Role of Fructans and Resistant Starch in Diabetes Care
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One objective of Healthy People 2020 is to decrease by 10% the number of individuals diagnosed with prediabetes and type 2 diabetes in the United States. One nutrition-based strategy to achieve this goal is to encourage individuals who are at risk of developing or who have prediabetes or type 2 diabetes to consume more fiber. An Academy of Nutrition and Dietetics position statement on the health implications of dietary fiber recommends that the variety of dietary fibers naturally occurring in and added to foods can promote healthy body weight, improve glycemia and insulin sensitivity, regulate digestive function, and reduce the risk of cardiovascular disease (CVD).

The Dietary Guidelines for Americans 2010 and Dietary Reference Intakes (DRIs) suggest that adults ≤ 50 years of age consume 25–38 g/day of dietary fiber and that those > 50 years of age consume 21–30 g/day. However, Americans continue to fall far short of these recommendations. Data from the 2003–2004 National Health and Nutrition Examination Survey revealed that fiber intake among individuals with type 2 diabetes was approximately 16 g/day. According to the baseline nutrient intake data from the Look AHEAD (Action for Health in Diabetes) lifestyle modification intervention trial, only 20% of participants with type 2 diabetes met dietary fiber intake goals.

Dietary fiber recommendations for individuals with type 2 diabetes are similar to those for the general population (DRI 14 g/1,000 kcal). However, research has shown that much higher intakes (44–50 g/day) are needed to improve glycemia, and many individuals may have difficulty consuming this amount on a daily basis. It is recommended that people with diabetes consume foods containing 25–30 g/day of fiber, with a special emphasis on soluble fiber (7–13 g/day).

The U.S. Food and Drug Administration (FDA) requires food manufacturing companies to list the total dietary fiber on the Nutrition Facts label of their products. Dietary fiber can be classified as soluble or insoluble, but the Institute of Medicine dissuades the use of these terms because physiological function—not solubility—may be important for health benefits. One problem associated with current food product labeling is that added or functional fibers with beneficial physiological functions such as fructans and resistant starch (RS) are not listed separately from total dietary fiber on Nutrition Facts labels. This issue is in part related to the FDA’s lack of an official definition of dietary fiber. In 2009, the Codex Alimentarius accepted a definition of dietary fiber that may influence future FDA decisions. The Codex defines dietary fiber as carbohydrate polymers with physiological benefits that are either found naturally in plants, obtained from foods by enzymatic, chemical, or physical means, or synthetically derived.

The Dietary Guidelines for Americans 2010 offers food manufacturers the opportunity to incorporate fructans and RS, also known as fermentable fibers, into their foods. Fermentable fibers are broken down by microorganisms in the colon to produce by-products such as short-chain fatty acids.
(SCFAs) and carbon dioxide. They can be incorporated into many types of foods as a way to increase fiber content without concomitant increases in energy. Fructans and RS are fermentable fibers added to foods because they minimally affect taste and can improve nutritional quality.

Research shows that for individuals at risk of or with type 2 diabetes, consumption of these fibers may have diabetes-related health benefits. This article summarizes the evidence regarding the beneficial metabolic effects of the fermentable fibers fructans and RS in individuals at risk of or with type 2 diabetes. It includes practical recommendations for clinicians for incorporating these fermentable fibers into their clients’ eating plans.

What are Fructans?
Fructooligosaccharides (FOS), also known as oligofructose, and inulin are known collectively as fructans. These indigestible polysaccharides are found naturally in chicory root, wheat, onions, leeks, garlic, asparagus, Jerusalem artichokes, and bananas. Structurally, FOS is a smaller molecule that is fermented more rapidly by microorganisms in the colon than inulin, which can cause gastrointestinal (GI) side effects. On average, Americans consume ≤ 3.5 g/day of fructans, and ingesting >15 g/day of fructans appears to increase flatulence, bloating, and abdominal cramping. The bland to mildly sweet taste of fructans make them desirable to the food industry as replacements for fat and sugar. Fructans contribute ~ 50% less energy than digestible carbohydrates and provide ~1.5–2 kcal/g.

What is RS?
RS, which occurs naturally in foods such as breads, cooked cereals and pastas, vegetables, and just-ripe bananas, resists digestion in the small intestine and reaches the large intestine to become fermented by microorganisms. Four types of RS have been classified and are known as RS1, RS2, RS3, and RS4. The average RS intake in the United States is 4.9 g/day (2.8–7.9 g). RS is well tolerated in amounts up to 45 g/day from commercially prepared products.

One of the most common forms of RS in use is high amylose corn starch (HAM-RS2), an ingredient available to both food manufacturers and consumers. HAM-RS2 is a bland, white substance that has a small particle size. It consists of 60% RS and 40% slowly digestible starch and can lower the caloric value of foods when replacing digestible carbohydrates such as flour.

In 2011, the European Food Safety Authority allowed food manufacturers to make health claims on products that partially replace digestible carbohydrates with HAM-RS2 providing at least 3.4 g/serving of RS. The health claims that can be made on these products are associated with the promotion of healthy blood glucose levels. As with fructans, replacing digestible carbohydrates with RS in foods also decreases the available energy. Interestingly, hyperinsulinemic individuals have been found to metabolize RS to produce 2.2 kcal/g, whereas healthy individuals average 2.8 kcal/g.

Mechanism of Fermentable Fibers
Several mechanisms have been proposed but not fully elucidated for the metabolic effects of fermentable fibers. For example, inulin is a soluble fiber that slows small intestinal motility after consumption, which may also delay or impede carbohydrate absorption, resulting in lower postprandial glycemic and insulin responses. RS is insoluble and does not directly contribute to blood glucose concentrations.

After entering the large intestine, fructans and RS are fermented to produce the SCFAs propionate, butyrate, and acetate, which can provide many health benefits. Elevated SCFA concentrations in humans have been shown to lower circulating free fatty acids (FFAs), thus improving insulin sensitivity.

Studies in rats have demonstrated several physiological roles resulting from fermentable fiber consumption. Increased concentrations of SCFAs may upregulate the expression of the proglucagon gene, which synthesizes the gut peptides glucagon-like peptide-1 (GLP-1) and peptide YY (PYY). Elevated levels of GLP-1 and PYY have been found to decrease food intake. In addition, GLP-1 has been shown to promote pancreatic β-cell proliferation and insulin secretion. Although increased concentrations of GLP-1 resulting from the consumption of fermentable fibers have occurred primarily in animal studies, this may represent one mechanism responsible for improvements in glycemia and insulin sensitivity and increases in satiety that may occur in humans.

Physiological Effects of Fructans and RS on Glycemic Health
Effects of fructans
Based on human trials, it appears unlikely that fructans significantly improve glycemia. However, a small study (n = 10) by Cani et al. found significant differences in the area under the curve for plasma glucose between healthy adults who ingested either 16 g/day of soluble fructans extracted from chicory root (treatment) or a fully digestible dextrin maltose (control). At the end of the 2-week study period, plasma glucose was lower in the treatment group after the consumption of a mixed-nutrient ad libitum breakfast.

Another study by Voss et al. evaluated the postprandial glycemic, insulinemic, and GLP-1 responses of individuals with type 2 diabetes after the consumption of three types of tube-feeding formulas using a crossover study design. The study included two diabetes-specific tube-feeding formulas: a slowly digestible carbohydrate (SDC) formula containing short-chain FOS and a diabetes-specific formula (DSF). A standard formula designed for people without diabetes served as the control.

The researchers found that both diabetes-specific formulas significantly lowered postprandial glucose responses compared to the standard formula. The SDC formula also produced significantly lower insulin and higher GLP-1 concentrations. The DSF formula had more fiber per serving (10.5 g) than the DSF (7.2 g), although both formulas had similar amounts of carbohydrate.
In contrast, a recent meta-analysis\(^3\) of randomized, controlled trials (RCTs) ranging from 2 to 24 weeks’ duration found that fructans lowered fasting blood glucose (FBG) in only 4 of 13 trials (31%). Of the four trials that decreased FBG, only one found significant reductions in FBG.

Despite limited data showing significant improvements in blood glucose after the consumption of fructans, elevated gut peptides involved in the regulation of satiety,\(^2\) increased SCFAs and reduced FFAs,\(^3\) and decreased body weight\(^3\) have all been found. The study by Cani et al.\(^2\) found that postprandial gut peptides GLP-1 and PYY were elevated at the end of the study period. Also, hunger sensations were blunted in the FOS group 3 hours after ingesting breakfast. A crossover trial\(^3\) in 33 healthy adults found that consuming 16 g/day of FOS for 13 days lowered energy intake by 11% and increased GLP-1 and PYY in healthy adults compared to baseline. In another RCT\(^3\) (\(n = 48\)), significant weight loss occurred after consumption of 21 g/day of FOS for 12 weeks in overweight and obese individuals. Total daily caloric intake decreased by 29% in the FOS group at week 6.

Research outcomes to date may be related to the fructan type, amount, study duration, and design. However, data appear promising that fructans (> 15 g/day) may decrease energy intake and increase satiety\(^2\) through the upregulation of gut peptides. Unfortunately, ingesting the recommended amount of fructans needed for positive metabolic outcomes may increase the presence of undesirable GI symptoms.

**RS effects**

Improved glucose tolerance, insulin sensitivity, and satiety have resulted from the consumption of RS in healthy humans\(^2\) and therefore have been hypothesized to have implications for glycemic control of individuals at risk of or with type 2 diabetes. The consumption of 60 g of RS from HAM-RS2 in 10 healthy participants resulted in significantly lower postprandial glycemia and insulin levels with improved insulin sensitivity on the following day.\(^4\) Robertson et al.\(^5\) also found significant improvements in insulin sensitivity but not glycemia in 10 healthy individuals who consumed 30 g/day of RS from HAM-RS2 for 4 weeks. Another study\(^6\) found that, although postprandial glucose concentrations in 20 healthy participants who consumed 48 g of RS from HAM-RS2 did not differ from those of control subjects, the individuals consuming the HAM-RS2 had lower energy intakes at dinner after the two test meals and throughout 24 hours.

Evidence suggests that RS may improve insulin sensitivity among individuals at risk of or with type 2 diabetes. Twenty adults with mildly elevated FBG levels who ingested 6 g of RS3 had significantly lower postprandial blood glucose and insulin concentrations at 1 and 1.5 hours compared to placebo.\(^7\) In a study by Maki et al.\(^8\) (\(n = 33\)), insulin sensitivity significantly improved after consuming 15 and 30 g/day of HAM-RS2 for 4 weeks in overweight and obese men but not in women. Two other studies\(^9,10\) (\(n = 15\) and 20, respectively) examined the administration of 40 g/day of fiber from HAM-RS2 in insulin-resistant adults. After 8 and 12 weeks, insulin sensitivity improved by 19 and 21%, respectively.

**Practical Recommendations for Clinicians**

**Fructans recommendations**

Emerging research suggests that incorporating fructans (16–21 g/day) into the diets of individuals at risk of or with type 2 diabetes may improve satiety and body weight. However, ingesting > 15 g/day of fructans, which is the amount needed for beneficial effects, may increase bloating, flatulence, and abdominal discomfort.

Inulin may be better tolerated than FOS because shorter fructans are fermented more rapidly than longer chains. To maximize digestive tolerance, low amounts of fiber (e.g., 5 g) from foods containing fructans should be consumed consecutively for several days, followed by moderate increases until the desired intake is achieved.

The amount of fiber contributed from fructans is not listed on the Nutrition Facts labels of packaged foods. Therefore, consumers must use the ingredient list of food products to detect added fructans. Table 1 provides examples of fructan-containing products. Inulin can now be purchased by consumers as a powder (Table 1) to be added to foods. Table 2 lists ingredients used to identify fructans in products.

**RS recommendations**

In healthy adults, improvements in glycemia, insulin sensitivity, and satiety, as well as decreased energy consumption, may result from consumption of 15–60 g/day of RS. It should be noted that RS is well tolerated up to 45 g/day and can be consumed with minimal digestive effects.

More research is needed to examine the role of RS in individuals with type 2 diabetes. Research has shown that 40 g of fiber from RS improves insulin sensitivity in individuals with insulin resistance. However, because a majority of RS studies that have been conducted in healthy individuals used HAM-RS2 rather than RS occurring naturally in food sources (e.g., potatoes, bananas, and wheat), generalizations to people at risk of or with type 2 diabetes are not well supported.

Increasing RS intake can be achieved by incorporating foods that naturally contain RS or foods that have added RS as an ingredient. Also, HAM-RS2, which is available for consumer purchase, can be added to casseroles, baked goods, sauces, soups, smoothies, and other foods. Up to 25% of flour can be replaced in recipes with HAM-RS2 to increase the total fiber and decrease the caloric value of foods. Table 1 offers a list of products containing RS, and Table 2 compares key points associated with fructans and RS.

**Conclusion**

Research on the role of a fiber-rich eating pattern and its association with decreased risk of type 2 diabetes, hypertension, stroke, CVD, and colon cancer has been conducted primarily in people without type 2 diabetes. Therefore, more research...
examining the effects of fructans and RS in individuals at risk of or with type 2 diabetes is needed. Encouraging such individuals to incorporate fiber-rich foods such as fruits, vegetables, and whole grains, as well as products containing fructans and RS, into their eating plans may aid in improving insulin sensitivity and glycemic health.

References


Table 1. Examples of Products With Added Fructans and RS

<table>
<thead>
<tr>
<th>Product</th>
<th>Fiber Type</th>
<th>Total Fiber (g/serving)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barbara’s Bakery products</td>
<td>Fructan</td>
<td>3–15</td>
</tr>
<tr>
<td>Dreamfield’s pasta products</td>
<td>Inulin</td>
<td>5</td>
</tr>
<tr>
<td>Horizon Dairy yogurt</td>
<td>Fructan</td>
<td>1</td>
</tr>
<tr>
<td>Inulin powder</td>
<td>Inulin</td>
<td>5</td>
</tr>
<tr>
<td>Kashi chewy granola bars</td>
<td>Chicory root</td>
<td>4</td>
</tr>
<tr>
<td>Fiber One products</td>
<td>Inulin, chicory root extract</td>
<td>Varies by product</td>
</tr>
<tr>
<td>Hi-maize</td>
<td>HAM-RS2</td>
<td>6</td>
</tr>
<tr>
<td>Barilla Piccolini Pasta</td>
<td>HAM-RS2</td>
<td>6</td>
</tr>
<tr>
<td>Ener-G foods</td>
<td>HAM-RS2</td>
<td>Varies by product</td>
</tr>
<tr>
<td>Aunt Millie’s potato and whole-grain white bread</td>
<td>HAM-RS2 and inulin</td>
<td>5</td>
</tr>
<tr>
<td>Maninis bread mix</td>
<td>HAM-RS2</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 2. Key Comparisons Between Fructans and RS

<table>
<thead>
<tr>
<th></th>
<th>Fructans</th>
<th>RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily intake (g/day)</td>
<td>( \leq 3.5^{15} )</td>
<td>4.9^{19}</td>
</tr>
<tr>
<td>Maximum GI tolerability level (g/day)</td>
<td>15 (FOS is tolerated less well than inulin because of the shorter chain length)^{16}</td>
<td>( \geq 45^{21} )</td>
</tr>
<tr>
<td>Fiber solubility</td>
<td>Soluble</td>
<td>Insoluble</td>
</tr>
<tr>
<td>Contribution to blood glucose level</td>
<td>Slows small intestine motility and delays carbohydrate absorption,^24 resulting in lower postprandial glucose concentrations</td>
<td>Does not directly affect blood glucose levels(^{49})</td>
</tr>
<tr>
<td>Natural foods in which the substance occurs</td>
<td>Chicory root, wheat, onions, leeks, garlic, asparagus, artichokes, and bananas(^{13})</td>
<td>Grains, seeds, tubers, legumes, bread, corn flakes, potatoes, just-ripe bananas(^{49})</td>
</tr>
<tr>
<td>Identifiers of the substance in ingredient lists on packaged foods</td>
<td>Inulin, chicory, chicory root, chicory root extract, fructooligosaccharides (FOS, scFOS), oligosaccharides</td>
<td>Resistant corn starch, corn starch</td>
</tr>
</tbody>
</table>


Higgins JA: Resistant starch: metabolic effects and potential health benefits. J AOAC Int 87:761–768, 2004


Robertson MD, Bickerton AS, Dennis AL, Vidal H, Frayn KN: Insulin-sensitizing effects of dietary resistant starch and effects on skeletal muscle and adipose tissue metabolism. Am J Clin Nutr 82:559–567, 2005


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