A review of the role of soluble fiber in health with specific reference to wheat ...

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Department ofFoodScienceand Nutrition, University of Minnesota, St Paul, Minnesota, USA; 2 Department of Internal Medicine, Gastroenterology Unit, Genoa, Italy; 3Novartis Consumer Health, Parsippany, New Jersey, USA; 4Novartis Consumer Health, Nyon, Switzerland dextrin, based on a search of PubMed. The evidence suggests that soluble fibers help to regulate the digestive system, may increase micronutrient absorption, stabilize blood glucose and lower serum lipids, may prevent several gastrointestinal disorders, and have an accepted role in the prevention of cardiovascular disease.

It is concluded that supplementation with soluble fibers (e. g. wheat dextrin) may be useful in individuals at risk of a lower than recommended dietary fiber intake. ACIDS; Dietary fiber is widely recognized to have a beneficial role in overall health, but only at adequate levels (25 – 38 g/day for healthy adults). Wheat dextrin in particular is a soluble fiber that can easily be added to the diet and is widely used in the food industry. There is some debate about whether increased intake of soluble fibers leads to health benefits.

This paper reviews the evidence regarding the physiological effects and potential health benefits of the addition of soluble dietary fibers, with specific reference to wheat KEY WORDS: SOLUBLE FIBER; WHEAT DEXTRIN; SHORT-CHAIN FATTY PHYSIOLOGICAL EFFECTS; HEALTH BENEFITS PREBIOTICS; Introduction Fiber, the indigestible part of plants such as cereals, fruits and vegetables (Table 1), has a fundamental role in the regulation of the digestive system and may help to prevent troublesome disorders such as constipation, 1 – 3 diarrhea4 – 6 and irritable bowel syndrome. – 9 Fiber may also help to regulate the absorption of micronutrients, 3, 10, 11 stabilize glucose12 – 14 and cholesterol levels, 15 – 17 have a role in cardiovascular health18 – 20 and possibly help to prevent some forms of cancer. 21 – 23 *Current address: 90 Possum Way, New Providence, NJ 07974, USA. Many nutrition and healthcare professionals use the terms ‘ soluble’ and ‘ insoluble’ fibers for nutrition labeling. 24 – 27 Soluble fibers dissolve in water and usually form a gel.

They are generally fermented by bacteria in the lower intestine, but they are indigestible and hence not absorbed into the bloodstream. 24, 28 Soluble fibers also ferment to form short-chain fatty acids (SCFAs) such as butyrate,

acetate and propionate (Table 2). 17, 29 – 34 Short-chain fatty acids generate approximately 1 – 2 kcal/g of ingested fiber, so are used as an energy source by the intestinal Downloaded from imr. sagepub. com by guest on March 27, 2013 1 JL Slavin, V Savarino, A Paredes-Diaz et al.

The health benefits of soluble fiber TABLE 1: Classification systems for fiber based on four different fiber characteristics Dietary fibers Lignin (polyphenolic compound, in cell walls of woody plants and seeds) Cellulose (glucose polymer, in all plant cell walls) ? -Glucans (glucose polymers, in oats, barley) Hemicelluloses (polysaccharides, in plant cell walls) Pectins (viscous polysaccharides, in fruits and berries) Gums (viscous polysaccharides, in seeds; e. g. uar gum) Inulin and oligofructose (mixture of fructose chains, in plants such as onions) Resistant starch (starch in plant cell walls; inaccessible to human digestive enzymes; often found in bananas and legumes; may also be formed by food processing) Soluble fibers Wheat dextrin ? -Glucans Gums (e. g. guar gum, partially hydrolyzed guar gum) Mucilages (e. g. psyllium) Pectins Fructo-oligosaccharides Some hemicelluloses Sources: oat products, legumes (dry beans, peas, lentils) Fermentable fibers Wheat dextrin Pectins ? Glucans Guar gum Partially hydrolyzed guar gum Inulin and oligofructose Sources: oats, barley, fruits, vegetables Viscous fibers Pectins ? -Glucans Some gums (e. g. guar gum) Mucilages (e. g. psyllium) Functional fibers Resistant dextrins (e. g. wheat dextrin) (indigestible polysaccharides formed when starch is heated and treated with enzymes; includes resistant maltodextrins) Psyllium (viscous mucilage, isolated from husks of psyllium seeds; also known as ispaghula husk) Chitin and chitosan (nondigestible carbohydrate from exoskeletons of

crustaceans, e. . crabs, lobsters; deacetylation of chitin gives chitosan, a nondigestible glucosamine polymer) Fructo-oligosaccharides (FOS, short synthetic fructose) Polydextrose and polyols (synthetic polysaccharides used as bulking agents and sugar substitutes in foods) Insoluble fibers Cellulose Lignin Some pectins Some hemicelluloses Sources: wheat bran, some vegetables Non-fermentable fibers Cellulose Lignin Sources: cereal fibers rich in cellulose (e. g. wheat bran)

Non-viscous fibers Cellulose Lignin Some hemicelluloses mucosa and are absorbed through the colonic wall, where they are metabolized to produce energy or transported into the general circulation. 29 SCFAs also stimulate epithelial cell differentiation and proliferation. 29 Soluble fibers can also promote the growth of colonic Downloaded from imr. sagepub. com by guest on March 27, 2013 2 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber

TABLE 2: Short-chain fatty acids (SCFA) produced by fermentable, soluble fiber17, 29 – 34 Butyrate Widely recognized as the most significant acid in terms of its documented effects in the colon The preferred nutrient for the cells lining the colonic epithelium, in particular the distal colon and rectum The preferred substrate for colonocytes Positive effects on colonic mucosal growth, crypt cell proliferation, and early-response gene expression Acetate A fuel for skeletal and cardiac muscle, kidney and the brain A substrate for fatty acid and cholesterol synthesis Propionate Metabolized by the liver Only SCFA that can be a major source of glucose (after metabolism, used for energy production) May play a role in cholesterol lowering bacterial flora (prebiotic effect). 35 – 37 Insoluble fibers, on the other and, do not dissolve

in water, are generally less fermentable by colonic microflora and are indigestible, 26 so pass through the intestines almost intact. Insoluble fibers have passive water-attracting properties that help to normalize large bowel function by acting like a sponge, pulling water into the stool and making it easier to pass. 38 They may also decelerate intestinal transit time, increase fecal weight through bulk action, delay glucose absorption and help to control and balance the pH in the intestines. 39, 40 In the USA, the daily intake recommended by the American Dietetic Association (ADA) is 20 – 35 g fiber/day for healthy adults, and ‘ age plus 5 g/day’ for children. 6 The World Health Organization (WHO) recommends > 25 g/day, 41 while the British Nutrition Foundation recommends 12 – 24 g/day for healthy adults. 42 The Food and Nutrition Board of the Institute of Medicine established the Adequate Intake (AI) recommendation for fiber (both soluble and insoluble), 24 which ranges from 19 to 38 g/day for children, depending on age, and from 25 to 38 g/day for healthy adults. The majority of people, however, do not seem to achieve the recommended daily intake of fiber, and women in general seem to consume lower amounts than men. 43, 44 Wheat dextrin is a soluble fiber that has been widely used in the food industry because it has a low viscosity and so has a good consistency when added to water, beverages or soft food. 4 It is formed by heating wheat starch at high temperature, followed by enzymatic (amylase) treatment to form a resistant starch. 24, 45 It qualifies as a dietary fiber because the non-digestible glucoside linkages (Fig. 1) lead to incomplete hydrolysation, so that only a small percentage of wheat dextrin is absorbed in the small intestine and the rest is slowly fermented in the large intestine. 3 This review aims to assess

the evidence regarding the physiological effects and potential health benefits of supplementing the diet with soluble fibers, with specific reference to wheat dextrin. Data source The PubMed database (US National Library Downloaded from imr. sagepub. om by guest on March 27, 2013 3 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber CH2OH O OH O OH O CH2OH O OH HO O CH2 O OH O OH O OH CH2OH O OH O OH CH2OH O OH OH O OH OH O OH O OH HO 1: 2 bond O O CH2OH O OH CH2OH O O OH OH O OH 1: 3 bond CH2OH O OH O CH2 O OH O HO CH2OH O OH 1: 6 bond O CH2 O H2 C O O CH2OH O CH2OH O OH O HO OH FIGURE 1: Chemical structure of wheat dextrin of Medicine, National Institutes of Health, Bethesda, MD, USA) was searched (to July 2007) using the terms ‘ wheat dextrin’ and ‘ soluble fiber’, and studies were selected based on whether they evaluated the physiological or clinical effects of soluble fibers.

Although this non-systematic approach limits the review in that a quantitative analysis was not performed, it does allow a general and potentially useful overview of the effects of supplementation with soluble fibers. Physiological effects of soluble fibers FERMENTABILITY In vitro fermentation of wheat dextrin, inulin and partially hydrolysed guar gum (PHGG), and analysis of the resulting SCFA production over a 24-h period17 revealed that all three fibers demonstrated detectable fermentability. Acetate was the main SCFA produced by all fibers, accounting for about 50% of the total SCFA. Over 24 h, wheat dextrin produced substantially more total SCFA, propionate and butyrate than PHGG, which consistently showed lower fermentability at all time points (Fig. 2A – 2C).

To reduce gas production (which can be socially undesirable and cause uncomfortable bloating), extensive fermentation at 24 h is desirable, while fast fermentation (e. g. high values at 4 h) may be undesirable. The total amount of SCFA produced by wheat dextrin at 4 h was just over half the amount produced by glucose Downloaded from imr. sagepub. com by guest on March 27, 2013 4 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber A Concentration (µmol/ml) 120 100 80 60 40 20 0 B Concentration (µmol/ml) 16 14 12 10 8 6 4 2 0 0 4 8 12 Time since start of fermentation (h) 24 0 4 8 12 Time since start of fermentation (h) 24 C Concentration (µmol/ml) 45 40 35 30 25 20 15 10 5 0 0 4 8 12 Time since start of fermentation (h) 24 Wheat dextrin PHGG Inulin F97 Glucose

FIGURE 2: Analysis of short-chain fatty acid (SCFA) production following in vitro fermentation of wheat dextrin, partially hydrolysed guar gum (PHGG) inulin and glucose (positive control) over 24 h: (A) total SCFA production; (B) butyrate production; and (C) propionate production17 (positive control) and almost half the amount produced by inulin at the same time point (Fig. 2A). The fermentation of wheat dextrin, therefore, occurred slowly over 24 h, so its consumption was less likely to result in the gas production that can occur as a result of rapid fiber fermentation. composition towards a more beneficial distribution. 17, 46 For example, the consumption of fructo-oligosaccharides led to an increase in fecal bifidobacteria, 36, 47, 48 while ingestion of polydextrose resulted in a dosedependent decrease in bacteriodes and an increase in beneficial lactobacilli and bifidobacteria. 49 Administration of PHGG for 3 weeks increased the Lactobacillus spp count in feces. 0 Consumption of wheat dextrin led to a lower colonic pH, an increase in the

fecal concentration of glucosidases, a statistically significant increase in the beneficial lactobacilli population and a statistically significant decrease in pathogenic Clostridium perfringens. 35 In another study, wheat dextrin increased the fecal concentration of glucosidase; 45, 51 increased glucosidase activity is considered beneficial to the host and is linked to substrate fermentation leading to more SCFAs and lactic acid production. PREBIOTIC EFFECT The SCFAs produced by soluble fermentable fibers are moderately strong acids (pK 4. 8)29 and so they lower colonic pH. Lowering the pH in the large ntestine may support the growth of bifidobacteria and lactobacilli because they have a strong intrinsic resistance to acid and the lower pH may help to prevent the growth of pH-sensitive pathogenic bacteria such as clostridia. 30 Many soluble fermentable fibers have demonstrated a significant prebiotic effect and alter the intestinal microflora Downloaded from imr. sagepub. com by guest on March 27, 2013 5 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber EFFECT ON LAXATION AND REGULARITY The formation of SCFAs helps to improve laxation and regularity by increasing fecal bulk and weight and increasing the waterholding capacity (and thus the hydration) of feces. 0, 46 The increase in fecal bulk and weight results from the presence of fiber, the water that the fiber holds and the partial fermentation of the fiber, which increases the amount of bacteria in the feces. 52 Studies have confirmed that consumption of the soluble fibers inulin or oligofructose result in an increase in fecal weight, 53 while inulin helped to reduce constipation2 and polydextrose increased fecal mass and sometimes stool frequency. 49, 54 Consumption of psyllium significantly increased stool frequency and stool

weight, increased stool water content, improved stool consistency, increased the frequency of bowel movements and reduced pain on defecation. 55 – 59 Wheat dextrin significantly increased dry fecal output by 70% (P < 0. 02) and wet fecal output by 45% (P < 0. 05) (Fig. 3). The increase in wet fecal output was due to increased dry matter output (38%) and increased water output (62%). IMPROVED NUTRIENT/MINERAL ABSORPTION Although dietary fibers are traditionally thought to decrease mineral absorption, animal models and human studies have demonstrated that soluble fermentable fibers appear to increase the absorption of certain minerals. 3, 10, 60 – 62 For example, soluble fibers may increase calcium absorption through the increased production of SCFAs, with an increase in the villus crypt height, number of epithelial cells per crypt, cecal vein flow and mucosal-to-serosal calcium fluxes and stimulation of the expression of calbindinD9K, thereby enhancing the active calcium transport route. 3 Soluble fibers may also increase the absorption of other minerals such as magnesium, zinc and iron. 3, 10, 11 Studies in rats showed that the absorption of calcium, magnesium and/or zinc may be enhanced by guar gum, 64 inulin, 10, 65 oligofructose65 and PHGG. 11 In healthy men supplemented with either wheat dextrin or dextrose (100 g/day), ingestion of wheat dextrin significantly increased magnesium apparent absorption (50. 9%, P = 0. 001) and retention (30. 9 mg/day, P = 0. 024) and tended 80 P < 0. 02 70 60 Increase (%) 50 40 30 20 10 0 Wet fecal output FIGURE 3: Effect of wheat dextrin on fecal output3 Dry fecal output P < 0. 05 45% 70% Downloaded from imr. sagepub. om by guest on March 27, 2013 6 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber (not statistically significant) to increase

calcium apparent absorption (37. 4%) and retention (111 mg/day) (Table 3). 3 prandial plasma glucose concentrations (–13 mg, P = 0. 04) and a significant reduction in the urinary excretion of glucose (P = 0. 008) compared with the low-fiber diet. 13 In fact, the effects of fiber on glucose concentrations are most evident in individuals withdiabetesmellitus and it has been suggested that diabetics should consume 25 – 50 g/day of dietary fiber, with ? 55% of their calorie intake coming from carbohydrate. 4 To assess the effect of fiber on the risk for diabetes, more than 65 000 women (40 – 65 years of age) were followed for 6 years; it was found that dietary glycemic index and glycemic load were positively associated with the development of type 2 diabetes, and dietary fiber was inversely associated. 75 Beyond the effects of fiber on post-prandial glucose and insulin, fiber alters the responses and actions of the gut hormones gastric inhibitory peptide, 76 glucagon-like peptide177 and cholecystokinin (CCK). 78 CCK is a peptide hormone and neurotransmitter that regulates gut motility, gall bladder contraction and pancreatic enzyme secretion and may mediate the post-prandial glycemic and insulinemic response to viscous fibers. A direct correlation has been reported between post-prandial CCK and subjective satiety scores following ingestion of foods with varying amounts of fiber. 79, 80 DECREASED GLYCEMIA AND INSULINEMIA

Through the production of SCFAs, soluble fibers can stimulate pancreatic insulin release and affect liver control of glycogen breakdown, 66, 67 and so may be effective in decreasing blood glucose and insulin levels and improving glycemic and insulinemic indices. 68 Guar gum, 69, 70 inulin12 and dextrin71 were all found to improve postprandial glycemia. In healthy

subjects, the glycemic index of wheat dextrin was 25% compared with dextrose and the insulin response with wheat dextrin was also low at 13% compared with dextrose. 14 Resistant dextrins led to reduced blood glucose concentrations and insulin secretion in rats after sucrose or maltose loading, 72, 73 reduced the post-prandial blood glucose concentrations in healthy men and women, 13 and significantly reduced fasting blood glucose concentrations in type 2 diabetics. 6 In patients with type 2 diabetes given a diet high (25 g soluble plus 25 g insoluble fiber) or low (8 g soluble plus 16 g insoluble fiber) in total fiber, the high-fiber diet resulted in significantly lower pre- TABLE 3: Effect of wheat dextrin supplementation (100 g/day) on the absorption and retention of magnesium and calcium in healthy men3 Dextrose diet Calcium Apparent absorption, mean, mg/day (%) Retention, mean, mg/day Magnesium Apparent absorption, mean, mg/day (%) Retention, mean, mg/day 187 (28. 8) 39. 3 65 (30. 4) –0. 3 Wheat dextrin diet 269 (37. 4) 111 117 (50. 9) 30. 9 Statistical significance (P-value) 0. 093 0. 122 0. 001 0. 024 Downloaded from imr. sagepub. com by guest on March 27, 2013 7 JL Slavin, V Savarino, A Paredes-Diaz et al.

The health benefits of soluble fiber REDUCED CHOLESTEROL LEVELS The SFCAs can suppress cholesterol synthesis by the liver and may reduce serum levels of low-density lipoprotein cholesterol (LDL-C) and triglycerides. 81 Soluble, viscous fibers are also thought to exert their hypocholesterolemic action by increasing fecal sterol excretion and stimulating hepatic bile acid synthesis. 82, 83 In a metaanalysis of 67 controlled trials, consumption of 2 – 10 g/day of fiber (i. e. pectin, oat bran, guar gum, psyllium) reduced total cholesterol by 4% and LDL-C by 7% compared with placebo. 15 No

significant effect was observed on serum high-density lipoprotein cholesterol (HDL-C) and triacylglycerol concentrations.

A greater reduction in serum total cholesterol and triacylglycerol concentrations was also noted in type 2 diabetics who consumed 60 g/day resistant dextrin compared with type 2 diabetics or healthy adults who consumed 30 g/day. 16 No difference was observed in the concentration of HDL-C. A diet high in total fiber (25 g soluble plus 25 g insoluble fiber) led to significantly reduced plasma total cholesterol (P = 0. 02), very-low-density lipoprotein cholesterol (VLDL-C) (P = 0. 01) and triglyceride (P = 0. 02) concentrations compared with a low-fiber diet, indicating that high fiber intake, especially soluble fiber, improves plasma lipid profile. 3 It has also been proposed that soluble fermentable fibers may lead to a reduction of cholesterol levels via the increased amounts of propionate produced during their fermentation by the commensal bacteria, because propionate may inhibit cholesterol biosynthesis. 84 Fibers producing high amounts of SCFAs (particularly propionate), such as wheat dextrin, may help to sustain cholesterol levels within the normal range. 17 The cholesterol-lowering effects of wheat dextrin have been demonstrated in animal trials. 85 The findings suggest that its cholesterol-lowering effect is likely to be related to reduced cholesterol and bile salt absorption. However, not all soluble fibers are hypocholesterolemic agents; for example, oat bran has been shown to lower serum lipids while wheat bran did not. 81 IMMUNE FUNCTION

It is possible that SCFAs help to improve immune function, as they stimulate the production of T helper cells, antibodies, leukocytes and splenocyte cytokines, all of which have a crucial role in immune protection. 86, 87 In

addition, SCFAs improve the barrier properties of the colonic mucosal layer, thus inhibiting inflammatory and adhesion irritants. 88 – 90 Lactic-acid-forming bacteria competitively inhibit and/or suppress the growth of pathogenic bacteria, and may have a positive influence on immune function. 91, 92 WEIGHT REDUCTIONObesityis associated with increased energy intake and decreased consumption of fiberrich foods, 93 while fiber intake is inversely associated with body weight and body fat. 94 – 97 Increasing daily fiber intake is an effective way of providing a satiating effect. 8 Dietary fiber also decreases gastric emptying and/or slows energy and nutrient absorption (a fiber-rich meal, which is also usually richer in micronutrients, is processed more slowly and nutrient absorption occurs over a greater period of time99), leading to lower post-prandial glucose and lipid levels. Furthermore, addition of dietary fiber to a low-calorie diet has been shown to lead to a significantly greater weight loss (8. 0 kg) compared with placebo (5. 8 kg). 100 When post-menopausal women consumed higher fiber diets, this was associated with significant weight loss. 101 A high Downloaded from imr. sagepub. com by guest on March 27, 2013 8 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber carbohydrate diet consumed ad libitum (i. e. elf-regulating), without energy restriction or change in energy intake, caused significant body weight and body fat losses in older men and women, with a significant decrease in thigh fat area (P = 0. 003). 102 A review of the effects of increased fiber (high-fiber foods or supplementation) on hunger, satiety, energy intake and body weight revealed that controlled energy intake with increased dietary fiber led to an increase in post-meal satiety and a decrease in subsequent hunger. 103 With ad libitum energy intake, increased dietary

fiber (14 g/day) resulted in an average 10% decrease in energy intake and 1. 9 kg weight loss over 3. 8 months of intervention. The effects of increasing dietary fiber were reported to be greater in obese individuals.

When evaluating the effects of 1 week of supplementation with soluble fiber (guar gum, 40 g/day) on hunger, satiety rating and energy intake, mean daily energy intake decreased significantly from 6. 7 to 5. 4 MJ, while hunger and satiety scores did not change. 104 Long-term (4 – 5 weeks) assessment of wheat dextrin (30 or 45 g/day) supplementation demonstrated a trend towards better weight maintenance; compared with baseline, body weight was increased in the control group supplemented with pure absorbable maltodextrin (+0. 87 kg; P = 0. 07), whereas body weight remained stable in the wheat dextrin-treated groups (+0. 0 kg). 35 sometimes stool frequency. 9, 54 Psyllium significantly increased stool frequency and stool weight, increased stool water content, improved stool consistency, increased the frequency of bowel movements and reduced pain on defecation. 55 – 59 Administration of PHGG for 3 weeks increased the frequency of defecation (+0. 17 /day), increased fecal moisture (+5%) and decreased fecal pH. 50 Supplementation with PHGG also helped to reduce the use of laxatives (from an average of 2. 0 to 0. 2 doses/day). 105 Wheat dextrin (100 g/day) had a positive effect on fecal output in healthy men, 3 with an average 45% increase in wet fecal weight (P < 0. 05) and 70% increase in dry fecal output (P < 0. 02) (Fig. 3). DIARRHEA Increased intake of soluble fiber may enhance recovery and improve stool consistency in diarrhea. , 5, 106 – 109 Persistent diarrhea resolved in more children taking PHGG (84%) compared with those on the control diet (62%) (odds ratio 3. 12), while the duration of diarrhea

was reduced and there was a trend towards reduction in daily stool weight that reached significance on days 4 – 7. 6 Compared with non-fiber control in children, PHGG significantly reduced the mean frequency of diarrhea (8. 8% versus 32. 0%; P = 0. 001), resulted in significantly fewer days with diarrhea per total feeding days (10. 8% versus 31. 5%; P < 0. 001) and led to a significantly lower mean diarrhea score (4. 8 versus 9. 4; P < 0. 001). 110 PHGG also suppressed diarrhea caused by the ingestion of high levels of non-digestible sugar substitutes. 11 In elderly patients with diarrhea, 4-week supplementation with soluble dietary fiber (7 g/day) significantly reduced the water content of feces (P < 0. 01), the fecal pH (P < 0. 05) and the frequency of daily bowel movements (P < 0. 05). 5 In addition, the fecal characteristics improved The role of soluble fiber in disease CONSTIPATION Increased daily fiber intake can ameliorate constipation. 40, 49, 52 – 59 Consumption of inulin or oligofructose was shown to increase fecal weight, 53 inulin reduced constipation2 and polydextrose increased fecal mass and Downloaded from imr. sagepub. com by guest on March 27, 2013 9 JL Slavin, V Savarino, A Paredes-Diaz et al.

The health benefits of soluble fiber and the total level of SCFAs increased significantly (P < 0. 05). 5 In patients with fecal incontinence, significantly fewer incontinent stools were observed in those who consumed dietary fiber (psyllium or gum arabic) than those receiving placebo. 4 Improvements in fecal incontinence or stool consistency did not appear to be related to unfermented dietary fiber. However, the effects of increased soluble fiber on diarrhea are inconclusive, as a meta-analysis of randomized, controlled trials found no evidence that dietary fiber was effective in treating diarrhea. 112

randomized studies would be useful to confirm the potentially beneficial effects of soluble fiber in IBS.

DIVERTICULOSIS A diet low in fiber is thought to play a role in the pathogenesis of diverticular disease. 114 Increasing dietary fiber produces bulky, soft stools, facilitating defecation and reducing intracolonic pressure. 114 Increased fiber also helps to promote regular bowel function and is important in controlling and minimizing diverticular disease. 115 – 117 Non-viscous soluble fiber is associated with a decreased risk of diverticular disease and an improvement of bowel pain. 115 In patients with diverticulosis, it is recommended that patients consume 20 – 35 g/day of fiber either through the diet or supplementation. 118 IRRITABLE BOWEL SYNDROME

Treatment for irritable bowel syndrome (IBS) is aimed at alleviating symptoms. In patients with mild symptoms, fiber supplementation (particularly non-gelling soluble fibers) may help to relieve the severity and frequency of IBS symptoms, including abdominal pain, spasms or distension/tension, bowel dysfunction (e. g. fluctuation between constipation and diarrhea) and flatulence. 8, 9, 113 PHGG was better tolerated than wheat bran and more readily accepted by IBS patients, resulting in an improved quality of life during the treatment period. 113 PHGG also had a positive effect on evacuation frequency with a decrease in the frequency of IBS symptoms such as flatulence, abdominal tension and abdominal spasm. 13 Based on its physiological properties, wheat dextrin may also help to alleviate gastrointestinal symptoms associated with IBS through increased fecal output, 3 enhanced prebiotic capabilities35, 45 and significant but slow

fermentation in the lower intestine, producing high concentrations of SCFAs but lower amounts of gas, which could be an important aspect in relieving the discomfort caused by IBS. 17 However, double-blind, HEMORRHOIDS A low-fiber diet is thought to contribute to the etiology of hemorrhoids. 119 Increasing the fiber content in the diet can have a beneficial effect in the treatment of symptomatic hemorrhoids. 120, 121 A recent meta-analysis demonstrated that increased fiber reduced the risk of bleeding and decreased the rate of recurrence of hemorrhoids, 120 while a Cochrane review found that the risk of not improving hemorrhoids and having persisting symptoms decreased by 53% with increased intake of fiber, with a significant reduction in bleeding. 121

CARDIOVASCULAR DISEASE A number of studies have consistently found that a fiber-enriched diet (14 g fiber/1000 kcal energy) is associated with a significant reduction (16 – 33%) in the risk of coronary heart disease (CHD). 19, 20, 122 – 126 A pooled analysis of studies evaluating dietary fiber Downloaded from imr. sagepub. com by guest on March 27, 2013 10 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber intake in the USA and Europe indicated that each 10 g/day increase in total fiber intake was associated with a 14% decrease in the risk of coronary events (e. g. myocardial infarction), and a 24% decrease in deaths from CHD. 9 A study on the relationship between dietary fiber and risk of cardiovascular disease (CVD) among women over a 10-year period showed that the ageadjusted relative risk for major CVD was 0. 53 for women consuming the highest amount of fiber (22. 9 g/day) compared with those on the lowest fiber intake (11. 5 g/day). 125 Although few interventional studies have

specifically assessed fiber intake on the risk of CVD, increased fiber has been shown to ameliorate some of the risk factors for CVD (e. g. high cholesterol levels, high blood pressure, obesity and diabetes). For example, fiber can significantly reduce blood cholesterol levels and so may be important to cardiovascular health. 5, 16, 81, 127 Consuming foods rich in viscous soluble fibers has been shown to reduce blood levels of LDL-C by 10 – 15%, with an expected reduction in CVD events of 10 – 15%, and it has been stated that a diet including 5 – 10 g/day of viscous soluble fiber reduces CVD events and death independent of baseline risk. 18 Although the cholesterol-lowering effect of soluble (especially viscous) fibers probably contributes the most to its cardioprotective effects, other mechanisms are likely to play a role. As part of a lifestyle modification program, fiber can help to reduce blood pressure significantly, 128 supporting research that found that highfiber intake was inversely associated with the risk of high blood pressure or hypertension. 129, 130 Two intervention trials found that increased fiber intake resulted in significant reductions in blood pressure compared with placebo. 31, 132 In an analysis of the association between nutrient intake and risk of stroke, dietary fiber was inversely correlated to the incidence of stroke, a relationship that was stronger in hypertensive than normotensive men. 133 Fiber is also effective at reducing the risk of diabetes and, thus, the risk of developing CVD, and can improve glycemic and insulinemic indices12, 14, 69 – 71 and decrease blood glucose and insulin levels. 13, 16, 72 Lowfiber, high-glycemic load diets are associated with higher serum triglyceride levels and lower HDL-C levels, which are risk factors for CVD. 134, 135 Increased fiber consumption may also help control body weight and

support a weight reduction program by helping to reduce obesity and, possibly, the associated risk of CVD. 94 – 104 Safety aspects of fiber supplementation

Reduced absorption of trace elements has traditionally been proposed as a potential negative effect of dietary fiber intake; 136, 137 however, it is unlikely that healthy adults who consume fiber in amounts within the recommended ranges will have problems with nutrient absorption. In fact, clinical data demonstrate that soluble fibers (e. g. inulin, fructo-oligosaccharides, wheat dextrin) may positively affect the absorption of certain minerals. 3, 10, 11, 64, 65 Fermentation of dietary fiber by anaerobic bacteria in the large intestine produces gas (including hydrogen, methane and carbon dioxide), which may be related to complaints of distention or flatulence, especially with high intakes of fiber. An increase in dietary fiber should also be accompanied by an increase in fluid intake, and fiber should be increased gradually to allow the gastrointestinal tract time to adapt.

Normal laxation may be achieved with relatively small amounts of dietary Downloaded from imr. sagepub. com by guest on March 27, 2013 11 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber fiber, and the smallest intake that results in normal laxation should be used. 138 Nevertheless, wheat dextrin has been shown to be well tolerated even up to the relatively high intake of 45 g/day. 51 Higher daily intakes (60 and 80 g) resulted in greater flatulence ($P < 0.05$) and some bloating compared with placebo, but no intake resulted in diarrhea. fiber can have beneficial effects on constipation, diarrhea and the symptoms of IBS.

Soluble fiber also has additional positive effects on cardiovascular health, leading to a significant risk reduction of CHD. Thus, this review of the physiological effects and subsequent health benefits of soluble fibers suggests that daily fiber supplementation could be beneficial in those individuals who are at risk of inadequate fiber in their diet. Most servings of common foods contain between 1 and 3 g of dietary fiber so it may be difficult to consume the recommended amounts of fiber. Dietary assessment programs can estimate fiber intake for different population groups, allowing the identification of groups that have deficient fiber intake.

At an individual level, fiber intake can be generally estimated based on servings of fruits, vegetables and whole grains having 2 g of dietary fiber per serving, and servings of legumes having 5 g of dietary fiber per serving. Values from high-fiber cereals or fiber supplements can be added to these totals. Wheat dextrin is one example of a soluble fiber supplement that has been shown to help normalize bowel function and is well tolerated, even at large intakes. It is slowly but extensively fermented, leading to a significantly high production of SCFAs, while its slow fermentation profile could help minimize the undesirable effects of gas production and flatulence. Wheat dextrin has also demonstrated enhanced prebiotic capabilities when used at an intake of 30 – 45 g/day.

Based on its physiological properties, supplementation with wheat dextrin should be useful in individuals that need to complete their dietary intake with a fiber in order to achieve the daily recommended dietary levels of fiber. Conclusion Review of the evidence indicates that soluble, fermentable fibers, including wheat dextrin, have positive physiological effects that may help to

improve bowel regularity and result in some health benefits. Soluble fibers are fermented in the large intestine, leading to the production of SCFAs that lower colonic pH and result in a significant prebiotic effect in which the growth of beneficial intestinal microflora (e. g. ifidobacteria, lactobacilli) and fecal glucosidase concentrations are increased, while the growth of pH-sensitive pathogenic bacteria (e. g. clostridia) is prevented or suppressed. In this way, SCFAs could promote normal bowel regularity and may help to reduce serum glucose and cholesterol levels. SCFAs also positively influence the absorption and retention of certain micronutrients (e. g. calcium, magnesium, zinc), and may improve immune function by stimulating the production of immunoprotective factors (e. g. T helper cells, antibodies) and improving the barrier properties of the colonic mucosal layer. Soluble fibers that are slowly yet extensively fermented in the large intestine (e. g. heat dextrin) are tolerated more easily than those that ferment quickly, as the latter can produce larger amounts of gas in a shorter period of time, leading to bloating and flatulence. By improving digestive balance, regularity and hydration in the gut, soluble Downloaded from imr. sagepub. com by guest on March 27, 2013 12 JL Slavin, V Savarino, A Paredes-Diaz et al. The health benefits of soluble fiber Acknowledgments Editorial support was given by Deborah Nock, DPP-Cordell Ltd, Saxthorpe, UK. Funding for the review was provided by Novartis Consumer Health, Nyon, Switzerland. Conflicts of interest Alberto Paredes-Diaz and Grigorios Fotopoulos were Novartis Consumer Health, employees at the time of manuscript preparation.

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