis of hypertension is supported very strongly by reductions in blood pressure with diets that reverse this cationic composition.[110,111]

Retained sodium not only replaces potassium, which is then excreted in the urine, but it is also stored extracellularly in skin, cartilage, and bone. It is readily mobilized to increase its level in body fluids. Thus, in the absence of conservation, a low-potassium diet leads to a potassium deficit in the body. Sodium retention and potassium depletion have direct effects on arterial wall endothelium and nitric oxide synthesis to promote vasoconstriction. Sodium restriction and a high-potassium diet reverse these effects.[111] Moreover, potassium deficiency is associated with glucose intolerance and impaired insulin secretion, whereas potassium infusion increases insulin secretion. Membrane depolarization induced by potassium may be the trigger for insulin secretion by pancreatic β cells.[112,113]

Phytonutrients. The major phenolic compounds in pulses are tannins, phenolic acids, and flavonoids. Phenolics have at

Table 2. Vitamin Contents of Common Legumes and Cereals[a]

	serving size	thiamin (mg)	riboflavin (mg)	niacin (mg)	pantothenic acid (mg)	pyridoxine (mg)	folate (μg)	vitamin E (α-tocopherol, mg)
legumes								
pinto beans	1/2 cup	0.165	0.053	0.272	0.180	0.196	147	0.800
great northern beans	1/2 cup	0.140	0.052	0.603	0.235	0.104	90	
navy beans	1/2 cup	0.216	0.060	0.591	0.242	0.126	127	0.010
black beans	1/2 cup	0.21	0.051	0.434	0.208	0.059	128	
cowpeas	1/2 cup	0.173	0.047	0.423	0.351	0.086	178	0.240
kidney beans	1/2 cup	0.142	0.051	0.512	0.195	0.106	115	0.030
chickpeas	1/2 cup	0.095	0.052	0.431	0.235	0.114	141	0.290
split peas	1/2 cup	0.186	0.055	0.872	0.583	0.047	64	0.030
lentils	1/2 cup	0.167	0.072	1.049	0.632	0.176	179	0.110
lupin	1/2 cup	0.111	0.044	0.411	0.156	0.007	49	
whole-grain products								
bread, whole wheat	1 slice	0.126	0.053	1.420	0.207	0.069	13	0.850
English muffin, whole	1/2 muffin	0.099	0.046	1.125	0.229	0.054	16	0.140
bread pita, whole wheat	1, 4 in. diameter	0.095	0.022	0.795	0.233	0.074	10	0.170
crackers, whole wheat	6 crackers	0.050	0.006	1.278	0.230	0.051	8	0.390
oats, regular or quick, cooked with water	1/2 cup	0.089	0.019	0.262	0.363	0.006	7	0.090
ready-to-eat cereal, All Bran	1/2 cup	0.704	0.840	4.588	0.329	3.720	406	0.380
rice, brown, medium grain, cooked	1/2 cup	0.099	0.012	1.297	0.382	0.145	4	-
spaghetti, whole wheat, cooked	1/2 cup	0.076	0.032	0.495	0.293	0.055	4	0.210
popcorn, air popped	3.5 cups	0.029	0.023	0.646	0.143	0.044	9	0.080
refined grain products								
bread, white	1 slice	0.149	0.068	1.338	0.150	0.024	31	0.060
bread, rye	1 slice	0.139	0.107	1.218	0.141	0.024	35	0.11
barley, pearled, cooked	1/2 cup	0.065	0.049	1.619	0.106	0.090	13	0.01
pseudocereals								
amaranth, cooked	1/2 cup	0.018	0.027	0.289	[b]	0.139	27	0.230
quinoa, cooked	1/2 cup	0.099	0.102	0.381	[b]	0.114	39	0.580
buckwheat, cooked	1/2 cup	0.034	0.033	0.790	0.302	0.065	12	0.080

[a]Values are for one serving of mature dry legume seeds, cooked (boiled without salt), and one serving of cereals. Source: U.S. Department of Agriculture (USDA), Agricultural Research Service, 2012. USDA National nutrient database for Standard Reference26. Nutrient Data Laboratory Home Page, http://www.ars.usda.gov/ba/bhnrc/ndl. [b]Value unavailable at source.

least one aromatic ring with one or more hydroxyl groups. They can transfer electrons to remove free radicals, chelate metal catalysts, activate enzymes, and inhibit oxidases.[114] These compounds are known to have antioxidant, anti-inflammatory, and antimicrobial properties[115] that protect body tissues against oxidative stress.[116] Flavonoids limit free radicals, free radical mediated cellular signaling, and inflammation.[117] They improve endothelial dysfunction and platelet aggregation.[118] Enhanced reactive oxygen species release from the vascular wall can affect the platelet activity cascade by scavenging nitric oxide and thereby decreasing the antiplatelet activity of the endothelium.[119]

Polyphenols reduce the expression of NADPH oxidase, an enzyme that generates superoxide anions in arterial cells, and increase the expression of antioxidant enzymes such as catalase and superoxide dismutase. Their antioxidant effects extend to inflammation-related proteins such as nuclear factor κB and cyclooxygenase-2. Thus, polyphenols reduce vasoconstriction and pro-inflammatory responses and promote vascular health by reducing oxidative stress induced degradation of nitric oxide.[120,121] Anthocyanins are present in pulses such as black beans,[82] red kidney beans, and pinto beans.[116] They have been shown to increase phase II antioxidant and detoxifying enzymes in human gastric adenocarcinoma cells[122] and breast epithelial cell lines exposed to a carcinogen.[123] Phenolic compounds have the potential to prevent tumor development. Lentils have the highest phenolic content, followed by red kidney beans and black beans.[82] The high pigmentation in dark-colored beans such as red kidney beans and black beans appears to increase their phenolic content.

Pulses contain other minor constituents such as phytic acid and saponins that promote human health. Phytic acid induces differentiation and maturation of malignant cells, often reverting cells to the normal phenotype. It can regulate the cell cycle to impede uncontrolled cell division, forcing malignant cells to either differentiate or go into apoptosis.[124] Saponins suppress the metastatic potential of tumors by regulation of enzymes involved in the apoptosis pathway, leading to programmed cell death.[82] Saponins form an insoluble complex with cholesterol to inhibit its intestinal absorption. By increasing the excretion of bile acids some saponins indirectly decrease cholesterol.[71,125] The energy, macronutrient, and fiber composition of select pulses and cereal products are presented in Table 1. The vitamin and mineral components are presented in Tables 2 and 3, respectively.

HEALTH BENEFITS OF WHOLE GRAINS

The evidence for an association between whole-grain consumption and health is largely supported by observational

Table 3. Mineral Contents of Common Legumes and Cereals[a]

	serving size	Ca (mg)	Fe (mg)	Mg (mg)	P (mg)	K (mg)	Na (mg)	Zn (mg)	Cu (mg)	Mn (mg)	Se (mg)
legumes											
pinto beans	1/2 cup	39	1.79	43	126	373	1	0.84	0.187	0.387	5.3
great northern beans	1/2 cup	60	1.89	44	146	346	2	0.78	0.219	0.458	3.6
navy beans	1/2 cup	63	2.15	48	131	354	0	0.94	0.191	0.480	2.6
black beans	1/2 cup	23	1.81	60	120	305	1	0.96	0.180	0.382	1.0
cowpeas	1/2 cup	21	2.15	45	133	238	3	1.10	0.229	0.406	2.1
kidney beans	1/2 cup	31	1.96	37	122	358	1	0.88	0.191	0.381	1.0
chickpeas	1/2 cup	40	2.37	39	138	239	6	1.25	0.289	0.845	3.0
split peas	1/2 cup	14	1.26	35	97	355	2	0.98	0.177	0.388	0.6
lentils	1/2 cup	19	3.30	36	178	365	2	1.26	0.248	0.489	2.8
lupin	1/2 cup	42	1.00	45	106	203	3	1.15	0.192	0.561	2.2
whole-grain products											
bread, whole wheat	1 slice	52	0.79	24	68	81	146	0.57	0.073	0.696	8.2
wheat	1/2 muffin	87	0.81	23	93	69	120	0.53	0.070	0.591	13.3
bread pita, whole wheat	1, 4 in. diameter	r4	0.86	19	50	48	124	0.43	0.081	0.487	12.3
crackers, whole wheat	6 crackers	10	0.92	30	91	95	194	0.73	0.016	0.594	2.8
oats, regular or quick, cooked with water	1/2 cup	11	1.05	32	90	82	5	1.17	0.087	0.679	6.3
ready-to-eat cereal, All Bran	1/2 cup	121	5.46	112	356	316	80	3.84	0.322	2.297	2.9
rice, brown, medium grain cooked	1/2 cup	10	0.52	43	75	77	1	0.6	0.079	1.070	*b*
spaghetti, whole wheat, cooked	1/2 cup	10	0.74	21	62	31	2	0.57	0.117	0.965	18.1
popcorn, air popped	3.5 cups	2	0.89	40	100	92	2	0.86	0.073	0.312	0
refined grain products											
bread, white	1 slice	73	1.01	7	29	32	137	0.24	0.035	0.166	6.2
bread, rye	1 slice	23	0.91	13	40	53	193	0.36	0.060	0.264	9.9
barley, pearled, cooked	1/2 cup	9	1.04	17	42	73	2	0.64	0.082	0.203	6.8
pseudocereals											
amaranth, cooked	1/2 cup	58	2.58	80	182	166	7.00	1.06	0.183	1.050	6.8
quinoa, cooked	1/2 cup	16	1.38	59	141	159	6.00	1.01	0.178	0.584	2.6
buckwheat, cooked	1/2 cup	6	0.67	43	59	74	3.00	0.51	0.123	0.339	1.8

[a]Values are for one serving of mature dry legume seeds, cooked (boiled without salt) and one serving of cereals. Source: U.S. Department of Agriculture (USDA), Agricultural Research Service, 2012. USDA National nutrient database for Standard Reference26. Nutrient Data Laboratory Home Page, http://www.ars.usda.gov/ba/bhnrc/ndl. [b]Value unavailable at source.

studies, which precludes the establishment of causality.[126] Epidemiological data collected among a predominantly Caucasian population suggest that the consumption of three or more servings (3 oz equivalents) of whole grains is associated with a positive impact on body mass index (BMI), abdominal obesity, CVD risk reduction, and glucose homeostasis.[32] A comprehensive meta-analysis showed that compared with those who rarely or never consume whole grains, 48−80 g of whole grains or three to five servings of whole grains per day reduces the risk for type 2 diabetes and CVD by 26 and 21%, respectively. An inverse association between whole-grain intake and weight gain was also observed.[127]

Observational studies that reported an inverse association between whole grains and chronic disease investigated mixtures of whole grains and ≥25% of bran rather than whole grains alone.[128] However, there is a paucity of randomized controlled trials (RCTs) assessing the health effects of whole-grain consumption. Moreover, they are of short duration (≤1 year), measured biomarkers rather than end points of disease, and used a specific fiber, whole grain, or bran in doses that do not represent daily consumption. The existing evidence from RCTs suggests that whole grains alone are insufficient to exert a beneficial effect on disease risk reduction.[128,129]

Cardiovascular Disease. There is fairly consistent evidence to support an association between whole-grain consumption and a reduction in blood pressure.[130,131] Four or more servings of whole grains are associated with a 23% lower risk of hypertension.[130] The evidence from RCTs is less consistent. In one study substitution of three servings of refined cereals foods with whole-grain foods (100−120 g of whole-wheat foods or whole-wheat foods and oats) for 12 weeks lowered blood pressure.[132] In another study among 14 normal-weight healthy individuals, 48 g/day of whole-grain consumption for 3 weeks reduced blood pressure.[133] Replacement of 20% of the energy content of the Step 1 diet of the American Heart Association with whole grains reduced blood pressure in mildly hypercholesterolemic individuals.[134] However, 3 months of high-fiber cereal foods did not improve blood pressure in 23 diabetic individuals.[135]

A positive association between whole-grain consumption and improvements in coronary artery intima media thickness has been observed,[136,137] but the effect of whole-grain consumption on blood lipids is not clear. The effect of β-glucan, a soluble fiber found in oats and barley, on reducing low-density lipoprotein cholesterol is well documented,[138−142] but, apart from the quantity, other properties such as the molecular weight and solubility of β-glucan influence its physiological effects.[143] These properties, which determine the cholesterol-lowering effects, may be altered during processing. Thus, it is difficult to draw any definite conclusions as to the effects of these extracts compared to consumption of the whole grain. Furthermore, the effect of whole-grain foods prepared from other cereal grains in lowering blood lipids is not consistent.[144−146]

Whole-grain consumption has been shown to decrease C-reactive protein, a marker of inflammation, in overweight adults with the metabolic syndrome consuming a hypocaloric diet for 4 weeks.[147] However, in the WHOLEheart study the addition of up to 120 g of whole grains to the diet over 8 and 16 weeks did not significantly improve markers of CVD risk, including C-reactive protein, among 316 overweight individuals.[144] A majority of the studies evaluating the effect of whole-grain consumption on cardiovascular risk included the fiber-rich bran and the germ as well as the whole grain in the definition of whole grain. When only studies that meet the FDA definition of whole grain are analyzed, it appears that there is insufficient evidence to support a claim that whole grains reduce the risk of CVD, suggesting that the fiber content of whole grains may to a large extent mediate its cardiovascular effects.[26] On conducting a systematic review of the scientific evidence including controlled clinical trials and prospective cohort studies in healthy individuals, Health Canada concluded that the current evidence may not be sufficient to support a health claim about whole grains and coronary heart disease.[148]

Diabetes and the Metabolic Syndrome. Epidemiological evidence indicates an inverse association between whole-grain consumption and type 2 diabetes.[10,149] A meta-analysis showed that a two serving per day increase in whole-grain consumption is associated with a 21% reduction in the risk for type 2 diabetes.[10] In a randomized crossover trial among 30 overweight individuals, markers of insulin sensitivity and inflammation were not significantly affected by the inclusion of whole grains in the diet for 6 weeks compared to refined grains intake. Insulin sensitivity was measured using the euglycemic hyperinsulinemic glucose clamp, which is considered the gold standard for measurement of insulin sensitivity.[150] However, in a smaller randomized crossover study among 11 overweight or obese hyperinsulinemic individuals, consumption of whole grains for 6 weeks improved insulin sensitivity measured using the glucose clamp.[151] Whole-grain consumption for 12 weeks had no effect on insulin sensitivity, compared to consumption of refined cereals assessed by the frequently sampled intravenous glucose tolerance test.[152] In other studies, consumption of high-fiber cereal foods for 3 months did not improve markers of glycemic control or risk factors for coronary heart disease in 23 subjects with type 2 diabetes.[135] However, in 61 subjects with the metabolic syndrome, a 12 week diet based on whole grains reduced postprandial insulin and triglyceride responses compared to a diet based on refined grains.[153] In a review of studies evaluating the effects of oat and barley products on blood glucose, it was determined that at least 4 g of β-glucan is needed to lower the glycemic response.[154] The FDA concurred with The 2010 Dietary Guidelines Advisory Committee and concluded that there is limited evidence for an association between whole-grain intake and reduced risk of type 2 diabetes.[155] The Grains for Health Foundation Summit 2012 arrived at a similar conclusion[156]

Obesity. Whole-grain products from rye, oats, barley, and wheat have been shown to increase satiety. Whole-grain rye is a good source of soluble and insoluble dietary fiber.[157] Arabinoxylan is the dominant fiber, and the water extractable component of arabinoxylan is highly viscous when dispersed in water.[158] Similarly, oats and barley contain the soluble fiber β-glucan in significant amounts, which exhibits a high viscosity at relatively low concentrations.[159] Viscous soluble dietary fiber delays gastric emptying and slows intestinal transit to reduce the absorption rate of nutrients, thereby increasing the possibility of interaction between nutrients and the cells that release satiety hormones.[160]

Whole-grain rye products have consistently been shown to increase satiety, compared to wheat bread.[161−168] The results of studies investigating the effect of β-glucan from oats and barley on satiety are inconsistent. Using β-glucan in doses ranging from 2.2 to 9 g, several studies found that satiety or satiety hormones increased,[143,169−174] whereas others found no effect of β-glucan on satiety.[175−177] The insoluble fiber found in breakfast cereals made with whole-grain wheat in amounts ranging from 26 to 33 g/meal also increased satiety compared to cornflakes of equal weight,[178] or equal energy content,[179] as well as compared with a breakfast of bacon and eggs.[180] However, subjective satiety and food intake following consumption of whole-grain bread providing 10.5 g of fiber per day for 3 weeks was not significantly different compared to refined grain bread providing 5.8 g of fiber per day.[133] Thus, the fiber component of whole grains through its effects on bulking and viscosity may help to keep consumers full for a prolonged period.

Observational studies have consistently shown that whole-grain consumption of approximately three servings ($\geq$3 oz equivalents of whole-grain foods) per day is associated with lower BMI compared to refined grain intake.[11,181,182] Reductions in weight gain and abdominal obesity have also been observed with whole-grain consumption.[34,183] In the Health Professionals follow-up study, a prospective study assessing 8 year weight gain among health professionals, a 40 g per day increase in whole-grain intake from all foods reduced body weight by 0.49 kg. The addition of bran was found to further reduce the risk of weight gain. Every 20 g per day increase in bran intake reduced weight gain by 0.36 kg.[183]

The results of intervention trials have been less consistent. In studies evaluating the effect of whole-grain consumption over 4−12 weeks, no differences in weight loss were found when compared with control diets,[146,147,184−186] although one study found a reduction in fat mass[146] and another found a decrease in waist circumference[186] compared to refined grain consumption. In a meta-analysis including 21 RCTs, whole-grain intake reduced weight gain compared to control diets. However, heterogeneity among the studies, short intervention periods, and relatively small sample sizes limit the results of this analysis.[127]

More recently, a meta-analysis[187] evaluating the evidence from 26 RCTs investigating the effect of whole-grain consumption on body weight and body composition compared to non-whole-grain and refined-grain controls found no effect on body weight but a small beneficial effect on body fat. The average duration of the studies included in this analysis was 4−6 weeks, and to compensate for the short duration, the doses used in the studies represented whole-grain consumption that exceeded the highest level of intake among population groups that consume whole grains. Nevertheless, a meta-regression showed no dose−response relationship between whole-grain intake and differences in body weight.

Observational studies show reductions in weight gain of approximately 0.5 kg,[187] rather than weight loss, between consumers and nonconsumers of whole grains, which raises the possibility that the differences are a marker of a healthy lifestyle rather than the effect of whole grain intake per se. These subtle differences may be difficult to capture in relatively short-term intervention trials, but longer-term trials may be fraught with the possibility of nonadherence to the diet. Thus, although there is some evidence to indicate that whole-grain consumption may lead to a reduction in fat mass, weight loss that is clinically significant remains to be established.

■ HEALTH BENEFITS OF PULSES

Cardiovascular Disease. Epidemiological evidence shows a 22% reduction in coronary heart disease and an 11% reduction in cardiovascular disease with consumption of legumes four times or more per week compared with once a week.[15] Intake of one serving of beans per day is associated with a reduced risk of myocardial infarction by 38% compared to no or less than one serving per day, after adjustment for factors such as smoking, diabetes, hypertension, abdominal obesity, and physical activity.[188] The evidence is not as strong as the evidence for a similar association from whole grain consumption; however, intervention trials, which permit the establishment of causality, show fairly consistently that legume consumption lowers total cholesterol and LDL-C, which is the most atherogenic lipoprotein.[71] Total cholesterol LDL-C levels were significantly improved by a high-pulse diet, compared to a high-protein diet, a fatty fish diet, and a control diet.[189] In hypercholesterolemic individuals, consumption of half a cup of baked beans per day as part of the usual diet for 8 weeks reduced total cholesterol by 5.6% and LDL-C by 5.4% compared to a control treatment consisting of half a cup of carrots.[190] Among individuals 50 years or older a pulse-based diet for 2 months reduced total cholesterol and LDL-C.[191] In other studies, chickpea supplementation significantly reduced total cholesterol and LDL-C.[192−194]

In the Legume Inflammation Feeding Experiment, a legume-rich, high-fermentable fiber diet designed to include foods that have a low glycemic index (GI), 21 g fiber/1000 kcal with a GI = 38 led, to greater reductions in total cholesterol and LDL-C compared to an American diet (9 g fiber/1000 kcal having a GI = 69, no legumes).[195] In diabetic participants, a pulse-rich low-GI diet consumed for 3 months lowered total cholesterol and triglycerides.[196] Meta-analyses of RCTs assessing the effect of pulses on blood lipids have shown that legume consumption lowers total and LDL-C levels.[197,198]

The hypocholesterolemic effects of pulses appear to be related to their soluble fiber component, which binds bile acid and decreases the reabsorption of bile acids. Furthermore, fermentation of soluble fiber in the colon and the production of SCFAs contribute to decreased hepatic cholesterol synthesis.[198] Pulse proteins containing the 7S globulin fraction also appear to lower plasma cholesterol and triglyceride levels.[199] Moreover, diets containing vegetable sources of fat and protein may reduce the risk factors for CVD.[200] Other components such as phospholipids and saponins may also contribute to the cholesterol-lowering effects.[198]

Consistent results from RCTs suggest that diets containing pulses may positively affect blood pressure. Consumption of four servings of pulses per week for 8 weeks within an energy-restricted diet reduced total cholesterol, LDL-C, and systolic blood pressure compared to an energy-restricted control diet without pulses.[201] In patients without diabetes, the consumption of pulses as part of energy-restricted diets reduced blood pressure.[189,201−203] A low-GI diet containing pulses reduced blood pressure and heart rate among diabetic individuals, compared to a high wheat fiber diet.[196] Isocalorically replacing foods with pulses significantly lowered the systolic and mean arterial blood pressure in individuals with and without hypertension.[204]

The reduction in cardiometabolic risk factors associated with pulse consumption may also be attributed to their antioxidant components. Besides, pulses have other components such as folic acid that reduce homocysteine levels to reduce the risk of stroke.[205] Markers of systemic inflammation such as interleukin-6 and tumor necrosis factor-α receptor-2,[206] as well as C-reactive protein[207] are inversely associated with intake of dietary fiber, which may contribute to the beneficial effect of pulse consumption on risk factors for cardiometabolic disease. Four servings of pulses per week within an energy-restricted diet reduced pro-inflammatory markers and markers of oxidative stress, after adjustment for weight loss, compared to an energy-restricted control diet without pulses.[201]

Diabetes and the Metabolic Syndrome. Besides being high in protein, pulses are a low-GI food. In a comparison of 24 common foods including grains, cereals and pasta, breakfast cereals, biscuits, and tuberous vegetables, legumes lowered the glycemic response by 45% when eaten by healthy individuals.[74] Compared to eight cereal foods, legumes have been shown to release 56% less sugars and oligosaccharides over a period of 5 h in healthy individuals.[208] When compared to isoenergetic meals containing potato flakes and meat, meals containing bean flakes and meat produced a significantly lower glycemic response.[209,210] In a meta-analysis of 20 randomized controlled trials, it was concluded that low-carbohydrate, low-GI, Mediterranean, and high-protein diets lead to greater improvements in glycemic control compared to control diets.[211]

Epidemiological as well as randomized controlled trials have demonstrated a beneficial effect of pulse consumption on the prevention and management of diabetes as well as the metabolic syndrome. Among middle-aged Chinese women, followed for approximately 5 years, a high intake of legumes, particularly soybeans, was associated with a decreased risk for diabetes.[212] In short-term experimental studies pulse consumption lowered blood glucose and insulin responses[74,213,214] and increased insulin sensitivity[214] when compared with white bread or pasta. A meta-analysis of RCTs evaluating the effects of pulse consumption on markers of glycemic control showed that pulses alone, or as part of a low-GI or high-fiber diet, improved glycosylated hemoglobin (HbA_{1c}) and fructosamine, both markers of glycemic control.[215] A low-GI pulse diet consumed by 121 diabetic individuals for 3 months, led to a fall in levels of HbA_{1c} by a mean of 0.5% compared to the wheat fiber diet. Participants were encouraged to increase pulse intake by 1 cup of cooked pulses/day or to increase insoluble fiber by consumption of whole-wheat products.[196] In subjects with diabetes, pinto, dark red kidney, and black beans each served with rice lowered the glycemic load (product of the GI and the available carbohydrate) of the meal and attenuated the blood glucose response compared to white rice alone.[216]

Pulses have also been shown to have a second-meal effect, whereby postprandial blood glucose response to a meal eaten a period of time after consumption of a particular food is lowered. Chickpeas and lentils have been shown to have a second-meal effect.[217−220] Although yellow peas did not have a second-meal effect,[217] 20 g of isolated yellow pea protein served in a tomato soup manifested a first-meal as well as a second-meal effect to lower the postprandial blood glucose response on both occasions.[221]

Central to the metabolic syndrome is insulin resistance and a cluster of associated cardiovascular risk factors such as abdominal obesity, elevated blood pressure, and dyslipidemia. A significant association between legume intake and decreases in mean systolic blood pressure, fasting blood glucose, and increase in high-density lipoprotein cholesterol (HDL-C) levels was observed in 80 subjects diagnosed with the metabolic syndrome.[222] Consumption of 5 cups per week of pulses (yellow peas, chickpeas, navy beans, and lentils) over 8 weeks in an ad libitum diet reduced the risk factors of the metabolic syndrome, and these effects were equivalent to, or greater than, those precipitated by an energy-restricted diet.[17]

Obesity. Lentils have been shown to increase satiation (termination of a meal) compared to a meal consisting of pasta and sauce, but showed no effect on energy intake at a subsequent pizza meal served 4 h later.[213] Lentils as well as yellow peas reduced appetite and energy intake at a subsequent meal compared to a meal consisting of macaroni and cheese.[217] In other studies, daily energy intake decreased by 380 kcal in the subjects consuming 5 cups of pulses per week, which was similar to the reduction in intake of subjects placed on an energy-restricted diet.[17] A meal containing bean purée increased satiety over 4 h compared to the same meal substituted with potato purée.[209] The acute effect of chickpea breakfasts on satiety and energy intake was not significantly different,[223] but chickpea supplementation of approximately 104 g/day for 12 weeks increased satiety.[224] Bread in which 40% of wheat flour was replaced with lupin kernel produced greater satiety and lower energy intake at lunch compared to white bread.[225] Furthermore, a lupin-kernel fiber-enriched sausage patty produced greater effects on satiety than a conventional patty and an inulin fiber-enriched patty.[226] However, in another study consumption of bread produced by replacing of 10% of wheat flour with lupin flour had no effect on satiety or energy intake.[227] Thus, pulse consumption may have an effect on satiety, which can help consumers overcome environmental cues to eat or help them to adhere to calorie restriction.[71]

Epidemiological evidence shows an inverse association between bean consumption and body weight.[14] In intervention trials, rice and bean meals consumed twice daily increased weight loss at 1 month compared to meals consisting of lean meat; however, the effects did not persist over 2 months, possibly as a result of subjects dropping out of the study.[228] In a comparison of a high-pulse diet, a high-protein diet, a fatty fish diet, and a control diet excluding pulses and fish, for 8 weeks, the high-protein and high-pulse diets produced similar effects on weight loss. Furthermore, both diets increased weight loss compared to the control diet.[189] Four servings of pulses per week for 8 weeks within a 30% energy-restricted diet produced greater weight loss than an energy-restricted control diet that excluded pulses.[201]

A diet high in legumes including beans and peas for 3 weeks had no significant effect on body weight, but this duration may have been too short to assess weight change.[229] A high-pulse–low-GI diet reduced body weight after 3 months.[196] However, subjects provided pulses and whole grains for incorporation into their diets did not show significantly different weight loss after 6 or 18 months, compared to a control group provided refined cereals and high glycemic index foods, although waist circumference reduced at 18 months in subjects on the high-legume diet.[230] The endosperm of lupin seeds is used to produce flour that contains 40–45% protein and 25–30% fiber with negligible amounts of sugar and starch.[225] Although bread made with lupin flour has been shown to increase satiety,[225,231] it had no effect on weight loss, weight maintenance, or body composition in studies lasting for 12 months.[202,232] Thus, the consumption of pulses and other legumes may enhance weight loss, but its effects on long-term weight management have yet to be convincingly demonstrated.

WHOLE GRAINS AND PULSES

Dietary recommendations emphasize increasing intakes of foods that are nutrient dense and contain fiber while achieving and maintaining a healthy body weight.[22] The challenge lies in meeting these goals, especially, because grains, which are a major component of most diets, provide a substantial amount of energy. Whole grains provide approximately 2.4 g of fiber per serving (1 oz equivalent), whereas refined grains provide 0.7 g per serving.[233] According to the National Health Interview Survey 2000,[234] the average American consumes only half the intakes of dietary fiber (25–38 g/day) recommended by the Institute of Medicine.[235] A shift from low-fiber refined grains to whole-grain foods will help to meet dietary recommendations while lowering the metabolizable energy. Three servings of whole grains would provide approximately 7.5 g of fiber or one-fourth of the recommendation. Moreover, essential vitamins, minerals, and phytonutrients are lost in the milling process, making whole grains nutritionally dense compared to refined grains.[62,236]

Epidemiological data provide consistent evidence for the health benefits of whole-grain consumption; however, the same cannot be said for the results from RCTs. Part of the reason for the inconsistent results may be the grain structure. An intact botanical structure may delay or preclude starch absorption. Milling of wheat, for instance, separates the bran, germ, and endosperm. Reconstitution of the separated parts produces wholemeal flour, which elicits the same glycemic response as refined flour when incorporated into bread.[237] Nevertheless, the nutritional benefits of whole-grain foods are without doubt, and their consumption can make a fairly significant contribution to meeting dietary fiber recommendations, the health benefits of which have long been appreciated.[238] The consumption of cereal fiber, or mixtures of whole grains and bran, is modestly associated with reducing the risk of chronic disease including obesity, type 2 diabetes, and cardiovascular disease.[128]

Pulses are a rich source of protein, slow-release carbohydrates, dietary fiber, micronutrients, and other bioactive components associated with health benefits.[19] One serving of pulses contains approximately 7.6 g of fiber.[239] Unlike the evidence for whole-grain cereal foods, both epidemiological and experimental results provide substantial evidence for a protective effect against chronic disease. A diet that includes pulses meets the recommendations of the Dietary Guidelines for Americans 2010[22] and could contribute to increasing the fiber and lowering the energy density of a diet. Diets high in pulses may be recommended in the prevention and management of obesity and chronic diseases including diabetes, cancer, and cardiovascular disease. Vegetables, fruits, lean meats, and whole grains are among the other recommendations of the Dietary Guidelines. However, some of these products are expensive sources of energy,[240] which may in part explain their substitution with less expensive, energy-dense, nutrient-poor foods. Legumes, dried beans and peas in particular are relatively less costly than animal sources of protein, which can help to overcome the cost constraints of nutritious diets while providing a host of benefits in terms of improving the

Table 4. Impact of Whole Grain Intake on Obesity and Related Co-morbidities Based on Experimental Trials Reviewed

whole grain type	impact on disease		
	obesity	cardiovascular disease	metabolic syndrome/eiabetes
whole grains/ wheat bran	reduced cumulative energy intake (from breakfast and lunch);[178] reduced appetite and energy intake[179,180]	reduced blood pressure;[132−134] decreased C-reactive protein;[147] beneficial effect on total cholesterol and LDL-C[146]	improved insulin sensitivity;[151,185] reduced postprandial insulin and triglyceride responses;[153] improved postprandial glucose response[178,179]
	no effect on subjective satiety and/or energy intake[174,176]	no effect on blood pressure;[135] no effect on cardiometabolic risk factors;[144] no effect on total cholesterol and LDL-C[147]	no effect on postprandial blood glucose;[176] no effect on markers of insulin sensitivity and inflammation[150,152,135]
	no effect on body weight[146,147,184,185] but fat mass[146] and abdominal obesity reduced[147]		
barley and oats/ β-glucan	increased subjective satiety and reduced energy intake;[169,170,173] increased subjective satiety but no effect on energy intake[174]	reduced total cholesterol and/or LDL-C[138−142,186]	decreased insulin response response;[173] reduced postprandial glucose response;[175] at least 4 g of β-glucan needed to reduce postprandial glucose response[154]
	positively affected satiety hormones[169,172,173]		no effect on postprandial blood glucose[176]
	no effect on subjective satiety[175,177]		
	no effect on body weight but waist circumference reduced[186]		
rye	increased subjective satiety;[161,163,165,166,168] increased colonic fermentation and reduced energy intake at a subsequent meal but no effect on subjective satiety[167]	not assessed as a single component of the diet	improved glycemic/insulinemic response[161]
	no effect on energy intake[165,166]		

nutritional quality of the diets, lowering the energy density, and aiding in the prevention and management of chronic disease.

The emphasis on increasing intakes of whole grains has been consistent since the first Dietary Guidelines for Americans was released in 1980, yet, according to the NHANES 1999−2004, daily consumption of whole-grain servings was less than one-third of the recommended intakes.[20] In the absence of a universal definition of whole grains, part of the reason for the limited consumption of whole grains may be that consumers are confused as to what constitutes a whole-grain product.[129] Furthermore, in foods that are partially whole grain the relative proportions of whole-grain ingredients is unknown. Hence, a product that does not have whole grains as the first ingredient listed on the product package may contain anywhere from 1 to 49% whole-grain ingredients.[32] Ironically, among the USDA's top 20 food sources of fiber, whole-wheat bread, the most commonly consumed whole-grain component of the U.S. diet, is not present. On the other hand, 12 varieties of pulses are among the top 20 fiber sources.[239]

All refined grains are not completely devoid of nutrition. The enrichment process returns to the grains the nutrients lost in processing. Enriched grain products are required to have iron, thiamin, riboflavin, niacin, and folic acid added at specified minimum and maximum levels, according to the U.S. Code of Federal Regulations.[241] Nationwide fortification of enriched uncooked cereal grains with folic acid became mandatory in the United States in 1998.[242] Refined grain foods remain a major component of the diet in the United States, the United Kingdom, and Australia, which may be due to traditional preferences for refined grain products or unfamiliarity with cooking techniques. However, consumption of half the recommended grain intakes as refined grains is not associated with an increase in disease risk.[243] The inclusion of pulses in a meal containing refined grains provides a means of lowering the energy density of the meal and the postprandial glycemic response while helping to substantially meet dietary fiber recommendations. A meal containing pinto beans, dark red kidney beans, or black beans served with approximately half a cup of white rice has been shown to reduce the glycemic response compared to a meal containing only white rice.[216]

Pulses and whole grains contain a host of macronutrients, micronutrients, and other bioactive components essential for health, some of which are greater in one food group compared to the other. For instance, 1 cup (two servings) of beans and peas contains 15.2 g of fiber compared to 5 g contained in two servings of whole grains.[233] Pulses provide approximately 230 μg of folate per cup of cooked dried pulses (two servings) compared to 26 μg in two slices (two servings) of whole-wheat bread. Bread made with enriched flour has 90 μg of folate in two servings. Magnesium intake is often below the recommendations, and whole grains are a good source of magnesium.[244] However, the bran component has a higher content at 89 mg per one-fourth cup of wheat bran compared to 86 mg per cup of cooked brown rice. The content of magnesium in a cup of cooked pinto beans is 86 mg. The vitamin E content of two servings of whole-wheat bread is 1.70 mg, whereas in 1 cup of pulses it is 0.58 mg.[80]

Together, pulses and grains provide all of the indispensable amino acids to meet human requirements for growth and health. They are a rich source of nondigestible carbohydrates, which may strategically alter the balance of gut microbiota to promote health.[44] In a study among Korean adults, a dietary pattern consisting of whole grains and legumes was found to be

Table 5. Impact of Legume Intake on Obesity and Related Co-morbidities Based on Experimental Trials Reviewed[a]

legume type	impact on disease		
	obesity	cardiovascular disease	metabolic syndrome/diabetes
legumes	increased mitochondrial oxidation[189]	reduced total cholesterol[196] and LDL-C[189,195,201] but reduced HDL-C[189,195,201]	reduced risk factors for metabolic syndrome;[17] reduced HbA1C[196] and blood glucose[74,213,216]
	reduced appetite and/or energy intake;[17,217] reduced body weight over 4−8 weeks[189,201,228] and over 3 months[196]	reduced blood pressure[189,196,201]	
	no effect on body weight but waist circumference reduced at 18 months[230]		
chickpeas	increased satiation[224] no effect on satiety and energy intake[223]	lowered total cholesterol and LDL-C[192−194]	lowered blood glucose;[74,213] reduced single-meal blood glucose but no effect over 6 weeks;[214] produced second-meal effect on blood glucose[217]
lentils	reduced appetite and/or energy intake[17,213,217]	not assessed as a single component of diet	lowered blood glucose;[74,213] produced second-meal effect on blood glucose;[217] produced first- and second-meal effects on blood glucose[218,219]
navy beans	no effect on appetite or energy intake compared to control	reduced total cholesterol and LDL-C[190]	lowered blood glucose[213]
yellow split peas	reduced appetite and energy intake[217]	not assessed as a single component of diet	lowered blood glucose[213]
lupin seeds	increased satiety and/or reduced energy intake[225,226,231] no effect on satiety or energy intake;[227] no effect on body weight[202,232]	reduced blood pressure;[202,203] no effect on blood lipids[232]	inconsistent effects on blood glucose[202,225,231,232]
Swedish brown beans	reduced hunger and positively affected satiety hormones following a subsequent meal[220]	lowered inflammatory markers and increased short-chain fatty acid concentrations following a second meal[220]	produced a second-meal effect on blood glucose and insulin responses[220]

[a]Adapted from Rebello et al., *Obesity Reviews* **2014**, *15*, 392−407.

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inversely associated with insulin resistance.[245] In a cross-sectional study among subjects participating in the Tehran Lipid and Glucose study, an inverse association was found between intake of fiber from cereal and legume sources and risk for the metabolic syndrome.[246] In participants with coronary artery disease, the replacement of refined grains at breakfast with a whole-grain and legume powder for 16 weeks had a positive impact on glucose, insulin, and homocysteine concentrations as well as lipid peroxidation.[247] The inclusion of whole-grain barley and legumes in a diet reduced cardiometabolic risk factors in 46 overweight women compared to a diet with a similar nutrient composition but lacking whole-grain barley and legumes.[248] Thus, a synergistic effect of legumes and whole grains on promoting human health is not entirely unfounded and bears further investigation. The impacts of whole-grain and legume consumption on obesity, cardiovascular disease, and diabetes, based on the experimental trials reviewed, are presented in Tables 4 and 5 respectively.

In conclusion, plant-based diets that include pulses and cereals, although associated with lower socioeconomic status[249] and fraught with difficulty in incorporating into the diet due to a bland taste, lack of knowledge of cooking techniques, and perceptions of flatulence from pulse consumption, can be a dietary strategy with significant implications on health. The evidence for the health benefits of pulse consumption is fairly robust from observational as well experimental studies. Whether the incorporation of pulses in the diet can be sustained in the long term is an important consideration that warrants investigation. Nevertheless, there is a need to establish more convenient delivery systems for pulses in familiar food forms to lower the energy density of these foods and provide health benefits. Federally mandated funding to promote consumption of pulses and the incorporation of pulse foods into the National School Lunch Program, which is presently being considered, will help to increase consumption.

Despite strong evidence from epidemiological studies assessing the health effects of whole-grain consumption, causality is difficult to establish mainly due to the dearth of RCTs. The assessment of biomarkers rather than disease end-points, variability in the definition of whole grains, and, especially, differences in grain structure are some of the factors associated with the lack of consistency in the results from RCTs. Although this should not undermine the potential health benefits of whole grains, it may be worthwhile to promote incorporating pulses into the diet along with traditionally preferred enriched grains to derive some of the benefits of whole-grain consumption. Finally, the host of nutrients and bioactive components contained in whole grains and pulses suggests the potential for a synergistic effect that could provide significant health benefits when these food groups are included in the diet.

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Notes

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