

The Ins and Outs of Oligosaccharides

By Kimberly J. Decker, Contributing Editor

After a recent *E. coli* 0157:H7 outbreak, newspapers were rife with commentaries on how to prevent another such public-health breakdown. Jeff D. Leach, archaeologist, anthropologist and director of Paleobiotics Lab, New Orleans, wrote: “Among the lush greens, yellows and reds of the American produce landscape lies a simple, but critical, component to our evolutionary success as a species and the best defense we have ever had against reducing our risk from *E. coli* and other pathogens that seek to harm us on the biological battlefield that is us. The simple defense to be found in these fields is good old dietary fiber.”

Fiber as food-safety solution? It’s not as far-fetched as it first seems. Our guts play host to a menagerie of bacteria, both healthful and not-so, and the trick is to encourage the former at the expense of the latter. As Leach puts it, “Stimulating the growth of a group of healthy bacteria in the human gut known as *Bifidobacterium* by consuming special prebiotic dietary fibers known as oligosaccharides —found in plants such as onions, leeks, garlic, chicory and artichokes—can fortify our natural resistance.”

Gut feelings

As more people develop digestive disorders, and as evidence mounts on the advantages of diets that cultivate desirable intestinal microflora, researchers, product developers and consumers are learning that the foundation of total health lies in a healthy GI tract.

“Americans typically understand gut health in terms of regularity and laxation,” explains Christine Cerkenik, product manager, Oligo-Fiber inulin, Cargill Health & Food Technologies, Minneapolis. “They know that fiber is good for those conditions. What I think we’re lacking is an understanding of the other factors related to gut health. Gut health really relates to most afflictions we have in life. It can be related to heart health. It even gets at the factors affecting metabolic syndrome. So gut health is a core issue for people to stay healthy.”

And the core of gut health is a well-tended intestinal environment. “One way to think about the intestinal tract is as an ecosystem,” Jennifer Shomonta, corporate fiber leader, Cargill, says. “Good gut health could be defined as maintaining the optimal balance of intestinal microflora —or bacteria—in that ecosystem.” While pathogenic *E. coli*, *Clostridium* and *Listeria* can rank among the inhabitants, more than 400 species of beneficial, or probiotic, bacteria such as bifidobacteria and lactobacilli also call our guts home. “Probiotics are those bacteria

When Chain Length Throws You for a Loop

A central tenet of formulating with inulin and oligofructose holds that longer chain lengths are best for fat-sparing and texture-enhancing functions, while shorter species are the go-to ingredients for sweetener replacement. But this isn't always true. Two applications—ice cream and chocolate—go against the conventional wisdom for sugar and fat replacement, says Scott Turowski, technical sales, Sensus America, Monmouth Junction, NJ.

To replace fat in ice cream, Turowski says, “you actually want to use the short-chain product.” Why? Shorter-chain oligofructose, like sugar, can depress freezing point, which slows down the ice crystallization that gives low-fat ice creams a gritty, glassy, just-plain-icy texture. “It’s a blend of short and long chains that I’ve found to work the best,” he says, recommending a product whose chain lengths average around eight units.

For an alternative sweetener in a low-sugar chocolate, turn to a long-chain inulin. “Again, it has to do with crystallization and the processing of chocolate,” Turowski says. “Inulin doesn’t crystallize” —at least not to the extent that sugar does. As in ice cream, that’s a plus. Longer-chain inulin will have some crystalline material associated with it, but even that’s easy to mitigate by blending it with sugar alcohols like isomalt and maltitol.

that are naturally found living in the intestinal tract,” she says. “The purpose of the good bacteria in our systems is to protect us from toxins or keep other ‘bad’ bacteria from proliferating. These good bacteria promote overall digestive, or gut, health.”

Prebiotic primer

Deep within our GI tracts, probiotic bacteria ferment dietary fibers that are indigestible to us. According to an article in *The Journal of Nutrition* (1995; 125:1401-1412), probiotic bacteria preferentially ferment nondigestible substances defined as prebiotics: oligosaccharides and disaccharides that selectively benefit probiotic growth or activity and, by extension, the probiotics’ hosts.

“Prebiotics are essentially the fertilizer that promotes probiotics,” says Joe O’Neill, executive vice president of sales and marketing, Orafit Active Food Ingredients, Malvern, PA. Among prebiotics, he adds, “inulin is the classic.” Inulin is a mixture of linear fructan chains ranging in length from 2 to 5 up to 50 to 60 fructose units. “Native” inulin averages around 15 units per chain (although some quote 16 to 20 units), while what’s known as oligofructose is essentially inulin, but shorter: anything with a degree of polymerization of 10 units or fewer.

Then there’s fructooligosaccharide, or FOS, which Robert Veghte, marketing, Roxlor International, Wilmington, DE, says “is different because the linked fructose molecules have a glucose terminal, whereas inulin and oligofructose are mostly linked fructose molecules.” The variation owes largely to production idiosyncrasies. After extracting inulin (mainly from chicory root, which, at 16% to 20% inulin, is the industry’s primary source) with hot water, producers hydrolyze it to shorter oligofructose units using inulase. This yields a mixture of fructose- and glucose-terminal chains. Alternatively, transfructosylation of sucrose via beta-fructofuranosidase produces all glucose-terminal chains.

“You naturally have a distribution of chain lengths, and you might cleave them at a certain point or combine multiple long chains to make a long-chain product,” Cerkvénik adds. Therefore, inulin—a fiber that occurs naturally in everything from artichokes, onions and wheat to garlic, bananas, barley, asparagus, raisins and tomatoes—is highly manipulable, allowing for proprietary improvements that make each oligosaccharide product unique.

A crucial commonality among inulin, oligofructose and FOS is the beta (2,1) glycosidic linkages joining the individual monomers. Impervious to human enzymes and gastric juices, these bonds qualify the substances as soluble dietary fibers, according to AOAC Fructan Method 977.08 analysis. As soluble fiber, they possess all the associated virtues, such as the ability to increase fecal bulk and frequency and, when swollen in the stomach, to generate feelings of fullness. In the small intestine, that bulking viscosity gives cells more time to absorb nutrients and, coupled with inulin’s zero impact on glycemic index, to regulate blood glucose.

pH: Inulin’s Achilles’ Heel

Highly soluble, heat stable, mild in flavor and innocuous in texture. When it comes to inulin, it’s hard to imagine what’s not to like. But this multifunctional prebiotic fiber is vulnerable to low pH. “Around 3.8, you start having concerns,” says Scott Turowski, technical sales, Sensus America, Monmouth Junction, NJ. “It hydrolyzes at low pHs into fructose.” While that’s not tragic, it does compromise the ingredient’s nutritional and functional benefits—and it puts applications like lemon soda off limits. “The biggest limitation becomes shelf-stable beverages,” which need to be low-pH for preservative reasons, he says.

The reaction doesn’t happen quickly, so acidic applications with a quick turnaround time don’t face the same threat as those with long shelf lives. “There are a couple ways to combat it a bit,” Turowski says. Low temperatures slow the reaction drastically, so while a shelf-stable soda might not work, a fresh fruit juice, because it’s refrigerated, is OK. High solids also stabilize inulin at a low pH, as in “very high-Brix things like bakery fillings with Brix levels of 70 or 80,” he adds. “It all has to do with there being less water available for that hydrolysis reaction to happen.” That means more protection to keep inulin from falling apart.

The genesis: bifidogenesis

Inulin's effects on bifidobacteria best explain its health implications. About 95% of the intestinal flora in breastfed infants consists of bifidobacteria—a concentration that drops to about 25% in the average adult. Inulin and oligofructose are uniquely stimulative—or “bifidogenic”—to these probiotics, which ferment the fibers in the large intestine to produce such short-chain fatty acids (SFCAs) as acetate, butyrate and propionate.

The results of this fermentation and its SFCAs are wide-reaching. For one, SFCAs lower gut pH such that, although still tolerable to probiotics, it discourages pathogens like *E. coli*, *Salmonella* and *Campylobacter*. But, “there are a lot of things that go on with those bacteria, the short-chain fatty acids they're producing and how those affect your body,” says Scott Turowski, technical sales, Sensus America, Monmouth Junction, NJ.

“Short-chain fatty acids promote protective effects on the gut and host, such as increased gut integrity, enhanced immunity through pathogen inhibition, improved normal bowel function, and improved nutrient metabolism and absorption,” says Coni Francis, Ph.D., R.D., senior manager for science, marketing and technical services, GTC Nutrition, Golden, CO. “Significant increases in bifidobacteria and additional health benefits can be seen with as little as 1 gram per day of scFOS,” a short-chain fructooligosaccharide produced through a special fermentation process designed to yield two to four fructose units per chain.

Building better bones

Inulin has garnered the greatest attention in enhanced nutrient absorption, specifically calcium and, to a lesser extent, magnesium and iron. “In the gastrointestinal tract, minerals must stay in solution in order to be absorbed, as they tend to precipitate out of solution at the higher pH ranges,” Francis explains. “The production of SFCAs lowers the luminal pH to an optimal level for keeping minerals in solution longer, thereby enhancing their absorption.” SFCAs also directly stimulate calcium absorption, and the bifidobacterial fermentation that produces them triggers intestinal mucosal-cell proliferation, increasing surface area for mineral exchange.

Inulin doesn't just increase calcium absorption, it increases the amount of calcium actually deposited and retained in the bones. More than a dozen human and animal studies confirm that inulin can increase calcium absorption and bone mineral density to the tune of 58% at 40 grams of inulin per day, 26% at 15 grams of oligofructose per day, and 20% at 8 grams of an inulin-oligofructose hybrid per day.

Furthermore, internal research from GTC Nutrition claims its scFOS boosts absorption of soy isoflavones, amplifying their effects on bone mineral density in the absence of estrogen. Combining the short-chain product with soy isoflavones, the company says, almost doubled total femur bone mineral density (BMD) over a control.

The body's best defense

Probiotics' fermentation of inulin not only sets up conditions advantageous to their own survival, but favors their hosts' immune systems, as well. “If you consider that over 60% of our immune system is housed in the intestinal tract, it's important to maintain the right balance of ‘good’ vs. ‘bad’ bacteria there,” says Shomonta.

A Johns Hopkins University study (*British Journal of Nutrition*, 2002; 87, Supp. 2: S241- S246) of 123 infants fed for six months on either inulin-supplemented cereal or a placebo found that those in the inulin group had less fever, vomiting, antibiotic use, need for doctor visits and time away from daycare than their control

counterparts. “A particularly important immune benefit of scFOS consumption is the proliferation of gut-associated lymphoid tissue, or GALT, which offers a protective effect to the immune system,” Francis says. The GALT, she says, “is constantly interacting with the colonic microflora, making this organ extremely dynamic in terms of immune function.”

Inulin’s influence goes beyond crowding out the bad bacteria with the good. Bernhard Watzl, Ph.D., of the Federal Research Center for Nutrition and Food, Karlsruhe, Germany, supplemented pigs’ diets with Orafiti’s Beneo Synergy1 inulin and oligofructose ingredient and measured immune-function markers after three weeks and three months. Short-term supplementation increased phagocytic activity in white blood cells and the numbers of natural killer T-cells (NKT-cells) in the spleen, while longterm feeding boosted NKT-cell activity in Peyer’s patches in the lymphatic system and splenocytes, the white cells found in the spleen.

On the horizon

Research also is establishing inulin’s role in carcinogenesis and cardiovascular disease. Inulin, as a soluble fiber, already claims heart-healthy credentials, but what intrigues researchers is how its fermentation affects fattyacid synthesis. “It has to do with the short-chain fatty acids,” Turowski says. “These short-chain fatty acids are absorbed through the gut and into the liver, and in the liver, they’re regulators of cholesterol synthesis, and possibly inhibit synthesis.” Propionic acid may be the main SCFA the liver uses to reduce serum triglycerides and cholesterol levels.

As for cancer, the European Commission-sponsored SYNCAN study has mounted in vitro, animal and human clinical trials to evaluate how synbiotics—foods combining probiotic cultures with prebiotic boosters— may cut colon cancer risk. Apparently, an active complement of bifidobacteria can lower levels of the beta-glucuronidase enzyme that converts procarcinogens to carcinogen. Perhaps by generating butyrate for use in colon cells, bifidobacterial inulin fermentation may suppress lesions known as aberrant crypt foci that are possible colon-cancer precursors.

Even satiety may not escape inulin’s sway. But the satiety effects, Turowski says, “are not the typical fiber-type satiety ... inulin is actually creating more of a hormonal response.” It appears to promote the release of glucagon-like peptide 1 (GLP-1), a gut hormone that stimulates the ileal break. By putting a “brake” on food’s passage through the ileum, the small intestine’s final section, it gives food time to touch off signals that tell our brains we’re full.

Playing it safe

However, O’Neill cautions that “different areas are under different stages of research.” FDA will want to see quantifiable results, he says. “And when our customers want to make a claim, their regulatory departments get involved, and they want to see the clinicals, too,” he adds. “They want to see the science, and they want to see the specific products that work.”

The wisest course is to play it safe. “When it comes to the regulatory side, you certainly don’t want to mention disease,” O’Neill says. “Nobody’s going to put ‘helps prevent cancer’ on the package.”

While no specific claim exists, you can say, “three grams of inulin gets you to a ‘good source’ fiber claim,” Veghte says. “Five grams will give you an ‘excellent source’ of fiber.” But, he adds, “that doesn’t mean that you can’t market the ingredient on your label. You can put, ‘includes prebiotic fiber.’ You may be able to put, ‘helps

mineral absorption,' 'improved gut health'—but it really plays the line between food and supplement in that gray functional-food area.”

Moreover, while all prebiotics have some health benefits, all oligosaccharides are not created equally. For example, terminal glucose and short chain length “are extremely important to the fermentation profile and ingredient functionality,” says Francis. “The chemical structure and relative chain length of a prebiotic will determine how easily it can be used by probiotic bacteria.” Inulin’s longer chains, she says, “narrow the good bacteria’s fermentation profile excessively, and therefore it is not readily used by important probiotic bacteria.”

In the end, O’Neill says, “when you’re formulating, you want to be able to add something at a usage rate that will have an effect. When it’s digested, the short chains are fermented quickly, the medium chains more slowly, and the longer chains even more slowly, so they make their way further down the digestive tract and populate it in its entirety with bifidobacteria.”

The long and short of it

Beyond being good for you, inulin is good for a product’s processing and organoleptic properties. Those merits have everything to do with the type of inulin you’re using, the product in which you use it, and the goals you want it to achieve.

“It’s all about what you want to get out of it,” Turowski says. “When I talk to product developers and R&D people about functionality, what I tell them is to break the chain length down a little bit. You’re talking about that range of 2 to 60 units. When you’re starting with 2, 3, 4 and 5 units, those ingredients have sweetness, very high solubilities, and behave a lot like sugar.”

As the units increase, “it’s the longer chains that are binding water and, therefore, are more for replacing fats,” Turowski says. “Longer-chain inulin solutions actually form a gel that is similar to shortening in the way it looks and feels.”

Those two properties—sugar replacement and fat mimesis—are the calling cards of oligofructose and inulin, respectively. The shorter oligofructoses may only have 30% to 50% sucrose’s sweetness—which means you can’t rely on it as your sole sweetener (plus most inulin and oligofructose products contribute 1.5 to 2 kcal per gram from lactate metabolism). But oligofructose is more soluble than sucrose and helps amplify high-intensity sweeteners.

Humectancy lets shorter chains retain moisture in baked goods and bars. An oligofructose solution “keeps the bars soft and you can use it as a binding syrup,” Turowski says. “A binding syrup is typically corn syrup and sucrose, so replace that with a combination of inulin and oligofructose,” letting the latter stand in for the syrup, and the longer inulin build viscosity.

But for a creamy mouthfeel that spares fat without sparing its texture, “you have to look at the long chains,” Turowski says. The most-popular applications for this are low-fat and nonfat yogurts, where inulin not only adds body, but provides prebiotic benefits that nurture probiotic cultures and enhance calcium absorption.

Such multifunctional yogurts are a hit overseas. “In Europe, everyone knows about prebiotics and probiotics and gut health and bacteria,” Veghte says. “You walk into a grocery store and there are three aisles of yogurt.” Stateside, we’re still getting a handle on just what inulin can do for us.

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