Cereal Fiber and Health: Current Knowledge

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The AACC International (AACCI) Scientific Advisory Panel and AACCI leaders have identified “Unifying the Grain Health Benefits Message” as one of five scientific opportunity areas. To this end, a two-day thought-leader meeting was held in January 2013 (21). One of the proposed action steps from this meeting was to develop a review of the benefits of grains. This is the third in a series of papers published in Cereal Foods World to provide unified grain health messages as part of this scientific initiative.

ABSTRACT

The average American consumes only half of the recommended daily intake of fiber, and despite dietary guidance to increase intake, fiber consumption has not increased. Thus, additional consumer choices and consumer-oriented messaging on the sources and benefits of fiber is warranted. Fiber, in particular cereal fiber, is associated with protection against development of gastrointestinal disorders such as constipation, as well as weight gain, cardiovascular disease, type 2 diabetes, and total mortality. Fiber in cereal grains is primarily located in the bran: wheat bran is 4 times higher in fiber than whole grain wheat and more than 10 times higher in fiber than white wheat flour. Cereal fiber and bran contain fewer calories than whole grains or white flour; and bran is a concentrated source of other bioactive compounds that may contribute to many of the health benefits associated with cereal fiber and whole grains. Formulating foods with cereal fiber and bran would provide consumers with more choices for health-promoting foods, promote healthier dietary practices, and help individuals meet public health recommendations for fiber intake without increasing calorie consumption.

Fiber is a long-standing and sometimes contentious topic of discussion, including definition, methodology, and health benefits. Various fiber definitions exist, e.g., AACCI, Codex Alimentarius Commission, Institute of Medicine (IOM), Health Canada, European Commission, Food Standards Australia New Zealand, and others. Definitions typically incorporate the following common elements: carbohydrate materials that are not digested or absorbed in the small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibers promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation.

Regarding the physiological effects listed, AACCI suggested that as additional scientific evidence accumulates on the link between fiber and health, the definition could be updated to reflect the changing state of knowledge.

In 2005 the IOM used three distinct terms to describe fiber (18)—dietary fiber, functional fiber, and total fiber (sum of dietary and functional fiber)—where wheat bran and oat bran would be considered intrinsic dietary fiber sources and wheat arabinoxylan and oat β-glucan would be considered isolated functional fibers. The IOM set adequate intake levels for total fiber at 38 and 25 g/day for young men and women, respectively, based on epidemiological data suggesting that an intake of 14 g of dietary fiber/1,000 kcal, particularly from cereals, promotes heart health.

Currently, most Americans do not meet recommended fiber intakes, and fiber consumption has not progressively increased over time (22). This could reflect both inadequate intake and limitations in diet and nutrient assessment tools, e.g., tools in use potentially may not capture all fiber sources available in the food supply. Mean daily fiber intake by adults aged 18 years and older who were surveyed as part of the National Health and Nutrition Examination Survey was 15.6 g/day in 1999–2000, 16.1 g/day in 2001–2002, 15.5 g/day in 2003–2004, 15.8 g/day in 2005–2006, and 15.9 g/day in 2007–2008 (22). Individuals with self-reported excellent health status tended to have higher fiber intakes. For example, individuals with a body mass index (BMI) ≥30 reported lower fiber intakes (14.6–15.4 g/day) compared with those with a BMI <30 (15.6–16.8 g/day). Grain foods contributed the most to fiber intake (43.7%), followed by vegetables (20.8%), fruits (13.0%), and dry beans, peas, and other legumes (10.1%).

The 2010 USDA Dietary Guidelines for Americans (38) reported that fiber intake is low enough to be considered a public health concern. Increased consumption of bran-rich foods was identified as an option that could contribute to improved fiber intake (38). Bran is a concentrated source of cereal fiber, vitamins, minerals, and phytonutrients and may contribute to some of the benefits associated with whole grain intakes while providing less starch and fewer calories at the same total weight. Use of cereal fiber and bran-based ingredients would provide consumers with more healthy food choices, promote healthier dietary practices, and help individuals meet fiber recommendations while limiting intake of excess calories.

Nutrient Composition of Bran, Whole Grains, and Debranned Grains

Wheat, oats, rice, corn, and rye are the most commonly consumed grains in the United States, with wheat constituting 66–75% of the total consumption (36). The major anatomical component of a whole grain is the endosperm, which contributes 50–75% of the starch in the grain and is the major energy source for the embryo during germination. Other anatomical components include the bran (15%) and germ (5%). Cereal grains typically contain <20% fiber: from as low as 3.5% in brown rice to 15.1 and 17.3% in rye and hulled barley, respectively (37).

Table I compares the composition of wheat, rice, and oats with regard to their fiber and select micronutrient contents in...
There is a progressive decline in fiber content from bran to whole grain to debranned flour at the same weight. For example, the fiber content of wheat bran is 4 times higher than that of whole grain wheat and more than 10 times higher than that in the debranned complement. In addition, grain fractions differ in their distribution of specific fiber types. For example, oat β-glucan, which is known to have cholesterol-lowering effects in humans, is more concentrated in the bran (3). The energy content of bran is always lower than that of whole grain or debranned flour for the same weight due to the fiber content and removal of the endosperm (37).

Similarly, distribution of minerals and vitamins varies throughout the grain. With the exception of selenium, the mineral content of rice bran is typically 2- to 13-fold higher than that of brown rice and 2- to 4-fold higher in wheat bran than in whole wheat flour (37). Bran typically also has a higher vitamin content. For example, wheat bran is higher in thiamin, riboflavin, niacin, pantothenic acid, vitamin B<sub>6</sub>, folate, and vitamin E than are whole and white wheat flours (37).

The antioxidant capacity of cereal grains depends on the species and anatomical fraction of the grain, with relevant bioactive components primarily associated with the bran and germ. Martinez-Tome et al. (24) measured antioxidant capacity across a selection of grain-based ingredients using several different assays and reported that antioxidant activity was consistently higher for oat bran than for whole oat flour and higher for wheat bran than for wheat flour. Adom et al. (2) studied the distribution of phytochemicals and antioxidant activity in different milled fractions of wheat, particularly comparing the endosperm with the bran and germ. In the study, bran and germ contributed 83% of the total phenolic content, 79% of the total flavonoid content, 51% of the total lutein content, 78% of the total zeaxanthin content, 42% of the total β-cryptoxanthin content, and 85–94% of the antioxidant activity of whole wheat flour. Thus, the bran is a concentrated source of cereal fiber that together with the germ plays an important role as a carrier of the bioactive compounds found in whole grains and, thus, is a potentially important effector of associated health benefits.

### Effects Associated with Cereal Fiber Intake

#### Gastrointestinal Health and Cancer Prevention

Increased fiber intake, in particular cereal fiber, has been linked to improvements in gastrointestinal function, primarily because certain fibers can increase stool weight (bulking) and/or stool frequency (8,44). Wheat bran and psyllium have been recommended as laxatives for treating constipation (13). In particular, wheat bran fiber is noted for its high fecal bulking capacity relative to other fibers (11,18), and the Canadian Food Inspection Agency has approved a claim for wheat bran fiber and laxation (9). The properties of fiber linked to gastrointestinal function include fermentability (leading to the production of short-chain fatty acids such as butyrate, which is the preferred energy source for colonic mucosa cells and may potentially accelerate transit time and suppress colonic inflammation), stimulation of bacterial proliferation, viscosity, and water holding capacity (8,13).

Fiber has also been linked to a reduced risk of certain cancers, such as colon and breast cancers, and mortality from cancer (4,5,30). Specifically, cereal fiber, but not fruit or vegetable fiber, was inversely associated with colon cancer risk and mortality from cancer in several studies (5,30,34). Potential protective mechanisms proposed for fiber include alteration or dilution of aqueous-phase bile acids, reduced colonic pH, growth and rebalancing of intestinal microflora, increased fecal bulk and reduced transit time, reduction in fecal mutagenicity, altered mucosal enzyme activity, neurogenic effects caused by changes in fecal bulk or short-chain fatty acids and gut hormones or other peptide growth factors (6).

The U.S. Food and Drug Administration (FDA) has approved a health claim related to grain products that contain fiber and

### Table I. Nutrient composition of edible portions of different cereal grains and cereal grain components (per 100 g, as is)<sup>a</sup>

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<td>Proximate</td>
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<tr>
<td>Energy (kcal)</td>
<td>216</td>
<td>340</td>
<td>364</td>
<td>316</td>
<td>370</td>
<td>365</td>
<td>246</td>
<td>389</td>
<td>404</td>
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<tr>
<td>Fiber (g)</td>
<td>42.8</td>
<td>10.7</td>
<td>2.7</td>
<td>21.0</td>
<td>3.5</td>
<td>1.3</td>
<td>15.4</td>
<td>10.6</td>
<td>6.5</td>
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<td>Mineral</td>
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<tr>
<td>Calcium (mg)</td>
<td>73</td>
<td>34</td>
<td>15</td>
<td>57</td>
<td>23</td>
<td>28</td>
<td>58</td>
<td>54</td>
<td>55</td>
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<td>Iron (mg)</td>
<td>10.57</td>
<td>3.60</td>
<td>1.17</td>
<td>18.54</td>
<td>1.47</td>
<td>0.80</td>
<td>5.41</td>
<td>4.72</td>
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<td>Magnesium (mg)</td>
<td>611</td>
<td>137</td>
<td>22</td>
<td>781</td>
<td>143</td>
<td>25</td>
<td>235</td>
<td>177</td>
<td>144</td>
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<tr>
<td>Phosphorus (mg)</td>
<td>1,013</td>
<td>357</td>
<td>108</td>
<td>1,677</td>
<td>333</td>
<td>115</td>
<td>734</td>
<td>523</td>
<td>452</td>
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<td>Potassium (mg)</td>
<td>1,182</td>
<td>363</td>
<td>107</td>
<td>1,485</td>
<td>223</td>
<td>115</td>
<td>566</td>
<td>429</td>
<td>371</td>
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<td>Zinc (mg)</td>
<td>7.27</td>
<td>2.60</td>
<td>0.70</td>
<td>6.04</td>
<td>2.02</td>
<td>1.09</td>
<td>3.11</td>
<td>3.97</td>
<td>3.20</td>
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<tr>
<td>Copper (mg)</td>
<td>0.998</td>
<td>0.410</td>
<td>0.144</td>
<td>0.728</td>
<td>0.277</td>
<td>0.220</td>
<td>0.403</td>
<td>0.626</td>
<td>0.437</td>
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<tr>
<td>Manganese (mg)</td>
<td>11.500</td>
<td>4.067</td>
<td>0.682</td>
<td>14.210</td>
<td>3.743</td>
<td>1.088</td>
<td>5.630</td>
<td>4.916</td>
<td>4.019</td>
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<tr>
<td>Selenium (mg)</td>
<td>77.6</td>
<td>61.8</td>
<td>33.9</td>
<td>15.6</td>
<td>25.4</td>
<td>15.1</td>
<td>45.2</td>
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<tr>
<td>Vitamin</td>
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<tr>
<td>Thiamin (mg)</td>
<td>0.523</td>
<td>0.502</td>
<td>0.120</td>
<td>2.753</td>
<td>0.401</td>
<td>0.070</td>
<td>1.170</td>
<td>0.763</td>
<td>0.692</td>
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<td>Riboflavin (mg)</td>
<td>0.577</td>
<td>0.165</td>
<td>0.040</td>
<td>0.284</td>
<td>0.093</td>
<td>0.049</td>
<td>0.220</td>
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<tr>
<td>Niacin (mg)</td>
<td>13.578</td>
<td>4.957</td>
<td>1.250</td>
<td>33.995</td>
<td>5.091</td>
<td>1.600</td>
<td>0.934</td>
<td>0.961</td>
<td>1.474</td>
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<tr>
<td>Pantothenic acid (mg)</td>
<td>2.181</td>
<td>0.603</td>
<td>0.438</td>
<td>7.390</td>
<td>1.493</td>
<td>1.014</td>
<td>1.494</td>
<td>1.349</td>
<td>0.201</td>
</tr>
<tr>
<td>Vitamin B&lt;sub&gt;6&lt;/sub&gt; (mg)</td>
<td>1.303</td>
<td>0.407</td>
<td>0.044</td>
<td>4.070</td>
<td>0.509</td>
<td>0.164</td>
<td>0.165</td>
<td>0.119</td>
<td>0.125</td>
</tr>
<tr>
<td>Folate (µg)</td>
<td>79</td>
<td>44</td>
<td>26</td>
<td>63</td>
<td>20</td>
<td>8</td>
<td>52</td>
<td>56</td>
<td>32</td>
</tr>
<tr>
<td>Vitamin E (µg)</td>
<td>1.49</td>
<td>0.71</td>
<td>0.06</td>
<td>4.92</td>
<td>1.20</td>
<td>0.11</td>
<td>1.01</td>
<td>Not listed</td>
<td>0.70</td>
</tr>
</tbody>
</table>

<sup>a</sup> USDA National Nutrient Database for Standard Reference (37).

<sup>b</sup> Food item number in the USDA National Nutrient Database for Standard Reference (37).
reduced risk of cancer (21 CFR 101.76) (40). Eligible food products must contain at least 2.5 g of total fiber/reference amount customarily consumed (RACC).

**Type 2 Diabetes and Metabolic Syndrome.** Fiber is thought to protect against the development of type 2 diabetes, with cereal fiber potentially providing more protection than other food sources of fiber, such as fruits and vegetables (35,42,43). In the European Prospective Investigation into Cancer and Nutrition-Potsdam Study, higher cereal fiber intake was inversely associated with diabetes risk, while fruit and vegetable fibers were not associated with diabetes risk (35). A meta-analysis of nine cohort studies was conducted and confirmed an inverse association for cereal fiber and magnesium intake and diabetes risk but reported no beneficial association for fiber from other sources (35).

A recent systematic review of 10 reports from 8 independent prospective cohorts (10) found a consistently reduced risk of type 2 diabetes with high intake of cereal fiber (18–40% risk reduction). A few studies included in the systematic review analyzed the effects of cereal fiber, whole grains, and/or bran in the same population. The associations of mixtures of whole grains and bran were attenuated or disappeared after adjustments for other dietary factors such as dietary fiber, cereal fiber, and magnesium intake (14,27,28).

A cross-sectional study reported an inverse association for intake of total, cereal, and fruit fibers, but not vegetable fiber, and the risk of metabolic syndrome (16). Metabolic syndrome is a cluster of metabolic disorders that together increase the risk for type 2 diabetes and cardiovascular disease (CVD). Approximately 25% of the population worldwide is estimated to have metabolic syndrome, and prevalence increases with age (32). Several mechanisms have been proposed for the protective effect associated with cereal fiber intake. Certain fibers, such as oat fiber, have been shown to improve insulin sensitivity, and high fiber–lower glycemic index diets that include oat β-glucan, for example, have been associated with reduced risk factors for metabolic syndrome (19,42). Other components of whole grains such as magnesium may also contribute to improved insulin sensitivity (25).

**Weight Management and Body Composition.** Cereal fiber and bran ingredients may be useful for helping to lower the energy density of foods formulated for weight management (45). Consumption of fiber-rich foods is associated with decreased food intake and improved body weight and composition measures. In a cross-sectional study of older adults, intake of cereal fiber, but not fibers from fruit or vegetables, was inversely associated with BMI, body fat, and trunk fat mass (26). Howarth et al. (17) reviewed intervention trials for the effects of fiber on energy intake and body weight. The majority of studies reviewed reported an increase in postmeal satiety and a decrease in subsequent hunger with diets high in fiber. An additional intake of 14 g of fiber/day was associated with a 10% decrease in energy intake and weight loss averaging 1.9 kg over =3.8 months of intervention.

Various potential mechanisms have been proposed for the relationship between cereal fiber intake and weight management, including the following: the low caloric value of fiber; higher fiber foods typically require greater mastication and, hence, more effort and time; excess chewing may promote gastric distention through the additional production of saliva and gastric acid; delayed gastric emptying; blunted postprandial glycermic and insulinemic response; stimulation of gastrointestinal hormones; and reduction of digestible energy (17).

**Heart Disease Risk Reduction.** The cardiovascular benefits of fiber are well documented, and cereal fiber seems to be more strongly associated with these benefits than fibers from other food sources (7,29,31,33). In a prospective cohort study, intake of cereal fiber, but not fruit or vegetable fibers, was inversely associated with risk of CVD in the elderly (29). Soluble cereal fibers, which include β-glucans present in cereals such as oats and barley, are known to lower blood cholesterol, which is a risk factor for CVD (3,7). Viscosity is a proposed mechanism for the cardio-protective effects of β-glucan (19). A comparative human intervention study on oat bran and oatmeal showed that lower amounts of oat bran were required to reach a plateau in blood cholesterol reduction compared with oatmeal, which is likely explained by the higher β-glucan content of the bran (12).

A systematic review revealed cereal fiber intake was associated with a consistent, modest risk reduction in stroke and CVD mortality in prospective epidemiological studies (10). Risk reductions ranged from 14 to 26% for CVD mortality and from 22 to 43% for stroke. Liu et al. (23) reported that insoluble fiber was more strongly associated with a reduced risk of CVD than was soluble fiber; however, the authors cautioned readers about the limitations of interpreting results between fiber types due to nonstandardized fiber fraction characterizations. Prospective studies have compared bran or cereal fiber and whole grain intakes for risk of coronary heart disease (CHD) or CVD and have shown that bran and cereal fiber intake was associated with greater risk reductions than whole grain intake (15,20).

In the Health Professionals Follow-Up Study, whole grain intake in the highest quintile (median 42.4 g/day) was associated with an 18% lower risk of CHD than in the lowest quintile (median 3.5 g/day), and participants with the highest intake of added bran (11.1 g/day) showed a 30% lower risk of CHD compared with participants with a negligible bran intake (20). In this study, the whole grain association was attenuated after further adjustment for dietary fiber intake and other dietary factors, potentially indicating the importance of cereal fiber in the role of grains in reduced risk of CVD.

Currently, the FDA allows two health claims related to cereal fiber intake and reduced risk of heart disease: 1) a health claim associating diets low in saturated fat and cholesterol and high in fruits, vegetables, and grain products that contain fiber with reduced risk of heart disease, in particular 0.6 g of soluble fiber/RACC (21 CFR 101.77) (39); and 2) a health claim associating diets that are low in saturated fat and cholesterol and that include soluble fiber from certain foods with reduced risk of heart disease, such as oat bran, rolled oats, whole oat flour, whole grain barley, and dry-milled barley containing at least 0.75 g of soluble fiber/RACC and Oatrim that contains at least 0.75 g of β-glucan soluble fiber/RACC (21 CFR 101.81) (41).

**Mortality.** A recent observational study compared fiber intake from various sources with associated total and cause-specific mortality (30). Based on a 9 year follow-up analysis of the NIH-AARP Diet and Health Study cohort, Park et al. (30) reported that dietary fiber intake was associated with a significantly lower risk of total mortality in both men and women; the highest intake group had a 22% lower risk than the lowest intake group for both men and women. Dietary fiber intake also was associated with lower risk of death from cardiovascular, infectious, and respiratory diseases; by 24–56% in men and 34–59% in women. An inverse association between dietary fiber intake and death due to cancer was observed in men but not in women. Intake of cereal fiber was significantly inversely related
to risk of total and cause-specific mortality in both men and women, whereas fewer significant inverse associations were noted for intake of fiber from fruits, vegetables, and beans (30). The authors (30) noted that fiber may be a marker of a healthy diet: a marker for food choices rich in vitamins, minerals, antioxidants, and phytochemicals—all of which are found in higher quantities in bran (a concentrated source of cereal fiber) than in other grain-based components.

Conclusions

Current observational and intervention clinical evidence indicates that fiber, in particular cereal fiber, is positively associated with health outcomes. Cereal fiber may protect against CVD, type 2 diabetes, higher body weights, and total and cause-specific mortality. In some cases, observational studies indicate that foods containing cereal fiber may provide more protection than other sources of fiber, such as fruits and vegetables. Other bioactive components are present in whole grains and are particularly associated with the cereal fiber concentrated in the bran. These components may also contribute to the protective role of cereal fiber. Mechanisms for the beneficial effects of cereal fiber and its associated bioactive components have been proposed in the scientific literature. However, there is a need for additional human nutrition research

1) To better understand the potential health benefits of these cereal components at relevant dietary inclusion levels
2) To study longer term health impacts, i.e., years versus weeks or months
3) To develop a broader array of validated biomarkers that measure and reflect the health potential of cereal fiber and other associated bioactive components
4) To better understand the impact of food processing, food form, other food components, and storage on the bioavailability and bioactivity of these components

In the meantime, cereal fiber and bran ingredients can provide food formulators an expanded range of consumer-oriented solutions to help promote increased fiber consumption, better meet fiber intake recommendations, and better realize the potential health benefits of cereal grain-based foods.

References


