Carbohydrates, Grains, and Wheat in Nutrition and Health: An Overview Part II. Grain Terminology and Nutritional Contributions[1,2]

Julie M. Jones, Roberto J. Peña, Renee Korczak, and Hans J. Braun[3]
Global Wheat Program, CIMMYT

Grain and Whole Grain Terminology and Definitions

Grains are carbohydrate-rich foods that must undergo some degree of processing prior to their ingestion. Even ancient records, such as the Bible and Egyptian hieroglyphs, note the removal of the outer inedible layer (husk, hull, or chaff) of grains. In addition to the removal of the outer grain layer, cleaning to remove dirt, stones, and other foreign matter is basic to any grain processing.

A number of methods can be used to process grains. In some cases, the kernel is eaten after soaking and cooking in its whole (intact) form, but even with soaking long cooking times are these often required. Soaking also may reduce unwanted toxic, bitter, or antinutritional components and improve nutrient availability, which is especially important for certain grains, such as maize (1).

More frequently the kernel is broken to some degree. Cracking, flattening, grinding, or milling enables easy entry of water into the kernel, as do parching, toasting, and other heat treatments. In addition, heat treatments may enhance storage stability and help retain nutrients such as vitamin E by inactivating enzymes that would otherwise cause rancidity. Process-ing also may involve flaking, extrusion, or other techniques. If various parts of the kernel are retained in their original ratio, they are considered processed but not refined. Refined grains have some part of the kernel removed—usually the outer layers, bran, and germ. This often occurs with milling.

Grain Milling and Flour Fractions. Milling crushes the grain. After crushing, it is separated by particle size into mill streams for further crushing. If all mill streams are combined at the mill, the end product is a whole grain flour, grit, or meal. However, any of the mill streams can be sold separately. For consumer markets, these would be germ, bran, and endosperm (white flour). The higher the proportion of the grain used to produce flour, the higher its "extraction rate." Whole meal and flours containing 90% or more of the entire grain are considered "high-extraction" flours, whereas those containing 75% or less of the whole grain are considered "low-extraction" flours (generally called "white" or "refined" flour) and consist of most of the endosperm and a very small part of the inner layers of the bran. Very low-extraction flours are used for cakes, in which the low protein content and small particle size create a product with a finer texture. However, the more the flour is refined, the lower its retention of fiber, vitamins, minerals, and bioactive compounds.

Enriched and Fortified Refined Flours. In many countries, refined flours are enriched to replace nutrients lost during milling. Figure 1 shows the differences in nutrients found in whole grain, refined, and enriched wheat flours. B vitamins such as thiamine, riboflavin, niacin, and pyridoxine and iron are frequent additions. The specifics as to which micronutrients are added and their amounts vary by grain type and the nutritional needs of the region. For example, in the United States, each pound (454 g) of flour labeled as enriched contains 2.9 mg of thiamin, 1.8 mg of riboflavin, 24 mg of niacin, 0.7 mg of folic acid, and 20 mg of iron (2). In addition, it may contain added calcium.

Flour may also be fortified to address specific regional needs. In fortification, nutrients are added in amounts higher than are found in the original grain, such as folic acid, or nutrients not naturally present in the grain, such as B_{12} or vitamin D, may be added.

Enrichment and fortification initiatives, both mandatory and voluntary, have reduced thiamine, niacin, folate, and iron deficiency in many parts of the world (3–5). The World Health Organization (WHO) recommendations for enrichment and fortification of flour are provided in Table I (6).

The fortification of flour with folic acid has been particularly beneficial in preventing neural tube and other birth defects. In some countries, enrichment or fortification of refined flours with folate is mandatory. A comparison of nutrients contributed by a sampling of enriched, fortified, unenriched, and whole grain flours is shown in Table II. The one component that is not customarily added back through enrichment or fortification is dietary fiber.

Whole Grains. In 1999 an ad hoc committee of experts from AACC International formally defined whole grains (7):

Whole grains shall consist 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.

Other scientific and health-promoting organizations and some regulatory bodies around the world have adopted the essence of this definition. Some groups have tweaked the definition and made slight amendments in the wording to make it easier for consumers to understand (8) or to more accurately reflect milling practices, as in the definition adopted by the European HEALTHGRAIN consortium in 2009 (9). However, all of these whole grain definitions state that whole grain must contain the bran, germ, and endosperm in the same proportions as is found in the original grain.

Consumer Confusion

Cereal, Grain, and Whole Grain Terminology. The terminology used for grain around the world is not standardized and, therefore, creates some confusion among consumers (10). For example, in much of the world the term "cereal" refers to the crop in the field or the raw commodity; however, the term "grain" is also used. As another example, in North America, cereal is commonly used to refer to a hot or cold breakfast entrée, often served in a bowl with milk. In some countries, hot cereals are referred to as gruel or porridge, whereas in others porridge refers only to cooked oats. In addition, some grains sold as "meals" are nearly always whole grains, such as oatmeal, whereas others, such as cornmeal, are almost never whole grains.

The seed head is referred to variously as the "kernel," "grain," "groat," or "berry." Whole grain flour in some regions is referred to as wholemeal flour or by the type of grain, such as whole wheat flour. In most countries, the latter is a whole grain flour, but there are a few exceptions. Regulations in Canada allow a small amount of the bran and germ (<5%) to be removed and still allow the flour to be labeled as whole wheat (11).

Processing terms are equally confusing. Many terms are used to describe the removal of the outer layers of grain. For example, wheat is milled, rice is polished, barley is pearled, corn is degermed, and sorghum is decorticated—just to name a few.

Some grains, such as oats, teff, and quinoa, have traditionally been marketed in their whole form and are rarely refined. Thus, some consumers are unaware that foods such as "porridge" or "oatmeal" are whole grain and that barley, except for pot barley, is not. The light color of white wheat, oatmeal, and barley also frequently causes consumers to not believe they are whole grain, while other dark-colored foods may be misidentified by consumers as being whole grain. For example, many North American rye breads are thought by consumers to be whole grain because caramel color is added. In addition, label descriptions such as "multigrain," "100% wheat," or even "organic" may be assumed by consumers to indicate a product contains whole grains, when they may or may not.

Characterization of Whole Grain Food Products. While processing terms confuse most consumers, identifying a whole grain food—one that contains nutritionally significant amounts of whole grain—confuses almost everyone.

Among countries, research papers, and food labels, various criteria exist for the amount of whole grain that must be present for a food to be called "whole grain" (12). For example, a number of epidemiological studies characterize a food as whole grain if 25% of the ingredients, by weight, meet the whole grain definition (13–16). One study characterizes a food as whole grain if the first ingredient on the ingredient statement is whole grain (17), and in yet another study, only fiber-rich whole grains are counted as whole grains (18). The first ingredient is generally reliable as a touchstone for characterizing a food product as whole grain but may fail to identify a product as whole grain if it contains several whole grain ingredients when each is present in amounts smaller than the first ingredient, even when the total whole grains in the food sums to more than 50% of the ingredients.

Refining wheat flour removes the bran and germ, decreasing essential nutrients to levels ranging from 8% (vitamin E) to 59% (folate) of the level naturally occurring in whole wheat. Only the calories increase!

Enriching wheat flour adds back five of these nutrients, in amounts different from their original levels in whole wheat flour. All other nutrients stay at the levels shown for refined flour above.
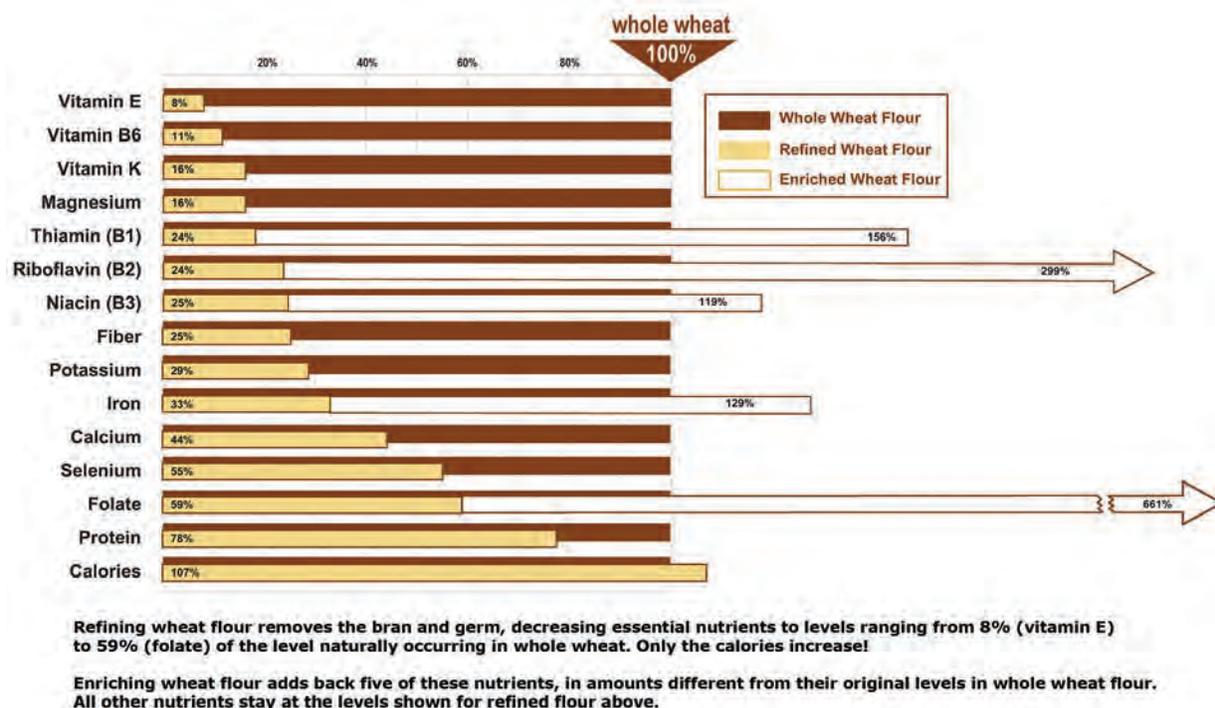
Fig. 1. Comparison of nutrients in whole, refined, and enriched/fortified refined wheat flours. Reprinted with permission from Oldways/The Whole Grains Council.

Some epidemiological studies also have miscategorized whole grain foods by counting all "dark bread," bran or germ, barley, and couscous as whole grain. In reality, these foods rarely are whole grain at the time of the study (10,19). Reevaluation of studies linking whole grain intake and certain health outcomes has shown that significant inverse associations occur only with the inclusion of bran foods and not with whole grain foods alone (20).

The lack of a standard for characterizing whole grain foods in research carries over into nutrition education and regulations for product labeling. This creates a Wild West atmosphere in the marketplace and is problematic for consumers trying to assess products to meet whole grain recommendations.

Foods containing whole grains may be identified using a unique or trademarked logo or statements such as "contains whole grains" and "made with 100% whole grains." Some regulatory codes, such as those in the Canadian *Guide to Food Labelling and Advertising* (21), recommend that when the presence of an ingredient, component, or substance is emphasized, the label should include a statement regarding the amount present in the food. However, many countries do not require a statement of an amount, and many consumers would need education or a label declaration of a daily goal to know if the quantity in a particular food contributes a dietarily significant amount of whole grains.

Whole grain health claims are permitted in some countries. Requirements for permitting a health claim in terms of amount of whole grains and other ingredients vary by country. For example, the U.S. Food and Drug Administration (FDA) requires 51% of the wet weight of the product to be whole grain in order for a health claim to be used. Basing a claim on a percentage of product wet weight gives a clear advantage to lower moisture products, such as crackers and dry cereals, and penalizes foods with higher moisture, such as ready-to-heat oatmeal and sliced breads. Some regions have addressed this unfair advantage by using product dry weight for the basis of their regulations.

Some countries allow a whole grain designation or claim only if the overall nutritional contribution of the product is considered. For example, in parts of Scandinavia whole grain may be highlighted on the front of a package only if the product does not contain significant quantities of ingredients that may negatively impact health, such as fat and sugar (22,23). Sweden introduced and trademarked a Keyhole logo for packaged foods to designate foods that are better for you than other foods in the category (24). Foods labeled with the Keyhole logo contain less fat, sugar, and salt and more dietary fiber and have a healthier fat composition than other similar foods.

The Whole Grain Council's Whole Grain Stamp is a fee-based identification logo that certifies the amount of whole

Table II. Nutrient comparison in enriched, whole grain and organic flours (30 g serving [^{1}/4 cup]; mg, g, or % DV)

Nutrient	Refined Flour		Whole Grain Flour	
	Enriched All Purpose	Unbleached Organic	Traditional	Organic
Sodium (mg)	0	0	0	0
Potassium (mg)	35	0	51	0
Dietary Fiber (g)	<1	<1	2	6
Sugars (g)	<1	<1	2	1
Protein (g)	3	3	7	9
Vitamin A (%)	0	0	0	0
Vitamin C (%)	0	0	0	0
Calcium (%)	0	0	2	2
Iron (%)	6	0	4	15
Vitamin D (%)	0	0	0	0
Thiamin (%)	10	–	4	4
Riboflavin (%)	6	–	2	2
Niacin (%)	8	–	4	4
Vitamin B$_6$ (mg)	0.01	–	0.12	–
Folic Acid (%)	10	–	2	2
Phosphorus (mg)	42	–	106	–
Magnesium (mg)	9	–	41	30
Zinc (mg)	0.28	–	0.74	–
Copper (mg)	–	–	4	10%

Table I. Average levels of nutrients to consider adding to fortified wheat flour based on extraction, fortificant compound, and estimated per capita flour availability[a]

Nutrient	Flour Extraction Rate	Compound	Level of Nutrient to Be Added (ppm) Based on Estimated Average per Capita Wheat Flour Availability (g/day)[b,c]			
			<75[d]	75–149	150–300	>300
Iron	Low	NaFeEDTA	40	40	20	15
		Ferrous sulfate	60	60	30	20
		Ferrous fumarate	60	60	30	20
		Electrolytic iron	NR	NR	60	40
	High	NaFeEDTA	40	40	20	15
Folic acid	Low or high	Folic acid	5.0	2.6	1.3	1.0
Vitamin B$_{12}$	Low or high	Cyanocobalamin	0.04	0.02	0.01	0.008
Vitamin A	Low or high	Vitamin A palmitate	5.9	3	1.5	1
Zinc[e]	Low	Zinc oxide	95	55	40	30
	High	Zinc oxide	100	100	80	70

[a] Data source: WHO (6).
[b] These estimated levels consider only wheat flour as the main fortification vehicle in a public health program. If other mass-fortification programs with other food vehicles are implemented effectively, suggested fortification levels in wheat flour could be adjusted downward.
[c] NR = not recommended because the very high levels of electrolytic iron needed could negatively affect sensory properties of fortified flour.
[d] Estimated per capita consumption of <75 g/day does not allow for addition of sufficient level of fortificant to cover micronutrient needs for women of childbearing age. Fortification of additional types of food would be the only way to reach adequacy.
[e] These levels of fortification with zinc assume 5 mg of zinc intake and no additional phytate intake from other dietary sources.
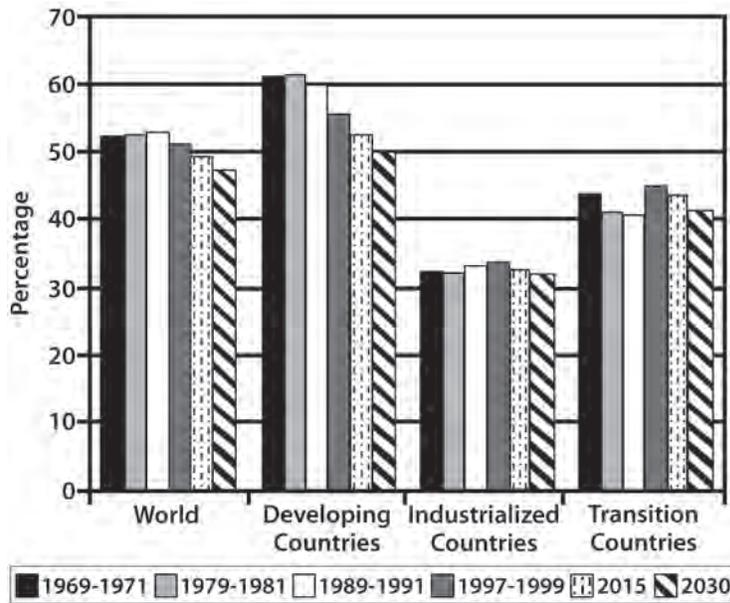
Fig. 2. Changes over time in the share of dietary energy derived from cereals. (Adapted from data in FAO, "World Agriculture: Towards 2015/2030. An FAO Perspective," J. Bruinsma, ed., Earthscan Publications Ltd., London, 2003.)
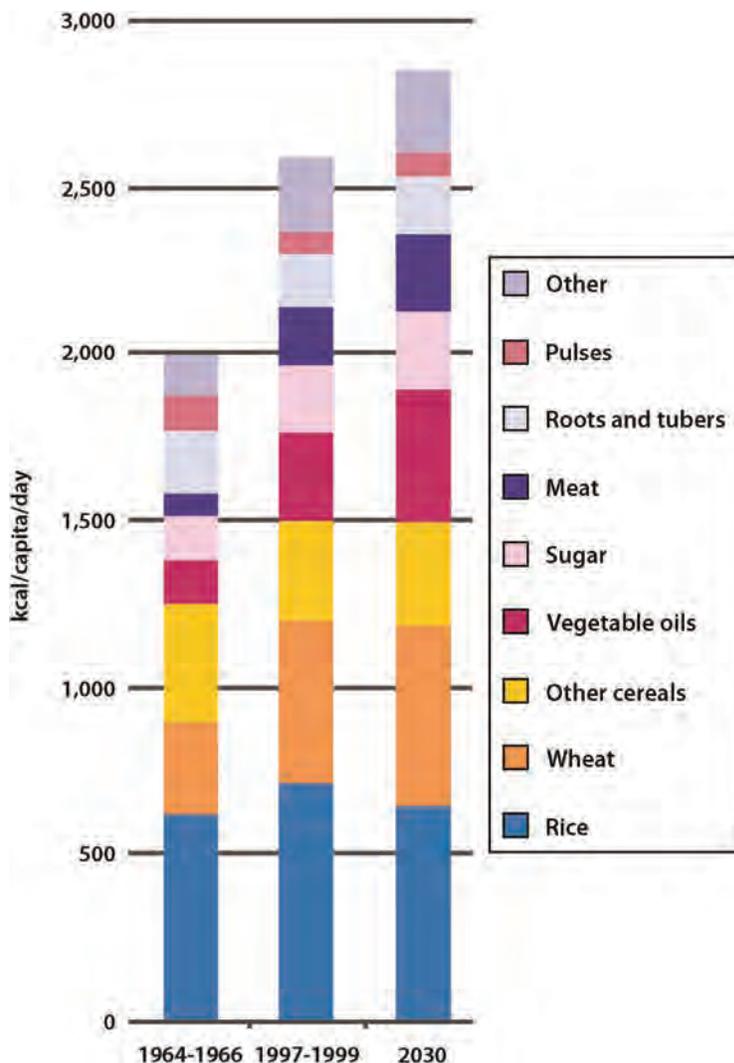

Fig. 3. Calories consumed per day from various food groups. (Adapted from data in FAO, "World Agriculture: Towards 2015/2030. Summary Report," FAO, Rome, 2002.)

grains in a product serving (in grams) with a gold-colored stamp. Products with a large serving size may have an advantage in such a system. Products that contain only bran and whole grain but that contain more bran than whole grain could not receive the stamp even if they contain a significant amount of whole grain. Further, some consumers do not understand that products without the seal may be characterized as whole grain but that the manufacturer did not opt into the program. Thus, guidelines characterizing a whole grain food, also referred to as a "whole cereal food," are important (25).

In 2013 the AACCI Whole Grain Working Group released its whole grain characterization (26). The characterization asserts that a whole grain food product must contain ≥8 g of whole grain/30 g of product. This addresses some, but not all, of the issues associated with characterizing a whole grain food.

Nutritional Contribution of Grains

Calories, Protein, and Fat. Worldwide grains contribute around half of calories in the diet—52% in developing countries and 32% in developed countries (27). Changes over time in the share of dietary energy derived from cereals are shown in Figure 2. A breakdown of calories consumed per day from various food groups is provided in Figure 3.

Grains are important protein sources, not because they are notable for either their protein quantity or quality, but rather because they are affordable, readily available, easily stored at room temperature, and found in many commonly eaten foods. Further, the amino acids they contribute complement other plant-based proteins, such as those from legumes, creating combinations that provide all the essential amino acids in quantities needed for maintenance and growth.

Cereal grains as a group are low in lysine (1.5–4.5% versus WHO recommendation of 5.5%), tryptophan (0.8–2.0% versus WHO recommendation of 1.0%), and threonine (2.7–3.9% versus WHO recommendation of 4.0%) but rich in sulfur amino acids. Of the traditional grains, oats have the highest protein content and rice the lowest. Quinoa, a pseudocereal, contains more protein and lysine than most grains but contains limited quantities of tyrosine, phenylalanine, and threonine. The pseudocereals amaranth and buckwheat also are complementary protein sources and can be used to improve protein quality in a variety of ways (28).

Research to develop cultivars with more high-quality proteins is needed given the importance of grains as sources of protein in various parts of the world (29). Protein contents of selected grains are compared in Table III.

Grain proteins are important to the diet, but like all proteins they can pose risks to susceptible individuals. First, grain proteins do have the capacity to be allergenic, and most processing methods do not render these proteins nonallergenic. Currently, only fermentation and hydrolysis may have the potential to reduce allergenicity to a noticeable extent (30,31). Second, some grains contain the composite protein gluten. Gluten in the diet is one of several triggers necessary in genetically susceptible individuals for development of the autoimmune disease celiac, which affects about 1% of the population (32). Third, grains contain antinutritional factors that adversely affect the digestibility of protein, bioavailability of amino acids, and protein quality of foods (33–35). The effects of these are most apparent in regions where traditional diets are marginal and much coarse grain is eaten. Issues associated with the lower digestibility of coarse grains and poor overall diet quality contribute to problems of protein nutriture. For example, protein digestibility in countries such as India, Guatemala, and Brazil is considerably lower than protein digestibility in typical North American diets (54–78% versus 88–94%) (28).

Grains are low in fat, and the fat they contain is found primarily in the germ, which often contains some unsaturated fatty acids, fat-soluble vitamins, and phytonutrients. Corn and oats contain higher levels of fat than some other grains. Oats contain some unusual fatty acids, and the oils from rice bran and wheat germ are sought because of their nutritional properties, such as their high levels of tocotrienols and various vitamin E isomers (36, 37). Fat contents of selected grains are compared in Table III.

Vitamins. Grains are important sources of micronutrients as well, contributing many B vitamins (thiamin, riboflavin, niacin, and folate), vitamin E, and minerals (iron, magnesium, and selenium). The bioavailability of any of these can be increased or decreased by other components in the diet and by processing. Ironically, a factor that may increase the bioavailability of one nutrient may impair that of another. For example, soaking grain to reduce phytate and polyphenols and improve absorption of metals such as iron may also reduce

thiamin. Heating may destroy thiaminases (enzymes), protect thiamin, and disrupt carotenoid–protein complexes, thereby increasing the bioavailability of vitamin A (38), but they also may lower levels of heat-labile components.

The role of grains in contributing to micronutrient status has been examined in studies conducted in developed and developing countries with differing food patterns and ethnic backgrounds (9,39–43). These studies show that the consumption of grains and grain-based foods, including enriched and fortified grains, is an important means of meeting recommended micronutrient intakes. In the Multiethnic Cohort Study conducted with nearly 190,000 adults in Hawaii and Los Angeles, Sharma et al. (44) showed that grain-based foods contributed 30–46% of thiamin, 23–29% of riboflavin, 27–36% of niacin, 23–27% of vitamin B_6, and 23–28% of folic acid in the diet. A comparison of the nutrient contributions of some grain foods containing enriched/fortified grain versus unenriched and/or whole grain is provided in Table IV.

Grains are important contributors of B vitamins. Their bioavailability depends on the processing method used and can be more or less than animal-based foods. In some cases, as with corn, greater bioavailability occurs in finely ground, dry-milled products or in nixtamalized products in which bound niacin is released (45,46). In terms of thiamin, intestinal availability from grain foods is on par with animal-based foods, with an average absorption of ≈85% (47).

Riboflavin. Survey data indicate that in the United States grains contribute 20–30% of riboflavin intake. In countries where

milk and meat intakes are limited, the percentage of riboflavin contributed by grains is higher (48,49). Because riboflavin works with other B vitamins to impart immunity and synthesize and optimize red blood cell function, lack of this vitamin is especially concerning in regions with marginal diets (50).

Niacin. Grains are also a source of niacin, which is important for the metabolism of all macronutrients; utilization of energy from foods; and synthesis, growth and repair, and cell signaling. Its presence in grains may differ from the quantity it delivers because its bioavailability may be impaired. For example, the availability of niacin from non-nixtamalized corn is poor. Nixtamalization, the process of liming corn practiced by Amerindians in Central America, releases the tightly bound niacin from niacytin and thereby increases the availability of certain amino acids and reduces the incidence of pellagra (niacin deficiency) in areas where corn in the form of masa is eaten. At 59%, niacin availability from wheat-based foods is more than 20 points lower than niacin availability from beef-based meals (51). Whole meal bread has a particularly negative nutritional effect on the apparent intestinal availability of dietary niacin relative to other foods.

Pantothenic Acid. Grains and whole grains supply pantothenic acid, but its bioavailability varies. Oat-based cereals and whole grains are among the better sources, supplying from 2 to 9 mg/1,000 kcal (52), whereas corn-based and presweetened cereals were among the poorest sources of this vitamin. Whole grain components, especially those in coarse whole meal bread, appear to decrease the bioavail-

Table III. Crude protein and fat contents of cereal and pseudocereal grains[a]

Grain	Crude Protein (% dry weight)	Fat (g/100 g edible portion)
Cereal		
Brown rice	7.3	2.9
Sorghum	8.3	3.1[b]
Rye	8.7	1.6
Oats	9.3	7.5
Maize	9.8	4.3
Wheat	10.6	2.0
Barley	11.0	2.3
Pearl millet	11.5	1.5–5.2[b]
Pseudocereal		
Amaranth	15.2	8.0
Cassava	2–5	<1
Quinoa	13.3	7.5
Buckwheat	10.9	2.7

[a] Source: Alais, C., and Linden, G. *Food Bio-chemistry. Ellis Horwood Series in Food Science and Technology.* Springer Science+Business Media, Dordrecht, Netherlands, 1991.
[b] Source: FAO. Sorghum and millets in human nutrition. FAO Food and Nutrition Series, No. 27. FAO, Rome, 1995. (www.fao.org/docrep/t0818e/T0818E0b.htm)

ability of pantothenic acid to as much as 30% lower than meat-based foods.

Vitamin B_6. Grains can be a source of vitamin B_6, which is a fundamental component in a wide range of metabolic, physiological, and developmental processes. In addition, it is a powerful antioxidant, works with other B vitamins to promote health, and may play a role in the prevention of a number of chronic diseases and help prevent cognitive decline. However, vitamin B_6 is slightly less available from grains (≈70% available) than from other sources of protein (≈79% available) (53), and its bioavailability varies by grain type and is affected by other factors in diets. For example, B_6 from barley is more available than B_6 from wheat bran, which has greater availability than B_6 from rye. Vitamin B_6 availability from boiled brown rice is very low (16%) (53).

Vitamin A. Grains can contain some carotenoid pigments, but most grain-based foods are poor sources of vitamin A unless it is added through fortification, biofortification, or gene transfer. Grains are a prime candidate for increasing intake of this nutrient because these staple foods are more likely to be available to those most at risk for vitamin A deficiency. The development of Golden rice, as well as other measures, to address high rates of childhood blindness and infection related to inadequate amounts of this vitamin in some countries may be an important strategy (54).

Vitamin E. Whole grain cereal and bran foods are one of the main dietary sources for vitamin E and its isomers. The vitamin E content of refined flours is one-third to one-half that of whole wheat flour because vitamin E is concentrated in the bran and germ, which contain 6–15 times more vitamin E than the endosperm. Grains and pseudocereals contain more tocotrienols than most other food products (55). These key antioxidants quench free radicals and inhibit lipid oxidation, thereby protecting cell membranes and other cellular components (56). Studies suggest that vitamin E may have immunostimulatory, neuroprotective, anti-inflammatory, and cholesterol-lowering properties and may be linked to the prevention of certain chronic diseases, including cardiovascular disease (57,58).

The main vitamin E isomers found in wheat, barley, rye, and oats are α- and β-tocopherols; α-tocopherol is the form with the highest vitamin E activity (55). β-Tocotrienol is the main isomer found in wheat and oats. α-Tocotrienol, the isomer with the highest biological activity among the tocols, is predominate in barley and rye. Small quantities of γ-tocotrienol have been found only in barley. α-Tocotrienol appears to suppress β-hydroxy-β-methylglutaryl coenzyme A reductase, the key enzyme in cholesterol synthesis and, therefore, is hypocholesterolemic. In addition, all tocotrienol isomers have been suggested to have antithrombotic and antitumor effects. The contribution of these antioxidant isomers may be one way in which whole grains are associated with reduced risk of cardiovascular disease (55).

The bioavailability of vitamin E varies widely and is affected by numerous factors, such as the particular isomer, food matrix and its processing, and presence of other dietary components, as well as the nutritional status of the individual (59,60). In some cases a particular isomer is affected by a certain type of processing.

Minerals. Because of their high consumption in a variety of food products, grains are important contributors of minerals to the diet. Minerals play both structural and catalytic roles in many enzymatic and other reactions. Specific mineral deficiencies not only lead to specific disorders, such as anemia caused by deficient iron intake, but also are associated with a higher risk of many chronic diseases. More than one-third of the global population, especially in developing countries, suffers from anemia, zinc deficiency, and poor mineral status, which negatively effect growth, learning, immune function, and capacity to work (61). Thus, adequate dietary intake of minerals is important, and grains play an essential role.

The bioavailability of minerals can be even more problematic than it is for vitamins and is affected by many factors. The mere presence of a mineral does not mean that it will be absorbed. For example, although comparisons of mineral concen-

Table IV. Comparison of vitamin and mineral nutrient composition of some grain food products

| Nutrient | Corn Flake Cereal (30 g serving [1 cup]; mg, g, or % DV) | | | Spaghetti Noodles (56 g serving [1 cup]; mg, g, or % DV) | | | |
| | Refined Grain | | Whole Grain[a] | Refined Grain | | Whole Grain | |
	Enriched/Fortified	Organic	Organic	Enriched/Fortified	Organic	Traditional	Organic, Enhanced[b]
Sodium (mg)	200	80	110	0	0	0	0
Potassium (mg)	45	–	70	0	0	0	0
Dietary fiber (g)	11.8	<1	2	2	2	5	6
Sugars (g)	3	2	3	2	2	2	1
Protein (g)	2	2	2	7	7	7	9
Vitamin A (%)	10	0	0	0	0	0	0
Vitamin C (%)	10	0	0	0	0	0	0
Calcium (%)	0	0	0	0	0	2	2
Iron (%)	45	2	4	10	4	10	15
Vitamin D (%)	10	0	–	0	0	–	–
Vitamin E (%)	–	0.96	–	–	–	–	–
Thiamin (%)	25	0.364	–	35	–	10	10
Riboflavin (%)	25	0.109	–	15	–	–	–
Niacin (%)	25	5.2	–	20	–	–	–
Vitamin B_6 (%)	25	–	–	–	–	–	–
Folic acid (%)	25	36	–	30	–	–	–
Vitamin B_12 (%)	25	–	–	–	–	–	–
Phosphorus (mg)	29	81	–	29	–	10	10
Magnesium (mg)	11	225	–	11	–	12	12
Zinc (mg)	0.28	1.5	–	0.28	–	–	–
Copper (%)	–	–	–	–	–	10	10

[a] Enriched/fortified whole grain was not found.
[b] Fiber and nutrients added.

trations in whole grain foods show them to be much higher than those in refined grains, the actual amount absorbed may differ little due to various factors impacting bioavailability (62). In some cases the mineral in the whole grain kernel is inaccessible or is bound to the fiber or phytic acid, which inhibits the absorption of iron, calcium, zinc, and magnesium (63).

The concentration of minerals in grains is determined genetically by species and variety and by growing conditions. Mineral bioavailability can be improved through biofortification and processing. Biofortification, the amplification of a mineral or minerals in staple crops, is performed through field applications or biotechnology and has been used successfully to improve mineral status in both developed and developing countries (64). Processing techniques such as soaking, germination, enzymatic treatment with phytase, sourdough and long fermentations, and addition of minerals through enrichment and fortification are some of the strategies used to improve mineral nutriture. Such techniques can not only decrease the influence of inhibitors but also offset losses from processing.

Iron and Zinc. Iron and zinc are the two most abundant trace minerals in the human body. These minerals share common dietary sources, such as cereals, and their absorption is inhibited and enhanced by similar dietary constituents. Dietary fiber, tannins and other phenolic antioxidants, and phytate inhibit absorption of both minerals. As a consequence, iron and zinc deficiencies often occur simultaneously.

According to the WHO, iron deficiency is the most common and widespread nutritional disorder in the world, causing anemia in 30% of the global population (65). Low iron intakes and status not only affect a large number of children and women in developing countries, it also affects those in developed countries, 50–100% of the elderly in Europe not meeting the estimated average reference (EAR) (66). According to a study by Lindenmayer et al. (67), zinc deficiency affects 20% of the global population and leads to substantial morbidity and mortality, especially in children under 5 years of age in low- and middle-income countries (67).

Iron plays a part in a wide variety of metabolic processes, including its critical role in electron transport and DNA synthesis for all cells, in synthesis of some hormones and connective tissue, and as a component in the heme portion of blood

and muscle necessary to facilitate oxygen transport (68). Inadequate iron is linked to anemia, impaired physical and mental development, decreased capacity to work, reproductive problems, cognitive impairments, and behavioral changes, including changes in attention span, intelligence, and sensory perception (69).

Zinc deficiency not only impairs growth, but also contributes to significant diarrhea and pneumonia- and malaria-related morbidity and mortality among young children (70). In Sub-Saharan Africa and southern Asia, low zinc intake has been estimated to account for 800,000 child deaths a year. Surveys in various parts of Europe show that roughly 1–16% of males and 3.7–31% of females were below the estimated average requirement (66).

In some developing countries such as India, nearly 75% of pregnant women were deficient in zinc; nearly 55% were deficient in both zinc and iron; 25% were deficient in zinc, magnesium, and iron; and ≈10% were deficient in zinc, magnesium, iron, and folic acid (71). Cereals, including those that are enriched and fortified, offer important sources of low-cost iron and zinc and other nutrients. Even in developed countries, cereal and bread products provide 40–47% of iron and 25–33% of zinc intake (72).

The bioavailability of these minerals from grains, especially whole grains, may be impaired. In fact, iron availability from enriched and fortified grains, especially those fortified with an available iron chelate (e.g., iron EDTA) as recommended, usually surpasses that from whole grains (73,74). However, many countries continue to use nonrecommended, low-bioavailability, atomized, reduced, or hydrogen-reduced iron powders. Zinc bioavailability has also been shown to be better from fortified, degermed grain than from whole grain (75). Ingestion of vitamin C-rich foods or beverages with cereals also improves the bioavailability of both these minerals (76,77). In summary, the fortification and biofortification of grains, especially wheat, with iron and zinc are successful, proven public health strategies for both developed and developing countries.

Magnesium. The role of magnesium in more than 600 enzymatic reactions emphasizes its critical role in vital processes, including those key to signaling transduction, energy metabolism, protein synthesis, DNA replication and repair, and cell proliferation (78). Magnesium inadequacy may play an important role in the etiology

of cardiovascular diseases, including thrombosis, atherosclerosis, ischemic heart disease, myocardial infarction, hypertension, arrhythmias, congestive heart failure, and diabetes, as well as a variety of other conditions. Supplementation of magnesium intake has shown success in treating pre-eclampsia, migraine, depression, and asthma.

Magnesium intake is often below that recommended in both developed and developing countries because dietary sources rich in magnesium, such as whole grains, may not be consumed in adequate quantities. Although whole grain products are one of the main sources of magnesium in human nutrition, its availability from whole grains is inhibited by phytate and dietary fiber (79).

Selenium. Selenium is an essential micronutrient because selenocysteine is a component of a key detoxifying enzyme, glutathione peroxidase. Health benefits attributed to selenium include decreased cancer risk, protection against cardiovascular diseases, and development of and boost in immune function.

The selenium content of grain is dependent primarily on the amount of selenium in the soil the crop is grown in, but also on the effects of processing (80). Thus, cereal grains grown in regions with adequate selenium in the soil are important dietary contributors. There are regions of the world with very low levels of selenium in the soil, including parts of China and Russia. Up to 47% of the European population is below the EAR for selenium (66). If soil levels are low, then there is the risk of endemic selenium inadequacy, which can be dealt with either by importing grains from regions with adequate selenium in the soil or biofortification strategies that incorporate selenium fertilizer. Lack of selenium leads to Keshan disease, a type of heart disease (81). However, excess selenium is toxic (82).

Effects of Excess Nutrient Intake. Excess intake of nutrients can create problems, and excess intake of minerals can be a particular problem. Studies on the fortification of foods have shown that foods fortified with ≤25% of the required intake would not be problematic, whereas excess consumption of foods that are fortified to 100%, termed "multivitamin and multimineral supplement cereals" could be potentially harmful.

Excess iron can form free radicals that act as a pro-oxidant and can damage a wide range of tissues. Excess iron stores have been associated with insulin resis-

tance and neurodegenerative disorders. Excess zinc and magnesium intake from foods is unlikely as these are not customarily part of enrichment and fortification formulas.

Phytochemicals. The positive contributions of dietary phytochemicals from grains are well documented and have been reviewed (83). Whole grains are a good source of anti-inflammatory and antioxidant compounds. In fact, the in vitro antioxidant activity of whole grain foods is similar to that of vegetables and fruits (84). This activity is due not only to antioxidant vitamins and minerals, as already discussed, but also to phytochemicals such as phytates, phenolics such as ferulic acid in corn and wheat (85), lignans (86), alkylresorcinols in wheat and rye (87,88,89), oryzanol in rice, and avenanthramides in oats (90,91). Some of these have antiatherogenic activity through mitigation of nitric oxide production (92). Certain other flavonoids, phenolics, and phenolic lipids boost immune function, as well as being antimutagenic and anti-inflammatory (83,84). Alkylresorcinols, which are particularly high in wheat and rye, may be markers of whole grain intake (93). Betaine, which is particularly high in quinoa and wheat, is involved in methyl transfers, improved vascular functioning, and enhanced performance.

The amount and type of phytochemical in grain depends on the cultivar, species, and agronomic conditions and can vary markedly even for the same cereal grain. Environmental stresses may increase levels of certain phytochemicals.

The synergy among whole grains, dietary fiber, vitamins, minerals, and phytochemicals has important effects on health. The availability of certain phytochemicals and where they exert their action in the body and gut depends on how a food is processed. Components not absorbed in the upper gut may act locally in the lower gut. A mix of processing methods may be used to optimize availability for the body.

Nutrition and Health Benefits of Whole and Refined Grains

Refined Grains. Intake of refined grain foods was not associated with risk of cardiovascular disease, diabetes, weight gain, or overall mortality in a systematic review of 135 relevant papers published after 2000 (95). The authors stated that the "consumption of up to 50% of all grain foods as refined-grain foods (without high levels of added fat, sugar, or sodium) (e.g. staple foods) is not associated with

any increased disease risk" (95). Studies using National Health and Nutrition Examination Survey (NHANES) data show that an optimal mix of whole grains and refined staple grain foods in the diet, with only limited intake of indulgent grain foods, not only cost-effectively delivered key nutrients, it was associated with lower weight and equal or better nutrient intakes than grain food patterns that did not include refined grains (96–98).

Additional studies also show health benefits for a mix of both whole and refined grains in the diet—hence the recommendation to make "half your grains whole." A recent analysis of NHANES data shows that a mix of whole and refined grain staples was associated with smaller waist circumference (96) and lower visceral adipose, which is the fat around the midsection that is related to increased risk of coronary disease and diabetes (16). Further, refined grains often enable greater absorption of certain components, such as minerals, than occurs with whole grains (75,76). However, excess consumption of grain-based desserts and snacks, especially those that cause high postprandial glucose excursions, has been associated with excess weight and adverse health outcomes (99–101).

An optimal mix of whole and refined grain intake can be beneficial as a way to protect against toxicity that can occur in regions where sludge and overuse of certain agricultural chemicals and other questionable practices are employed or where grains are not regularly monitored for contaminants. Because heavy metals and many other contaminants primarily reside in the outer layers of whole grains, recommendations for consumption of whole grains exclusively may not be the best dietary advice in these regions (102). Also, as mentioned earlier, intake of phytates, tannins, and other phytochemicals can cause problems if excess amounts are ingested and no measures are taken to reduce their effects, especially in plant-based diets (103).

Whole Grains. Whole grains have long been regarded as healthy dietary components; however, the documentation of health benefits beyond their nutrient contribution is much more recent. As mentioned earlier, whole grains deliver important dietary components such as magnesium and dietary fiber, both of which are often low in Western diets. Beyond their nutrients, the ingestion of whole grains is associated with lower risk of coronary disease, diabetes, hypertension,

overweight, and even overall mortality (104). As a result, dietary guidance by a variety of government and health promotion organizations recommends the inclusion of whole grain foods in the diet. Most call for an increase in whole grain intake by replacing some refined grain products (105,106). For example, the last three U.S. Dietary Guidelines Advisory Committees (DGAC) have recommended that consumers "make at least half their grains whole" (107–109), with the 2010 DGAC recommending that the replacement of refined grains should be with high-fiber whole grains (109).

The upcoming reviews will detail studies linking whole grains with lower risks of a variety of chronic diseases. In many cases staple grains are also associated with lower disease risks. In general, consistent links with better health outcomes have occurred across widely different population groups, often with culturally very different diet patterns and genetic make-ups. For many chronic diseases, risk reduction was ≥25% for those ingesting somewhere between 2 and 3 servings of whole grains each day. Because the average intake of whole grains in many countries is <1 serving of whole grains/day, it is critical that grains and whole grains are emphasized in dietary guidance (110).

Conclusions

Carbohydrate-rich staple foods, including those from a wide array of whole and refined grains, are inexpensive sources of energy, protein, and other nutrients, e.g., dietary fiber, minerals, vitamins, and other beneficial phytochemicals. Grain-based staple ingredients are incorporated into an enormous variety of foods. In nearly all of these dishes, grain-based staple ingredients provide complementary amino acid patterns that combine to make complete proteins.

The important health benefits provided by grains argues for their incorporation in the everyday diets of healthy people. Whole grains, in particular, are associated with decreased risk of certain chronic diseases, and consumption of an optimal mix of whole and refined grains is asso-ciated with a number of health benefits, including decreased visceral adipose tissue.

Cereal grains provide a wide variety of nutrients, dietary fibers, and phytochemicals. This combination uniquely positions them as a source of nutrition to both sustain and nourish a population.

References

1. Vázquez-Durán, A., Díaz-Torres, R., Ramírez-Noguera, P., Moreno-Martínez, E., and Méndez-Albores, A. Cytotoxic and genotoxic evaluation of tortillas produced by microwave heating during alkaline-cooking of aflatoxin-contaminated maize. J. Food Sci. 79:T1024, 2014.

2. U.S. Food and Drug Administration and Department of Health and Human Services. Cereal flours and related products: Food for human consumption. 21 CFR, Part 137, Subpart B. *Code of Federal Regulations*. Published online at www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=137&showFR=1&subpartNode=21:2.0.1.1.25.2. Government Printing Office, Washington, DC, 2013.

3. Steyn, N. P., Wolmarans, P., Nel, J. H., and Bourne, L. T. National fortification of staple foods can make a significant contribution to micronutrient intake of South African adults. Public Health Nutr. 11:307, 2008.

4. Hennessy, Á., Walton, J., and Flynn, A. The impact of voluntary food fortification on micronutrient intakes and status in European countries: A review. Proc. Nutr. Soc. 72:433, 2013.

5. WHO. Part I. The role of food fortification in the control of micronutrient malnutrition. In: *Guidelines on Food Fortification with Micronutrients*. L. Allen, B. de Benoist, O. Dary, and R. Hurrell, eds. Published online at www.who.int/nutrition/publications/micronutrients/GFF_Part_1_en.pdf. WHO, Geneva, 2009.

6. WHO. Recommendations on wheat and maize flour fortification meeting report: Interim consensus statement. Published online at www.who.int/nutrition/publications/micronutrients/wheat_maize_fort.pdf. WHO, Geneva, 2009.

7. AACC International. Whole grains definition. Published online at www.aaccnet.org/initiatives/definitions/Pages/WholeGrain.aspx. The Association, St. Paul, MN, 1999.

8. Whole Grains Council. Definition of whole grains. Published online at www.wholegrainscouncil.org/whole-grains-101/definition-of-whole-grains. The Council, Boston, 2004.

9. van der Kamp, J. W., Poutanen, K., Seal, C. J., and Richardson, D. P. The HEALTHGRAIN definition of 'whole grain.' Food Nutr. Res. DOI: dx.doi.org/10.3402/fnr.v58.22100, 2014.

10. Jacobs, D. R., Jr. Grain v. cereal: An impediment to public understanding of food and a study in language. Br. J. Nutr. 86:543, 2001.

11. Health Canada. 2013 Whole grains—Get the facts. Published online at www.hc-sc.gc.ca/fn-an/nutrition/whole-grain-entiers-eng.php. Health Canada, Ottawa, 2013.

12. Ross, A. B., Kristensen, M., Seal, C. J., Jacques, P., and McKeown, N. M. Recommendations for reporting whole-grain intake in observational and intervention studies. Am. J. Clin. Nutr. DOI: 10.3945/ajcn.114.098046. 2015.

13. Jacobs, D. R., Jr., Meyer, K. A., Kushi, L. H., and Folsom, A. R. Whole-grain intake may reduce the risk of ischemic heart disease death in postmenopausal women: The Iowa Women's Health Study. Am. J. Clin. Nutr. 68:248, 1998.

14. Liu, S., Manson, J. E., Stampfer, M. J., Rexrode, K. M., Hu, F. B., Rimm, E. B., and Willett, W. C. Whole grain consumption and risk of ischemic stroke in women: A prospective study. JAMA 284:1534, 2000.

15. Fung, T. T., Hu, F. B., Pereira, M. A., Liu, S., Stampfer, M. J., Colditz, G. A., and Willett, W. C. Whole-grain intake and the risk of type 2 diabetes: A prospective study in men. Am. J. Clin. Nutr. 76:535, 2002.

16. McKeown, N. M., Troy, L. M., Jacques, P. F., Hoffmann, U., O'Donnell, C. J., and Fox, C. S. Whole- and refined-grain intakes are differentially associated with abdominal visceral and subcutaneous adiposity in healthy adults: The Framingham Heart Study. Am. J. Clin. Nutr. 92:1165, 2010.

17. Katcher, H. I., Legro, R. S., Kunselman, A. R., Gillies, P. J., Demers, L. M., Bagshaw, D. M., and Kris-Etherton, P. M. The effects of a whole grain-enriched hypocaloric diet on cardiovascular disease risk factors in men and women with metabolic syndrome. Am. J. Clin. Nutr. 87:79, 2008.

18. Melanson, K. J., Angelopoulos, T. J., Nguyen, V. T., Martini, M., Zukley, L., et al. Consumption of whole grain cereals during weight loss: Effects on dietary quality, dietary fiber, magnesium, vitamin B-6, and obesity. J. Am. Diet. Assoc. 106:1380, 2006.

19. Pereira, M. A., Jacobs, D. R., Jr., Pins, J. J., Raatz, S. K., Gross, M. D., Slavin, J. L., and Seaquist, E. R. Effect of whole grains on insulin sensitivity in overweight hyperinsulinemic adults. Am. J. Clin. Nutr. 75:848, 2002.

20. de Munter, J. S., Hu, F. B., Spiegelman, D., Franz, M., and van Dam, R. M. Whole grain, bran, and germ intake and risk of type 2 diabetes: A prospective cohort study and systematic review. PLoS Med. 4:e261, 2007.

21. Canadian Food Inspection Agency. Composition, quality, quantity and origin claims. Section 4.2.3, Stressing or highlighting particular ingredients. In: *Guide to Food Labelling and Advertising*. Published online at www.alimentheque.com/divers/GuideFoodLabellingAdvertising_CFIA_dec2011.pdf. CFIA, Ottawa, 2011.

22. Frølich, W., Åman, P., and Tetens, I. Whole grain foods and health—A Scandinavian perspective. Food Nutr. Res. DOI: 10.3402/fnr.v57i0.18503. 2013.

23. Frølich, W., and Åman, P. Whole grain for whom and why? Food Nutr. Res. DOI: 10.3402/fnr.v54i0.5056. 2012.

24. National Food Agency. The Keyhole. Published online at www.livsmedelsverket.se/en/food-and-content/labelling/nyckelhalet. National Food Agency, Uppsala, Sweden, 2002.

25. Ferruzzi, M. G., Jonnalagadda, S. S., Liu, S., Marquart, L., McKeown, N., et al. Developing a standard definition of whole-grain foods for dietary recommendations: Summary report of a multidisciplinary expert roundtable discussion. Adv. Nutr. 5:164, 2014.

26. AACC International. AACCI's Whole Grains Working Group unveils new whole grain products characterization. Published online at www.aaccnet.org/about/newsreleases/Pages/WholegrainProductCharacterization.aspx. The Association, St. Paul, MN, 2013.

27. FAO. Global and regional food consumption patterns and trends. In: *Joint WHO/FAO Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases*. Published online at www.fao.org/docrep/005/ac911e/ac911e05.htm. FAO, Rome, 2003.

28. Aguilar, E. G., Albarracín, G. J., Uñates, M. A., Piola, H. D., Camiña, J. M., and Escudero, N. L. Evaluation of the nutritional quality of the grain protein of new amaranths varieties. Plant Foods Hum. Nutr. 70:21, 2015.

29. Nuss, E. T., and Tanumihardjo, S. A. Quality protein maize for Africa: Closing the protein inadequacy gap in vulnerable populations. Adv. Nutr. 2:217, 2011.

30. Verhoeckx, K., Vissers, Y., Baumert, J. L., Faludi, R., Feys, M., et al. Food processing and allergenicity. Food Chem. 174:319, 2015.

31. Tatham, A. S., and Shewry, P. R. Allergens to wheat and related cereals. Clin. Exp. Allergy 38:1712, 2008.

32. Sapone, A., Bai, J. C., Ciacci, C., Dolinsek, J., Green, P. H., et al. Spectrum of gluten-related disorders: Consensus on new nomenclature and classification. BMC Med. 10:13, 2012.

33. Sarwar Gilani, G., Wu Xiao, C., and Cockell, K. A. Impact of antinutritional factors in food proteins on the digestibility of protein and the bioavailability of amino acids and on protein quality. Br. J. Nutr. 108(Suppl. 2):S315, 2012.

34. Sumczynski, D., Bubelova, Z., Sneyd, J., Erb-Weber, S., and Mlcek, J. Total phenolics, flavonoids, antioxidant activity, crude fibre and digestibility in non-traditional wheat flakes and muesli. Food Chem. Toxicol. 174:319, 2015.

35. van Buul, V. J., and Brouns, F. J. P. H. Health

effects of wheat lectins: A review. J. Cereal Sci. 59:1, 2014.

36. Ahsan, H., Ahad, A., and Siddiqui, W. A. A review of characterization of tocotrienols from plant oils and foods. J. Chem. Biol. 8:45, 2015.

37. Brandolini, A., and Hidalgo, A. Wheat germ: Not only a by-product. Int. J. Food Sci. Nutr. 63(Suppl. 1):71, 2012.

38. Hwang, E. S., Stacewicz-Sapuntzakis, M., and Bowen, P. E. Effects of heat treatment on the carotenoid and tocopherol composition of tomato. J. Food Sci. 77:C1109, 2012.

39. Galvin, M. A., Kiely, M., and Flynn, A. Impact of ready-to-eat breakfast cereal (RTEBC) consumption on adequacy of micronutrient intakes and compliance with dietary recommendations in Irish adults. Public Health Nutr. 6:351, 2003.

40. van den Boom, A., Serra-Majem, L., Ribas, L., Ngo, J., Pérez-Rodrigo, C., Aranceta, J., and Fletcher, R. The contribution of ready-to-eat cereals to daily nutrient intake and breakfast quality in a Mediterranean setting. J. Am. Coll. Nutr. 25:135, 2006.

41. Holmes, B. A., Kaffa, N., Campbell, K., and Sanders, T. A. The contribution of breakfast cereals to the nutritional intake of the materially deprived UK population. Eur. J. Clin. Nutr. 66:10, 2012.

42. Williams, P. G. The benefits of breakfast cereal consumption: A systematic review of the evidence base. 5:636S, 2014.

43. Montenegro-Bethancourt, G., Vossenaar, M., Kuijper, L. D., Doak, C. M., and Solomons, N. W. Ready-to-eat cereals are key sources of selected micronutrients among schoolchildren from public and private elementary schools in Quetzaltenango, Guatemala. Nutr. Res. 29:335, 2009.

44. Sharma, S., Sheehy, T., and Kolonel, L. N. Ethnic differences in grains consumption and their contribution to intake of B-vitamins: Results of the Multiethnic Cohort Study. Nutr. J. 12:65, 2013.

45. Yu, B. H., and Kies, C. Niacin, thiamin, and pantothenic acid bioavailability to humans from maize bran as affected by milling and particle size. Plant Foods Hum. Nutr. 43:87, 1993.

46. Kodicek, E., and Wilson, P. W. The availability of bound nicotinic acid to the rat. 1. The effect of lime-water treatment of maize and subsequent baking into *tortilla*. Br. J. Nutr. 13:418, 1959.

47. Roth-Maier, D. A., Wild, S. I., Erhardt, W., Henke, J., and Kirchgessner, M. Investigations on the intestinal availability of native thiamin in selected foods and feedstuffs. Eur. J. Nutr. 38:241, 1999.

48. Swaminathan, S., Edward, B. S., and Kurpad, A. V. Micronutrient deficiency and cognitive and physical performance in Indian children. Eur. J. Clin. Nutr. 67:467, 2013.

49. Powers, H. J. Riboflavin (vitamin B-2) and health. Am. J. Clin. Nutr. 77:1352, 2003.

50. Bhaskaram, P. Micronutrient malnutrition, infection, and immunity: An overview. Nutr. Rev. 60:S40, 2002.

51. Roth-Maier, D. A., Wauer, A., Stangl, G. I., and Kirchgessner, M. Precaecal digestibility of niacin and pantothenic acid from different foods. Int. J. Vitam. Nutr. Res. 70:8, 2000.

52. Walsh, J. H., Wyse, B. W., and Hansen, R. G. Pantothenic acid content of 75 processed and cooked foods. J. Am. Diet. Assoc. 78:140, 1981.

53. Roth-Maier, D. A., Kettler, S. I., and Kirchgessner, M. Availability of vitamin B6 from different food sources. Int. J. Food Sci. Nutr. 53:171, 2002.

54. Moghissi, A. A., Pei, S., and Liu, Y. Golden rice: Scientific, regulatory and public information processes of a genetically modified organism. Crit. Rev. Biotechnol. 21:1, 2015.

55. Zielinski, H., Ciska, E., and Kozlowska, H. The cereal grains: Focus on vitamin E. Czech J. Food Sci. 19:182, 2001.

56. McLaughlin, P. J., and Weihrauch, J. L. Vitamin E content of foods. J. Am. Diet. Assoc. 75:647, 1979.

57. Siti, H. N., Kamisah, Y., and Kamsiah, J. The role of oxidative stress, antioxidants and vascular inflammation in cardiovascular disease (a review). Vasc. Pharmacol. 71:40, 2015.

58. Feki, M., Souissi, M., and Mebazaa, A. Vitamin E deficiency: Risk factor in human disease? Ann. Med. Interne 152:398, 2001.

59. Borel, P., Preveraud, D., and Desmarchelier, C. Bioavailability of vitamin E in humans: An update. Nutr. Rev. 71:319, 2013.

60. Eitenmiller, R. R., and Lee, J. *Vitamin E: Food Chemistry, Composition, and Analysis*. Marcel Dekker, New York, 2004.

61. WHO. Quantifying selected major risks to health. In: *The World Health Report 2002—Reducing Risks, Promoting Healthy Life*. Published online at www.who.int/whr/2002/chapter4/en/index3.html. WHO, Geneva, 2002.

62. Trinidad, T. P., Mallillin, A. C., Sagum, R. S., Briones, D. P., Encabo, R. R., and Juliano, B. O. Iron absorption from brown rice/brown rice-based meal and milled rice/milled rice-based meal. Int. J. Food Sci. Nutr. 60:688, 2009.

63. Gupta, R. K., Gangoliya, S. S., and Singh, N. K. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. J. Food Sci. Technol. 52:676, 2015.

64. La Frano, M. R., de Moura, F. F., Boy, E., Lönnerdal, B., and Burri, B. J. Bioavailability of iron, zinc, and provitamin A carotenoids in biofortified staple crops. Nutr. Rev. 72:289, 2014.

65. WHO. Micronutrient deficiencies: Iron deficiency anemia. Published online at www.who.int/nutrition/topics/ida/en. WHO, Geneva, 2015.

66. Roman Viñas, B., Ribas Barba, L., Ngo, J., Gurinovic, M., Novakovic, R., et al. Projected prevalence of inadequate nutrient intakes in Europe. Ann. Nutr. Metab. 59:84, 2011.

67. Lindenmayer, G. W., Stoltzfus, R. J., and Prendergast, A. J. Interactions between zinc deficiency and environmental enteropathy in developing countries. Adv. Nutr. 5:1, 2014.

68. Abbaspour, N., Hurrell, R., and Kelishadi, R. Review on iron and its importance for human health. J. Res. Med. Sci. 19:164, 2014.

69. Jáuregui-Lobera, I. Iron deficiency and cognitive functions. Neuropsychiatr. Dis. Treat. 10:2087, 2014.

70. Mayo-Wilson, E., Junior, J. A., Imdad, A., Dean, S., Chan, X. H., Chan, E. S., Jaswal, A., and Bhutta, Z. A. Zinc supplementation for preventing mortality, morbidity, and growth failure in children aged 6 months to 12 years of age. Cochrane Database Syst. Rev. DOI: 10.1002/14651858. CD009384.pub2. 2014.

71. Pathak, P., Kapil, U., Kapoor, S. K., Saxena, R., Kumar, A., Gupta, N., Dwivedi, S. N., Singh, R., and Singh, P. Prevalence of multiple micronutrient deficiencies amongst pregnant women in a rural area of Haryana. Indian J. Pediatr. 71:1007, 2004.

72. Lim, K. H., Riddell, L. J., Nowson, C. A., Booth, A. O., and Szymlek-Gay, E. A. Iron and zinc nutrition in the economically-developed world: A review. Nutrients 5:3184, 2013.

73. Randall, P., Johnson, Q., and Verster, A. Fortification of wheat flour and maize meal with different iron compounds: Results of a series of baking trials. Food Nutr. Bull. 33(Suppl. 4):S344, 2012.

74. Hurrell, R., Ranum, P., de Pee, S., Biebinger, R., Hulthen, L., Johnson, Q., and Lynch, S. Revised recommendations for iron fortification of wheat flour and an evaluation of the expected impact of current national wheat flour fortification programs. Food Nutr. Bull. 31(Suppl. 1):S7, 2010.

75. Moretti, D., Biebinger, R., Bruins, M. J., Hoeft, B., and Kraemer, K. Bioavailability of iron, zinc, folic acid, and vitamin A from fortified maize. Ann. N.Y. Acad. Sci. 1312:54, 2014.

76. Gibson, R. S., Perlas, L., and Hotz, C. Improving the bioavailability of nutrients in plant foods at the household level. Proc. Nutr. Soc. 65:160, 2006.

77. Welch, R. M., and Graham, R. D. Breeding for micronutrients in staple food crops from a human nutrition perspective. J. Exp. Bot. 55:353, 2004.

78. de Baaij, J. H., Hoenderop, J. G., and Bindels, R. J. Magnesium in man: Implications for health and disease. Physiol. Rev. 95:1, 2015.

79. Lopez, H. W., Leenhardt, F., and Remesy, C. New data on the bioavailability of bread magnesium. Magnes. Res. 17:335, 2004.

80. Lazo-Vélez, M. A., Chávez-Santoscoy, A., and Serna-Saldivar, S. O. Selenium-enriched breads and their benefits in human nutrition and health as affected by agronomic, milling, and baking factors. Cereal Chem. 92:134, 2015.

81. Chen, J. An original discovery: Selenium deficiency and Keshan disease (an endemic heart disease). Asia Pac. J. Clin. Nutr. 21:320, 2012.

82. Hatfield, D. L., Tsuji, P. A., Carlson, B. A., and Gladyshev, V. N. Selenium and selenocysteine: Roles in cancer, health, and development. Trends Biochem. Sci. 39: 112, 2014.

83. Jones, J. M., and Engleson, J. Whole grains: Benefits and challenges. Annu. Rev. Food Sci. Technol. 1:19, 2010.

84. Miller, H. E., Rigelhof, F., Marquart, L., Prakash, A., and Kanter, M. Antioxidant content of whole grain breakfast cereals, fruits and vegetables. J. Am. Coll. Nutr. 19(Suppl. 3):312S, 2000.

85. Klepacka, J., and Fornal, Ł. Ferulic acid and its position among the phenolic compounds of wheat. Crit. Rev. Food Sci. Nutr. 46:639, 2006.

86. Adlercreutz, H. Lignans and human health. Crit. Rev. Clin. Lab. Sci. 44:483, 2007.

87. Zhu, Y., Shurlknight, K. L., Chen, X., and Sang, S. Identification and pharmacokinetics of novel alkylresorcinol metabolites in human urine, new candidate biomarkers for whole-grain wheat and rye intake. J. Nutr. 144:114, 2014.

88. Kulawinek, M., and Kozubek, A. 5-n-Alkylresorcinols of whole grain cereals and whole grain cereal products as biomarkers of healthy food. Postepy Biochem. 53:287, 2007.

89. Jones, J. M. Mining whole grains for functional components. Food Sci. Technol. Bull. Funct. Foods 4:67, 2007.

90. Clemens, R., and van Klinken, B. J. Oats, more than just a whole grain: An introduction. Br. J. Nutr. 112(Suppl. 2):S1, 2014.

91. Chu, Y. F., Wise, M. L., Gulvady, A. A., Chang, T., Kendra, D. F., van Klinken, J.-W., Shi, Y., and O'Shea, M. In vitro antioxidant capacity and anti-inflammatory activity of seven common oats. Food Chem. 139:426, 2013.

92. Park, H. Y., Yu, A. R., Choi, I. W., Hong, H. D., Lee, K. W., and Choi, H. D. Immunostimulatory effects and characterization of a glycoprotein fraction from rice bran. Int. Immunopharmacol. 17:191, 2013.

93. Söderholm, P. Alkylresorcinol metabolites as potential biomarkers for whole-grain rye intake and the effect of rye bread intake on plasma low-density lipoproteins. Doctoral thesis. Institute for Preventive Medicine, Nutrition, and Cancer Folkhälsan Research Center and Faculty of Medicine, Department of Cardiology, Institute of Clinical Medicine, University of Helsinki, Finland, 2012.

94. Keaveney, E. M., Price, R. K., Hamill, L. L., Wallace, J. M., McNulty, H., et al. Postprandial plasma betaine and other methyl donor-related responses after consumption of minimally processed wheat bran or wheat aleurone, or wheat aleurone incorporated into bread. Br. J. Nutr. 113: 445, 2015.

95. Williams, P. G. Evaluation of the evidence between consumption of refined grains and health outcomes. Nutr. Rev. 70:80, 2012.

96. Fulgoni, V., and Papanikolaou, Y. Cost of nutrients analyses using the national health and nutrition examination survey: A focus on grain foods. FASEB J. 29(April): 903.5, 2015.

97. Papanikolaou, Y., and Fulgoni, V. Consumption of certain grain food patterns is associated with improved diet quality and nutrient intakes in US adults: A NHANES 2005–2010 analysis. FASEB J. 29(April):736.7, 2015.

98. Papanikolaou, Y., and Fulgoni, V. Modeling changes in daily grain foods intake: An analysis to determine the impact on nutrient intakes in comparison to the USDA ideal food pattern. FASEB J. 29(April):741.8, 2015.

99. Bachman, J. L., Reedy, J., Subar, A. F., and Krebs-Smith, S. M. Sources of food group intakes among the US population, 2001–2002. J. Am. Diet. Assoc. 108:804, 2008.

100. Reedy, J., and Krebs-Smith, S. M. Dietary sources of energy, solid fats, and added sugars among children and adolescents in the United States. J. Am. Diet. Assoc. 110:1477, 2010.

101. Maki, K. C., and Phillips, A. K. Dietary substitutions for refined carbohydrate that show promise for reducing risk of type 2 diabetes in men and women. J. Nutr. 145:159S, 2015.

102. Bermudez, G. M. A., Jasan, R., Plá, R., and Pignata, M. L. Heavy metal and trace element concentrations in wheat grains: Assessment of potential non-carcinogenic health hazard through their consumption. J. Hazard. Mater. 193:264, 2011.

103. Gibson, R. S., Bailey, K. B., Gibbs, M., and Ferguson, E. L. A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. Food Nutr. Bull. 31(Suppl. 2):S134, 2010.

104. Jonnalagadda, S. S., Harnack, L., Liu, R. H., McKeown, N., Seal, C., Liu, S., and Fahey, G. C. Putting the whole grain puzzle together: Health benefits associated with whole grains—Summary of American Society for Nutrition 2010 Satellite Symposium. J. Nutr. 141:1011S, 2011.

105. Health Canada. Canada's Food Guide. Published online at www.hc-sc.gc.ca/fn-an/food-guide-aliment/basics-base/quantit-eng.php. Health Canada, Ottawa, 2007.

106. Folloni, S., and Ranieri, R. Whole grain products in (Southern) Europe: Consumer trends and technological implications. In: *Proceedings Whole Grains Summit 2012.* CFW Plexus. DOI: http://dx.doi.org/10.1094/CPLEX-2013-1001-22B. 2013.

107. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Scientific report of the 2015 Dietary Guidelines Advisory Committee. Published online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. U.S. Government Printing Office, Washington, DC, 2015.

108. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans, 2005,* 6th ed. Published online at www.health.gov/dietaryguidelines/dga2005/document. U.S. Government Printing Office, Washington, DC, 2005.

109. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans, 2010,* 7th ed. Published online at www.cnpp.usda.gov/DietaryGuidelines. U.S. Government Printing Office, Washington, DC, 2010.

110. Cleveland, L. E., Moshfegh, A. J., Albertson, A. M., and Goldman, J. D. Dietary intake of whole grains. J. Am. Coll Nutr. 19(Suppl. 3):331S, 2000.