Whole Grains: Benefits and Challenges

Julie Miller Jones[1] and Jodi Engleson[2]

[1]Family, Consumer, and Nutritional Sciences, St. Catherine University, St. Paul, Minnesota 55105; email: juliemjones@comcast.net

[2]Grains for Health Foundation, St. Paul, Minnesota 55121

Annu. Rev. Food Sci. Technol. 2010. 1:19–40

First published online as a Review in Advance on November 16, 2009

The *Annual Review of Food Science and Technology* is online at food.annualreviews.org

This article's doi:
10.1146/annurev.food.112408.132746

1941-1413/10/0410-0019$20.00

Key Words

fiber, bioactive, obesity, cardiovascular disease, diabetes

Abstract

Inclusion of whole grains (WG) in the diet is recommended in dietary guidance around the world because of their associations with increased health and reduced risk of chronic disease. WGs are linked to reduced risk of obesity or weight gain; reduced risk of cardiovascular disease (CVD), including coronary heart disease (CHD), hypertension, and stroke; improved gut health and decreased risk of cancers of the upper gut; perhaps reduced risk of colorectal cancer; and lower mortality rate. The 2005 United States Dietary Guidelines Advisory Committee has recommended that consumers make "half their grains whole." Yet, whole grains are puzzling both consumers and scientists. Scientists are trying to determine whether their health benefits are due to the synergy of WG components, individual WG components, or the fact that WG eaters make many of the recommended diet and lifestyle choices.

Consumers need to understand the WG benefits and how to identify WG foods to have incentive to purchase and use such foods. Industry needs to develop great-tasting, clearly-labeled products. With both these factors working together, it will be possible to change WG consumption habits among consumers.

INTRODUCTION

In the world of food selection, it is the "best of times and the worst of times." At no other time in human history have we faced endless choice coupled with knowledge that allows us to select a diet with all the important nutritional components. Despite knowledge about, and availability of, the "right stuff," many of us fail to exercise the wisdom to regularly choose food that enhances diet quality and lessens disease risk. Thus, in an era of globesity and increased chronic diseases, we find ourselves in need of a major dietary overhaul. We need to select diets high in fiber and whole grains (WGs), vegetables and fruits, match calories with energy expenditure, regulate type and amount of fat, and make other healthy lifestyle choices. Inclusion of WGs in the diet, according to health experts, is one risk-reducing choice. However, consumers are confused by WGs and choose grain foods based on past practices. Consumers need cogent reasons to change to WG foods; they need a clear picture of WG benefits.

Fiber: carbohydrates resistant to digestion and absorption in the human small intestine and completely or partially fermented in the large intestine

Whole Grains (WGs): having the principal anatomical components present in similar relative proportions as in the intact grain

AACCI: AACC International, **www.aaccnet.org**

Consumers and health professionals are often unable to identify WGs, let alone WG foods (Chase et al. 2003), so clear definitions are needed. This will enable WGs to be identified on package labels and encourage commercialization of great-tasting foods that deliver dietarily significant amounts of WGs. Government, food scientists, and industry need to work together because consumption of WGs is influenced by government policy, food supply availability, and industry offerings. Thus, nutritionists, food scientists, and health professionals are working to understand how WGs improve health.

Grain milling occurred in most ancient civilizations. This involved removing various anatomical parts of the grain. Grain endosperm (white flour or refined flour) was separated from the bran- and germ-rich fractions, which usually was fed to animals. The endosperm was preferred and often eaten by the wealthy. In the past 150 years, far and away the largest percentage of grain and flour consumed in Western diets was refined. Iron and B vitamin deficiencies in United States World War II recruits initiated enrichment of refined grains and flours. More recently, folate was added as a fortificant. The recent focus on WGs by various nutritional advisory groups has prompted the scientific community to address a number of issues surrounding WGs.

SCIENTIFIC DEFINITION OF WHOLE GRAINS

Getting consumers to choose WG products and manufacturers to produce them requires that all involved have an agreed upon definition so that food labels clearly communicate what is in the food. Industry and regulators must also agree so that when a food is labeled as WG it meets the requirement. In 1999, the American Association of Cereal Chemists International (AACCI), which has a long tradition of using science-based information to define issues, defined WGs as follows: WGs shall consist of the intact, ground, cracked, or flaked caryopsis (kernel or seed), whose principal anatomical components—the starchy endosperm, germ, and bran—are present in the same relative proportions as they exist in the intact caryopsis. In 2006, the AACCI WGs Task Force in a letter to the FDA affirmed that WGs would refer to WG cereals and pseudocereals. The letter outlined that cereals are the seeds of specific grasses, which according to taxonomy belong to the Poaceae (also known as Gramineae) family (**Table 1**) (AACCI 2006). Pseudocereals are the seeds of a number of different plant species external to the Poaceae family (**Table 1**).

Pseudocereals were included with the cereal grains because their overall macronutrient composition (ratio of carbohydrate to protein to fat) is similar to that of cereals and they are used in the diet in the same traditional ways. Legumes, nuts, seeds (noncereal and nonpseudocereal), and roots, although often nutritious and providing important building blocks in a plant-based diet, were not included in the definition because of their very different nutrient composition (e.g., legumes,

Table 1 Cereals and pseudocereals (From AACC 2006)

True Cereals	Scientific name
Wheat* including spelled,* emmer,* farro,* einkorn,* kamut,* durums*	*Triticum* spp.
Rice, African rice	*Oryza* spp.
Barley*	*Hordeum* spp.
Corn (maize, popcorn)	*Zea mays*
Rye*	*Secale cereale* spp.
Oats**	*Avena* spp.
Millets	*Brachiaria* spp.; *Pennisetum* spp.; *Panicum* spp.; *Setaria* spp.; *Paspalum* spp.; *Eleusine* spp.; *Echinochloa* spp.
Sorghum	*Sorghum* spp.
Teff (tef)	*Eragrostis* spp.
Triticale	*Triticale*
Canary seed	*Phalaris arundinacea*
Jobs tears	*Coix lachrymal-jobi*
Fonio, Black fonio, Asian millet	*Digitaria* spp.
Wild rice	*Zizania aquatica*
Pseudocereals	**Scientific name**
Amaranth	*Amaranthus caudatus*
Buckwheat, Tartar buckwheat	*Fagopyrum spp*
Quinoa	*Chenopodium quinoa Wild*—is generally considered to be a single species within the Chenopodiaceae

*Gluten-containing.
**Gluten-containing unless grown and processed in a field and processing plant that has never contained a gluten-containing grain.

nuts, and seeds have more protein and nuts more fat). In addition, they are included in different dietary food groups in food guidance and are rarely milled to eat only a part of the seed. It is worth noting that all legumes, nuts, seeds, and roots, some WG cereals, and all WG pseudocereals are gluten-free and therefore safe for people with celiac disease or gluten sensitivity (**Table 1**).

The definition for WG cereals also includes the malted forms and traditionally processed forms of the grains. Malted forms would meet the WGs definition provided that (*a*) the amount of WGs in the food is computed on a dry basis, (*b*) any sprout growth does not exceed the seed length, and (*c*) nutrient values have not diminished. Traditionally processed forms of WGs that undergo minimal processing include lightly pearled barley or wheat (grano), bulghur, and nixtamalized corn (AACCI 2006). The AACCI Task Force is defining maximum losses allowed to be considered a WG. AACCI also accepted that milled and recombined flour (from a single grain type) may be labeled as WG if the final ingredient contains grain components in the same relative proportions as the intact kernel (AACCI 2006). Recently, AACCI has proposed modifying its 1999 definition of WGs such that the principal anatomical grain components be present in the same relative proportions as in the intact caryopsis to the extent feasible by the best modern milling technology (Jones 2008). This proposed change acknowledges that minimal processing can slightly alter components and aid food safety by enabling good manufacturing practices to control the levels of mycotoxins and heavy metals.

Phytochemicals: plant-derived chemical compounds under scientific research for their potential health-promoting properties

Bran, germ, and endosperm have different roles both in the grain and in the human body. The bran physically protects the plant from invaders. Bran's arsenal of nutrients and phytochemicals support the development of a healthy plant. It has similar roles in the diet. Bran's vitamins, minerals, and phytochemicals can be released and absorbed or remain bound and be carried to the large bowel to act in situ. The germ provides many critical nutrients needed to form a new plant and, as such, is rich in vitamin E, antioxidants, other phytochemicals and lipid-soluble components. The endosperm, approximately 80% of the kernel, provides energy and other components for the seedling to grow. For humans, it is also a source of energy and provides some protein, antioxidants, and B vitamins. Although the endosperm provides important nutrients, especially when fortified and enriched, there is a great need for diets to contain more WGs. More than 95% of milled wheat flour in the US is sold as refined flour. Given the health benefits attributed to WGs, this must change.

Antioxidant: substance that inhibits oxidation and can guard the body from the damaging effects of free radicals

Epidemiological: study of factors affecting the health of populations. The scientific basis for interventions made in the interest of public health and preventive medicine

WHOLE GRAINS: THEIR FUNCTIONAL COMPONENTS AND THEIR HEALTH BENEFITS

Whole grains have been associated with a number of health benefits. Unfortunately, the data are mostly associational. These data, although from a number of diverse populations with differing cultural customs and eating patterns, and the associations derived from them all suffer from the same confounding flaw. Namely, those who choose to eat WGs tend to do almost everything else right. They eat less red meat, smoke less, exercise more, and choose more vegetables and fruits. Adding to the confusion is that epidemiological studies have not been consistent in the classification of foods as WG. In some instances, a food needed to have 25% of its contents from WGs to be in the study versus higher levels in other studies. Foods such as barley, couscous, and high fiber ready-to-eat (RTE) cereals were sometimes classified as WG even though these foods were clearly not WG or were not likely to be WG. This leads to another challenge, which was posed in a recent Life Sciences Review Office review (De Moura 2008). It remains to be determined whether the associations were due to fiber, healthy plant foods, or functional components in the foods classified as WG.

Whole grains contain a vast array of functional components. Many of these suggest mechanisms by which WGs may reduce risk of a variety of chronic diseases. It remains to be determined whether disease reduction is due to a synergy of functional WG components or to any one component. Given that specific species of WGs, and even cultivars, contain different types and levels of components, a particular WG may use entirely different mechanisms to reduce disease risk. However, taken as an aggregate WGs seem to offer the same net health benefits, yet it is important to emphasize selection of a variety of grains in order to gain unique benefits of each grain type.

WGs have always been recognized for their contribution of traditional nutrients, B vitamins, minerals, and dietary fiber, to the diet. More recently, WGs have been shown to be a good source of antioxidants. In fact, the in vitro antioxidant activity of WG foods has been shown to be at parity with that of vegetables and fruits (Miller et al. 2000). This activity is due not only to antioxidant vitamins such as vitamin E and its isomers (tocopherols and tocotrienols) and minerals such as selenium, but also to phytochemicals such as phytates, phenolics, and lignans or alkylresorcinols (Jones 2007). Phenolics such as ferulic acid in corn and wheat, oryzonol in rice, and avenanthramides in oats are grain-specific antioxidants. Some of these have antiatherogenic activity by mitigating nitric oxide production (Nie et al. 2006, Bunzel et al. 2004, Hu et al. 2003, Xia et al. 2003). Certain other flavonoids, phenolics, phenolic lipids, tocopherols, and dietary fibers such as beta-glucan are antimutagenic and anti-inflammatory (Bulló et al. 2007). Other important compounds include alkylresorcinols particularly high in rye, (Ross et al. 2003), betaine, and choline. Through a variety of mechanisms, these compounds may help prevent cell mutations that are precursors to inflammatory responses and tumor formation. In addition, WGs' ability to affect the immune response may also play a role in reducing chronic disease risk (Jacobs et al. 2007, 1999).

WHOLE GRAINS AND HEALTH

Weight Management

WGs, and the carbohydrates they contain, have been named both as part of the problem and the solution to the obesity epidemic. However, epidemiological and clinical studies indicate that WGs are linked to reduced risk of obesity and weight gain (Slavin 2005). In the Framingham Offspring Study with participants older than 50 years of age (McKeown et al. 2002), the Baltimore Longitudinal Study of Aging (Newby et al. 2003), and in college students (Rose 2005), WGs intake, as deduced from food frequency questionnaires, was inversely related to body mass index and waist-to-hip ratio or waist circumference. Data from both the Harvard Health Professionals (n = 27,082) (Koh-Banerjee et al. 2004) and female nurses studies (n = 74,091) (Liu et al. 2003) showed that those who consumed more WG foods at the start of the study consistently weighed less at baseline than those who consumed fewer WG foods. This obesity-preventing effect was also observed after the 8 to 12 year follow-up in these prospective studies. Weight gain during the study was inversely related to intake of WG foods. Although the majority of the studies show an inverse association between WGs intake and some measure of body weight (Anderson 2008, Harland & Garton 2007, van de Vijver et al. 2009), not all do (Thane et al. 2007). Furthermore, no effect on weight was seen in a short-term intervention with 309 subjects in the United Kingdom (Brownlee et al. 2009a).

Once again, the data present several challenges. First, there is the puzzle regarding intervention studies versus epidemiological studies. Are the intervention studies too short? Were the subjects so diligent about increasing their WG consumption from much less than a serving to more than four servings a day that they increased calories as well (Brownlee et al. 2009b)? Second, is there confounding with dietary fiber? Higher intakes of most WGs mean that there is a higher intake of cereal fiber. Is the effect due to the fiber or the WG package? Third, the impact of other lifestyle factors along with WG biochemical mechanisms are needed to further understand the relationship between WGs and weight. Fourth, with manufacturers making many more foods with WGs (even foods that should be chosen infrequently such as pies, cookies, and cheesecake), will WGs become the low-fat of the 1990s, where low-fat options were often neither healthy nor lower in calories? Will the message to eat more whole grains be deemed by consumers an excuse to eat more calories overall?

Despite the lack of success with the intervention, a number of mechanisms has been suggested for whole grains and weight control. They are as follows:

1. Diets with adequate WGs and dietary fiber tend to offer greater food volume, more nutrients, and lower energy density. Large food volume may delay gastric emptying, which in turn may enhance feelings of fullness and reduce hunger.
2. Diets with adequate fiber and WGs alter the secretion of gut hormones and in turn may increase overall satiety (Anderson & Conley 2007, Greenway et al. 2007, Berti et al. 2005).
3. Whole grain foods provide beta-glucan and slowly digested and resistant starch, which may blunt glycemic response and possibly influence satiety (Berti et al. 2005, So et al. 2007, Skrabania et al. 2001, Kaplan & Greenwood 2002).
4. Intake of WG foods is associated with reduced concentrations of biochemical factors associated with obesity including: insulin, C-peptide, and leptin (Esposito 2004).

Hypertension

DASH: Dietary Approaches to Stop Hypertension

Higher consumption of WGs was associated with a reduced risk of hypertension in prospective epidemiological and intervention studies (Mozaffarian et al. 2003, Esmaillzadeh et al. 2005, Wang et al. 2007, Pins et al. 2002). For example, in the 29,000 women United States Health Professionals' Study, those who reported eating at least four daily servings of WGs versus those eating less than one-half a daily serving were 23% less likely to have hypertension (Wang et al. 2007). In an intervention study with 88 subjects, nearly twice as many subjects eating a whole oat cereal as part of a heart-healthy diet reduced or stopped their blood pressure medication compared with controls eating the heart-healthy diet not containing whole oats (Pins et al. 2002). In the Dietary Approaches to Stop Hypertension (DASH) trial, WGs were one of a number of dietary modifications that helped to lower blood pressure (Appel et al. 1997).

Once again, the data present several challenges. For hypertension there are fewer studies than for some of the disease endpoints. However, both the intervention and epidemiological data point in the same direction. The same question must be asked about the confounding of WGs and dietary fiber. Higher intakes of most WGs mean that there is a higher intake of dietary fiber. Intervention with specific WGs such as oats has shown a benefit. Further data are needed to understand the effects of all WGs. As with other disease endpoints discussed so far, the impact of other lifestyle factors along with WG biochemical mechanisms are needed to further understand the relationship between WGs and hypertension.

There are two proposed mechanisms by which WGs might impact blood pressure. These include:

1. In addition to fiber, which can contribute to lowering of systolic and diastolic hypertension, WGs contribute components including magnesium, potassium, and some protein, which have been shown to help lower blood pressure (Lee et al. 2008, Anderson 2002).
2. Whole grains have been shown to elevate plasma concentrations of the anti-inflammatory and blood pressure-lowering hormone adiponectin (Qi et al. 2006).

Stroke

Whole grains are related to decreased risk of stroke. This should come as no surprise as the relationship between stroke and elevated blood pressure is well established. Epidemiological data show that a diet high in cereal fiber was one of a number of healthy lifestyle factors associated with a decreased risk of total and ischemic stroke. Such associations are seen in the Women's Health Study, a large prospective cohort of 39,053 healthy women over age 45 (Kurth et al. 2006) and in the 18-year follow-up of the nearly 88,000 female nurses (Oh et al. 2005). In the latter study, total and hemorrhagic stroke risk inversely associated with cereal fiber intake. For those with the highest cereal fiber intake compared with the lowest intake, total stroke risk decreased by 36% and hemorrhagic stroke risk was cut nearly in half. Ding & Mozaffarian (2006) concluded, after a review of 121 publications, that WGs and cereal fiber were likely to be two of several dietary factors that reduce the incidence of stroke.

Once again, the data present several challenges. First, there are only epidemiological data for stroke, and second, there are questions about the confounding of WGs and dietary fiber, and other diet and lifestyle factors. Additional data are needed to understand the effects of all WGs. As with other diseases discussed so far, the impact of other lifestyle factors along with WG biochemical mechanisms are needed to further understand the relationship between WGs and stroke.

METABOLIC SYNDROME AND TYPE 2 DIABETES

Epidemiological data show inverse associations between WG intake and diabetes and its precursor, metabolic syndrome (Anderson & Pasupuleti 2008). Metabolic syndrome is characterized by abdominal obesity, atherogenic dyslipidemia, elevated blood pressure, and insulin resistance, as well as prothrombotic and proinflammatory states. Metabolic syndrome is estimated to affect at least 24% of the adult population in the United States (Cameron et al. 2004) and is related to development of type 2 diabetes and cardiovascular disease (CVD). In the Framingham Offspring Study (n = 2941), WGs were associated with a 33% lower risk of metabolic syndrome for the quintile eating the most, compared with the quintile eating the least, WGs (McKeown et al. 2002). A similar inverse association was also seen for high intakes of cereal fiber. A small study in Iran showed a similar effect (Kochar et al. 2007). Therefore, cereal fiber and WGs appear to lower the risk of metabolic syndrome and are part of an important public health strategy.

CVD: cardiovascular disease

T2DM: type 2 diabetes mellitus

Given that metabolic syndrome is associated with the risk of diabetes, it is not surprising that WG intake inversely associated with the risk of type 2 diabetes in a number of studies in the United States and abroad (de Munter et al. 2007, Lutsey et al. 2007, Fung et al. 2002, Liese et al. 2003). These studies show that the quintiles eating approximately three WG servings per day had a 25% to 33% lower risk of type 2 diabetes.

The challenges regarding the relationship between WG intake and incidence of type 2 diabetes are not different from the associations already discussed. This was best summed up in a Cochrane review, which assessed one randomized controlled trial and eleven prospective cohort studies (Priebe et al. 2008). The authors concluded that although "prospective studies consistently showed a reduced risk for high intake of WG foods (27% to 30%) or cereal fiber (28% to 37%) on the development of T2DM . . . the evidence from prospective cohort trials is too weak to be able to draw a definite conclusion about the preventive effect of WG foods on the development of T2DM."

Other challenges include the fact that WGs and specific types of fiber can impact blood glucose quite differently. Some WG foods such as RTE cereal and hearty breads have large pieces of intact and semi-intact grains. These may contain type I resistant starch, which is inaccessible to amylases. However, some WG foods have little or no ability to positively affect glycemic response because their structure is porous and easily attacked by amylases (Brand-Miller et al. 2008). WGs such as barley and oats contain beta-glucan, which can slow absorption of glucose and in turn reduce spikes in blood glucose (Kim et al. 2009, Behall 2006). Product-specific health claims to this effect exist in Sweden (Swedish National Food Administration 2002).

There are several potential mechanisms by which WGs can lower the risk of type 2 diabetes. These include:

1. Whole grains' ability to decrease insulin resistance and improve insulin sensitivity is one such mechanism (Pereira et al. 2002, Jacobs et al. 1999). For example, in the nearly 1000 IRAS participants, WG intake was associated with increased insulin sensitivity and improved glucose tolerance. Those in the IRAS cohort with higher intake of dark breads (including whole wheat, rye, pumpernickel, and other high-fiber bread) and high-fiber RTE cereals (high-fiber bran or granola cereals and shredded wheat) showed improved insulin sensitivity and lower fasting insulin. Both of these changes associated with high WG intake may have led to reduced risk for type 2 diabetes seen in various cohorts in epidemiological studies. The improved insulin sensitivity was also seen in an intervention study by Panahi et al. (2007).
2. Whole grains offer constituents that could contribute to improvement in glucose tolerance and, in turn, diabetes. WGs contain fibers such as beta-glucan and arabinoxylans, which help control blood sugar (Garcia et al. 2007, Lu et al. 2004, Bo & Pisu 2008).

3. Whole grains contain magnesium, which may be limited in the diets of persons with metabolic syndrome or diabetes (McCarty 2005).

CHD: coronary heart disease

IRAS: insulin resistance atherosclerosis study

Randomized control trial: experiment in which investigators randomly assign eligible subjects into groups to receive or not receive one or more treatments being compared

LDL: low-density lipoprotein

Cardiovascular Disease (CVD)

Large epidemiological studies, such as the Iowa Women's Health Study, the Male Health Professionals' Study, and the Nurses' Health Study, showed an inverse association between WG ingestion and risk of CVD, including coronary heart disease (CHD), hypertension, and stroke. A meta-analysis assessing the relationship between CHD and WGs showed that regular intake of WG foods was associated with a 26% reduction in the risk of CHD (Anderson 2004). When the impact of WG intake on CHD was compared with cereal fiber or with the impact of dietary fiber in general, WGs protected more strongly against the development of CHD than intake of cereal fiber alone or dietary fiber from either vegetables or fruits (Anderson 2002, 2003).

Positive associations were seen not only in prospective studies of Iowa women and health care workers, but also in studies involving the elderly, women with existing CHD, and a multiethnic cohort. Regarding the elderly (65 and older, n = 3588), cereal fiber intake inversely associated with CVD risk (Mozaffarian et al. 2003). At the end of the eight-year follow-up of this study, participants in the highest quintile of cereal fiber intake had a 21% lower risk of CVD than those in the lowest quintile of intake. Also, higher cereal fiber intake was associated with a lower risk of total and ischemic stroke. However, no such relationship was found for vegetable or fruit fiber intake in this elderly population. In postmenopausal women with existing coronary artery disease (the Estrogen Replacement and Atherosclerosis Trial), ingestion of one serving of WG per day, compared with those who ate less WG, resulted in better maintenance of wider internal coronary artery diameter as determined by sequential coronary artery angiography (Erkkilä et al. 2005). Similar results were seen in the more than 1000 multiethnic individuals participating in the Insulin Resistance Atherosclerosis Study (IRAS). These showed less carotid intimal medial thickness progression in the subjects ingesting the most WGs (Mellen et al. 2007). WG intake, and not refined grain intake, has also been associated with lower risk of heart failure (Djoussé & Gaziano 2007).

More recently in a randomized control trial, arterial stiffness as measured by pulse wave velocity was significantly reduced in the intact whole-grain treatment group after eight weeks, versus no significant changes in the refined-control and milled-whole-grain groups (n = 25 healthy males) (Tripkovic 2009). Participants consumed rolls containing either 48 g intact WG, 48 g milled WG, or isocaloric refined grain, suggesting that milling may reduce the efficacy of WGs (i.e., the matrix effect) in healthy subjects. However, this may not be the case for long-term consumption of milled WGs.

In terms of blood lipids (a marker for CVD) and WGs, recent randomized control trials on healthy subjects have reported conflicting results. This has in turn caused consternation and reconsideration of the use of randomized clinical trials on healthy subjects. In the United Kingdom WHOLEheart Study (Brownlee et al. 2009a), overweight but otherwise healthy subjects (n = 316, age 18–65 years, BMI > 25 kg/m^2) who habitually consumed less than 30 g WGs per day were randomized to three groups: control (no dietary change), 60 g WGs per day for 16 weeks, and 60 g WGs per day for the first eight weeks followed by 120 g WGs per day for the last eight weeks. Results showed no impact of WG inclusion in the diet on plasma LDL (low-density lipoprotein) cholesterol. However, in the Italian randomized sequential crossover trial in slightly hyperlipidemic subjects (n = 15, mean age = 54.5 ± 7.6, BMI = 27.4 ± 73.0 kg/m^2), Giacco et al. (2009) reported significantly reduced fasting and postprandial plasma cholesterol as well as LDL cholesterol with consumption of wholemeal wheat foods for three weeks. Participants were randomly assigned to two isoenergetic diets with similar macronutrient composition, one rich in

WHOLE GRAIN HEALTH CLAIMS WORLDWIDE

United States: Food and Drug Administration (FDA)—Diets rich in whole grain foods and other plant foods and low in total fat, saturated fat, and cholesterol, may help reduce the risk of heart disease and certain cancers.

Sweden: Voluntary Code of Practice (SNF Swedish Nutrition, Swedish Food Federation, Swedish Food Retailers Federation)—A healthy lifestyle and well-balanced diet high in whole grain products reduces the risk of (coronary) heart disease. Product name has a high whole grain content or Product name contains X% whole grain.

United Kingdom: Voluntary Code of Practice—Health Claim Initiative (JHCI) has published guidelines for policing cholesterol claims.

Finland: Finnish Food Safety Authority has also published guidelines.

wholemeal wheat foods and the other with the same foods in refined form (cereal fiber 21.3 g versus 9.8 g per day). What are the differences between these two studies?

One key difference is that Brownlee et al. (2009a) effectively told subjects to eat more WGs. Giacco et al. (2009), however, held calories and macronutrients constant, which means people should increase whole grains in the diet withour increasing the total grain intake or as Bittman (2009) says, "eat less meat and junk food, eat more vegetables and WGs." If we simply tell people to eat more, then they will. Perhaps weight gain in many cases attenuates the WG effect on CVD and other chronic diseases. If isoenergetic diets do in fact explain the apparent discrepancy between these studies, then the success of WGs in improving public health may come down to messaging. Perhaps an even bigger question to ask is whether or not healthy subjects are appropriate in trials with plasma cholesterol as an endpoint (the subjects in both studies were well within their plasma cholesterol goal and would not be prescribed lifestyle change or drug therapy for cholesterol reduction by a physician) and does this complicate their applicability to larger populations?

At least one other recent randomized control trial is worth noting here. The GrainMark Study by Haldar et al. (2009) reported that incorporation of WG foods made with rye into the diet (48 g WGs per day for four weeks followed by 96 g WGs for another four weeks, $n = 67$, mean $age = 54.6 \pm 5.86$, $BMI = 25.6 \pm 3.17\ kg/m^2$) was more effective in reducing blood cholesterol concentrations than WG foods made with wheat. Haldar et al. (2009) suggested that this may be due to the higher soluble fiber content of rye. There are likely other factors. In general, not all WGs (or dietary fibers) have equal effects on health (Jones 2009).

The challenges regarding the relationship of WG intake to CHD are similar to those discussed for diabetes. There is the confounding of nutritional and lifestyle factors in the epidemiological studies that were discussed in the LSRO review (De Moura 2008). This was also summarized in a Cochrane review, which assessed one randomized control trial and eleven prospective cohort studies (Priebe et al. 2008). As was seen with diabetes and blood glucose control, not all grains have the same impact. Human interventions or animal experiments done with rye (high in alkylresorcinols), oats (high in beta-glucan and avenanthremides), barley (high in beta-glucan), or brown rice (high in oryzanol) have positive effects on various heart disease markers. Often the disease markers and the biochemical mechanisms influenced by the specific grains are different. Nonetheless, there are WG health claims in a number of countries (See Sidebar on Whole Grain Health Claims Worldwide) as well as cholesterol lowering claims for barley and oats.

There are a number of mechanisms that suggested as to why whole grains might reduce CHD risk. These include:

1. Gut fermentation of WG fibers such as beta-glucan (Karmally et al. 2005, Behall et al. 2004) lowers serum cholesterol.
2. Colonic fermentation of WG carbohydrates produces short-chain fatty acids, which are absorbed and go to the liver, where they inhibit cholesterol synthesis by the same mechanisms that statin drugs do (Marcil et al. 2003).
3. Fiber and its components bind bile acids (Sayar et al. 2006, Chronakis et al. 2004) and encourage their excretion, and force bile acid synthesis from circulating cholesterol (Lundin et al. 2004, Yang et al. 2003).
4. High fiber intakes, including fibers from WGs, decrease serum triglycerides, which are another risk factor for CHD (Anderson 2000).
5. Whole grain phenolic antioxidants inhibit both LDL cholesterol oxidation (Madhujith & Shahidi 2007) and platelet aggregation. Also, they are antithrombotic and improve vascular reactivity (Kris-Etherton et al. 2002).
6. Whole grain alkyresorcinols increase serum enterolactone, which reduces risk (Vanharanta et al. 2003).

Statistically significant: a result is called statistically significant if it is unlikely to have occurred by chance

Cancers

Human studies show that WGs (cereal fiber) decrease risk of cancers of the upper gut (La Vecchia et al. 2003) but are unclear about whether WGs reduce risk of colorectal cancer. Case-control studies consistently show that WGs (cereal fiber) reduce colorectal cancer risk 35% to 50% (Wakai et al. 2006). Several large epidemiological studies, including the European Prospective Investigation into Cancer and Nutrition ($n = 519{,}978$), show that the quintile ingesting the most cereal fiber had a 25% reduction in risk of large bowel cancer (Bingham et al. 2003). However, several studies with United States cohorts found no protective effect of cereal fiber (Schatzkin et al. 2000; Fuchs et al. 1999) The lack of effect was seen in the Pooling Project of Prospective Studies of Diet and Cancer, which included 13 prospective cohort studies and a total of 725,628 men and women (Park et al. 2005). The Pooling Project showed a 16% decrease in risk associated with dietary fiber, but the association was no longer statistically significant after adjusting for other factors. It is possible that epidemiological studies with United States cohorts, as opposed to studies in Europe, fail to show significant colorectal cancer risk reduction because the amount of fiber eaten even by those ingesting the most cereal fiber may be below levels needed to have a disease-reducing effect.

Although early epidemiological studies flagged an inverse association between WG intake and colorectal cancer (Fraser 1999, Chatenoud et al. 1999, Jacobs et al. 1998), later studies left some questions. For example, the risk of invasive colorectal cancer inversely related to WG intake in the prospective National Institutes of Health-AARP Diet and Health Study with 291,988 men and 197,623 women aged 50–71 years (Schatzkin et al. 2007). There was a 21% decrease in risk for the highest versus the lowest quintile, and the reduced risk associated with WG intake was stronger for rectal cancer than for colon cancer. However, in a case-control study with subjects from the western United States, rectal cancer risks, but not colon cancer risks, were reduced by 31% for the quintile eating the most WGs (Slattery et al. 2004). The results from the latter two studies were different than those in the Swedish Mammography Cohort ($n = 61{,}433$). Women reporting the greatest consumption of WGs ($\geq$4.5 servings per day versus those eating $<$1.5 servings per day) had lower risk of cancer of the colon, but not the rectum (Larsson et al. 2005).

A meta-analysis of 11 cohort studies looking at the relationship between WG intake and colorectal cancer showed that WG consumption inversely associated with the risk of developing colorectal cancer, but the effect was small (Haas et al. 2009).

A delineation of the roles of WGs and cereal fiber in reducing colon cancer risk is needed, along with research designed to establish a minimum daily amount of WGs. Further, biochemical mechanisms and characterization of genetic, dietary, and lifestyle factors that may influence study results are needed. Perhaps greater clarity will emerge by assessing the roles of specific WGs, given that the amounts and types of fermentable carbohydrate and specific phytochemicals vary in the different grains, species, and cultivars (Charalampopoulos et al. 2002a,b; Kuijsten et al. 2006; Hallmans et al. 2003; Adom et al. 2005; Adom & Liu 2002).

The association between WGs and other types of cancer is less well studied and often results in conflict. Whole grain intake was unrelated to breast cancer among postmenopausal women (Egeberg et al. 2009). Results of the few studies on pancreatic cancer are conflicting. For example, a case-control study in California with more than 500 cases showed that eating two or more servings of WG per day significantly reduced the risk of pancreatic cancer, but eating cooked oatmeal or oat bran two or more times per week increased risk (Chan et al. 2007). For oral and pharyngeal cancer, it appears that WGs may reduce risk (Garavello et al. 2009). More studies are needed in all these areas. Potential biochemical mechanisms need to be proposed.

For all cancer types a number of mechanisms for whole grains have been proposed: These include the following:

1. Whole grains deliver cereal fibers and fermentable carbohydrates to the gut, where they act as prebiotics (Charalampopoulos et al. 2003, Charalampopoulos et al. 2002a, Pool-Zobel & Sauer 2007).
2. Substrates like butyrate promote growth of healthy colonic cells and cause aberrant cells to apoptose (Kim & Milner 2007). Butyrate has been shown in animal studies to exert antineoplastic activity and to upregulate tumor suppressor activity (Gråsten et al. 2000).
3. Short-chain fatty acids decrease colonic pH, which is associated with lower colon cancer risk (Charalampopoulos et al. 2002a,b; Gråsten et al. 2000; Bird et al. 2008).
4. Binding of bile acids inhibits conversion of primary bile acids to the more problematic secondary bile acids and in turn lowers carcinogenic potential (Alberts et al. 2003, McGarr et al. 2005, Reddy et al. 1998).
5. Whole grains, fiber, and resistant starch shorten transit time and increase fecal bulking (van Bennekum et al. 2005, Hongisto et al. 2006) and therefore carcinogenic moieties have less time to form and to interact with gut epithelium.
6. Whole grain antioxidants and phytochemicals in the lower bowel directly protect colonic cells from damage by reactive oxygen and other constituents (Muir et al. 2004).
7. Lignans like alkylresorcinols, especially prevalent in rye, can be converted to mammalian lignans (enterodiol or enterolactone) (Muir et al. 2004), which are associated with a reduction in colorectal adenoma risk (Adom & Liu 2002, Adlercreutz 2007).

ALL-CAUSE MORTALITY

Epidemiological studies such as the Iowa Women's Health Study (Sahyoun et al. 2006) showed that those who ate the most WGs had approximately a 20% lower mortality rate than those who ate the least. The lower mortality rate included reductions in deaths from CHD, CVD, and cancer. Vastly different elderly cohorts—in Iran (Esmaillzadeh et al. 2005, Esmaillzadeh & Azadbakht 2006) and in the Atherosclerosis Risk in Communities (ARIC) Study—and a mixed-ethnicity, population-based prospective study with nearly 12,000 subjects (Steffen et al. 2003) gave similar results. In both groups, the consumption of fruits, vegetables, and WGs inversely related to the risk of total mortality.

The relationship of all-cause mortality and WG consumption suffers from the same confounding that all observational studies do. Perhaps WGs are simply a marker of someone who selects healthier food options on a regular basis, does regular exercise, tries to maintain weight and has a whole battery of other healthy behaviors. More research is needed to understand the biochemical mechanisms of action of the functional components of WGs alone and in various food matrices.

WHOLE GRAIN RECOMMENDATIONS, REGULATORY CHALLENGES, AND THE CONSUMER

Given the healthy halo associated with WGs, government bodies and health promotion organizations around the world have recommended increased WG intake. For example, the 2005 United States Dietary Guidelines Advisory Committee recommends that consumers make "half their grains whole." For adults on a 2000 calorie diet, this means that three of the six grain servings be WG. Given that a slice (1 oz or 30 g) of WG bread is considered a serving and has 16 g of WGs per slice, at least 48 g of WGs per day are recommended. The European Union Healthgrain platform and organizations such as Australia's GoGrains have similar recommendations.

Some WG proponents argue that all grains consumed should be WGs. Yet, there are several reasons for recommending that only half of grain servings be whole. Enriched and fortified refined grains provide several important B vitamins, including folate, which was listed by the 2005 Dietary Guidelines Advisory Committee as a nutrient of concern because many segments of the population fail to meet the folate recommendation (**Table 2**). Since the mandatory fortification of enriched flour began in the United States on January 1, 1998, folate has been shown to reduce the risk of

Table 2 Nutrient content of whole grain and enriched wheat flour (USDA 2008)

	Whole grain wheat flour	Enriched wheat flour
Nutrient (units)	per cup (120 g)	per cup (125 g)
Calories	407	455
Protein (g)	16.44	12.91
Fat (g)	2.24	1.23
Dietary fiber (g)	14.6	3.4
Sugars (g)	0.49	0.33
Vitamins		
Iron (mg)	4.66	5.80
Zinc (mg)	3.52	0.88
Copper (mg)	0.458	0.180
Manganese (mg)	4.559	0.853
Selenium (mcg)	84.8	42.4
Minerals		
Thiamin (mg)	0.536	0.981
Riboflavin (mg)	0.258	0.618
Niacin (mg)	7.638	7.380
Vitamin B_6 (mg)	0.409	0.055
Folate/folate, total (mcg)	44	183
Vitamin E (mg)	0.98	0.28

pregnancies affected by neural tube defects (spina bifida and other neurological abnormalities) by more than 50% and as much as 70% (Canfield et al. 2005, Mills & Signore 2004). Other studies indicate an association between folate intake and decreased risk of incident hypertension, CHD, stroke, and cancer (Nie et al. 2006, Zhang et al. 2006, Yang et al. 2006).

Refined grains offer other advantages. Minerals within such are more bioavailable because of fewer inhibitory factors such as phytate (Reeves et al. 2007, Frontela et al. 2009). Given that outer grain layers contain the majority of the contaminants including heavy metals and mycotoxins, refined grains often are lower in these (Brera et al. 2006, Sales and Yoshizawa 2005, Ryu et al. 2002, Wang et al. 2002).

Despite universal agreement that WG intake should increase, consumers in western countries fail to meet recommended intakes (Thane et al. 2007, 2005). In North America, more than 90% of the population fails to meet the recommendations (Jones 2004). Data are just starting to show increased WG consumption (Lipson 2009), due in part to increased WG products. Lipson's (2009) recent report noted that there were increases of 17% per year since 2005 both in food service and the grocery aisle. Yet they still comprise less than 10% of the offerings in most categories.

There are a number of barriers to increased consumption. Although there are many groups recommending more WG foods, the WG message is one among many messages consumers hear, from the need to control weight, to lower salt and added sugar, and to eat more vegetables and fruits. Thus, the WG message can be lost in the cacophony of messages that try to capture consumers' attention. Health professionals rarely have time to spend on this message in counseling patients (Chase et al. 2003). Consumers, health professionals, and food service providers are confused about what constitutes a WG or WG food. They do not always understand the definition of a WG, amounts of WG in a food, or the amount recommended (Chase et al. 2003, Hesse et al. 2009).

Cost is an issue for both industry and the consumer. Production of WGs costs more than their refined counterparts. Acceptable WG breads use expensive ingredients such as white whole wheat and vital wheat gluten to give them the lighter color and texture. Such breads take longer time on the bakery floor to rise and bake. WG ingredients and foods are more perishable because of the fatty acids in the germ. This means they require special treatment or packaging, or they have shorter shelf life. All of the above increases cost. Companies who for years have produced little WG food may have massive up-front costs as they retool lines to accommodate differences in dough flow and panning for WG foods, in addition to food product development work required to make an acceptable WG food. There are also marketing, labeling, and other introduction costs that go along with a new product. Further a new product may simply change what brand-loyal consumers buy (WG versus refined grain), resulting in no net change in sales. Thus, a company may invest significantly in new WG foods and not increase profit. For home consumers and foodservice operators, the higher cost of WG foods compared with their refined grain counterparts is problematic especially for those on tight budgets or operations with razor-thin margins such as nursing homes and schools (Darmon & Drewnowski 2008).

Another issue is the consumers' willingness to try foods that are not part of the regular diet. Children and adults need repeated opportunities to try and accept unfamiliar foods, and WGs are no exception (Cooke 2007). Interventions that gradually increase WGs in school lunch improved children's WG intake. Simultaneous parent education programs reinforced WG consumption in the home (Burgess-Champoux et al. 2008). For adults, increased WG acceptance by non-WG (less than 30 g per day at baseline) overweight consumers occurred in a recent intervention study (Brownlee et al. 2009b). Volunteers ($n = 266$) were assigned either to a WG intervention or to continue with their ordinary diet. The intervention group increased their WG consumption by greater than 70 g per day. The interesting result was that the control group's eating pattern remained the same both during and post intervention, whereas the WG intervention group approximately doubled WG intake 12-months postintervention, showing that people can and do change. Brownlee et al. (2009a) also found similar results in their WHOLEheart Study with 316 United Kingdom subjects.

Issues about perception of the need for change, education, and communication also exist. A General Mills study noted that nearly two-thirds of respondents thought they were getting enough WGs, suggesting that many consumers think that they are meeting the WG recommendations and do not need to change. There needs to be more education regarding the benefits of WGs in health and disease prevention. This needs to be widely promulgated by trusted communicators to consumers and health professionals alike through a variety of media and community education outlets using motivating, consumer-friendly language. Industry needs to speak with one voice perhaps using a health promotion organization for more credibility. The publishing of the Dietary Guidelines 2010 may be an opportunity for more media outreach.

Rosen et al. (2009) also noted that communication barriers and unclear promotional messaging further fuel rampant confusion regarding identification of WG foods. There are three ways to identify WGs in foods. (*a*) If the first ingredient on the ingredient statement is WG, the food is WG. However, this may not be an effective identifier of a WG food if it contains multiple WG ingredients. For example, an ingredient statement could read: Enriched flour, whole wheat flour, oatmeal, whole meal rye, honey, yeast, and salt. This food could have almost no WGs as it could be 96% enriched flour, or the food could be 26% enriched flour, 25% whole wheat flour, 23% oatmeal, 23% brown rice flour, and 2% honey, yeast, and salt. The latter food would be 71% WGs, but there would be no way to tell this from the ingredient statement. Even fiber listings on the Nutrition Facts Panel may not be a fool-proof guide. (*b*) If the food carries a United States Food and Drug Administration-authorized health claim, then consumers can know that a food labeled as such contains at least 51% WG ingredients by weight. It also must be low in saturated fat and cholesterol and contain 1.7 g of dietary fiber per serving for all WGs except brown rice, which is naturally low in fiber (**Figure 1**) (Marquart et al 2003). However, even this health claim has some limitations. Although it works well for low-moisture foods such as cereals and crackers or other items that are sold by dry weight such as oatmeal, it is less workable for higher moisture foods such as bread. Achieving the 51% WGs in many breads as part of the total formulation is difficult because bread is 40% water and contains yeast and salt. If a bread contains nutritious additions such as flaxseed, walnuts, or raisins, it will not qualify for the health claim even if the bread is entirely made with whole wheat flour because WGs will not be 51% of the weight. (*c*) Foods that carry the WGs Council stamp are WG (**Figure 2**). Foods can be WG and not display the stamp if the food manufacturer does not pay the fees required for the program. At the time of this writing, the FDA has yet to define whole grains to help manufacturers and consumers determine what is—and what is not—a whole-grain food.

SUMMARY POINTS

1. Whole grains are confusing consumers and scientists.
2. As time goes on, scientists may well discover that the most important part of a healthy diet is increasing the relative amount of plants we eat, and this includes whole grains (Bittman 2009).

3. Whole grain cereals and pseudocereals were defined by the American Association of Cereal Chemists International (AACCI) in 1999 as follows: Whole grains shall consist of the intact, ground, cracked, or flaked caryopsis (kernel or seed), whose principal anatomical components—the starchy endosperm, germ, and bran—are present in the same relative proportions as they exist in the intact caryopsis.
4. The 2005 U.S. Dietary Guidelines Advisory Committee has recommended that consumers make "half their grains whole."
5. Whole grains contain a number of functional components. These components suggest many possible biochemical mechanisms by which whole grains may reduce risk of a variety of chronic diseases. It is yet to be determined whether disease reduction is due to a synergy of functional whole grain components or to any one component.
6. Whole grains are linked to reduced risk of obesity or weight gain; reduced risk of CVD including CHD, hypertension, and stroke; improve gut health and decrease risk of cancers of the upper gut; perhaps reduced risk of colorectal cancer; and lower mortality rate.
7. It is possible to change consumption habits with respect to whole grains in children and adults.
8. In order to improve public health, further research on whole grains as a category and on specific grains will hopefully lead to foods with more of all-health-protective components and to foods with high levels of selected components (Jones 2009). Meeting nutrient requirements has always been about variety and moderation, and these principles hold true in the area of grain selection.

Bioactive: a substance that has an effect on living tissue

FUTURE ISSUES

Further work is needed on the following (Jones 2009):

1. An internationally agreed definition of WGs for both research and general use.
2. True biomarkers of disease for assessing health effects of eating WGs and high fiber foods and a grain biomarker to test analytically for WGs in food.
3. A characterization of cofounders that impact study outcomes.
4. A characterization of the relationship between studies with isolated bioactive compounds and those of the compound in the WG food matrix with other dietary constituents.
5. A delineation of the synergy that exists between components of the grain.
6. A delineation of the strength of evidence for WGs as a category and for specific grains.
7. An industrial effort to broaden the use of nonwheat grains.
8. A multidisciplinary approach with foodservice, academia, government, and industry experts to develop a new paradigm for the development, delivery, and service of WGs.

DISCLOSURE STATEMENT

Author Julie Miller Jones has recently joined the Campbell's Vegetable/Plant International Scientific Advisory Panel.

ACKNOWLEDGMENTS

The authors would like to thank Craig F. Morris for editing this review.

LITERATURE CITED

AACCI Whole Grains Task Force. 1999. *Definition of Whole Grain*. **http://www.aaccnet.org/news/pdfs/wgPR.pdf**

AACCI Whole Grains Task Force. 2006. *Letter submitted to the FDA in response to docket 2006D – 0066*. **http://www.aaccnet.org/definitions/pdfs/AACCIntlWholeGrainComments.pdf**

Adlercreutz H. 2007. Lignans and human health. *Crit. Rev. Clin. Lab. Sci.* 44(5–6):483–525

Adom KK, Liu RH. 2002. Antioxidant activity of grains. *J. Agric. Food Chem.* 50(21):6182–87

Adom KK, Sorrells ME, Liu RH. 2005. Phytochemicals and antioxidant activity of milled fractions of different wheat varieties. *J. Agric. Food Chem.* 53(6):2297–306

Alberts DS, Einspahr JG, Earnest DL, Krutzsch MF, Lin P, et al. 2003. Faecal bile acid concentrations in a subpopulation of the wheat bran fiber colon polyp trial. *Cancer Epidemiol. Biomarkers Prev.* 12(3):197–200

Anderson JW. 2000. Dietary fiber prevents carbohydrate-induced hypertriglyceridemia. *Curr. Artheroscler. Rep.* 2:536–541

Anderson JW. 2002. Whole-grains intake and risk for coronary heart disease. In *Whole Grains in Health and Disease*, ed. L Marquart, JL Slavin, G Fulcher, pp. 100–114. St. Paul, MN: Am. Assoc. of Cereal Chem.

Anderson JW. 2003. Whole grains protect against atherosclerotic cardiovascular disease. *Proc. Nutr. Soc.* 62:135–42

Anderson JW. 2004. Whole grains and coronary heart disease: the whole kernel of truth. *Am. J. Clin. Nutr.* 80:1459–60

Anderson JW. 2008. Dietary fiber and associated phytochemicals in prevention and reversal of diabetes. In *Nutraceuticals, Glycemic Health and Diabetes*, ed. V Pasupuleti, JW Anderson. Ames, IA: Blackwell

Anderson JW, Conley SB. 2007. Whole grains and diabetes. In *Whole Grains and Health*, ed. L Marquart, DR Jacobs Jr, GH McIntosh, K Poutanen, M Reicks, pp. 29–47. Ames, IA: Blackwell

Anderson JW, Pasupuleti V. 2008. Future trends and directions. In *Nutraceuticals, Glycemic Health and Diabetes*, ed. V Pasupuleti, JW Anderson. Ames, IA: Blackwell

Appel LJ, Moore TJ, Obarzanek E, Vollmer WM, Svetkey LP, et al. 1997. A clinical trial of the effects of dietary patterns on blood pressure. DASH Collaborative Research Group. *N. Engl. J. Med.* 336(16):1117–24

Behall KM. 2006. *Beta-glucan in barley and oats and their health benefits*. USDA Agric. Res. Serv., Food Intake and Energy Regulation Lab. **http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=190926**

Behall KM, Scholfield DJ, Hallfrisch J. 2004. Diets containing barley significantly reduce lipids in mildly hypercholesterolemic men and women. *Am. J. Clin. Nutr.* 80:1185–93

Berti C, Riso P, Brusamolino A, Porrini M. 2005. Effect on appetite control of minor cereal and pseudocereal products. *Br. J. Nutr.* 94(5):850–58

Bingham SA, Day NE, Luben R, Ferrari P, Slimani N, et al. 2003. Dietary fibre in food and protection against colorectal cancer in the European Prospective Investigation into Cancer and Nutrition (EPIC), an observational study. *Lancet.* 361(9368):1496–501

Bird AR, Vuaran MS, King RA, Noakes M, Keogh J, et al. 2008. Wholegrain foods made from a novel high-amylose barley variety (Himalaya 292) improve indices of bowel health in human subjects. *Br. J. Nutr.* 99(5):1032–40

Bittman M. 2009. *Food Matters: A Guide to Conscious Eating*, pp. 4, 76. New York: Simon & Schuster. 326 pp.

Bo S, Pisu E. 2008. Role of dietary magnesium in cardiovascular disease prevention, insulin sensitivity and diabetes. *Curr. Opin. Lipidol.* 19(1):50–56

Brand-Miller J, McMillan-Price J, Steinbeck K, Caterson I. 2008. Carbohydrates–the good, the bad and the whole grain. *Asia Pac. J. Clin. Nutr.* 17(Suppl. 1):16–19

Brera C, Catano C, de Santis B, Debegnach F, de Giacomo M, et al. 2006. Effect of industrial processing on the distribution of aflatoxins and zearalenone in corn-milling fractions. *J. Agric. Food Chem.* 54(14):5014–19

Brownlee I, Moore C, Chatfield M, Richardson D, Ashby P, et al. 2009a. *Impact of whole grain inclusion on biomarkers of cardiovascular disease risk in a large-scale randomized, controlled dietary intervention (the WHOLEheart Study)*. Presented at C&E Spring Meeting 2009—Whole Grain Global Summit, 3rd, New Castle

Brownlee I, Moore C, Chatfield M, Richardson D, Ashby P, et al. 2009b. *Whole grain consumption and dietary change in the 12-month period following participation in a randomized, controlled whole grain intervention (the WHOLEheart Study)*. Presented at C&E Spring Meeting 2009—Whole Grain Global Summit, 3rd, New Castle

Bulló M, Casas-Agustench P, Amigó-Correig P, Aranceta J, Salas-Salvadó J. 2007. Inflammation, obesity and comorbidities: the role of diet. *Public Health Nutr.* 10(10A):1164–72

Bunzel M, Ralph J, Lu F, Hatfield RD, Steinhart H. 2004. Lignins and ferulate-coniferyl alcohol cross-coupling products in cereal grains. *J. Agric. Food Chem.* 52(21):6496–502

Burgess-Champoux T, Chan HW, Rosen R, Marquart L, Reicks M. 2008. Healthy whole grain choices for children and parents: a multi-component school-based pilot intervention. *Public Health Nutr.* 11:849

Cameron AJ, Shaw JE, Zimmet PZ. 2004. The metabolic syndrome: prevalence in worldwide populations. *Endocrinol. Metab. Clin. North Am.* 33(2):351–75

Canfield MA, Collins JS, Botto LD, Williams LJ, Mai CT, et al. 2005. Changes in the birth prevalence of selected birth defects after grain fortification with folate in the United States: findings from a multi-state population-based study. *Birth Defects Res. A Clin. Mol. Teratol.* 73(10):679–89

Chan HW, Hesse D, Arndt E, Marquart L. 2009. Knowledge and practices of school foodservice personnel regarding whole grain foods. *J. Food Service* 20(3):109–116

Chan JM, Wang F, Holly EA. 2007. Whole grains and risk of pancreatic cancer in a large population-based case-control study in the San Francisco Bay Area, California. *Am. J. Epidemiol.* 166(10):1174–85

Charalampopoulos D, Pandiella SS, Webb C. 2002a. Growth studies of potentially probiotic lactic acid bacteria in cereal-based substrates. *J. Appl. Microbiol.* 92(5):851–59

Charalampopoulos D, Pandiella SS, Webb C. 2003. Evaluation of the effect of malt, wheat and barley extracts on the viability of potentially probiotic lactic acid bacteria under acidic conditions. *Int. J. Food Microbiol.* 82(2):133–41

Charalampopoulos D, Wang R, Pandiella SS, Webb C. 2002b. Application of cereals and cereal components in functional foods: a review. *Int. J. Food Microbiol.* 79(1–2):131–41

Chase K, Reicks M, Jones JM. 2003. Applying the theory of planned behavior to promotion of whole-grain foods by dietitians. *J. Am. Diet Assoc.* 103(12):1639–42

Chatenoud L, La Vecchia C, Franceschi S, Tavani A, Jacobs DR Jr, et al. 1999. Refined-cereal intake and risk of selected cancers in Italy. *Am. J. Clin. Nutr.* 70(6):1107–10

Chronakis IS, Fredholm A, Triantafyllou AO, Oste R. 2004. Complex formation in aqueous medium of partially hydrolysed oat cereal proteins with sodium stearoyl-2 lactylate (SSL) lipid surfactant and implications for bile acids activity. *Colloids Surf. B Biointerfaces* 35(3–4):175–84

Cooke L. 2007. The importance of exposure for healthy eating in childhood: a review. *J. Hum. Nutr. Diet.* 20(4):294–301

Darmon N, Drewnowski A. 2008. Does social class predict diet quality? *Am. J. Clin. Nutr.* 87(5):1107–17

De Moura F. 2008. *Whole Grain Intake and Cardiovascular Disease and Whole Grain Intake and Diabetes: A Review*. Rockville, MD: LSRO

de Munter JS, Hu FB, Spiegelman D, Franz M, van Dam RM. 2007. Whole grain, bran, and germ intake and risk of type 2 diabetes: a prospective cohort study and systematic review. *PLoS Med.* 4(8):e261

Ding EL, Mozaffarian D. 2006. Optimal dietary habits for the prevention of stroke. *Semin. Neurol.* 26(1):11–23

Djoussé L, Gaziano JM. 2007. Breakfast cereals and risk of heart failure in the physicians' health study I. *Arch. Intern. Med.* 167(19):2080–85

Egeberg R, Olsen A, Loft S, Christensen J, Johnsen NF, et al. 2009. Intake of whole grain products and risk of breast cancer by hormone receptor status and histology among postmenopausal women. *Int. J. Cancer* 124(3):745–50

Erkkilä AT, Herrington DM, Mozaffarian D, Lichtenstein AH. 2005. Cereal fiber and whole-grain intake are associated with reduced progression of coronary-artery atherosclerosis in postmenopausal women with coronary artery disease. *Am. Heart J.* 150:94–101

Esmaillzadeh A, Mirmiran P, Azizi F. 2005. Whole-grain consumption and the metabolic syndrome, a favorable association in Tehranian adult. *Eur. J. Clin. Nutr.* 59(3):353–62

Esmaillzadeh A, Azadbakht L. 2006. Whole-grain intake, metabolic syndrome, and mortality in older adults. *Am. J. Clin. Nutr.* 83(6):1439–40

Esposito K, Marfella R, Ciotola M, Di Palo C, Giugliano F, et al. 2004. Effect of a mediterranean-style diet on endothelial dysfunction and markers of vascular inflammation in the metabolic syndrome: a randomized trial. *JAMA* 289:1659–66

Frontela C, Scarino ML, Ferruzza S, Ros G, Martínez C. 2009. Effect of dephytinization on bioavailability of iron, calcium and zinc from infant cereals assessed in the Caco-2 cell model. *World J. Gastroenterol.* 15(16):1977–84

Fraser GE. 1999. Associations between diet and cancer, ischemic heart disease, and all-cause mortality in non-Hispanic white California Seventh-day Adventists. *Am. J. Clin. Nutr.* (3 Suppl):532S–38S

Fuchs CS, Giovannucci EL, Colditz GA, Hunter DJ, Stampfer MJ, et al. 1999. Dietary fiber and the risk of colorectal cancer and adenoma in women. *N. Engl. J. Med.* 340(3):169–76

Fung TT, Hu FB, Pereira MA, Liu S, Stampfer MJ, et al. 2002. Whole-grain intake and the risk of type 2 diabetes: a prospective study in men. *Am. J. Clin. Nutr.* Sep 76(3):535–40

Garavello W, Lucenteforte E, Bosetti C, La Vecchia C. 2009. The role of foods and nutrients on oral and pharyngeal cancer risk. *Minerva Stomatol.* 58(1–2):25–34

Garcia AL, Otto B, Reich SC, Weickert MO, Steiniger J, et al. 2007. Arabinoxylan consumption decreases postprandial serum glucose, serum insulin and plasma total ghrelin response in subjects with impaired glucose tolerance. *Eur. J. Clin. Nutr.* 61(3):334–41

Gråsten SM, Juntunen KS, Poutanen KS, Gylling HK, Miettinen TA, Mykkänen HM. 2000. Rye bread improves bowel function and decreases the concentrations of some compounds that are putative colon cancer risk markers in middle-aged women and men. *J. Nutr.* 130(9):2215–21

Giacco R, Clemente G, Cipriano D, Luongo D, Viscovo D, et al. 2009. *Effects of the regular consumption of wholemeal wheat foods on cardiovascular risk factors in healthy people*. Presented at C&E Spring Meeting 2009—Whole Grain Global Summit, 3rd, New Castle

Greenway F, ONeil CE, Stewart L, Rood J, Keenan M, Martin R. 2007. Fourteen weeks of treatment with Viscofiber(R) increased fasting levels of glucagon-like peptide-1 and peptide-YY. *J. Med. Food.* 10(4):720–24

Haas P, Machado MJ, Anton AA, Silva AS, De Francisco A. 2009. Effectiveness of whole grain consumption in the prevention of colorectal cancer: meta-analysis of cohort studies. *Int. J. Food Sci. Nutr.* 21:1–13

Haldar S, Bal W, Brandt K, Seal C. 2009. *Effect of consumption of either whole grain or rye as the sole whole grain source on plasma lipid profiles in healthy volunteers (the GrainMark Study)*. Presented at C&E Spring Meeting 2009—Whole Grain Global Summit, 3rd, Newcastle

Hallmans G, Zhang JX, Lundin E, Stattin P, Johansson A, et al. 2003. Rye, lignans and human health. *Proc. Nutr. Soc.* 62(1):193–99

Harland JI, Garton LE. 2007. Whole-grain intake as a marker of healthy body weight and adiposity. *Public Health Nutr.* 11(6):554–63

Hesse D, Braun C, Dostal A, Jeffrey E, Marquart L. 2009. Barriers and opportunities related to whole grain foods in Minnesota school foodservice. *J. Child. Nutr. Manag.* 33(1): **http://www.schoolnutrition.org/Content.aspx?id=12511**

Hongisto SM, Paajanen L, Saxelin M, Korpela R. 2006. A combination of fibre-rich rye bread and yoghurt containing *Lactobacillus* GG improves bowel function in women with self-reported constipation. *Eur. J. Clin. Nutr.* 60(3):319–24

Hu C, Zawistowski J, Ling W, Kitts DD. 2003. Black rice (*Oryza sativa L. indica*) pigmented fraction suppresses both reactive oxygen species and nitric oxide in chemical and biological model systems. *J. Agric. Food Chem.* 51(18):5271–77

Jacobs DR Jr, Andersen LF, Blomhoff R. 2007. Whole-grain consumption is associated with a reduced risk of noncardiovascular, noncancer death attributed to inflammatory diseases in the Iowa Women's Health Study. *Am. J. Clin. Nutr.* 85(6):1606–14

Jacobs DR Jr, Marquart L, Slavin J, Kushi LH. 1998. Whole-grain intake and cancer: an expanded review and meta-analysis. *Nutr. Cancer* 30(2):85–96

Jacobs DR Jr, Meyer KA, Kushi LH, Folsom AR. 1999. Is whole grain intake associated with reduced total and cause-specific death rates in older women? The Iowa Womens Health Study. *Am. J. Public Health* 89(3):322–29

Jones JM, Reicks M, Adams J, Fulcher G, Marquart L. 2004. Becoming proactive with the whole-grains message. *Nutr. Today* 39(1):10–17

Jones JM. 2007. Mining whole grains for health. *Food Sci. Technol. Bull. Funct. Foods* 4(7):67–86

Jones JM. 2008. Whole grains—issues and deliberations from the Whole Grains Task Force. *Cereal Foods World* 55:260–64

Jones JM. 2009. The second C&E spring meeting and third international whole grain global summit. *Cereal Foods World* 54:132–35

Kaplan RJ, Greenwood CE. 2002. Influence of dietary carbohydrates and glycaemic response on subjective appetite and food intake in healthy elderly persons. *Int. J. Food Sci. Nutr.* 53(4):305–16

Karmally W, Montez MG, Palmas W. 2005. Cholesterol-lowering benefits of oat-containing cereal in Hispanic Americans. *J. Am. Diet. Assoc.* 105:967–70

Kim YS, Milner JA. 2007. Dietary modulation of colon cancer risk. *J. Nutr.* 137(11 Suppl):2576S–79S

Kim H, Stote KS, Behall KM, Spears K, Vinyard B, Conway JM. 2009. Glucose and insulin responses to whole grain breakfasts varying in soluble fiber, beta-glucan: a dose response study in obese women with increased risk for insulin resistance. *Eur. J. Nutr.* 48(3):170–75

Kochar J, Djoussé L, Gaziano JM. 2007. Breakfast cereals and risk of type 2 diabetes in the physicians' health study I. *Obesity (Silver Spring)* 15(12):3039–44

Koh-Banerjee P, Franz M, Sampson L, Liu S, Jacobs DR Jr, et al. 2004. Changes in whole-grain, bran, and cereal fiber consumption in relation to 8-y weight gain among men. *Am. J. Clin. Nutr.* 80(5):1237–45

Kris-Etherton PM, Hecker KD, Bonanome A, Coval SM, Binkoski AE, et al. 2002. Bioactive compounds in foods: their role in the prevention of cardiovascular disease and cancer. *Am. J. Med.* 113(Suppl. 9B):71S–88S

Kuijsten A, Arts IC, Hollman PC, vant Veer P, Kampman E. 2006. Plasma enterolignans are associated with lower colorectal adenoma risk. *Cancer Epidemiol. Biomarkers Prev.* 15(6):1132–36

Kurth T, Moore SC, Gaziano JM, Kase CS, Stampfer MJ, et al. 2006. Healthy lifestyle and the risk of stroke in women. *Arch. Intern. Med.* 166(13):1403–9

La Vecchia C, Chatenoud L, Negri E, Franceschi S. 2003. Session, whole cereal grains, fibre and human cancer: wholegrain cereals and cancer in Italy. *Proc. Nutr. Soc.* 62(1):45–49

Larsson SC, Giovannucci E, Bergkvist L, Wolk A. 2005. Whole grain consumption and risk of colorectal cancer, a population-based cohort of 60000 women. *Br. J. Cancer* 92(9):1803–7

Lee YP, Puddey IB, Hodgson JM. 2008. Protein, fibre and blood pressure: potential benefit of legumes. *Clin. Exp. Pharmacol. Physiol.* 35(4):473–76

Liese AD, Roach AK, Sparks KC, Marquart L, DAgostino RB Jr, Mayer-Davis EJ. 2003. Whole-grain intake and insulin sensitivity: the Insulin Resistance Atherosclerosis Study. *Am. J. Clin. Nutr.* 78:965–71

Lipson E. 2009. *The U.S. market for whole and other grains: trends and developments*. **http://www.reportlinker.com/p0116175**

Liu S, Willett WC, Manson JE, Hu FB, Rosner B, Colditz G. 2003. Relation between changes in intakes of dietary fiber and grain products and changes in weight and development of obesity among middle-aged women. *Am. J. Clin. Nutr.* 78(5):920–27

Lu ZX, Walker KZ, Muir JG, O'Dea K. 2004. Arabinoxylan fibre improves metabolic control in people with type II diabetes. *Eur. J. Clin. Nutr.* 58(4):621–28

Lundin EA, Zhang JX, Lairon D, Tidehag P, Aman P, et al. 2004. Effects of meal frequency and high-fibre rye-bread diet on glucose and lipid metabolism and ileal excretion of energy and sterols in ileostomy subjects. *Eur. J. Clin. Nutr.* 58(10):1410–19

Lutsey PL, Jacobs DR Jr, Kori S, Mayer-Davis E, Shea S, et al. 2007. Whole grain intake and its cross-sectional association with obesity, insulin resistance, inflammation, diabetes and subclinical CVD: The MESA Study. *Br. J. Nutr.* 98(2):397–405

Madhujith T, Shahidi F. 2007. Antioxidative and antiproliferative properties of selected barley (*Hordeum vulgarae L.*) cultivars and their potential for inhibition of low-density lipoprotein (LDL) cholesterol oxidation. *J. Agric. Food Chem.* 55(13):5018–24

Marcil V, Delvin E, Garofalo C, Levy E. 2003. Butyrate impairs lipid transport by inhibiting microsomal triglyceride transfer protein in Caco-2 cells. *J. Nutr.* 133(7):2180–183

Marquart L, Wiemer KL, Jones JM, Jacob B. 2003. Whole grains health claims in the USA and other efforts to increase whole-grain consumption. *Proc. Nutr. Soc.* 62(1):151–60

McCarty MF. 2005. Magnesium may mediate the favorable impact of whole grains on insulin sensitivity by acting as a mild calcium antagonist. *Med. Hypotheses* 64(3):619–27

McGarr SE, Ridlon JM, Hylemon PB. 2005. Diet, anaerobic bacterial metabolism, and colon cancer: a review of the literature. *J. Clin. Gastroenterol.* 39(2):98–109

McKeown NM, Meigs JB, Liu S, Wilson PW, Jacques PF. 2002. Whole-grain intake is favorably associated with metabolic risk factors for type 2 diabetes and cardiovascular disease in the Framingham Offspring Study. *Am. J. Clin. Nutr.* 76(2):390–98

Mellen PB, Liese AD, Tooze JA, Vitolins MZ, Wagenknecht LE, Herrington DM. 2007. Whole-grain intake and carotid artery atherosclerosis in a multiethnic cohort: the Insulin Resistance Atherosclerosis Study. *Am. J. Clin. Nutr.* 85(6):1495–502

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

Mills JL, Signore C. 2004. Neural tube defect rates before and after food fortification with folic acid. *Birth Defects Res. A Clin. Mol. Teratol.* 70(11):844–45

Mozaffarian D, Kumanyika SK, Lemaitre RN, Olson JL, Burke GL, Siscovick DS. 2003. Cereal, fruit, and vegetable fiber intake and the risk of cardiovascular disease in elderly individuals. *JAMA* 289:1659–66

Muir JG, Yeow EG, Keogh J, Pizzey C, Bird AR, et al. 2004. Combining wheat bran with resistant starch has more beneficial effects on fecal indexes than does wheat bran alone. *Am. J. Clin. Nutr.* 79(6):1020–28

Newby PK, Muller D, Hallfrisch J, Qiao N, Andres R, Tucker KL. 2003. Dietary patterns and changes in body mass index and waist circumference in adults. *Am. J. Clin. Nutr.* 77(6):1417–25

Nie L, Wise ML, Peterson DM, Meydani M. 2006. Avenanthramide, a polyphenol from oats, inhibits vascular smooth muscle cell proliferation and enhances nitric oxide production. *Atherosclerosis* 186(2):260–66

Oh K, Hu FB, Cho E, Rexrode KM, Stampfer MJ, et al. 2005. Carbohydrate intake, glycemic index, glycemic load, and dietary fiber in relation to risk of stroke in women. *Am. J. Epidemiol.* 161(2):161–69

Panahi S, Ezatagha A, Temelli S, Vasanthan T, Vuksan V. 2007. Beta-glucan from two sources of oat concentrates affect postprandial glycemia in relation to the level of viscosity. *J. Am. Coll. Nutr.* 26(6):639–44

Park Y, Hunter DJ, Spiegelman D, Bergkvist L, Berrino F, et al. 2005. Dietary fiber intake and risk of colorectal cancer, a pooled analysis of prospective cohort studies. *JAMA* 294(22):2849–57

Pereira MA, Jacobs DR Jr, Pins JJ. 2002. Effect of whole grains on insulin sensitivity in overweight hyperinsulinemic adults. *Am. J. Clin. Nutr.* 75:848–55

Pins JJ, Geleva D, Keenan JM, Frazel C, O'Connor PJ, Cherney LM. 2002. Do whole-grain oat cereals reduce the need for antihypertensive medications and improve blood pressure control? *J. Fam. Pract.* 51(4):353–59

Pool-Zobel BL, Sauer J. 2007. Overview of experimental data on reduction of colorectal cancer risk by inulin-type fructans. *J. Nutr.* 137(11 Suppl):2580S–84S

Priebe MG, van Binsbergen JJ, de Vos R, Vonk RJ. 2008. Whole grain foods for the prevention of type 2 diabetes mellitus. *Cochrane Database Syst. Rev.* (1):CD006061

Qi L, Meigs JB, Liu S, Manson JE, Mantzoros C, Hu FB. 2006. Dietary fibers and glycemic load, obesity, and plasma adiponectin levels in women with type 2 diabetes. *Diabetes Care* 29(7):1501–5

Reddy S, Sanders TA, Owen RW, Thompson MH. 1998. Fecal pH, bile acid and sterol concentrations in premenopausal Indian and white vegetarians compared with white omnivores. *Br. J. Nutr.* 79(6):495–500

Reeves PG, Gregoire BR, Garvin DF, Hareland GA, Lindlauf JE, et al. 2007. Determination of selenium bioavailability from wheat mill fractions in rats by using the slope-ratio assay and a modified torula yeast-based diet. *J. Agric. Food Chem.* 55(2):516–22

Rose NE. 2005. *Whole Grain Intake in College Students and its Association with Body Mass Index*. 2005. Masters thesis. Va. Polytech. Inst.

Ross AB, Kamal-Eldin A, Lundin EA, Zhang JX, Hallmans G, Aman P. 2003. Cereal alkylresorcinols are absorbed by humans. *J. Nutr.* 133(7):2222–24

Ryu D, Jackson LS, Bullerman LB. 2002. Effects of processing on zearalenone. *Adv. Exp. Med. Biol.* 504:205–16

Sahyoun NR, Jacques PF, Zhang XL, Juan W, McKeown NM. 2006. Whole-grain intake is inversely associated with the metabolic syndrome and mortality in older adults. *Am. J. Clin. Nutr.* 83(1):124–31

Sales AC, Yoshizawa T. 2005. Updated profile of aflatoxin and Aspergillus section Flavi contamination in rice and its byproducts from the Philippines. *Food Addit. Contam.* 22(5):429–36

Sayar S, Jannink JL, White PJ. 2006. In vitro bile acid binding activity within flour fractions from oat lines with typical and high beta-glucan amounts. *J. Agric. Food Chem.* 54(14):5142–48

Schatzkin A, Mouw T, Park Y, Subar AF, Kipnis V, et al. 2007. Dietary fiber and whole-grain consumption in relation to colorectal cancer in the NIH-AARP Diet and Health Study. *Am. J. Clin. Nutr.* 85(5):1353–60

Schatzkin A, Lanza E, Corle D, Lance P, Iber F, et al. 2000. *N. Engl. J. Med.* 342(16):1149–55

Skrabanja V, Liljeberg Elmståhl HG, Kreft I, Björck IM. 2001. Nutritional properties of starch in buckwheat products: studies in vitro and in vivo. *J. Agric. Food Chem.* 49(1):490–96

Slattery ML, Curtin KP, Edwards SL, Schaffer DM. 2004. Plant foods, fiber, and rectal cancer. *Am. J. Clin. Nutr.* 79(2):274–81

Slavin JL. 2005. Dietary fiber and body weight. *Nutrition* 21(3):411–18

So PW, Yu WS, Kuo YT, Wasserfall C, Goldstone AP, et al. 2007. Impact of resistant starch on body fat patterning and central appetite regulation. *PLoS ONE* 2(12):e1309

Swedish National Food Administration. 2002. Health Claim Regarding Blood Glucose Levels. Sweden, *Swedish Code of Practice*

Steffen LM, Jacobs DR Jr, Stevens J, Shahar E, Carithers T, Folsom AR. 2003. Associations of whole-grain, refined-grain, and fruit and vegetable consumption with risks of all-cause mortality and incident coronary artery disease and ischemic stroke: the Atherosclerosis Risk in Communities (ARIC) Study. *Am. J. Clin. Nutr.* 78:383–90

Thane CW, Jones AR, Stephen AM, Seal CJ, Jebb SA. 2007. Comparative whole-grain intake of British adults in 1986–7 and 2000–1. *Br. J. Nutr.* 97(5):987–92

Thane CW, Jones AR, Stephen AM, Seal CJ, Jebb SA. 2005. Whole-grain intake of British young people aged 4–18 years. *Br. J. Nutr.* 94(5):825–31

Tripkovic L, Muirhead N, Frost G, Lodge J. 2009. *Whole-grain consumption improves arterial stiffness in young, adult males*. Presented at C&E Spring Meeting 2009—Whole Grain Global Summit, 3rd, New Castle

USDA. 2008. *Nutrient content of whole grain and enriched wheat flour*. **http://www.nal.usda.gov/fnic/foodcomp/search**

van Bennekum AM, Nguyen DV, Schulthess G, Hauser H, Phillips MC. 2005. Mechanisms of cholesterol-lowering effects of dietary insoluble fibres: relationships with intestinal and hepatic cholesterol parameters. *Br. J. Nutr.* 94:331–37

van de Vijver LP, Van Den Bosch LM, Van Den Brandt PA, Goldbohm RA. 2009. Whole-grain consumption, dietary fibre intake and body mass index in the Netherlands cohort study. *Eur. J. Clin. Nutr.* 63(1):31–38

Vanharanta M, Voutilainen S, Rissanen TH, Adlercreutz H, Salonen JT. 2003. Risk of cardiovascular disease-related and all-cause death according to serum concentrations of enterolactone: Kuopio Ischaemic Heart Disease Risk Factor Study. *Arch. Intern. Med.* 163(9):1099–104

Wakai K, Hirose K, Matsuo K, Ito H, Kuriki K, et al. 2006. Dietary risk factors for colon and rectal cancers: a comparative case-control study. *J. Epidemiol.* 16(3):125–35

Wang L, Gaziano JM, Liu S, Manson JE, Buring JE, Sesso HD. 2007. Whole- and refined-grain intakes and the risk of hypertension in women. *Am. J. Clin. Nutr.* 6(2):472–79

Wang QR, Liu XM, Cui YS, Dong YT, Christie P. 2002. Responses of legume and non-legume crop species to heavy metals in soils with multiple metal contamination. *J. Environ. Sci. Health Part A Toxic/Hazard. Subst. Environ. Eng.* 37(4):611–21

Xia M, Ling WH, Ma J, Kitts DD, Zawistowski J. 2003. Supplementation of diets with the black rice pigment fraction attenuates atherosclerotic plaque formation in apolipoprotein E deficient mice. *J. Nutr.* 133(3):744–51

Yang JL, Kim YH, Lee HS, Lee MS, Moon YK. 2003. Barley beta-glucan lowers serum cholesterol based on the up-regulation of cholesterol 7alpha-hydroxylase activity and mRNA abundance in cholesterol-fed rats. *J. Nutr. Sci. Vitaminol. (Tokyo)* 49(6):381–87

Yang Q, Botto LD, Erickson JD, Berry RJ, Sambell C, et al. 2006. Improvement in stroke mortality in Canada and the United States 1990–2002. *Circulation* 113(10):1335–43

Zhang SM, Moore SC, Lin J, et al. 2006. Folate, vitamin B6, multivitamin supplements, and colorectal cancer risk in women. *Am. J. Epidemiol.* 163:108–15

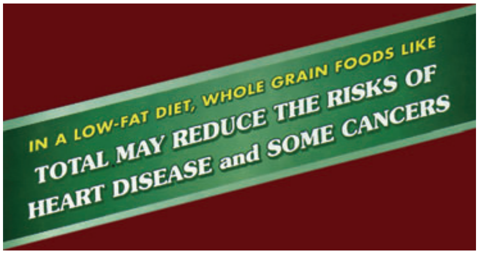

Figure 1

The Whole Grain Health Claim.

Figure 2

Whole Grain Stamp. Stamp created by the Whole Grains Counsel to aid in the identification of whole grain foods.

Annual Review
of Food Science
and Technology

Volume 1, 2010

Contents

Errata

An online log of corrections to *Annual Review of Food Science and Technology* articles may be found at http://food.annualreviews.org