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 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, which is especially important for certain grains, such as maize (1).

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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.

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.
Series of Reviews on Carbohydrates, Wheat, and Cereal Grains and Their Impact on Health

To address many claims now occurring that disparage and discourage the ingestion of carbohydrates (CHOs), wheat, and cereal grains, even whole grains, as well as to celebrate the versatility, nutritional and health benefits, and contribution of these foods to the world food supply, we felt compelled to defend their role in the diet and write this series of reviews. This second article in the series will build on the first article, which documents dietary recommendations from around the globe that state that CHOs should be at the base of the diet and should provide 45–65% of calories. This second review will show that grain- and wheat-based staples are important contributors of CHOs (including cereal fiber) and will discuss how these foods contribute necessary protein, vitamins, and minerals as part of a balanced diet for most healthy individuals. Terminology associated with grains and whole grains and their processing will also be discussed and defined. Definitions of dietary fiber and resistant starch and the characterization of a whole grain food will be included. Clear delineation of terms is critical because they differ from country to country and are a source of consumer confusion in nutrition education and labeling. The importance of the nutritional contributions and bioavailability of vitamins, minerals, and phytonutrients from CHO-rich staples and grain-based foods will be emphasized.

In the next grouping of reviews, the impacts of CHO-rich staple foods, including wheat- and grain-based foods, on a number of physiological outcomes and disease states will be addressed. The third article will look at the basic mechanisms of how CHO-rich staples and wheat- and grain-based foods impact health, including their impacts on blood glucose, inflammation and immunity, and composition and metabolic activity of the microbiome. This article also will summarize the latest findings on how these foods are digested, and how their digestion impacts health outcomes. Further, the review will provide data regarding the role of CHO-rich staples, wheat, and grains on the small segment of the population who have digestive disorders, allergies, and celiac-related disorders. This is especially important because many are attributing digestive problems and exacerbation of conditions such as irritable bowel to gluten and wheat. The literature on caveats concerning the effects of consumption and overconsumption of CHOs and grain- and wheat-based staples on such disorders will also be reviewed.

The other article in the second grouping will focus specifically at the effects of consumption and overconsumption of CHOs, grains, and wheat on body weight maintenance and loss, blood pressure, metabolic syndrome, diabetes, stroke, cardiovascular disease, cancer, immunity, and longevity. Because inflammation, glycemic response, and insulin resistance all are associated with these chronic diseases, information from the first article in this grouping will be applied to various health and disease outcomes.

The third group of review articles will assess the role of CHOs, grains, and wheat in neurological and brain functioning. The first of these will provide an overview of CHOs and other nutrients in brain functioning. It will include an introduction to specific terms and measures used in neuroanatomy and neurophysiology, such as cognition, working memory, attention, and executive functioning. The contribution of nutrients and phytonutrients from CHO-rich staples, with a focus on grains and wheat, in promoting normal brain functioning and fighting ill effects caused by inflammation will also be discussed. This article also will include an overview of dietary patterns, such as the dietary approaches to stop hypertension (DASH) and Mediterranean diets, that are associated with optimal brain health and neurological functioning.

The next set of articles in this grouping will describe the relationship between CHOs, grains, and wheat and various dementias, such as mild cognitive impairment and Alzheimer’s, and degenerative disorders, such as Parkinson’s. The articles will include a look at the relationship between diabetes, insulin resistance, and abnormal glucose tolerance and various dementias. The last article in this group will review the scientific literature on the role of nutrition, CHOs, grains, and wheat in autism, attention deficit hyperactivity disorder (ADHD), major depression disorder, epilepsy, foggy brain, headache, multiple sclerosis, and schizophrenia.

The last two articles in the series will deal with the nutritional contributions of wheat and wheat-based foods in the diet and address the role of cereal grains and their global importance in providing a sustainable supply of calories and nutrients for the general population. The final article will have a global focus on wheat and its cultivation and processing and will assess similarities and differences in practices and uses. It will look at how wheat has evolved and continues to evolve and will describe how increases in yield and other factors have impacted different cultures and health. The cultural and nutritional contributions of wheat products in various regions will be compared and contrasted. The role of grains and wheat as part of a sustainable strategy for feeding the global population in 2050 and beyond will also be considered.
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.

![Fig. 1. Comparison of nutrients in whole, refined, and enriched/fortified refined wheat flours. Reprinted with permission from Oldways/The Whole Grains Council.](image-url)
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.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Refined Flour</th>
<th>Unbleached Organic</th>
<th>Traditional Whole Grain Flour</th>
<th>Organic Whole Grain Flour</th>
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</thead>
<tbody>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Potassium (mg)</td>
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<td>0</td>
<td>51</td>
<td>0</td>
</tr>
<tr>
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<td>&lt;1</td>
<td>2</td>
<td>6</td>
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<td>Sugars (g)</td>
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<td>&lt;1</td>
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<td>Protein (g)</td>
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<tr>
<td>Thiamin (%)</td>
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<td>Riboflavin (%)</td>
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<td>Niacin (%)</td>
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<td>–</td>
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<td>0.74</td>
<td>–</td>
</tr>
<tr>
<td>Copper (mg)</td>
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<td>–</td>
<td>4</td>
<td>10%</td>
</tr>
</tbody>
</table>

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

| Nutrient | Flour Extraction Rate | Compound | Level of Nutrient to Be Added (ppm) Based on Estimated Average per Capita Wheat Flour Availability (g/day)\textsuperscript{ab} |
|----------|-----------------------|----------|---------------------------------------------------------------------------------
| Iron | Low | NaFeEDTA | \(<75\) | 40 | 40 | 20 | 15 |
| | | Ferrous sulfate | 60 | 60 | 30 | 20 |
| | | Ferrous fumarate | 60 | 60 | 30 | 20 |
| | | Electrolytic iron | NR | NR | 60 | 40 |
| Folic acid | High | NaFeEDTA | \(<75\) | 40 | 40 | 20 | 15 |
| Vitamin B$_12$ | Low or high | Folic acid | 5.0 | 2.6 | 1.3 | 1.0 |
| Vitamin A | Low or high | Cyanocobalamin | 0.04 | 0.02 | 0.01 | 0.008 |
| Zinc\textsuperscript{c} | Low | Vitamin A palmitate | 5.9 | 3 | 1.5 | 1 |
| | High | Zinc oxide | 95 | 55 | 40 | 30 |
| | | | 100 | 100 | 80 | 70 |

\textsuperscript{a} Data source: WHO (6).

\textsuperscript{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.

\textsuperscript{c} NR = not recommended because the very high levels of electrolytic iron needed could negatively affect sensory properties of fortified flour.

\textsuperscript{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.

\textsuperscript{e} These levels of fortification with zinc assume 5 mg of zinc intake and no additional phytate intake from other dietary sources.
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).


![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.)](image2)
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 nutrition. 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 phytoneutraceuticals. 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 B6, 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 white 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>
<thead>
<tr>
<th>Table III. Crude protein and fat contents of cereal and pseudocereal grainsa</th>
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<tr>
<td>Grain</td>
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<tr>
<td>Cereal</td>
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<td>Brown rice</td>
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<td>Sorghum</td>
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<td>Rye</td>
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<td>Oats</td>
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<td>Maize</td>
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<td>Barley</td>
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<td>Pearl millet</td>
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<td>Pseudocereal</td>
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<tr>
<td>Quinoa</td>
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<td>Buckwheat</td>
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Vitamin B6. Grains can be a source of vitamin B6, 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 B6 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, B6 from barley is more available than B6 from wheat bran, which has greater availability than B6 from rye. Vitamin B6 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 tocotrienols, 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 antioxidant 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 affect 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                                      | Enriched/Fortified | Organic | Whole Grain | Enriched/Fortified | Organic | Traditional | Organic, Enhanced |
| Sodium (mg)                                   | 200            | 80      | 110         | 0               | 0       | 0           | 0               |
| Potassium (mg)                                | 45             | 70      | 2           | 2               | 2       | 5           | 6               |
| Dietary fiber (g)                             | 11.8           | <1      | 1           | 2               | 2       | 2           | 2               |
| Sugars (g)                                    | 3              | 2       | 3           | 2               | 2       | 1           | 9               |
| Protein (g)                                   | 2              | 2       | 7           | 0               | 0       | 0           | 0               |
| Vitamin A (%)                                 | 10             | 0       | 0           | 0               | 0       | 0           | 0               |
| Vitamin C (%)                                 | 10             | 0       | 0           | 0               | 0       | 0           | 0               |
| Calcium (%)                                   | 0              | 4       | 10          | 4               | 10      | 15          |
| Iron (%)                                      | 45             | 2       | 4           | 0               | 0       | 0           | 0               |
| Vitamin D (%)                                 | 10             | 0       | 0           | 0               | 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 B6 (%)                                | 25             | –       | –           | –               | –       | –           | –               |
| Folic acid (%)                                | 25             | 36      | 30          | –               | –       | –           | –               |
| Vitamin B12 (%)                               | 25             | –       | –           | –               | –       | –           | –               |
| Phosphorus (mg)                               | 29             | 81      | 29          | 11              | 12      | 12          |
| Magnesium (mg)                                | 11             | 225     | 11          | 12              | 12      | 12          |
| Zinc (mg)                                     | 0.28           | 1.5     | 0.28        | –               | –       | 10          |
| Copper (%)                                    | –              | –       | –           | –               | –       | 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 multi-mineral 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, andavananthamides 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 antiinflammatory and anti-infectious (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 body 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 oversuse 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 phytoestrogens, 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 argue 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 associated 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.
Clemens, R., and van Klinken, B. J. Oats,