

Enrichment of Whole Grain Foods with Soluble Fiber: Enhancing Health Benefits and Remediating a Critical Shortfall

L. Niba
Ingredient Incorporated
Bridgewater, NJ, U.S.A.

Grain-based foods are the primary source of caloric energy in many parts of the world and are the basis for bread, pasta, noodle, and breakfast cereal products. Research spans epidemiological, clinical, and analytical studies, and there is considerable scientific evidence showing that various components of whole grains contribute to improved overall nutritional status, disease prevention, and even disease management. Longitudinal epidemiological studies that have looked at food consumption habits among various populations, in turn, have provided great insights into target diseases and markers for case-control clinical studies. A comprehensive assessment of research evidence demonstrating that whole grain consumption is associated with the prevention of diabetes, cardiovascular disease, and weight gain was recently published by Ye et al. (29). Their study examined both cohort studies and clinical intervention trials.

One of the essential components associated with the benefits of whole grains is dietary fiber, both insoluble and soluble. In the United States, there is inadequate consumption of both whole grains and dietary fiber, with intakes falling far short of recommendations. The 2010 USDA Dietary Guidelines Advisory Committee (DGAC) reported that the intake of whole grains in the United States is at only $\approx 15\%$

of the target, while fiber consumption is at $\approx 40\%$ (6) (Fig. 1). The recommended daily intake for whole grains is 3–5 servings (16 g constitutes a serving), while the daily recommendation for fiber is 25–38 g.

Based on the National Health and Nutrition Examination Survey (NHANES) food consumption data, only 11–16% of the grains and grain-based foods consumed in the United States are consumed

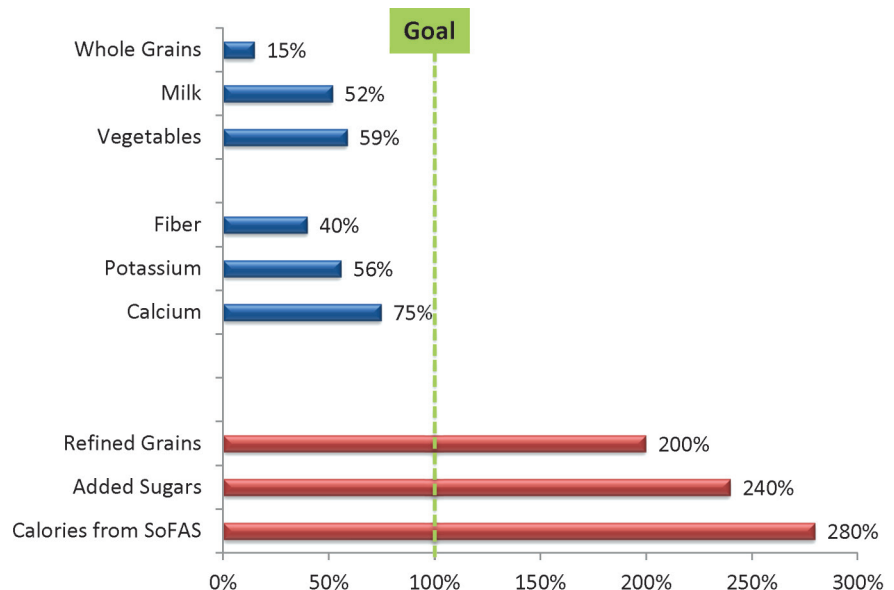


Fig. 1. U.S. consumer intake of key foods and nutrients as a percentage of the recommended intake goal. (Adapted from the 2010 USDA Dietary Guidelines Advisory Committee Report [6])

<http://dx.doi.org/10.1094/CFW-57-6-0256>
©2012 AACC International, Inc.

as whole grains (5,15). Of these, snacks and ready-to-eat (RTE) cereals are the top two categories of foods from which consumers obtain whole grains (Fig. 2). American consumers primarily eat whole grains at breakfast. NHANES consumption data indicate that of the total daily intake of whole grains, ≈40% are consumed at breakfast (15). Only 23% of whole grain foods are consumed at lunch, while dinner accounts for 17%. Snack foods account for the remaining 10% of whole grain consumption.

Fiber, a Critical Component of Whole Grain Products

Key nutritional benefits associated with whole grains arise from their fiber and antioxidant contents. Epidemiological and clinical research has shown that whole grain consumption influences a variety of diet-related conditions, such as cardiovascular disease, diabetes, metabolic syndrome, and gut health.

Consumption of complex carbohydrates is known to result in the reduction of glycemic response. Because of the association of complex carbohydrates with the incidence of diabetes, this has been an area of interest for whole grain and fiber research. Consumption of dietary fiber and low glycemic index foods has been shown to decrease the incidence of diabetes in various populations. For example, Schulze et al. (24) reported a reduction in the incidence of diabetes among middle-aged women. In addition, whole grains with high levels of fiber have been shown to reduce glycemic response, which has implications for mitigating the risk of diabetes mellitus (16,21). Nilsson et al. (21) demonstrated that the effect was extended over time, with the effect observed at 10 hr postconsumption—high-fiber whole grain barley consumed at breakfast resulted in glucose reduction later in the day.

Whole grains and fiber have also been shown to influence body weight. Using data from the Nurses' Health Study, a cohort study of healthy nurses over a 12 year period, Liu et al. (17) demonstrated that there was an inverse association between the consumption of high-fiber, whole grain foods and weight gain, while refined foods directly impacted weight gain. This study (17) essentially reflects the data from studies by other researchers who have found similar effects of high-fiber, whole grain products on body weight, with whole grains being associated with adiposity as well (9,12). McKeown et al.

(18) also showed that in older adults consumption of whole grains and cereal fiber was inversely associated with body fat and body mass index (BMI), even though there were no significant differences in body composition.

Colonic fermentation of fiber contributes to the enhancement of gut health, particularly through the production of short-chain fatty acids, which have various physiological benefits. High-fiber whole grains are fermented in the colon, producing short-chain fatty acids. Nilsson et al. (22) demonstrated that consumption of food containing high-fiber, whole grain barley increases the plasma concentration of short-chain fatty acids, particularly acetate and butyrate. This complements the findings of Drzikova et al. (7), who reported that fermentation rates and binding of bile acids are related to the fiber content of cereals.

Fermentation is also thought to enhance metabolic and satiety response. Nilsson et al. (21) reported that short-chain fatty acid production impacts markers of metabolism such as plasma glucagon-like peptide (GLP-1) and the rate of gastric emptying.

Fiber Shortfall in Whole Grain Products

AACC International defines whole grains as "...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." The FDA guidelines for label statements pertaining to whole

grains are adapted from this definition (26).

In parallel with these definitions, the U.S. Whole Grains Council requires that whole grain foods "...contain all the essential parts and naturally-occurring nutrients of the entire grain seed. If the grain has been processed (e.g. cracked, crushed, rolled, extruded, and/or cooked), the food product should deliver approximately the same rich balance of nutrients that are found in the original grain seed" (28). The Whole Grain Council's Whole Grain Stamp can be used on products that contain a minimum of 8 g of whole grains per serving, which constitutes half of one recommended serving of whole grains (28).

Consumers often associate whole grains with fiber. However, the fiber content of whole grains varies widely (25). As shown in Table I, barley has a high fiber content (17.3%), while whole grains such as brown rice are low in fiber, containing as little as 3.5%. As a result, despite consumer expectations consumption of the recommended 3–5 servings of most whole grain foods per day does not meet a significant portion of the recommended daily fiber intake of 25 to 38 g (Table I).

Another issue affecting the potential impact is the widely varying nature and distribution of fiber in whole grains: in some grains, most of the fiber is found in the bran, while in others fibers such as resistant starch are found in the endosperm. In corn, for instance, most of the fiber is found in the bran, ≈85% of which is fiber (2). In other grains, such as oats, soluble fiber is found in the endosperm.

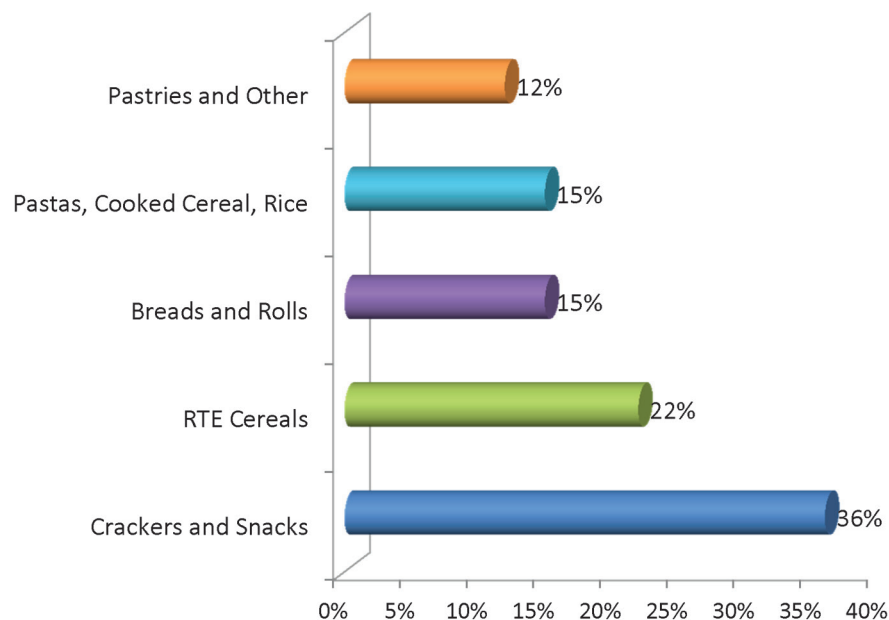


Fig. 2. U.S. consumer intake of whole grain foods by category (5).

Advances in scientific research methods that have led to the development of new analytical methods for fiber and nondigestible carbohydrates are providing a greater understanding of the fiber content of whole grains.

Due to the variability in the type and distribution of fiber among whole grains, health benefits reported for specific whole grains may not be transferable to products labeled simply as containing whole grains. For example, after reviewing the evidence for the FDA cardiovascular health claim Fabiana et al. (8) found that the inclusion of the bran, which is the primary fiber source in whole grains, is a key component of most of the studies on the benefits of whole grains with regard to cardiovascular health (8). Even more importantly, they concluded that whole grain benefits are not universal. For instance, data from studies in which oat and barley were consumed over a 6 week period showed a decrease in total cholesterol and plasma LDL cholesterol, while the same effects were not observed with whole grain wheat (3,4,8,27).

In essence, clinical research shows different effects and physiological responses associated with different whole grains even when consumed under the same conditions for the same length of time. Fabiana et al. (8) point out the importance of examining specific grains for specific benefits, because benefits do not apply equally across all whole grains. There are likely multiple mechanisms for observed differences in the physiological effects of various whole grains. However, it is likely that the fiber content and nature of the fiber in these grains play a central role in the observed physiological effects.

Several epidemiological studies do not separate the effects of fiber versus whole grains. McKeown et al. in their 2009 study (18) controlled for nongrain fiber sources, examining the effects of fiber from veg-

etables and fruits on body weight compared with cereal fiber and concluded that cereal fiber intake (as whole grain) did have a positive impact on BMI and body fat in older adults (18). Although some researchers, including like O'Neil et al. (23), have reported that cereal fiber alone does not show a significant effect, they still suggest that fiber from whole grains plays a role in weight gain. Researchers, including Liu (16), have also proposed that the whole grain-fiber complex directly influences metabolic efficiency.

Consumer Interest in Increasing Fiber and Whole Grain Intakes

American consumers believe that both whole grains and fiber have health benefits beyond basic nutrition. Consumer studies show a relatively high level of consumer awareness and clear indications that consumers are actively seeking to increase both their fiber and whole grain intakes to obtain the associated health benefits.

The 2012 International Food Information Council (IFIC) Food and Health Survey shows that consumers are trying to increase their intake of whole grains and fiber: 57% of consumers reported they seek to get as much whole grain in their diet as possible, while 56% reported the same for fiber (14). In the 2011 IFIC Functional Foods/Foods for Health Consumer Trending Survey, consumers listed both whole grains and fiber among the top 10 functional foods (13). Consumers also associated both whole grains and fiber with specific health benefits. In the same survey, 79% of consumers reported they were aware that fiber provides digestive health benefits, while 58% reported they were aware that whole grains provide digestive health benefits. Of these groups, 60% indicated they were already consuming fiber or whole grains for their digestive health benefits. Among consumers

who were aware of the heart health benefits of whole grains and fiber, 62% reported they were already consuming fiber for improved heart health, while 57% were already consuming whole grains for these benefits. The majority of consumers also indicated an awareness that fiber and whole grains are associated with weight management: 64 and 58%, respectively. Of these, 60% reported they were already consuming fiber for weight management, while 59% reported consuming whole grains for weight management (13).

The data on consumer use of whole grains and fiber for weight management parallel the data in the 2011 Gallup Survey of Satiety to some extent: both fiber and whole grains ranked high as ingredients in diets targeted at satiety and weight management. Among dieters, 45% reported they consumed more fiber and whole grains as a means to lose weight compared with 30% who reported consumption of protein as a means to lose weight (11). According to the 2010 Gallup Study of Weight Management (10), the consumption of whole grains and fiber for satiety also increased from 2009 to 2010: in 2010, 33% of dieters reported they consumed high-fiber cereals to promote satiety versus 28% in 2009, while 44% of dieters reported consuming whole grains to promote satiety in 2010 versus 39% in 2009.

Public policy programs and recommendations do appear to influence consumer attitudes toward fiber (Fig. 3). In a proprietary consumer study by Ingredion Incorporated, 53% of consumers reported that government public health programs like the USDA Food Guide Pyramid and the USDA Dietary Guidelines for Americans have influenced their consumption of fiber. It is clear, therefore, that consumers are educating themselves about these critical food components and actively seeking ways to increase their whole grain and fiber intakes.

Table I. Fiber content of commonly consumed whole grains

Whole Grain	Whole Grain Fiber Content ^a (%)	Fiber Content/1 Serving of Whole Grain (g)	Fiber Content/3 Servings of Whole Grain (g)
Brown rice	3.5	0.6	1.8
Quinoa	5.9	0.9	2.7
Wild rice	6.2	1.0	3.0
Corn	7.3	1.2	3.6
Millet	8.5	1.4	4.2
Sorghum	9.0	1.4	4.2
Oats	10.6	1.7	5.1
Wheat	12.2	2.0	6.0
Rye	14.6	2.3	6.9
Barley	17.3	2.8	8.4

^a Adapted from the USDA National Nutrient Database SR 17 (25).

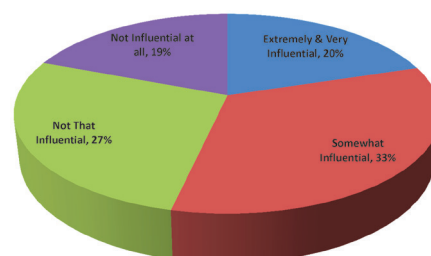


Fig. 3. Influence of public health programs on consumer fiber intake. (Proprietary consumer research, Ingredion Incorporated, 2011)

Enrichment of Whole Grain Products with Fiber

Despite the fact that fiber-rich whole grains have numerous proven health benefits, it is clear that consumption of these grains remains inadequate to obtain these benefits. In addition, consumers face various constraints to increasing their intake of whole grains as a means of increasing fiber consumption. One drawback of simply recommending an increase in current whole grain consumption levels as a means to increase fiber intake is that it has the potentially negative impact of a large increase in caloric intake. Using current NHANES consumption data, Nicklas et al. (20) examined multiple approaches for increasing fiber intake to meet the 25 g/day minimum recommendation. Their research found that if Americans only increased their current whole grain intake to obtain 25 g of fiber per day in their diet, it would entail consumption of an additional 1,266 cal/day. As an alternative option, researchers have demonstrated that a hypocaloric diet containing fiber-rich whole grains in combination with exercise can be effective in reducing weight and increasing fiber intake in overweight and obese adults (19). Another viable option is augmentation of whole grains with added fiber to improve the nutritional and health potential of whole grains without increasing caloric intake. Through the addition of 2.5–5 g of fiber per serving to whole grain foods it is possible to meet the daily fiber recommendation without an increase in caloric energy intake.

Another advantage of fiber enrichment of whole grain foods is the ability to add specific types and levels of fiber. Such fiber-enriched foods have been shown to have beneficial physiological effects. In animal studies by Abnous et al. (1) diets supplemented with oat or wheat bran impacted colonic fermentation and bacterial populations. In addition, populations of beneficial colonic bacteria such as bifidobacteria were specific to the bran source. Fiber fortification also facilitates the combination of both soluble and insoluble fibers, further enhancing their physiological effects because they are metabolized differently.

A key challenge associated with using high levels of whole grains and fiber in food products is the fact that they may adversely impact processing and compromise the sensory quality of the product. For example, using high levels of whole grains or incorporating high levels of fiber

into certain breakfast cereals has traditionally been challenging due to the high water-holding capacity of bran. In low-moisture systems, this water-holding capacity can impact formulation and sensory quality. Furthermore, some fibers are susceptible to degradation during extrusion and shear processing.

Innovative technologies for functional fiber applications and novel product development approaches can be used to successfully augment the fiber content of whole grain products. For instance, soluble fibers can be added to RTE cereals or whole grain beverages and resistant starches can be added to pastas and breads without compromising sensory or processing quality. Although cereals and snacks remain the primary categories Americans look to for whole grains and fiber, there has been a substantial increase in the development and launch of high-fiber whole grain products in other categories, providing new opportunities for fiber enrichment.

Fiber enrichment provides a pathway to address a critical shortfall identified by the DGAC, which proposes an increase in consumption of nutrient-dense foods to minimize caloric intake, as well as increased intakes of fiber and whole grain foods. In addition, it enables the development of foods with the potential for enhanced health benefits.

References

1. Abnous, K., Brooks, S. P. J., Kwan, J., Matias, F., Green-Johnson, J., Selinger, L. B., Thomas, M., and Kalmokoff, M. Diets enriched in oat bran or wheat bran temporarily and differentially alter the composition of the fecal community of rats. *J. Nutr.* 139:2024, 2009.
2. Anderson, J. W., and Bridges, S. Dietary fiber content of selected foods. *Am. J. Clin. Nutr.* 47:440, 1988.
3. Andersson, A., Tengblad, S., Karlström, B., Kamal-Eldin, A., Landberg, R., Basu, S., Aman, P., and Vessby, B. Whole-grain foods do not affect insulin sensitivity markers of lipid peroxidation and inflammation in healthy, moderately overweight subjects. *J. Nutr.* 137:1401, 2007.
4. Behall, K. M., Scholfield, D. J., and Hallfrisch, J. Diets containing barley significantly reduce lipids in mildly hypercholesterolemic men and women. *Am. J. Clin. Nutr.* 80:1185, 2004.
5. Carlson, A., Mancino, L., and Lino, M. Grain consumption by Americans. *Nutrition Insight* No. 32. Published online at www.cnpp.usda.gov/publications/nutritioninsights/insight32.pdf. USDA, Center for Nutrition Policy and Promotion, Alexandria, VA, 2005.
6. Dietary Guidelines Advisory Committee. Report of the Dietary Guidelines Advisory Committee on the Dietary Guidelines for Americans, 2010, to the Secretary of Agriculture and the Secretary of Health and Human Services. Published online at www.cnpp.usda.gov/Publications/DietaryGuidelines/2010/DGAC/Report/2010DGACReport-camera-ready-Jan11-11.pdf. USDA, Agricultural Research Service, Washington, DC, 2010.
7. Drzikova, B., Dongowski, G., Gebhardt, E., and Habel, A. The composition of dietary fibre-rich extrudates from oat affects bile acid binding and fermentation in vitro. *Food Chem.* 90:181, 2005.
8. Fabiana, F. D., Lewis, K. D., and Falk, M. C. Applying the FDA definition of whole grains to the evidence for cardiovascular disease health claims. *J. Nutr.* 139(Suppl.):2220S, 2009.
9. Fukugawa, N. K., Anderson, J. W., Hageman, G., Young, V. R., and Minaker, K. L. High-carbohydrate, high-fiber diets increase peripheral insulin sensitivity in healthy young and old adults. *Am. J. Clin. Nutr.* 52:524, 1990.
10. Gallup. 2010 Gallup Study of Weight Management. Multi-Sponsor Surveys Inc., Princeton, NJ, 2011.
11. Gallup. 2011 Gallup Study of Satiety. Multi-Sponsor Surveys Inc., Princeton, NJ, 2012.
12. Harland, J. L., and Garton, L. E. Whole grain intake as a marker of healthy body weight and adiposity. *Public Health Nutr.* 11:554, 2004.
13. International Food Information Council. Functional Foods/Foods for Health Consumer Trending Survey. IFIC, Washington, DC, 2011.
14. International Food Information Council. 2012 Food and Health Survey. IFIC, Washington, DC, 2012.
15. Lin, B., and Yen, S. T. The U.S. grain consumption landscape: Who eats grain, in what form, where and how much. *Economic Research Report* No. 50. Published online at www.ers.usda.gov/media/216648/err50_1_.pdf. USDA, Economic Research Service, Washington, DC, 2007.
16. Liu, S. Intake of refined carbohydrates and whole grain foods in relation to risk of type 2 diabetes mellitus and coronary heart disease. *J. Am. Coll. Nutr.* 21:298, 2002.
17. Liu, S., Willett, W. C., Manson, J. E., Hu, F. B., Rosner, B., and Colditz, G. 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, 2003.
18. McKeown, N. M., Yoshida, M., Shea, M. K., Jacques, P. F., Lichtenstein, A. H., Rogers, G., Booth, S. L., and Saltzman, E. Whole-grain intake and cereal fiber are associated with lower abdominal adiposity in older adults. *J. Nutr.* 139:1950, 2009.

19. Melanson, K. J., Angelopoulos, T. J., Nguyen, V. T., Martini, M., Zukley, L., Lowndes, J., Dube, T. J., Flutem, J. J., Yount, B. W., and Rippe, J. M. Consumption of whole-grain cereals during weight loss: Effects on dietary quality, dietary fiber, magnesium, vitamin B-6, and obesity. *J. Am. Diet. Assoc.* 106:1380, 2006.
20. Nicklas, T. A., O'Neil, C. E., Liska, D. J., Almeida, N. A., and Fulgoni, V. A. Modeling dietary fiber intakes in US adults: Implications for public policy. *Food Nutr. Sci.* 2:925, 2011.
21. Nilsson, A. C., Ostman, E. M., Holst, J. J., and Bjorck, I. M. Including indigestible carbohydrates in the evening meal of healthy subjects improves glucose tolerance, lowers inflammatory markers, and increases satiety after a subsequent standardized breakfast. *J. Nutr.* 138:732, 2008.
22. Nilsson, A. C., Ostman, E. M., Knudsen, K. E. B., Holst, J. J., and Bjorck, I. M. E. A cereal-based evening meal rich in indigestible carbohydrates increases plasma butyrate the next morning. *J. Nutr.* 140:1932, 2010.
23. O'Neil, C. E., Zaven, M., Cho, S. S., and Nicklas, T. A. Whole grain and fiber consumption are associated with lower body weight measures in US adults: National Health and Nutrition Examination Survey 1999–2004. *Nutr. Res.* 30:815, 2010.
24. Schulze, M. B., Liu, S., Rimm, E. B., Manson, J. E., Willet, W. C., and Hu, F. B. Glycemic index, glycemic load, and dietary fiber intake and incidence of type 2 diabetes in younger and middle-aged women. *Am. J. Clin. Nutr.* 80:348, 2004.
25. USDA, Agricultural Research Service and Nutrient Data Laboratory. Composition of foods: Raw, processed, prepared. USDA National Nutrient Database for Standard Reference, Release 17. Published online at www.nal.usda.gov/fnic/foodcomp/Data/SR17/sr17_doc.pdf. USDA ARS, Nutrient Data Laboratory, Beltsville, MD, 2004.
26. U.S. FDA. Draft guidance: Whole grain label statements. Guidance for industry and the FDA staff. Published online at www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/FoodLabelingNutrition/ucm059088.htm. FDA, Silver Spring, MD, 2006.
27. Van Horn, I., Moag-Stahlberg, A., Liu, K. A., Ballew, C., Ruth, K., Hughes, R., and Stamler, J. Effects on serum lipids of adding instant oats to usual American diets. *Am. J. Public Health* 86:183, 1986.
28. Whole Grains Council. Definition of whole grains. Published online at www.wholegrainscouncil.org/whole-grains-101/definition-of-whole-grains. Whole Grains Council, Boston, MA, 2004.
29. Ye, E. Q., Chacko, S. A., Chou, E. L., Kugizaki, M., and Liu, S. Greater whole-grain intake is associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. *J. Nutr.* 142:7, 2012.



Lorraine Niba is the business development manager for the Global Nutrition Springboard at Ingredion. She has several years of experience in carbohydrate and fiber research, development, and commercialization. Prior to joining Ingredion, Lorraine was assistant professor of food science at Virginia Tech, where she taught food science, managed a carbohydrate research lab, and directed graduate student research. She was also a visiting scientist at the USDA food composition lab. She has participated in the development of carbohydrate analytical methods and product concepts and published papers on carbohydrates and soluble fiber. Lorraine holds a Ph.D. degree in food science from the University of Maryland and an MBA in marketing. Lorraine is an AACCI member and

can be reached at lorraine.niba@ingredion.com.

A paid ad appeared here
in the printed version of the journal.