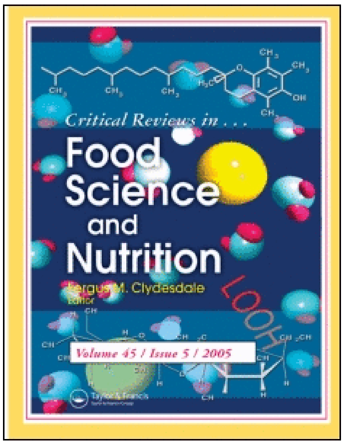


Critical Reviews in Food Science and Nutrition
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713606380

Health Benefits of Whole Grain Phytochemicals

Neal Okarter [a];Rui Hai Liu [ab]
[a] Department of Food Science, Cornell University, Ithaca, NY [b] Institute of Comparative and Environmental Toxicology, Cornell University, Ithaca, NY

Online publication date: 17 March 2010

To cite this Article Okarter, Neal andLiu, Rui Hai(2010) 'Health Benefits of Whole Grain Phytochemicals', Critical Reviews in Food Science and Nutrition, 50: 3, 193 — 208
To link to this Article: DOI: 10.1080/10408390802248734
URL: http://dx.doi.org/10.1080/10408390802248734

Critical Reviews in Food Science and Nutrition, 50:193–208 (2010)

ISSN: 1040-8398
DOI: 10.1080/10408390802248734

Health Benefits of Whole Grain Phytochemicals

NEAL OKARTER[1] and RUI HAI LIU[1,2]

[1]Department of Food Science, Cornell University, Ithaca, NY 14853-7201
[2]Institute of Comparative and Environmental Toxicology, Cornell University, Ithaca, NY 14853-7201

A whole grain consists 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. Whole grain food products can be intact, consisting of the original composition of bran, germ, and endosperm, throughout the entire lifetime of the product, or reconstituted, in which one or more of the original components of a whole grain is recombined to the relative proportion naturally occurring in the grain kernel. Increased consumption of whole grains has been associated with reduced risk of major chronic diseases including cardiovascular disease, type II diabetes, and some cancers. Whole grain foods offer a wide range of phytochemicals with health benefits that are only recently becoming recognized. The unique phytochemicals in whole grains are proposed to be responsible for the health benefits of whole grain consumption. In this paper, whole grain phytochemicals and the health benefits associated with their consumption are reviewed.

Keywords Whole grains, wheat, phytochemicals, phenolics

ABBREVIATIONS

CVD	cardiovascular disease
IHD	ischemic heart disease
CHD	coronary heart disease
NHS	Nurse's health Study
DW	dry weight
FW	fresh weight
Trolox	(S)-(-)-6-Hydroxy-2,5,7,8-tramethylchroman-2-carboxylic acid
TE	Trolox equivalents
ABTS	2,2′-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt
ABAP	2,2′-azobis(2-methylpropionamidine) dihydrochloride
NIRS	Near-Infrared Reflectance Spectroscopy

INTRODUCTION

Epidemiological studies have consistently shown that consumption of whole grain is associated with reduced risk of cardiovascular disease (CVD) (Fraser, 1999; Jacobs et al., 1998; Liu et al., 1999), type II diabetes (Liu et al., 2000; Meyer et al., 2000; Salmeron et al., 1997), and some cancers (Jacobs et al., 1995; Smigel, 1992). Because of the increased evidence indicating the health benefits of whole grain, the recommendation for whole grain consumption has been changed. In 1995, the USDA's Dietary Guidelines for Americans advised Americans to choose a diet with plenty of grain products, recommending 6 to 11 servings of grain products and several servings of whole grain breads and cereals (USDA, 1995). Although this recommendation did recognize the significance of whole grain consumption, emphasis and specificity were not placed on whole grain consumption. The 2005 Dietary Guidelines for Americans recommends Americans to consume at least three ounce-equivalents of whole grain products each day, being sure to "make half your grains whole" (USDA, 2005). The recognition of the potential health benefits of whole grain consumption is a step in the right direction for the improved health of the American public.

Industry has responded to the increased recommendation for whole grain consumption. Although consumption of all-wheat flour dropped in 2006, there were 446 new whole grain food products introduced into the market between 2003 and 2004 (Burros, 2006; Vocke, 2007). Nearly ten times more whole grain food products were launched in 2006 than in 2000 (WGC, 2007).

The objectives of this paper are to review the current literature on whole grains, especially on studies linking whole grain consumption and health benefits, and whole grain phytochemicals.

Address correspondence to Rui Hai Liu, Department of Food Science, Stocking Hall, Cornell University, Ithaca, NY 14853-7201. E-mail: RL23@cornell.edu

DEFINITIONS OF WHOLE GRAINS AND WHOLE GRAIN PRODUCTS

A whole grain consists 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 (AACC, 1999). The endosperm contains the food supply for the germ and provides energy for the rest of the plant. The endosperm is the largest component and contains starchy carbohydrates, proteins, vitamins, and minerals. The bran is the multi-layered outer skin of the grain that protects the germ and the endosperm from damage due to sunlight, pests, water, and diseases. It contains phenolic compounds, vitamins, minerals, and fiber. The germ refers to the embryo, the part of the grain that becomes a new plant when fertilized by pollen. It contains vitamins, some protein, minerals, and fats.

Whole grain products can be defined by one of two definitions. An intact whole grain product is a product that has the original composition of bran, germ, and endosperm throughout the entire lifetime of the product, from field to consumption. A reconstituted whole grain product is a product that has the original components of a whole grain recombined to the relative proportion naturally occurring in the grain kernel. Due to advances in food processing and the commonplace nature in which these processes take place, the bulk of the whole grain food products found on shelves would be considered reconstituted whole grain products.

There are many grains such as wheat, corn, barley, and rice, both whole and refined, which are consumed on a daily basis in a number of products from around the world. Wheat has become the prominent grain based on consumption. There are two types of wheat that are common in foods typically eaten in North America and Europe, durum wheat, *Triticum turgidum durum*, which is used in pasta products and bread, and *Triticum aestivum vulgare*, which is used in most other wheat products. Wheat varieties are characterized by the hardness and color of the bran and the season in which they are planted. Hard red winter wheat cultivars are most popular due to high gluten content, making them particularly good for cookies and some bread (Distaam and Carcea, 2001). White wheat cultivars, both hard and soft, are often exported from North America for use in making flat breads and noodles (Seib et al., 2000). Gluten content has been used as a basis for determining wheat quality (Distaam and Carcea, 2001). Spelt, *Triticum aestivum spelta*, is a variety of wheat that typically has higher protein content than wheat. Corn, *Zea mays L.*, is another commonly eaten grain that recently has gained more attention because of its antioxidant content. Rice, *Oryza sativa L.*, is the major staple for a majority of the world's population. Rice is rarely eaten as a whole grain. Generally, the endosperm fraction, polished rice, without the bran and germ fractions, is eaten. Rice can also be parboiled, incorporating B vitamins into the endosperm of the grain. White rice is not considered a whole grain. Oats, *Avena sativa L.*, are almost always eaten whole since their bran and germ fractions are rarely removed. They also tend to have a sweet taste, making good breakfast cereals and beers. Millet, *Panicum miliaceum L.*, is rarely consumed by humans in North America, but is very common in Asia. In the United States, it is mainly used as bird feed or mixed with other grains. Barley, *Hordom vulgare L.*, has a tough hull that is difficult to remove and therefore has long cooking times. Rye, *Secale cereale L.*, has high fiber content in its endosperm and is consumed with the highest frequency in parts of Scandinavia (Table 1).

Table 1 Common whole grains and food products

Species	Common Name	Common food products
Triticum aestivum	Wheat	Breads, flours, pasta, baked goods
Zea mays	Corn	Corn cakes, tortilla, popcorn, hominy
Oryza sativa	Rice	White rice, brown rice, parboiled rice
Avena sativa	Oats	Oatmeal, flour
Panicum miliaceum	Millet	Bird food, porridge, millet
Hordum vulgare	Barley	Hulled barley
Triticum aestivum spelta	Spelt	Breads, baked goods
Secale cereale	Rye	Breads

HEALTH BENEFITS OF WHOLE GRAINS

Whole grain consumption has been associated with reduced risk of CVD, type II diabetes, obesity, and some cancers.

Whole Grain Consumption and Risk of CVD

Epidemiological studies have consistently shown that consumption of whole grains is associated with reduced risk of CVD (Fig. 1). Pietinen et al. reported results from the Alpha-Tocopherol, Beta-Carotene Lung Cancer Prevention Study and showed that total dietary fiber was inversely associated with risk of coronary death. Further, a ten-gram per day higher intake of fiber appeared to lower the risk of coronary death by 17% (RR = 0.83; 95% CI = 0.80–0.86) (Pietinen et al., 1996). Rye products, which make up a large part of the whole grain intake in the study population, were also inversely associated with coronary death.

Jacobs et al. reported results from the Iowa Women's Health Study and showed that when the highest category of whole grain intake was compared to the lowest there was an inverse association between whole grain intake and risk of death from ischemic heart disease (IHD), even after adjustment for potentially confounding factors and adjustment for dietary fiber intake (RR = 0.70) (Jacobs et al., 1998). This association was independent of intake of refined grains. Specifically, these findings held true for dark bread and whole grain breakfast cereals, but not for wheat germ, cooked oatmeal, bulgar, kasha, and couscous. After adjustment for total dietary fiber intake, Jacobs et al. showed there was an inverse association between whole grain intake and IHD across all intakes of whole grain, RR = 0.77; 95% CI 0.54–1.10 for the highest quintile of whole grain intake (Jacobs et al., 1998).

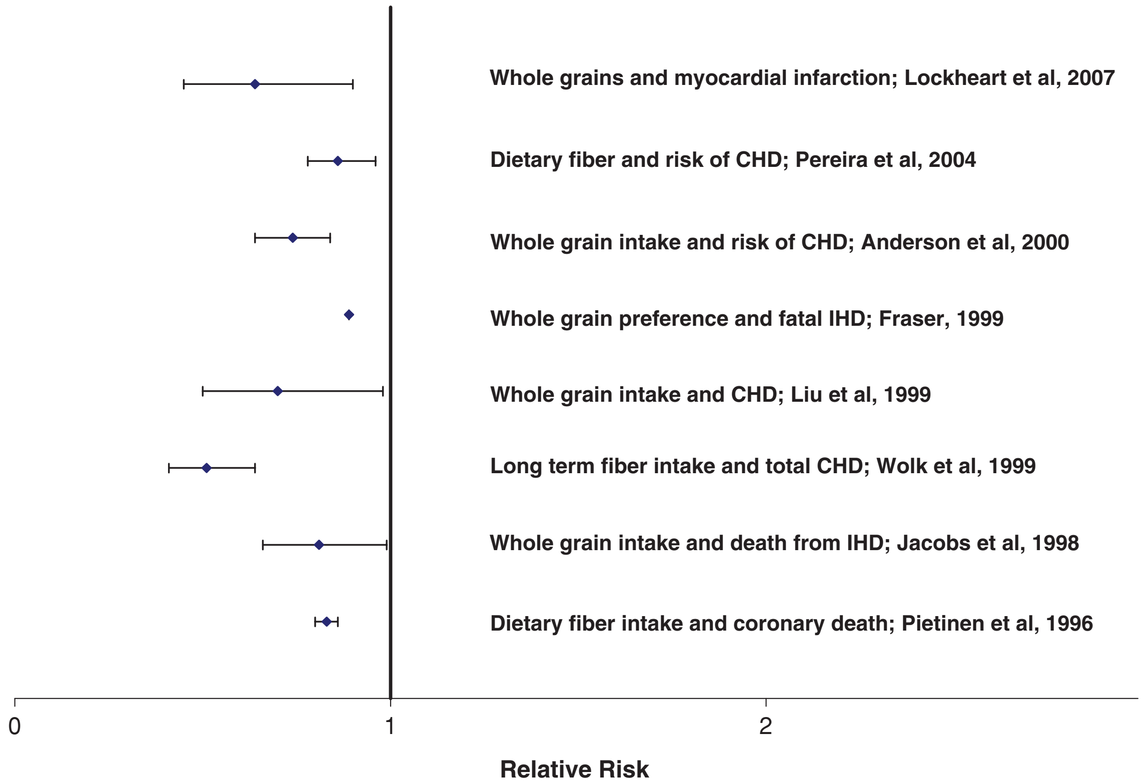


Figure 1 Consumption of whole grains or dietary fiber and relative risk of cardiovascular disease. Relative risk ±95% confidence interval.

Liu et al. reported results from the Nurse's Health Study (NHS) and showed that there was a strong inverse association between whole grain intake and risk of coronary heart disease (CHD) (RR = 0.51; 95% CI 0.41–0.64), for women in the highest quintile for whole grain consumption when compared to the lowest (Liu et al., 1999). This association was observed for both nonfatal CHD and fatal CHD (Liu et al., 1999). Higher intake of refined grains was also associated with greater risk of CHD in women who had never smoked (RR = 1.46), although this association was attenuated after adjustment for CHD risk factors and the inclusion of whole grain intake into the model. In age-adjusted analyses, Wolk et al. showed women in the highest quintile of long-term dietary fiber intake had 43% lower risk of nonfatal myocardial infarct and 59% lower risk of fatal coronary disease in comparison to those in the lowest quintile (Wolk et al., 1999). Further, each ten-gram increase in long-term fiber consumption correlated to the reduced risk of total CHD (RR = 0.81; 95% CI 0.66–0.99). Wolk et al. also showed that women in the highest category of long-term dietary fiber intake as compared to the lowest category had a 34% lower risk of total CHD. With regard to specific food products, consumption of cold breakfast cereal five or more times per week in comparison to no cold breakfast cereal was associated with a 19% lower risk of total CHD (RR = 0.81; 95% CI 0.62–1.06). This association was even stronger for oatmeal, having a 29% lower risk of total CHD (RR = 0.71; 95% CI 0.38–1.34) (Wolk et al., 1999).

The Adventist Health Study investigated incidences of chronic disease in relation to lifestyle in Seventh Day Adventists, a population that has a lower risk of fatal CHD when compared with others from California possibly due to adherence to a lacto-ovo vegetarian diet and lower rates of smoking (Beeson et al., 1989). Fraser et al. reported that although the food that was most consistently associated with reduced risk of IHD was nuts, preference for whole-grain bread instead of preference for white bread was also associated with reduced risk of IHD (Fraser, 1999). After adjustment for non-dietary risk factors and consumption of other foods, those who preferred whole-grain bread had a relative risk of 0.89 for fatal IHD and 0.56 for non-fatal IHD when compared to those who had a preference for white bread.

Anderson et al. performed a meta-analysis of studies that investigated the relationship between whole grain consumption and the risk of CHD. Of the twelve studies analyzed, four studies (when the data was pooled) showed that there was a significant inverse association between whole grain and whole wheat bread consumption and reduced risk of CHD (RR = 0.74; 95% CI 0.64–0.84), after adjustment for primary and secondary risk factors (Anderson et al., 2000).

Pereira et al. performed a meta-analysis of studies that investigated the relationship between dietary fiber and risk of CHD. After adjustment, Pereira showed a significant inverse association between dietary fiber and risk of CHD (RR = 86; 95% CI 0.78–0.96) (Pereira et al., 2004).

Erkkilä et al. investigated the association between cereal fiber and whole grain consumption and progression of coronary artery atherosclerosis in postmenopausal women with coronary artery disease using the data from the Estrogen Replacement and Atherosclerosis trial. The minimum coronary artery diameter (MCAD) was used as a measure of progression of coronary artery atherosclerosis. Erkkilä et al. reported that MCAD decreased less in those who consumed more than the median intake of cereal fiber compared to those who ate less than the median intake of cereal fiber, after adjusting for cardiovascular disease, blood pressure, and other possible confounding factors (Erkkila et al., 2005). This study shows that whole grain consumption has health benefit not only for those who do not have cardiovascular disease but also for those that do have cardiovascular disease.

Lockheart et al. investigated the association between dietary patterns and risk of first myocardial infarction using the data from a case-control study performed in Norway. After adjusting for family history of heart disease, smoking, energy intake, and other possible confounding factors, whole grain breakfast cereals were inversely associated with risk of first myocardial infarction (RR = 0.64; 95% CI = 0.45–0.90) (Lockheart et al., 2007) when comparing the group with the highest level of whole grain intake to the group with the lowest. However, whole grain breads were not inversely associated with risk of first myocardial infraction (RR = 0.94; 95% CI = 0.67–1.32). This is most likely due to the fact that whole grain bread (heavy wholegrain bread, dark flat bread, and medium wheat bread) consumption is common in Norway.

Wang et al. investigated the association between whole grain consumption and hypertension using data from the US Health Professional's Follow-Up Study. After adjusting for possible confounding lifestyle, clinical, and dietary factors, whole grain consumption was inversely associated with hypertension when comparing the highest quintile of whole grain intake to the lowest (RR = 0.89; 95% CI = 0.82–0.97) (Wang et al., 2007). No significant association was seen between refined grain consumption and hypertension.

Lutsey et al. investigated the association between whole grain consumption and common carotid artery intimal medial thickness (IMT) as a measure of subclinical cardiovascular disease using data from Multi-Ethnic Study of Atherosclerosis. After adjusting for fruit, vegetable, and refined grain intakes and other possible confounding factors, whole grain consumption was not associated with common carotid artery IMT, when comparing the highest quintile of whole grain consumption to the lowest (Lutsey et al., 2007). Associations between whole grain consumption and common carotid artery IMT were not found possibly because subclinical cardiovascular disease markers are weakly correlated with chronic diseases. Further, the cross-sectional design of the study may have made finding the association between whole grain consumption and common carotid artery IMT difficult.

Whole Grain Consumption and Risk of Type II Diabetes and Obesity

Lifestyle modification and weight control are major factors in the prevention and treatment of diabetes. Several large epidemiological studies have linked whole grain consumption with reduced risk of type II diabetes (Fig. 2). Salmerón et al. investigated the relationship between dietary fiber and risk of type II diabetes. Only cereal fiber was inversely associated with risk of type II diabetes (RR = 0.70, 95% CI = 0.51–0.96) when comparing the highest quintile of cereal fiber intake to the lowest (Salmeron et al., 1997). Total dietary fiber consumption was also inversely associated with risk of type II diabetes, but the association was not significant.

Liu et al. investigated the association between whole and refined grain intake and risk of type II diabetes. After adjusting for age and energy intake, it was found that there was a significant inverse association between whole grain intake and risk of type II diabetes, when comparing the highest quintile of whole grain intake to the lowest quintile (RR = 0.62, 95% CI = 0.53–0.71) (Liu et al., 2000). There was a positive association between refined grain intake and risk of type II diabetes, when the highest quintile of refined grain intake was compared to the lowest quintile after adjusting for age and energy intake (RR = 1.31, 95% CI = 1.12–1.53) (Liu et al., 2000). Those in the highest quintile of refined grain to whole grain intake had a significantly higher risk of type II diabetes when compared to those in the lowest quintile of refined grain to whole grain intake (RR = 1.57, 95% CI = 1.36–1.82) (Liu et al., 2000). This provided further supportive evidence that consumption of whole grains is associated with reduced risk of developing type II diabetes.

Meyer et al. investigated the association between cereal fiber and whole grain consumptions and relative risk of type II diabetes. Whole grain consumption was inversely associated with risk of type II diabetes when comparing the highest quintile of whole grain intake to the lowest (RR = 0.79; 95% CI = 0.65–0.96). Cereal fiber consumption was also inversely associated with risk of type II diabetes when comparing the highest quintile of cereal fiber consumption to the lowest (RR = 0.64; 95% CI = 0.53–0.79). Refined grain intake was positively associated with risk of type II diabetes when comparing the highest quintile of refined grain intake to the lowest, but the association was not as strong as that of whole grains or cereal fiber (RR = 0.87; 95% CI = 0.70–1.08; P for trend = 0.36) (Meyer et al., 2000).

van Dam et al. examined the association between dietary patterns and risk for type II diabetes using data from the Health Professionals Follow-Up Study. The sample population was divided into one of two dietary patterns (prudent or western patterns) based on the composition of the diet. The prudent dietary pattern was characterized by high consumption of whole grains, fruits, vegetables, seafood, legumes, white meat, nuts, and plant oils. The western dietary pattern was characterized by high consumption of refined grains, red meat, processed meat, potatoes, and foods with high saturated fats, cholesterol, and trans fats. After modeling western pattern foods simultaneously, refined grain intake remained positively associated with risk of type II diabetes (RR = 1.32, 95% CI = 1.09–1.60) (van Dam et al., 2002).

Fung et al. investigated the association between whole grain consumption and risk of type II diabetes using the data from

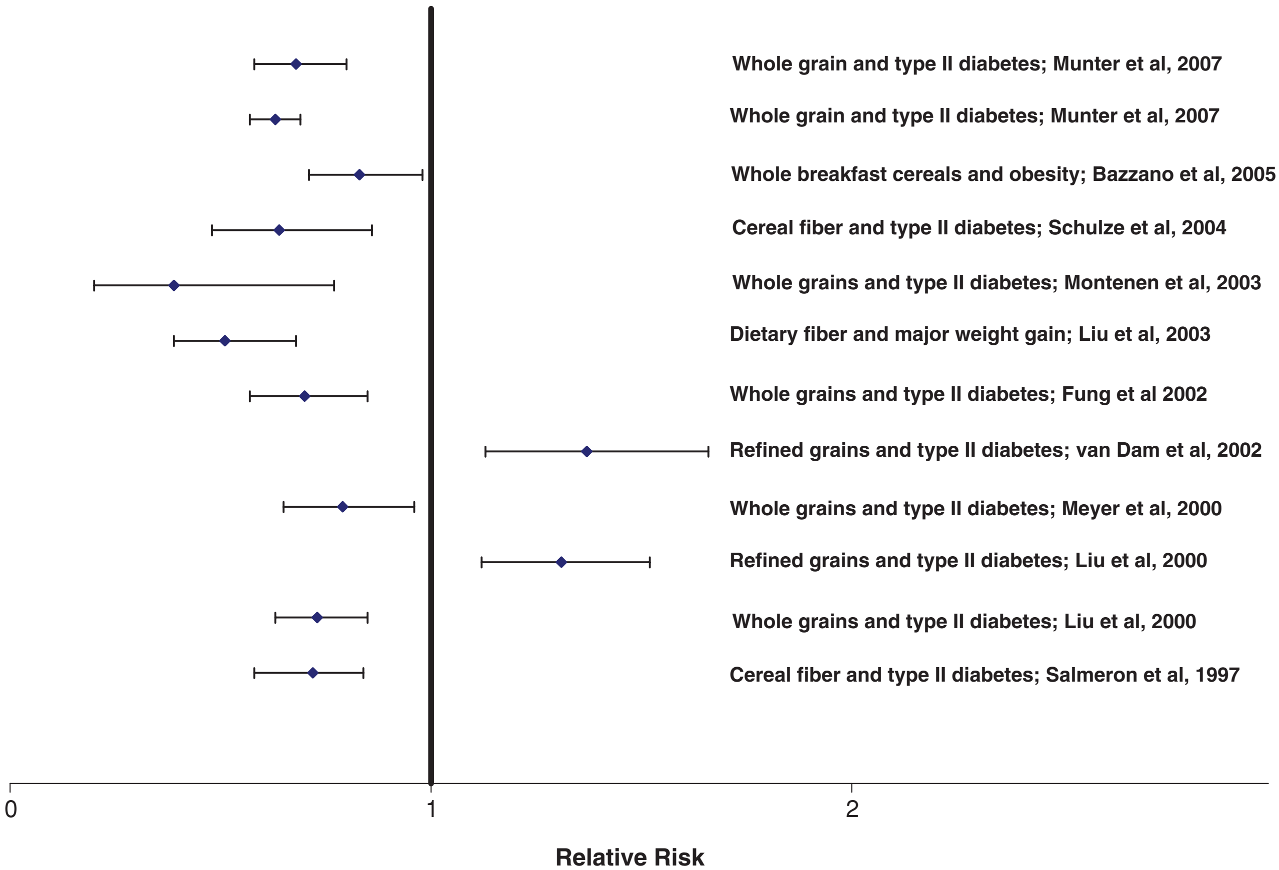


Figure 2 Consumption of whole grain or dietary fiber and relative risk of type II diabetes, obesity, or weight gain. Relative risk ±95% confidence interval.

the Health Professionals Follow-Up Study. After adjusting for fruit and vegetable consumption and other confounding factors, whole grain consumption was inversely associated with risk of type II diabetes when the highest quintile of whole grain intake was compared to the lowest (RR = 0.70; 95% CI = 0.57–0.85). Refined grain intake was positively associated with risk of type II diabetes when comparing the highest quintile of refined grain intake to the lowest (RR = 1.08; 95% CI = 0.87–1.33) (Fung et al., 2002).

Liu et al. also used data from the Nurses Health Study to investigate the association between whole grain intake, body weight, and long-term body weight changes. They found that women in the highest quintile of dietary fiber intake had a 49% reduced risk of major weight gain when compared to women in the lowest quintile of dietary fiber (RR = 0.51, 95% CI = 0.39–0.67) (Liu et al., 2003). Further, women who consumed larger amounts of whole grain consistently weighed less than women who consumed smaller amounts of whole grain.

Montonen et al. investigated the association between whole grain intake and risk of type II diabetes using data from the Finnish Mobile Clinic Health Examination Survey. After adjusting for fruit, berry, and vegetable consumption and other confounding factors, whole grain consumption was inversely associated with the risk of type II diabetes when compared the highest quartile of whole grain consumption to the lowest (RR = 0.65; 95% CI = 0.36–1.18). Cereal fiber consumption was inversely associated with risk of type II diabetes when the highest quartile of cereal fiber intake was compared to the lowest (RR = 0.39; 95% CI = 0.20–0.77) (Montonen et al., 2003).

Schulze et al. investigated the association between cereal fiber intake and incidence of type II diabetes using data from the Nurse's Health Study. After adjusting for familial history of type II diabetes, body mass index, and other confounding factors, cereal fiber consumption was inversely associated with incidence of type II diabetes when comparing the highest quintile of cereal fiber intake to the lowest (RR = 0.64; 95% CI = 0.48–0.86) (Schulze et al., 2004).

Bazzano et al. investigated the association between whole and refined grain breakfast cereal consumption and weight gain in men using data from the Physician's Health Study. After adjusting for baseline BMI, physical activity, age, and other possible confounding factors, whole grain breakfast cereal consumption was inversely associated with risk of having a BMI greater than 25 (RR = 0.83; 95% CI = 0.71–0.98) and body weight gain of more than 10 kg (RR = 0.78; 95% CI = 0.64–0.96), 8 years after initial subject evaluation (Bazzano et al., 2005). This inverse association was independent of the type of grains that constituted the whole grain breakfast cereal. The data

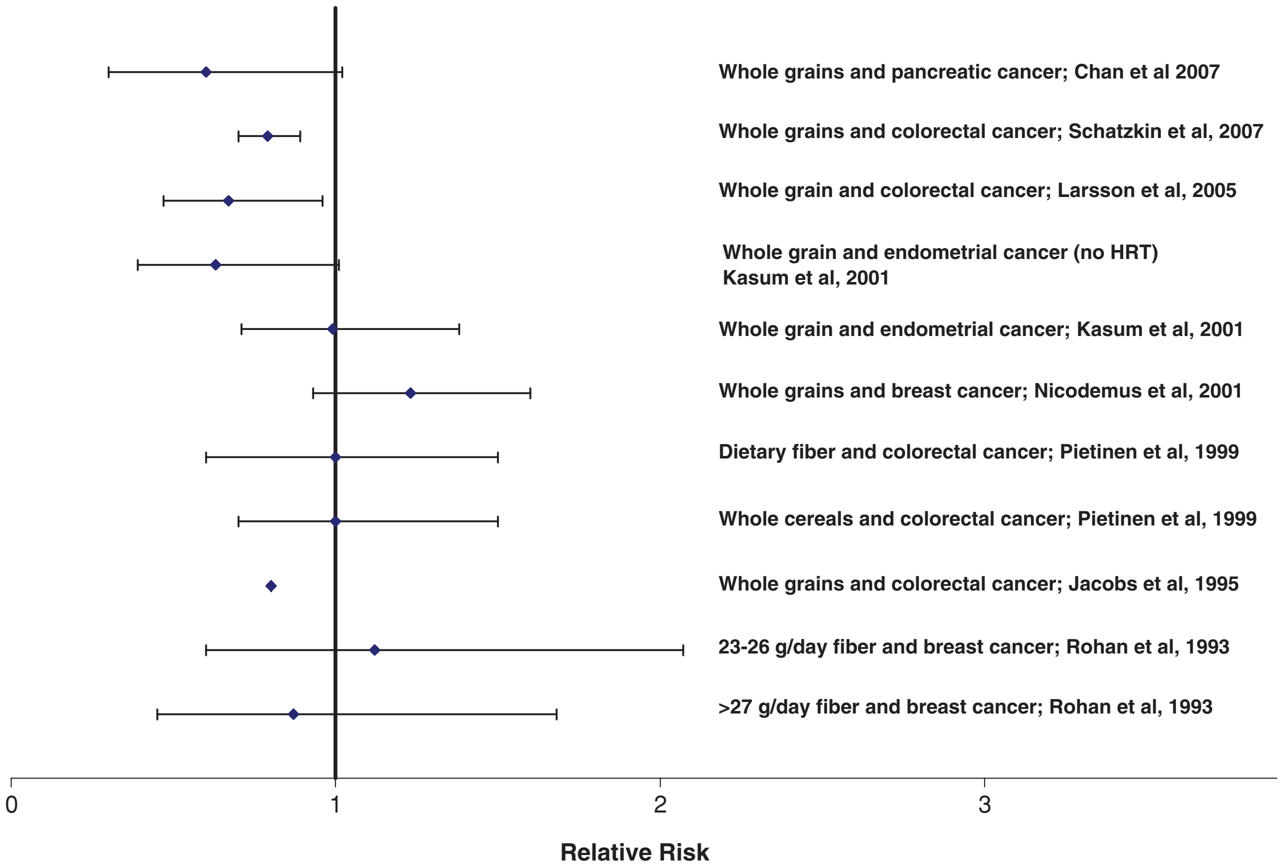


Figure 3 Consumption of whole grain or dietary fiber and relative risk of cancers. Relative risk ±95% confidence interval.

suggest that whole grain breakfast cereals are an important part of the prudent dietary pattern.

Munter et al. investigated the association between whole grain, bran, and germ intake using data from the first and second trials of the Nurse's Health Study. After adjusting for physical activity, total energy intake, and other possible confounding factors, whole grain intake was inversely associated with risk of type II diabetes in the first trial of the Nurse's Health Study (RR = 0.63; 95% CI = 0.57–0.69) and in the second trial of the Nurse's Health Study (RR = 0.68; 95% CI = 0.57–0.86) (Munter et al., 2007). Similar associations were found between bran consumption and risk of type II diabetes in both trials of the Nurse's Health study after adjusting for physical activity, total energy intake, and other possible confounding factors (RR = 0.57; 95% CI = 0.51–0.63 and RR = 0.64; 95% CI = 0.54–0.76, respectively) (Munter et al., 2007).

Newby et al. investigated the association between whole grain consumption and BMI, weight, and waist circumference using data from the Baltimore Longitudinal Study on Aging. Whole grain and cereal fiber intake were inversely associated with BMI, weight, and waist circumference when the highest quintile of whole grain or cereal fiber intake was compared to the lowest after adjusting for refined grain intake, total energy intake, percentage energy from saturated fat, and other possible confounding factors (Newby et al., 2007).

Whole Grain Consumption and Risk of Cancers

Many large epidemiological studies have investigated the association between whole grain consumption and relative risk of cancers (Fig. 3). Previous studies have shown an association between increased consumption of whole grains and colorectal and breast cancers (Jacobs et al., 1995; Rohan et al., 1993). A case control study was performed in southern Australia to investigate the association between diet and breast cancer. After adjusting for energy intake and other risk factors, Rohan et al. found that there was little association between dietary fiber and the risk of death from breast cancer as determined by hazard ratio across various levels of intake. Consumption of between 23 and 26 g dietary fiber led to a relative risk of 1.12 (95% CI = 0.60–2.07), while consumption greater than 27 g of dietary fiber led to a relative risk of 0.87 (95% CI = 0.45–1.68, p = 0.812 for trend) (Rohan et al., 1993). The data suggest that there is an unclear association between dietary fiber and risk of death from breast cancer.

Nicodemus et al. investigated the association between increased consumption of dietary fiber and risk of breast cancer. Women in the highest quintile of whole grain intake had a 23% higher risk of breast cancer incidence than women in the lowest quintile of whole grain intake. Further, there was no association between whole grain intake and risk of breast cancer incidence in women who had not received a mammography before 1989 (Nicodemus et al., 2001). This finding was similar to that of a study reported by Willett et al. (1992), which found a slightly increased, but non-significant risk of breast cancer in postmenopausal women who consumed more dietary fiber.

Pietinen et al. investigated the association between consumption of dietary fiber and risk of colorectal cancer using data from the Alpha-Tocopherol, Beta-Carotene Lung Cancer Prevention Study and found that there was no association between colorectal cancer and intake of total dietary fiber, soluble fiber, or insoluble fiber from the various rye products (Pietinen et al., 1999). Further, there was no association between vegetable, cereal, or fruit intake and risk of colorectal cancer. These findings are contrary to the general convention that increased consumption of fruits, vegetables, and whole grains decrease the risk of cancer, specifically colorectal cancer.

Kasum et al. investigated the association between whole grain consumption and risk of endometrial cancer, using data from the Iowa Women's Health Study. After adjusting for refined grain, fruit, vegetable, and red meat consumption and other confounding factors, there was no association between whole grain consumption and risk of endometrial cancer (RR = 0.99; 95% CI = 0.71–1.38). However, for women who had never had any hormone replacement therapy, whole grain consumption was inversely associated with risk of endometrial cancer when the highest quintile of whole grain consumption was compared to the lowest (RR = 0.63; 95% CI = 0.39–1.01) (Kasum et al., 2001).

Some studies have shown that there is an inverse association between whole grain consumption and risk of colorectal cancer (Adlercreutz and Mazur, 1997; Jacobs et al., 1995). Larsson et al. investigated the association between whole grain consumption and colon cancer using data from the Swedish Mammography Cohort. After adjusting for red meat, fruit, and vegetable consumption and other possible confounding factors, whole grain consumption was inversely associated with risk of colon cancer (RR = 0.67; 95% CI = 0.47–0.96) when comparing the highest quintile of whole grain intake to the lowest (Larsson et al., 2005).

Schatzkin et al. showed there was an inverse association between whole grain consumption and risk of colorectal cancer (RR = 0.79; 95% CI = 0.70–0.89) after multivariate analysis (Schatzkin et al., 2007). This association was stronger for men (RR = 0.79; 95% CI = 0.68–0.91) than for women (RR = 0.87; 95% CI = 0.70–1.07) (Schatzkin et al., 2007). The association between whole grain consumption and reduced risk of site specific tumors was strongest for the rectum (RR = 0.64; 95% CI = 0.51–0.81) (Schatzkin et al., 2007).

Chan et al. investigated the association between whole grain consumption and risk of pancreatic cancer using data from a large population-based case-control study on pancreatic cancer. After adjusting for history of smoking, red meat, fruit, and vegetable consumption, and other possible confounding factors, whole grain consumption was inversely associated with risk of pancreatic cancer (RR = 0.60; 05% CI = 0.30–1.2), when comparing the highest quartile of whole grain intake to the lowest (Chan et al., 2007).

WHOLE GRAIN PHYTOCHEMICALS

Phytochemicals are defined as bioactive non-nutrient plant compounds in fruits, vegetables, whole grains, and other plant foods that have been associated with reduced risk of major chronic diseases (Liu, 2003, 2004). Whole grains contain many phytochemicals with health benefits that are only recently becoming recognized. The most important groups of whole grain phytochemicals are phenolics (phenolic acids, alkylresorcinols, and flavonoids), carotenoids, vitamin E, γ-oryzanols, dietary fiber, and β-glucan.

Phenolics

The most studied whole grain phytochemicals are phenolics. Phenolics are compounds with one or more aromatic rings and one or more hydroxyl groups. Included in this group of compounds are phenolic acids, alkylresorcinols, and flavonoids.

Total Phenolics

Zieliński and Kozlowska (2000) reported the total phenolic content in seven cereal grains and their various fractions. The total phenolic content of the whole grains studied ranged from 1.5 μg catechin equivalents/mg of lyophilizate in oat (Slwako) to 11.3 μg catechin/mg of lyophilizate in barley (Mobek). When using a different extraction procedure, the total phenolic content of the whole grains studied ranged from 8.9 μg catechin equivalents/mg of lyophilizate in rye (Dañkowski Zlote) to 117.7 μg catechin equivalents/mg of lyophilizate in buckwheat (Kora) (Zielinski and Kozlowska, 2000).

The previous study and others greatly underestimated the total phenolic content of the grain samples by using finely powdered samples and long extraction times in an attempt to maximize the extraction of phenolic compounds from the grains. However, these studies only extracted soluble phenolic compounds and excluded insoluble-bound phenolic compounds, compounds that are esterified to macromolecules and capable of surviving digestion in the upper gastrointestinal tract (Adom and Liu, 2002). As Adom and Liu mentioned, as high as 74% of phenolic compounds of a whole grain can be found in the insoluble bound fraction, as is the case for wheat, corn, oat, and rice (Adom and Liu, 2002).

Sosulski et al. investigated the phenolic acid content, including free phenolic acids, soluble-conjugated phenolic acids, and bound phenolic acids in rice, oats, wheat, and corn flours (Sosulski et al., 1982). Although this study did recognize the existence of phenolic acids in all three forms (free, soluble-conjugated, and insoluble), the study did not investigate the total phenolic content of all three forms.

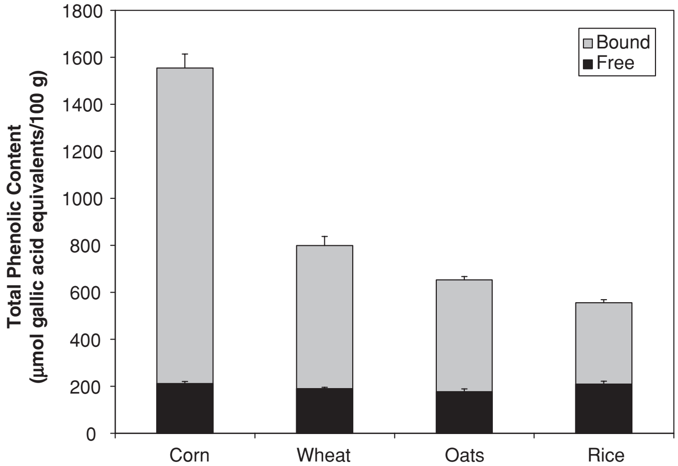
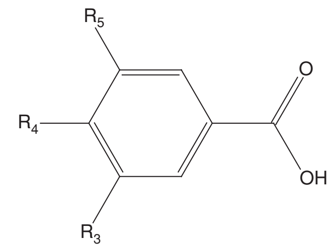


Figure 4 Total phenolic content of whole grains. Adapted from Adom and Liu (2002).

Adom and Liu determined the phytochemical profiles in all three forms of four grains, corn, wheat, oats, and rice. Corn had the most total phenolic content at 1560 ± 60 μmol gallic acid equivalents/100 g, followed by wheat at 800 ± 40 μmol gallic acid equivalents/100 g, oats at 650 ± 20 μmol gallic acid equivalents/100 g and lastly rice at 560 ± 20 μmol gallic acid equivalents/100 g (Adom and Liu, 2002). Corn had the most total phenolic content in the bound fraction at 1340 ± 60 μmol gallic acid equivalents/100 g, followed by wheat at 610 ± 40 μmol gallic acid equivalents/100 g, oats at 480 ± 10 μmol gallic acid equivalents/100 g and rice at 350 ± 10 μmol gallic acid equivalents/100 g (Fig. 4) (Adom and Liu, 2002). Bound phenolics contributed 85% of the total phenolic content in corn, 76% in wheat, 75% in oats, and 62% in rice (Adom and Liu, 2002).

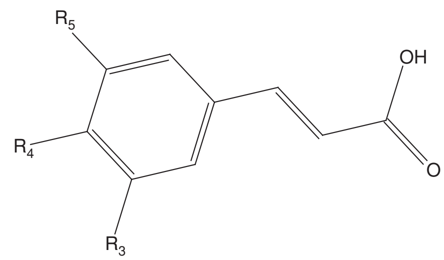
Adom et al. (2005) determined the phytochemical distribution in the milled fractions (endosperm and bran/germ) of different wheat varieties and showed that the majority of health beneficial phytochemicals of whole wheat grains were present in the bran/germ fraction. The total phenolic content in the bran/germ ranged from 2870 to 3120 μmol gallic acid eq./100 g compared to 180 to 200 μmol gallic acid eq./100 g in the endosperm (Adom et al., 2005). The data show that in whole grain wheat flour, the bran/germ fraction contributed 83% of total phenolic content.

Benzoic Acid Derivatives



	R_3	R_4	R_5
p-hydroxybenzoic acid	H	OH	H
gallic acid	OH	OH	OH
syringic acid	OCH_3	OH	OCH_3

Cinnamic Acid Derivatives



	R_3	R_4	R_5
p-coumaric acid	H	OH	H
ferulic acid	OCH_3	OH	H
sinapic acid	OCH_3	OH	OCH_3

Figure 5 Structure of phenolic acids: benzoic acid and cinnamic acid derivatives.

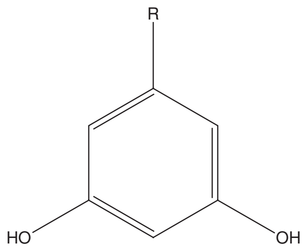
Phenolic Acids

Phenolic acids are hydroxylated compounds that are derived from benzoic acid or cinnamic acid, with derivatives of the latter being more common (Fig. 5). These compounds have been partially attributed to the positive physiological effects of whole grains consumption because of their unique composition and antioxidant activities. Phenolic acids, which are found mainly in the outer layer of grains, can be found as part of a complex structure such as lignin or as a sugar derivative.

Ferulic acid, a derivative of cinnamic acid, is the most abundant phenolic acid in grains. Adom and Liu reported the ferulic acid content of corn, wheat, oats, and rice (Adom and Liu, 2002). Corn had the highest total ferulic acid content at 906 ± 9 μmol ferulic acid/100 g, followed by wheat at 333 ± 16 μmol ferulic acid/100 g, oats at 185 ± 5 μmol ferulic acid/100 g, and rice at 154 ± 9 μmol ferulic acid/100 g (Adom and Liu, 2002). More than 93% of the total ferulic acid content was found in the insoluble-bound fraction. Adom and Liu found that the ratio of free:soluble conjugated:insoluble-bound ferulic acid was 0.1:1:100 (Adom and Liu, 2002).

Other phenolic acids have been reported in grains. Moore et al. determined the free, soluble conjugated, and insoluble bound phenolic acid contents of eight Maryland-grown soft wheat varieties. Total vanillic acid content ranged from 8.4 μg/g (SS560) to 12.7 μg/g (Roane) (Moore et al., 2005). The total syringic acid content ranged from 8.9 μg/g (MV5-46) to 17.8 μg/g (Choptank). The total p-coumaric acid content ranged from 10.4 μg/g (VA97W-024) to 14.1 μg/g (McCormick). In all cases, most of the phenolic acid content was found in the insoluble bound fraction (Moore et al., 2005).

Matilla et al. reported the phenolic acid content of commonly consumed grain products. Rye bran and wheat bran had the highest amount of ferulic acid, 2800 ± 150 and 3000 ± 180 mg/kg, respectively (Mattila et al., 2005). Whole grain rye flour



Name	R	Structural Formula
5-n-pentadecylresorcinol	$C_{15}H_{31}$	CH_3-$(CH_2)_3$-CH=CH-$(CH_2)_8$-CH_2-
5-n-heptadecylresorcinol	$C_{17}H_{35}$	CH_3-$(CH_2)_3$-CH=CH-$(CH_2)_{10}$-CH_2-
5-n-nonadecylresorcinol	$C_{19}H_{39}$	CH_3-$(CH_2)_3$-CH=CH-$(CH_2)_{12}$-CH_2-
5-n-heneicosylresorcinol	$C_{21}H_{43}$	CH_3-$(CH_2)_3$-CH=CH-$(CH_2)_{14}$-CH_2-
5-n-tricosylresorcinol	$C_{23}H_{47}$	CH_3-$(CH_2)_3$-CH=CH-$(CH_2)_{16}$-CH_2-

Figure 6 Structure of alkenylresorcinols.

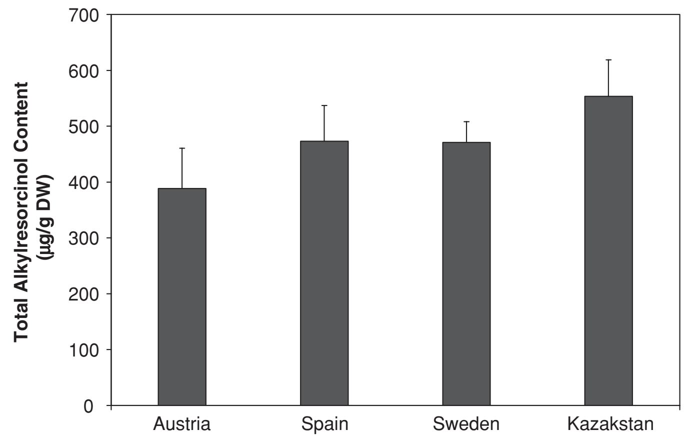


Figure 7 Total alkylresorcinol content of Durum wheat from different countries. Data obtained from Landberg et al. (2006).

and whole-wheat flour also had similarly high amounts of ferulic acid, 860 ± 71, 860 ± 79, and 890 ± 40 mg/kg, respectively. Most likely, the bulk of the ferulic acid in those whole-grain flour samples came from the bran, as the data shows that white wheat flour and organic white wheat flour have ferulic acid contents of only 120 ± 12 and 100 ± 7 mg/kg, respectively (Mattila et al., 2005).

Alk(en)ylresorcinols

Alkylresorcinols and alkenylresorcinols are amphiphillic derivatives of 1,3 dihydroxybenzene with an odd-numbered alkyl or alkenyl chain at position 5 of the benzene ring (Fig. 6). They are generally found in the bran fraction of the grain and, for this reason, are missing in refined grains (Ross et al., 2003).

Ross et al. reported the levels of alkylresorcinols in grains. Rye had the most total alkylresorcinol 734 ± 23 μg/g DW (Ross et al., 2003). Wheat had a total alkylresorcinol content of 583 ± 82 μg/g DW. Barley had a total alkylresorcinol content of 45 ± 5 μg/g DW. Rye was the only grain to have detectable amounts of the 15-carbon alkylresorcinol homologue. The 19 and 21 carbon homologues were prominent in wheat. The 25-carbon homologue was prominent in barley (Ross et al., 2003). No alkylresorcinols were detected in corn, millet, oats, rice, and sorghum.

Mattila et al. determined the amount of alkylresorcinols in whole grains. Of the cereal products analyzed, alkylresorcinol content ranged from 32 mg/kg FW (whole grain barley flour) to 4108 mg/kg FW (whole grain rye bread) (Mattila et al., 2005). Alkylresorcinols were not detected in any oat products, whole grain buckwheat grits, millet grits, long grain parboiled rice, and corn grits. The only alkenylresorcinol detected in these products was the 19:1 homologue. Content of this alkenylresorcinol ranged from 13 mg/kg FW (organic and conventional white wheat flour) to 130 ± 14 mg/kg FW (rye bran) (Mattila et al., 2005).

Landberg et al. reported the total alkylresorcinol content of durum wheat grown in different countries (Landberg et al., 2006). Whole wheat from Kazakstan had the most total alkylresorcinol content (554 ± 65 μg/g DW), followed by Spain (473 ± 65 μg/g DW), Sweden (471 ± 37 μg/g DW) and Austria (389 ± 72 μg/g DW) (Fig. 7). The 21 carbon homologue accounted for roughly 60% of the total alkylresorcinol content in all cases. These results suggest that growing conditions can affect the total alkylresorcinol content of wheat.

Flavonoids

Flavonoids are phenolic compounds consisting of two aromatic rings joined by a three-carbon structure generally found in an oxygenated heterocyclic ring. The differences in the structure of the heterocyclic ring determine the class of flavonoid (Fig. 8). Flavonoids are usually found as conjugates in glycosylated or esterified forms and may account for as much as two thirds of the phenolic content of the North American diet (Liu, 2004). Flavonoids have potent antioxidant activity, and are also linked to reduced risk of major chronic diseases.

Adom et al. reported the flavonoid content of 11 diverse wheat varieties. Total flavonoid content ranged from 122 ± 10 μmol catechin equivalents/g (Roane) to 149 ± 17 μmol catechin equivalents/g (Superior) (Adom et al., 2003). Most of the flavonoid content was located in the bound fraction of the grain ranging from 970 ± 4 μmol catechin equivalents/g (Roane) to 139 ± 17 μmol catechin equivalents/g (Superior). Adom et al. also reported that the majority of total flavonoids of whole wheat grains were present in the bran/germ fraction (Adom et al., 2005). Similar to total phenolics, in whole grain wheat flour, the bran/germ fraction contributed 79% of the total flavonoid content (Adom et al., 2005)

Intake of foods with significant amounts of flavonoid has been associated with health benefits. Naderi et al. showed that dietary intake of flavonoids has been shown to be inversely associated with risk of coronary artery disease (Naderi et al., 2003). Further, Duthie et al. (2000) showed that flavonoids have the ability to prevent oxidation of LDL (Duthie et al., 2000). This prevention of oxidation may be due to the finding that

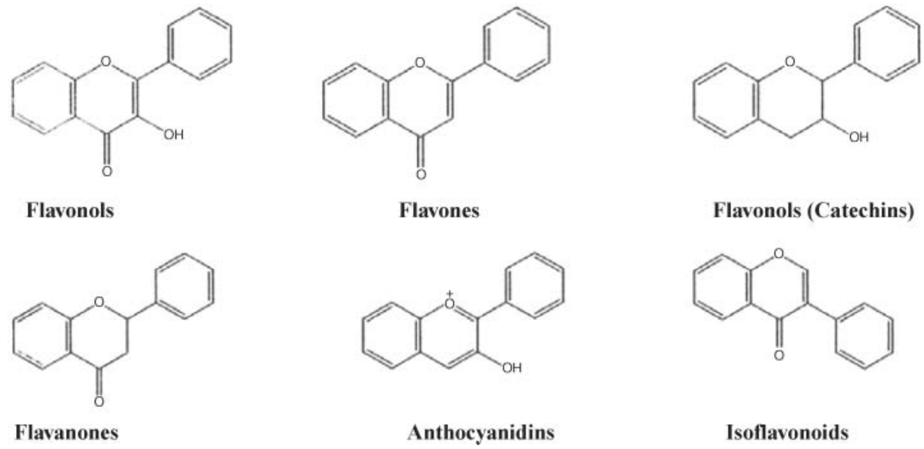


Figure 8 Structure of main classes of dietary flavonoids (Liu, 2004).

some flavonoids have the ability to chelate iron and copper (Yao et al., 2004), two metals that are important in the generation of hydroxyl radical, or the combination of a conjugated ring structure and hydroxyl groups that allows the compound to scavenge a free radical from singlet oxygen.

Carotenoids

Carotenoids, natural pigments of fruits, vegetables, and whole grains, are compounds consisting of a forty-carbon skeleton. These compounds are usually found in the all-trans form in nature. Carotenoids can be cyclized at one or both ends of the structure and may be hydrogenated to different degrees. Carotenoids can also have oxygen-containing functional groups (Fig. 9). One of the most characteristic features of carotenoids is the long series of alternating double and single bonds. This characteristic makes carotenoids very good antioxidants. Carotenoids can scavenge free radicals, becoming free radicals themselves in the process, and remain stable compounds because of their ability to delocalize the free radical amongst its alternating double and single bonds.

Adom et al. reported the carotenoid (lutein, zeazanthin, and β-cryptoxanthin) content of 11 diverse wheat varieties and experimental lines (Adom et al., 2003). β-Cryptoxanthin content from 1.1 $\pm$ 0.1 μg/g (W7985) to 13.3 $\pm$ 0.3 μg/g (Stoa); Zeaxanthin content from 8.7 $\pm$ 0.8 μg/g (Cham1) to 27.1 $\pm$ 0.5 μg/g (Superior); Lutein content ranged from 26.4 $\pm$ 1.4 μg/g (W7985) to 143.5 $\pm$ 6.7 μg/g (Roane).

Brenna and Berardo reported the carotenoid content of corn using Near-Infrared Reflectance Spectroscopy (NIRS) (Brenna and Berardo, 2004). β-Cryptoxanthin content of the 40 corn flour samples was 3.7 $\pm$ 0.2 mg/kg, lutein content was 11.5 $\pm$ 0.8 mg/kg, and zeaxanthin content was 17.5 $\pm$ 1.7 mg/kg.

Miller et al. reported that β-carotene and lycopene were responsible for anticarcinogenesis in fresh fruits and vegetables (Miller et al., 2002). Mannisto et al. (2007) investigated the relationship between dietary carotenoids and risk of colorectal cancer. There was no association between lycopene intake and risk of colorectal cancer in studies that included tomato sauce consumption in the food frequency questionnaire (RR = 1.08; 95% CI = 0.98–1.20) (Mannisto et al., 2007). When pooling the data, there was no association between intake of β-carotene and relative risk of colorectal cancer in subjects aged less than 65 years (RR = 1.08; 95% CI = 0.91–1.28) or subjects aged 65 years or more (RR = 0.90; 95% CI = 0.79–1.02) (Mannisto et al., 2007). Lutein and zeaxanthin intakes greater than

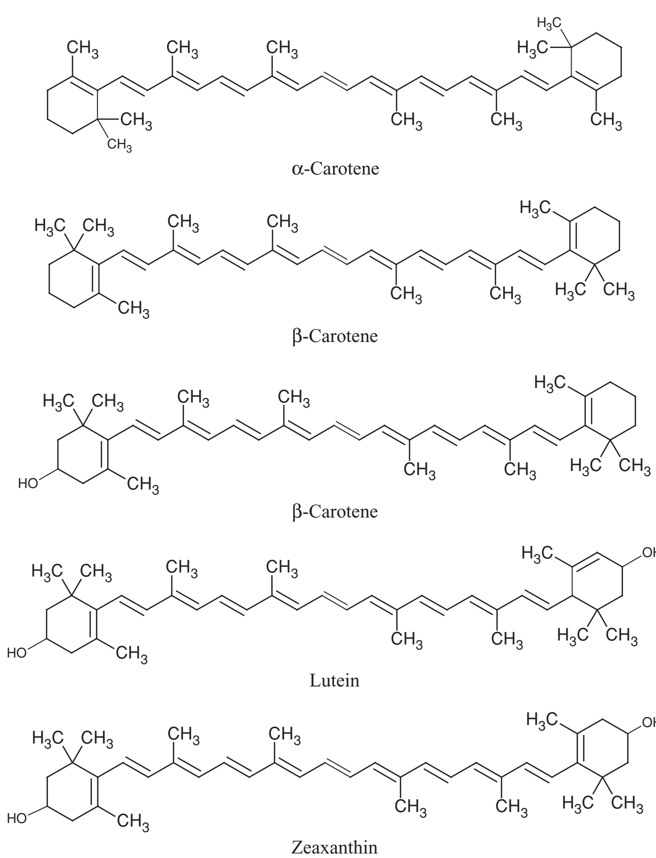
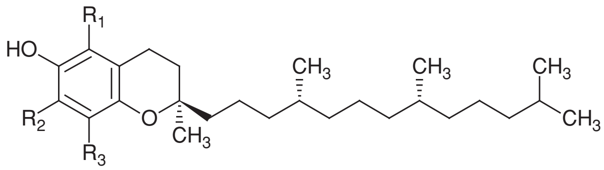
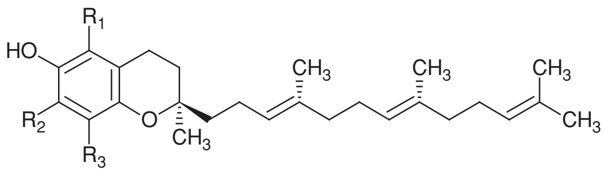


Figure 9 Structure of carotenoids.



Tocopherols



Tocotrienols

	R_1	R_2	R_3
α	CH_3	CH_3	CH_3
β	CH_3	H	CH_3
γ	H	CH_3	CH_3
δ	H	H	CH_3

Figure 10 Structure of vitamin E: tocopherols and tocotrienols.

4000 μg per day, an amount equal to roughly half of a pound of broccoli, was associated with reduced risk of colorectal cancer (RR = 0.87; 95% CI = 0.78–0.98) when compared to a lutein and zeaxanthin intake of less than 1000 μg per day (Mannisto et al., 2007).

Vitamin E

Vitamin E is a collective name for eight lipid-soluble compounds consisting of a chromanol ring and a phytyl tail (Fig. 10). Tocopherols refer to the vitamin E compounds with a fully saturated phytyl tail and tocotrienols refer to the vitamin E compounds with a polyunsaturated phytyl tail. Both tocopherols and tocotrienols vary in the degree of methylation of the chromanol ring, with four vitamers each; α, β, γ, and δ.

Panfili et al. determined the total vitamin E content and vitamer distribution of several whole grains. Barley and soft wheat had the most total vitamin E, 75 ± 13 mg/kg DW and 74 mg/kg DW, respectively (Panfili et al., 2003). Spelt had the lowest overall vitamin E content with 57 ± 8 mg/kg DW. Barley was the only grain to have all eight vitamers of vitamin E. Spelt, durum wheat, soft wheat, and triticale had the fewest number of vitamers, five, even though soft wheat had the second highest total vitamin E content. All six grains contained α-tocopherol. Corn had the least amount of α-tocopherol (4 mg/kg DW) while soft wheat had the most α-tocopherol (16 ± 2 mg/kg DW). β-Tocotrienol was the predominant vitamer in soft wheat, triticale, and spelt, followed by α-tocopherol, β-tocopherol and α-tocotrienol. α-Tocotrienol was the predominant vitamer in oats, followed by α-tocopherol, β-tocotrienol, β-tocopherol, and γ-tocopherol. γ-Tocopherol was the predominant vitamer in corn, followed by γ-tocotrienol, α-tocopherol, and β-tocotrienol. Oats, corn, and barley were the only grains that contained γ-tocopherol while corn and barley were the only grains that contained γ-tocotrienol. Corn and barley had similar γ-tocotrienol content, with 11 and 10 ± 3 mg/kg DW, respectively (Panfili et al., 2003).

In similar studies investigating the content of vitamin E in whole grains, Hakkarainen et al. did not report the presence of γ-tocotrienol in barley (Hakkarainen et al., 1983), while Grela reported γ-tocopherol in both spelt and durum wheat (Grela, 1996). This variation in quantities and presence of the various forms of vitamin E may be due to a lack of standardized methods for extraction and analysis (Panfili et al., 2003).

Vitamin E and its derivatives, mainly α-tocopheryl succinate, have been reported to have health benefits, including inhibition of lipoxygenase activity in vivo, induction of apoptosis in prostate cancer cells via inhibition of Bcl-2, and protection against photo-inflammation when applied on the skin (Konger, 2006; Phoenix et al., 1989; Shiau et al., 2006). Recently, using data from the Women's Health Study, Liu et al. reported that there is an inverse association between vitamin E consumption and risk of type II diabetes in women who had no familial history of type II diabetes (RR = 0.88, 95% CI = 0.78–1.00) (Liu et al., 2006). However, there was no significant association between vitamin E and the development of type II diabetes for all women (RR = 0.95, 95% CI = 0.87–1.05).

γ-Oryzanol

γ-Oryzanols are compounds that consist of a phenolic acid esterified to a sterol. Common γ-oryzanol compounds include cycloartenyl ferulate, 24-methylenecycloartanylferulate, and campesteryl ferulate (Fig. 11).

Generally, γ-oryzanol is found in rice, particularly in the bran fraction, and γ-oryzanol content is around 3000 mg/kg of rice (Xu and Godber, 1999). γ-Oryzanols have also been identified in wheat bran and rye bran. In wheat bran, γ-oryzanol content ranged from 300–390 mg/kg (Hakala et al., 2002). One of the main differences between the γ-oryzanols found in rice and in wheat or rye is that the sterols in rice are dimethyl sterols, with two methyl groups on the fourth carbon of the molecule in rice, whereas the γ-oryzanols in wheat or rye do not have the two methyl groups (Nystrom et al., 2005).

γ-Oryzanol has been shown to have antioxidant activity and serum cholesterol lowering effects. Xu et al. conducted a study using ABAP to initiate the oxidation of cholesterol and assessed the antioxidant potential of γ-oryzanols and vitamin E. The study showed that γ-oryzanols were more effective than tocopherols and tocotrienols in the prevention of cholesterol oxidation (Xu et al., 2001). Other γ-oryzanols, such as cycloartenyl ferulate and 24-methylenecycloartanyl ferulate, were shown to be radical scavengers in multiphase lipid systems (Kikuzaki et al., 2002) and, in the case of campesteryl ferulate, to be inhibitors of UV irradiation-initiated linoleic acid oxidation (Yagi and Ohishi, 1979). Trautwein et al. also reported

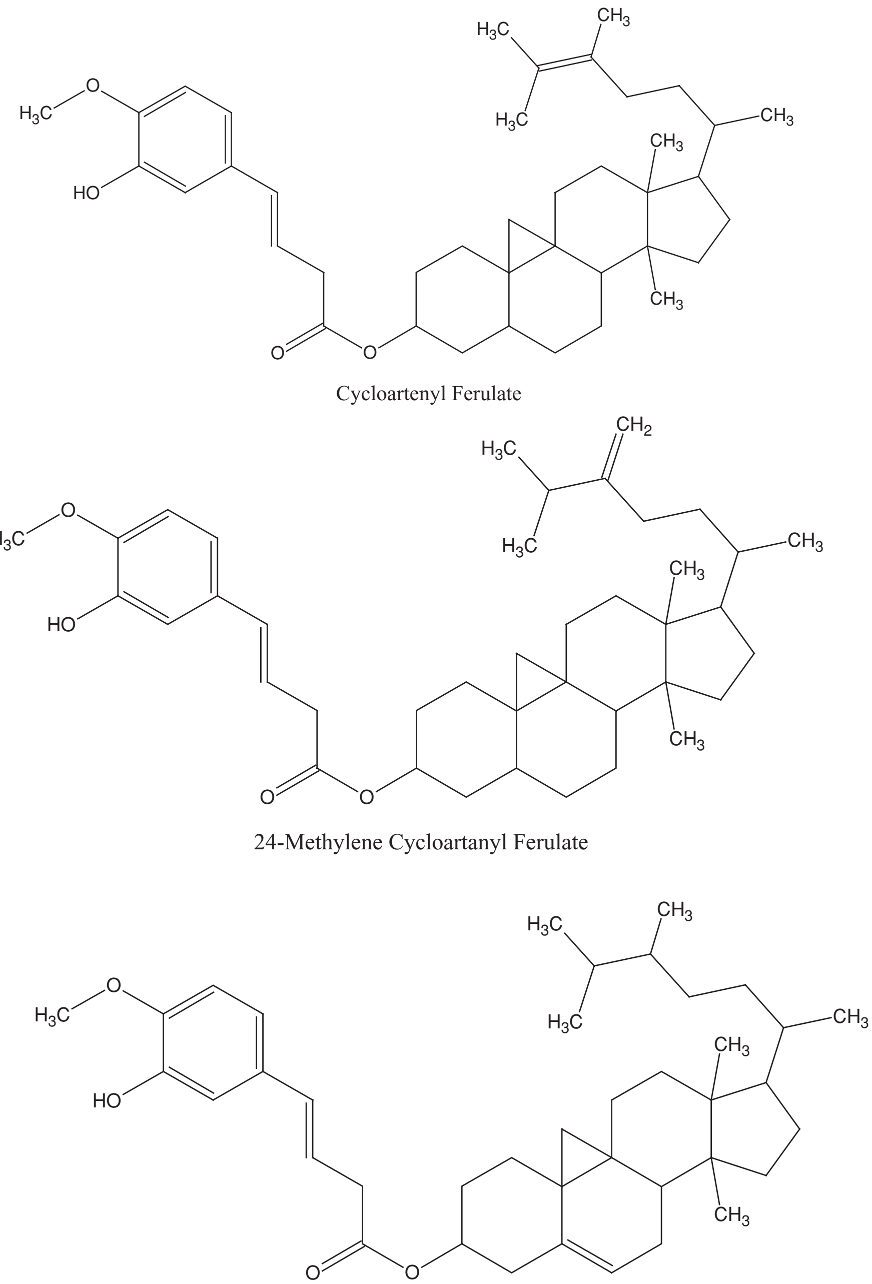


Figure 11 Structure of γ-oryzanols.

that dimethylsterols were as effective in lowering plasma total cholesterol and LDL cholesterol as dimethylstanols, although esterified dimethylsterols had a lesser effect (Trautwein et al., 2002).

Other studies have shown the cholesterol-lowering properties of γ-oryzanol, specifically in rats fed a high cholesterol diet with varying amounts of γ-oryzanol (Shinomiya et al., 1983). Although previous studies have investigated the cholesterol-lowering effect of rice bran oil in a population of schizophrenics and mixed clinical populations including hyperlipidemic men, few studies have looked specifically at the cholesterol-lowering properties of γ-oryzanols in humans (Sasaki et al., 1990; Yoshino et al., 1989). In a clinical trial consisting of hypercholesterolemic men, Berger et al. (2005) investigated the cholesterol-lowering properties of rice bran oils containing different amount of γ-oryzanols. LDL cholesterol decreased by 12% two weeks after the change from a peanut oil-based diet containing no γ-oryzanol to a rice bran oil-based diet containing γ-oryzanol (Berger et al., 2005). Further, the ratio of LDL cholesterol to HDL cholesterol decreased by 19% in four weeks following the change from the peanut oil-based diet to the rice bran oil-based diet (Berger et al., 2005). As the authors noted, other bioactive compounds such as unsaturated fatty acids, tocotrienols, and ferulic acid may had contributed to the cholesterol-lowering effects of rice bran oil consumption besides γ-oryzanol (Berger et al., 2005).

Dietary Fiber

Dietary fiber is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine and are completely or partially fermented in the large intestine (AACC, 2001). Major components of dietary fiber include lignin, hemicellulose, cellulose, and β-glucan. Consumption of dietary fiber has been associated with reduced risk of CHD, type II diabetes, major weight gain, and colorectal cancer (Liu et al., 2003; Meyer et al., 2000; Park et al., 2005; Pereira et al., 2004).

Lignin is an aromatic polymer formed from the condensation of coniferyl, sinapyl, and p-hydroxycimamyl alcohols. This condensation does not require enzymes and, for that reason, the polymerization can occur at random. The process of polymerization of lignin compounds can lead to hydrophobic regions in the plant cell wall. Lignin is found in the cell wall of plants and can form complexes with cellulose and hemicelluloses. Lignin is extremely resistant to degradation, remaining insoluble in 12 M sulfuric acid (Southgate, 1995).

Lignin's chemical heterogeneity, resistance to chemical reaction, conjugation to starches, and uneven and low distribution in plants makes the extraction and analysis of lignin particularly difficult. The Klason procedure is the most commonly used procedure for measuring lignin content and requires the removal of all other compounds in the cell wall with concentrated sulfuric acid followed by gravimetric measurement (Southgate, 1995). However, the Klason procedure does have some limitations. Some lignin is lost in the acid hydrolysis step because lignin is slightly soluble in some lipid solvents. Further, this procedure does not remove cutin and suberin, which can lead to the overestimation of lignin content (Vansoest, 1965). Lignin content can also be determined from acid detergent fibers using the procedure developed by Van Soest and Wine (Vansoest and Wine, 1967).

Hemicellulose is a group of water-insoluble heteropolysaccharides containing pentoses and hexoses. The true chemical nature of hemicelluloses has been difficult to determine due to a lack of uniform extraction, purification, and analytical procedures. Cellulose is a linear polymer of glucose with β-(1,4)-linkages. Due to its linearity and hydrogen bonding between chains, cellulose is highly insoluble and can be crystalline in structure. Sun et al. (2005) investigated the structure of original lignins and hemicelluloses from wheat straw. The hemicellulose consisted mainly of six sugars, rhamnose, arabinose, xylose, mannose, galactose, and glucose (Sun et al., 2005).

β-Glucans are polysaccharides composed of glucopyranosyl units (Zekovic et al., 2005). In grains, β-glucans are linear molecules consisting of 30% of (1$\rightarrow$3) and 70% of (1$\rightarrow$4) β linkages. Compared to cellulose with only β-(1-4)-linkages, the β-(1-3)–linkages interrupt β-(1-4)–linkages to make beta-glucan more flexible, soluble, and viscous. These β-glucans are components of the endosperm cell walls.

The health benefits of β-glucan include lowering of serum cholesterol level and controlling blood sugar (Wood, 1994; Wood et al., 1989). These health benefits are attributed to the viscosity of β-glucan in the gastrointestinal tract. The concentration and molecular weight of the β-glucan polymer affect this viscosity. Because β-glucan is a compound that is characteristic of oats and barley, it can be considered as a marker for whole oats or whole barley. Braaten et al. reported that β-glucan in oat products was responsible for the 10% decline in LDL cholesterol concentrations in hyperchlosterolemic men and women who ate a diet consisting of 5.8 g daily of β-glucan for four weeks (Braaten et al., 1994). This amount of β-glucan would equal roughly 70 g of oat bran per day. The FDA has approved the health claim about β-glucan that 3 g per day of β-glucan from oats can be eaten for a clinically relevant reduction in serum total cholesterol concentration (FDA, 1997). Mackay and Ball did not see a reduction in plasma LDL cholesterol concentration in hypercholesterolemic men and women who consumed a low-fat diet with roughly 3 g daily of β-glucan for six weeks, although they did notice an increase in plasma HDL cholesterol concentration (Mackay and Ball, 1992). β-Glucan also had an effect in controlling blood sugar in diabetes subjects, and was helpful in reducing the elevation in blood sugar levels after a meal (Braaten et al., 1994), probably by delay of gastric emptying, allowing dietary sugar to be absorbed more gradually, or by increasing the tissue sensitivity to insulin.

CONCLUSIONS

A whole grain consists 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 (AACC, 1999). Whole grain products can be intact, having the original composition of bran, germ, and endosperm throughout the lifetime of the product or reconstituted, in which one or more of the original components are added back to the product to achieve the relative proportions found in nature. Whole grain consumption is associated with reduced risk of chronic diseases including cardiovascular disease, type II diabetes, and some cancers (Anderson et al., 2000; Larsson et al., 2005; Lockheart et al., 2007; Munter et al., 2007; Schatzkin et al., 2007). Thus, the Dietary Guidelines for Americans recommends that Americans consume at least 3 ounce-equivalents of whole grain each day (USDA, 2005). The health benefit of whole grain consumption may be due to their unique phytochemicals that are complementary to those in fruits and vegetables when consumed together (Liu, 2007). Whole grain phytochemicals and bioactive compounds including phenolics, carotenoids, vitamin E,

γ-oryzanol, dietary fiber, and β-glucan may be responsible for the health benefits of whole grain consumption in the prevention of chronic diseases. Further research on the effect of milling and processing on bioavailability and health benefits of whole grain phytochemicals is warranted.

REFERENCES

AACC. (1999). AACC Members Agree on Definition of Whole Grain. AACC St. Paul, MN.

AACC. (2001). The Definition of Dietary Fiber. AACC, St. Paul, MN.

Adlercreutz, H. and Mazur, W. (1997). Phyto-oestrogens and Western diseases. *Ann. Med.* **29**:95–120.

Adom, K. K. and Liu, R. H. (2002). Antioxidant activity of grains. *J. Agric. Food Chem*. **50**:6182–6187.

Adom, K. K., Sorrells, M. E. and Liu, R. H. (2003). Phytochemical profiles and antioxidant activity of wheat varieties. *J. Agric. Food Chem*. **51**:7825–7834.

Adom, K. K., Sorrells, M. E. and Liu, R. H. (2005). Phytochemicals and antioxidant activity of milled fractions of different wheat varieties. *J. Agric. Food Chem*. **53**:2297–2306.

Anderson, J. W., Hanna, T. J., Peng, X. and Kryscio, R. J. (2000). Whole grain foods and heart disease risk. *J. Am. Coll. Nutr*. **19**:291S–299S.

Bazzano, L. A., Song, Y. Q., Bubes, V., Good, C. K., Manson, J. E. and Liu, S. M. (2005). Dietary intake of whole and refined grain breakfast cereals and weight gain in men. *Obesity Research*. **13**:1952–1960.

Beeson, W. L., Mills, P. K., Phillips, R. L., Andress, M. and Fraser, G. E. (1989). Chronic disease among Seventh-day Adventists, a low-risk group. Rationale, methodology and description of the population. *Cancer*. **64**:570–581.

Berger, A., Rein, D., Schafer, A., Monnard, I., Gremaud, G., Lambelet, P. and Bertoli, C. (2005). Similar cholesterol-lowering properties of rice bran oil, with varied gamma-oryzanol, in mildly hypercholesterolemic men*. *Eur. J. Nutr.* **44**:163–173.

Braaten, J. T., Wood, P. J., Scott, F. W., Wolynetz, M. S., Lowe, M. K., Bradley-White, P. and Collins, M. W. (1994). Oat beta-glucan reduces blood cholesterol concentration in hypercholesterolemic subjects. *Eur. J. Clin. Nutr*. **48**:465–474.

Brenna, O. V. and Berardo, N. (2004). Application of near-infrared reflectance spectroscopy (NIRS) to the evaluation of carotenoids content in maize. *J. Agric. Food Chem*. **52**:5577–5582.

Burros, M. (2006). Whole Grain Labels Become More Transparent. **In**: New York Times, New York.

Chan, J. M., Wang, F. and Holly, E. A. (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**:1174–1185.

Distaam, E. M. and Carcea, M. (2001). Pasta from nontraditional raw materials. *Cereal Foods World* 46:522–530.

Duthie, G. G., Duthie, S. J. and Kyle, J. A. M. (2000). Plant polyphenols in cancer and heart disease: Implications as nutritional antioxidants. *Nutr. Res. Rev.* **13**:79–106.

Erkkila, A. T., Herrington, D. M., Mozaffarian, D. and Lichtenstein, A. H. (2005). Cereal fiber and whole-grain intake are associated with reduced progression of coronary-artery atherosclerosis in postmenopausal women with coronary artery disease. *American Heart Journal*. **150**:94–101.

FDA. (1997). FDA allows whole oat foods to make health claim on reducing the risk of heart disease. **In**: FDA Talk Paper.

Fraser, G. E. (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*. **70**:532S–538S.

Fung, T. T., Hu, F. B., Pereira, M. A., Liu, S., Stampfer, M. J., Colditz, G. A. and Willett, W. C. (2002). Whole-grain intake and the risk of type 2 diabetes: a prospective study in men. *Am. J. Clin. Nutr*. **76**:535–540.

Grela, E. R. (1996). Nutrient composition and content of antinutritional factors in spelt (Triticum spelta L) cultivars. *Journal of the Science of Food and Agriculture.* **71**:399–404.

Hakala, P., Lampi, A. M., Ollilainen, V., Werner, U., Murkovic, M., Wahala, K., Karkola, S. and Piironen, V. (2002). Steryl phenolic acid esters in cereals and their milling fractions. *J. Agric. Food Chem*. **50**:5300–5307.

Hakkarainen, R. V. J., Tyopponen, J. T. and Bengtsson, S. G. (1983). Changes in the content and composition of vitamin-E in damp barley stored in airtight bins. *Journal of the Science of Food and Agriculture*. **34**:1029–1038.

Jacobs, D. R., Jr., Meyer, K. A., Kushi, L. H. and Folsom, A. R. (1998). Whole-grain intake may reduce the risk of ischemic heart disease death in post-menopausal women: The Iowa Women's Health Study. *Am. J. Clin. Nutr*. **68**:248–257.

Jacobs, D. R., Jr., Slavin, J. and Marquart, L. (1995). Whole grain intake and cancer: A review of the literature. *Nutr. Cancer*. **24**:221–229.

Kasum, C. M., Nicodemus, K., Harnack, L. J., Jacobs, D. R. and Folsom, A. R. (2001). Whole grain intake and incident endometrial cancer: The Iowa Women's Health Study. *Nutrition and Cancer-an International Journal*. **39**:180–186.

Kikuzaki, H., Hisamoto, M., Hirose, K., Akiyama, K. and Taniguchi, H. (2002). Antioxidant properties of ferulic acid and its related compounds. *J. Agric. Food Chem*. **50**:2161–2168.

Konger, R. L. (2006). A new wrinkle on topical vitamin E and photo-inflammation: Mechanistic studies of a hydrophilic gamma-tocopherol derivative compared with alpha-tocopherol. *J. Invest. Dermatol*. **126**:1447–1449.

Landberg, R., Kamal-Eldin, A., Andersson, R. and Aman, P. (2006). Alkylresorcinol content and homologue composition in durum wheat (Triticum durum) kernels and pasta products. *J. Agric. Food Chem*. **54**:3012–3014.

Larsson, S. C., Giovannucci, E., Bergkvist, L. and Wolk, A. (2005). Whole grain consumption and risk of colorectal cancer: A population-based cohort of 60 000 women. *British Journal of Cancer*. **92**:1803–1807.

Liu, R. H., (2003). Health benefits of fruits and vegetables are from additive and synergistic combination of phytochemicals. *Am. J. Clin. Nutr.* **78**:517S-520S.

Liu, R. H. (2004). Potential synergy of phytochemicals in cancer prevention: Mechanism of action. *J. Nutr.* 134:3479S-3485S.

Liu, R. H., (2007). Whole grain phytochemicals and health. *Journal of Cereal Science*. **46**(3):207–219.

Liu, S., Manson, J. E., Stampfer, M. J., Hu, F. B., Giovannucci, E., Colditz, G. A., Hennekens, C. H. and Willett, W. C. (2000). A prospective study of whole-grain intake and risk of type 2 diabetes mellitus in US women. *Am. J. Public Health*. **90**:1409–1415.

Liu, S., Stampfer, M. J., Hu, F. B., Giovannucci, E., Rimm, E., Manson, J. E., Hennekens, C. H. and Willett, W. C. (1999). Whole-grain consumption and risk of coronary heart disease: Results from the Nurses' Health Study. *Am. J. Clin. Nutr*. **70**:412–419.

Liu, S., Willett, W. C., Manson, J. E., Hu, F. B., Rosner, B. and 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**:920–927.

Liu, S. M., Lee, I. M., Song, Y. Q., Van Denburgh, M., Cook, N. R., Manson, J. E. and Buring, J. E. (2006). Vitamin E and risk of type 2 diabetes in the Women's Health Study randomized controlled trial. *Diabetes*. **55**:2856–2862.

Lockheart, M. S., Steffen, L. M., Rebnord, H. M., Fimreite, R. L., Ringstad, J., Thelle, D. S., Pedersen, J. I. and Jacobs, D. R., Jr. (2007). Dietary patterns, food groups and myocardial infarction: A case-control study. *Br J. Nutr.* **98**:380–387.

Lutsey, P. L., Jacobs, D. R., Kori, S., Mayer-Davis, E., Shea, S., Steffen, L. M., Szklo, M. and Tracy, R. (2007). Whole grain intake and its cross-sectional association with obesity, insulin resistance, inflammation, diabetes and subclinical CVD: The MESA study. *British Journal of Nutrition*. **98**:397–405.

Mackay, S. and Ball, M. J. (1992). Do beans and oat bran add to the effectiveness of a low-fat diet? *Eur. J. Clin. Nutr*. **46**:641–648.

Mannisto, S., Yaun, S. S., Hunter, D. J., Spiegelman, D., Adami, H. O., Albanes, D., van den Brandt, P. A., Buring, J. E., Cerhan, J. R., Colditz,

G. A., Freudenheim, J. L., Fuchs, C. S., Giovannucci, E., Goldbohm, R. A., Harnack, L., Leitzmann, M., McCullough, M. L., Miller, A. B., Rohan, T. E., Schatzkin, A., Virtamo, J., Willett, W. C., Wolk, A., Zhang, S. M. and Smith-Warner. S. A. (2007). Dietary carotenoids and risk of colorectal cancer in a pooled analysis of 11 cohort studies. *American Journal of Epidemiology*. **165**:246–255.

Mattila, P., Pihlava, J. M. and Hellstrom, J. (2005). Contents of phenolic acids, alkyl- and alkenylresorcinols and avenanthramides in commercial grain products. *J. Agric. Food Chem*. **53**:8290–8295.

Meyer, K. A., Kushi, L. H., Jacobs, D. R., Jr., Slavin, J., Sellers, T. A. and Folsom, A. R. (2000). Carbohydrates, dietary fiber and incident type 2 diabetes in older women. *Am. J. Clin. Nutr*. **71**:921–930.

Miller, E. C., Hadley, C. W., Schwartz, S. J., Erdman, J. W., Boileau, T. W. M. and Clinton, S. K. (2002). Lycopene, tomato products and prostate cancer prevention. Have we established causality? *Pure and Applied Chemistry*. **74**:1435–1441.

Montonen, J., Knekt, P., Jarvinen, R., Aromaa, A. and Reunanen, A. (2003). Whole-grain and fiber intake and the incidence of type 2 diabetes. *Am. J. Clin. Nutr*. **77**:622–629.

Moore, J., Hao, Z., Zhou, K., Luther, M., Costa, J. and Yu, L. L. (2005). Carotenoid, tocopherol, phenolic acid and antioxidant properties of Maryland-grown soft wheat. *J. Agric. Food Chem*. **53**:6649–6657.

Munter, J. S. L. d., Hu, F. B., Spiegelman, D., Franz, M. and Dam, R. M. v. (2007). Whole grain, bran and germ intake and risk of type 2 diabetes: a prospective cohort study and systematic review. *PLoS Medicine*. **4**:e261.

Naderi, G. A., Asgary, S., Sarraf-Zadegan, N. and Shirvany, H. (2003). Antioxidant effect of flavonoids on the susceptibility of LDL oxidation. *Mol. Cell Biochem*. **246**:193–196.

Newby, P. K., Maras, J., Bakun, P., Muller, D., Ferrucci, L. and Tucker, K. L. (2007). Intake of whole grains, refined grains and cereal fiber measured with 7-d diet records and associations with risk factors for chronic disease. *American Journal of Clinical Nutrition*. **86**:1745–1753.

Nicodemus, K. K., Jacobs, D. R., Jr. and Folsom, A. R. (2001). Whole and refined grain intake and risk of incident postmenopausal breast cancer (United States). *Cancer Causes Control*. **12**:917–925.

Nystrom, L., Makinen, M., Lampi, A. M. and Piironen, V. (2005). Antioxidant activity of steryl ferulate extracts from rye and wheat bran. *J. Agric. Food Chem*. **53**:2503–2510.

Panfili, G., Fratianni, A. and Irano, M. (2003). Normal phase high-performance liquid chromatography method for the determination of tocopherols and tocotrienols in cereals. *J. Agric. Food Chem*. **51**:3940–3944.

Park, Y., Hunter, D. J., Spiegelman, D., Bergkvist, L., Berrino, F., van den Brandt, P. A., Buring, J. E., Colditz, G. A., Freudenheim, J. L., Fuchs, C. S., Giovannucci, E., Goldbohm, R. A., Graham, S., Harnack, L., Hartman, A. M., Jacobs, D. R., Jr., Kato, I., Krogh, V., Leitzmann, M. F., McCullough, M. L., Miller, A. B., Pietinen, P., Rohan, T. E., Schatzkin, A., Willett, W. C., Wolk, A., Zeleniuch-Jacquotte, A., Zhang, S. M. and Smith-Warner. S. A. (2005). Dietary fiber intake and risk of colorectal cancer: A pooled analysis of prospective cohort studies. *Jama*. **294**:2849–2857.

Pereira, M. A., O'Reilly, E., Augustsson, K., Fraser, G. E., Goldbourt, U., Heitmann, B. L., Hallmans, G., Knekt, P., Liu, S., Pietinen, P., Spiegelman, D., Stevens, J., Virtamo, J., Willett, W. C. and Ascherio. A. (2004). Dietary fiber and risk of coronary heart disease: A pooled analysis of cohort studies. *Arch. Intern. Med*. **164**:370–376.

Phoenix, J., Edwards, R. H. and Jackson, M. J. (1989). Inhibition of Ca2+-induced cytosolic enzyme efflux from skeletal muscle by vitamin E and related compounds. *Biochem. J*. **257**:207–213.

Pietinen, P., Malila, N., Virtanen, M., Hartman, T. J., Tangrea, J. A., Albanes, D. and Virtamo, J. (1999). Diet and risk of colorectal cancer in a cohort of Finnish men. *Cancer Causes Control*. **10**:387–396.

Pietinen, P., Rimm, E. B., Korhonen, P., Hartman, A. M., Willett, W. C., Albanes, D. and Virtamo, J. (1996). Intake of dietary fiber and risk of coronary heart disease in a cohort of Finnish men. The Alpha-Tocopherol, Beta-Carotene Cancer Prevention Study. *Circulation*. **94**:2720–2727.

Rohan, T. E., Hiller, J. E. and McMichael, A. J. (1993). Dietary factors and survival from breast cancer. *Nutr. Cancer*. **20**:167–177.

Ross, A. B., Shepherd, M. J., Schupphaus, M., Sinclair, V., Alfaro, B., Kamal-Eldin, A. and Aman, P. (2003). Alkylresorcinols in cereals and cereal products. *Journal of Agricultural and Food Chemistry*. **51**:4111–4118.

Salmeron, J., Ascherio, A., Rimm, E. B., Colditz, G. A., Spiegelman, D., Jenkins, D. J., Stampfer, M. J., Wing, A. L. and Willett, W. C. (1997). Dietary fiber, glycemic load and risk of NIDDM in men. *Diabetes Care*. **20**:545–550.

Sasaki, J., Takada, Y., Handa, K., Kusuda, M., Tanabe, Y., Matsunaga, A. and Arakawa, K. (1990). Effects of gamma-oryzanol on serum lipids and apolipoproteins in dyslipidemic schizophrenics receiving major tranquilizers. *Clin. Ther*. **12**:263–268.

Schatzkin, A., Mouw, T., Park, Y., Subar, A. F., Kipnis, V., Hollenbeck, A., Leitzmann, M. F. and Thompson, F. E. (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**:1353–1360.

Schulze, M. B., Liu, S. M., Rimm, E. B., Manson, J. E., Willett, W. C. and Hu, F. B. (2004). Glycemic index, glycemic load and dietary fiber intake and incidence of type 2 diabetes in younger and middle-aged women. *American Journal of Clinical Nutrition*. **80**:348–356.

Seib, P. A., Liang, X., Guan, F., Liang, Y. T. and Yang, H. C. (2000). Comparison of Asian noodles from some hard white and hard red wheat flours. *Cereal Chemistry*. **77**:816–822.

Shiau, C. W., Huang, J. W., Wang, D. S., Weng, J. R., Yang, C. C., Lin, C. H., Li, C. and Chen, C. S. (2006). alpha-Tocopheryl succinate induces apoptosis in prostate cancer cells in part through inhibition of Bcl-xL/Bcl-2 function. *J. Biol. Chem*. **281**:11819–11825.

Shinomiya, M., Morisaki, N., Matsuoka, N., Izumi, S., Saito, Y., Kumagai, A., Mitani, K. and Morita, S. (1983). Effects of gamma-oryzanol on lipid metabolism in rats fed high-cholesterol diet. *Tohoku J. Exp. Med*. **141**:191–197.

Smigel, K. (1992). Fewer colon polyps found in men with high-fiber, low-fat diets. *J. Natl. Cancer Inst*. **84**:80–81.

Sosulski, F., Krygier, K. and Hogge, L. (1982). Free, esterified and insoluble-bound phenolic-acids. 3. composition of phenolic-acids in cereal and potato flours. *Journal of Agricultural and Food Chemistry*. **30**:337–340.

Southgate, D. A. T. (1995). Dietary Fibre Analysis. The Royal Society of Chemistry.

Sun, X. F., Sun, R., Fowler, P. and Baird, M. S. (2005). Extraction and characterization of original lignin and hemicelluloses from wheat straw. *J. Agric. Food Chem*. **53**:860–870.

Trautwein, E. A., Schulz, C., Rieckhoff, D., Kunath-Rau, A., Erbersdobler, H. F., de Groot, W. A. and Meijer, G. W. (2002). Effect of esterified 4-desmethylsterols and -stanols or 4,4′-dimethylsterols on cholesterol and bile acid metabolism in hamsters. *Br. J. Nutr*. **87**:227–237.

USDA. (1995). Nutrition and Your Health: Dietary Guidelines for Americans. USDA Human Nutrition Information Service, Hyattsville, MD.

USDA. (2005). Dietary Guidelines for Americans 2005. USDA Human Nutrition Information Service Hyattsville, MD.

van Dam, R. M., Rimm, E. B., Willett, W. C., Stampfer, M. J. and Hu, F. B. (2002). Dietary patterns and risk for type 2 diabetes mellitus in U. S. men. *Ann. Intern. Med*. **136**:201–209.

Vansoest, P. J. (1965). Use of detergents in analysis of fibrous feeds. 3. Study of effects of heating and drying on yield of fiber and lignin in forages. *Journal of the Association of Official Agricultural Chemists*. 48:785.

Vansoest, P. J. and Wine, R. H. (1967). Use of detergents in analysis of fibrous feeds. 4. Determination of plant cell-wall constituents. *Journal of the Association of Official Analytical Chemists*. 50:50.

Vocke, G. A. E. (2007). Wheat Situtation and Outlook Yearbook USDA Economic Research Service—Market and Trade Economics Division.

Wang, L., Gaziano, J. M., Liu, S. M., Manson, J. E., Buring, J. E. and Sesso, H. D. (2007). Whole- and refined-grain intakes and the risk of hypertension in women. *American Journal of Clinical Nutrition*. **86**:472–479.

WGC. (2007). Whole Grain Facts and Figures. Whole Grain Council Facts and Figures http://www.wholegrainscouncil.org/WGFacts+Figures.htm.

Willett, W. C., Hunter, D. J., Stampfer, M. J., Colditz, G., Manson, J. E., Spiegelman, D., Rosner, B., Hennekens, C. H. and Speizer,

F. E. (1992). Dietary-fat and fiber in relation to risk of breast-cancer—an 8-year follow-up. *Jama-Journal of the American Medical Association*. **268**:2037–2044.

Wolk, A., Manson, J. E., Stampfer, M. J., Colditz, G. A., Hu, F. B., Speizer, F. E., Hennekens, C. H. and Willett, W. C. (1999). Long-term intake of dietary fiber and decreased risk of coronary heart disease among women. *Jama*. **281**:1998–2004.

Wood, P. J. (1994). Evaluation of oat bran as a soluble fiber source–characterization of oat beta-glucan and its effects on glycemic response. *Carbohydrate Polymers*. **25**:331–336.

Wood, P. J., Anderson, J. W., Braaten, J. T., Cave, N. A., Scott, F. W. and Vachon, C. (1989). Physiological-effects of beta-D-glucan rich fractions from oats. *Cereal Foods World*. **34**:878–882.

Xu, Z. and Godber, J. S. (1999). Purification and identification of components of gamma-oryzanol in rice bran Oil. *J. Agric. Food Chem*. **47**:2724–2728.

Xu, Z., Hua, N. and Godber, J. S. (2001). Antioxidant activity of tocopherols, tocotrienols and gamma-oryzanol components from rice bran against cholesterol oxidation accelerated by 2,2′-azobis(2-methylpropionamidine) dihydrochloride. *J. Agric. Food Chem*. **49**:2077–2081.

Yagi, K. and Ohishi, N. (1979). Action of ferulic acid and its derivatives as antioxidants. *J. Nutr. Sci. Vitaminol (Tokyo)*. **25**:127–130.

Yao, L. H., Jiang, Y. M., Shi, J., Tomas-Barberan, F. A., Datta, N., Singanusong, R. and Chen, S. S. (2004). Flavonoids in food and their health benefits. *Plant Foods Hum. Nutr*. **59**:113–122.

Yoshino, G., Kazumi, T., Amano, M., Tateiwa, M., Yamasaki, T., Takashima, S., Iwai, M., Hatanaka, H. and Baba, S. (1989). Effects of gamma-oryzanol on hyperlipidemic subjects. *Current Therapeutic Research-Clinical and Experimental*. **45**:543–552.

Zekovic, D. B., Kwiatkowski, S., Vrvic, M. M., Jakovljevic, D. and Moran, C. A. (2005). Natural and modified (1→3)-beta-D-glucans in health promotion and disease alleviation. *Crit. Rev. Biotechnol*. **25**:205–230.

Zielinski, H. and Kozlowska, H. (2000). Antioxidant activity and total phenolics in selected cereal grains and their different morphological fractions. *Journal of Agricultural and Food Chemistry*. **48**:2008–2016.