Inulin and Oligofructose: What Are They?[1]

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ABSTRACT Inulin is a term applied to a heterogeneous blend of fructose polymers found widely distributed in nature as plant storage carbohydrates. Oligofructose is a subgroup of inulin, consisting of polymers with a degree of polymerization (DP) ≤10. Inulin and oligofructose are not digested in the upper gastrointestinal tract; therefore, they have a reduced caloric value. They stimulate the growth of intestinal bifidobacteria. They do not lead to a rise in serum glucose or stimulate insulin secretion. Several commercial grades of inulin are available that have a neutral, clean flavor and are used to improve the mouthfeel, stability and acceptability of low fat foods. Oligofructose has a sweet, pleasant flavor and is highly soluble. It can be used to fortify foods with fiber without contributing any deleterious organoleptic effects, to improve the flavor and sweetness of low calorie foods and to improve the texture of fat-reduced foods. Inulin and oligofructose possess several functional and nutritional properties, which may be used to formulate innovative healthy foods for today's consumer. J. Nutr. 129: 1402S–1406S, 1999.

KEY WORDS: • *inulin* • *oligofructose* • *dietary fiber* • *prebiotic* • *bifidogenic* • *fat reduction*

Natural occurrence

Inulin and oligofructose are natural food ingredients commonly found in varying percentages in dietary foods. They are present in >36,000 plant species (Carpita et al. 1989). In fact, it has been estimated that Americans consume on average 1–4 g of inulin and oligofructose per day and Europeans average 3–10 g/d (Van Loo et al. 1995). Inulin and oligofructose are present as plant storage carbohydrates in a number of vegetables and plants including wheat, onion, bananas, garlic and chicory.

Raw material

Most of the inulin and oligofructose commercially available on the industrial food ingredient market today is either synthesized from sucrose or extracted from chicory roots. The chicory root is best known for its use as a coffee substitute (Pazola and Ciesbak 1979) and also as the root of the Belgian endive plant. The root of the *Cichorium intybus* plant contains ~15–20% inulin and 5–10% oligofructose.

Manufacturing

The manufacturing process for inulin is rather similar to that of sugar extracted from sugar beets. The roots are typically harvested, sliced and washed. Inulin is then extracted from the root by using a hot water diffusion process, then purified and dried (Belval 1927). The resulting product has an average degree of polymerization (DP)[2] of 10–12 and a distribution of molecules with chain lengths from 2–60 units. The finished inulin powder typically contains 6–10% sugars represented as glucose, fructose and sucrose. These are native to the chicory root; they are not added after extraction.

A "high performance" (HP) type of inulin has also been made available recently to the market. This product is manufactured by removing the shorter-chain molecules. HP inulin has an average DP of 25 and a molecular distribution ranging from 11 to 60. Thus, the residual sugars as well as the oligomers have been removed. This product provides almost twice the fat mimetic characteristics of standard inulin with no sweetness contribution. Oligofructose is derived from chicory in much the same manner as inulin. The major difference is the addition of a hydrolysis step after extraction. Inulin is broken down using an inulase enzyme into chain lengths ranging from 2 to 10, with an average DP of 4. The resulting oligofructose product has ~30% of the sweetness of sucrose and contains ~5% glucose, fructose and sucrose on a dry solids basis. Oligofructose may also be synthesized from sucrose by transfructosylation, which is accomplished by means of an enzyme, β-fructofuranosidase, that links additional fructose monomers to the sucrose molecule. Fructans formed in this manner contain 2–4 fructose units linked to a terminal glucose. The glucose and fructose molecules formed as by-products of the process, as well as any unreacted sucrose, may be removed with the use of chromatography (Crittenden et al. 1996). Typical commercial products contain 5% sugars.

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[2] Abbreviations used: DP, degree of polymerization F_m, fructose chains; GF_n, fructose chains with terminal glucose; HP, high performance.

Chemical structure

Inulin is not simply one molecule; it is a polydisperse $\beta(2—1)$ fructan (Phelps 1965). The fructose units in this mixture of linear fructose polymers and oligomers are each linked by $\beta(2—1)$ bonds. A glucose molecule typically resides at the end of each fructose chain and is linked by an $\alpha(1—2)$ bond, as in sucrose. The chain lengths of these fructans range from 2 to 60 units, with an average DP of ~10 (DeLeenheer and Hoebregs 1994, IUB-IUPAC Joint Commission on Biochemical Nomenclature 1982, VanHaastrecht 1995). The unique aspect of the structure of inulin is its $\beta(2—1)$ bonds. These linkages prevent inulin from being digested like a typical carbohydrate and are responsible for its reduced caloric value and dietary fiber effects. Oligofructose is defined by the IUB-IUPAC Joint Commission on Biochemical Nomenclature and the AOAC as fructose oligosaccharide containing 2–10 monosaccharide residues connected by glycosidic linkages (Hoebregs 1997, IUB-IUPAC Joint Commission on Biochemical Nomenclature 1982). Oligofructose derived from chicory contains both fructose chains (F_m) and fructose chains with terminal glucose units (GF_n). Synthesized oligofructose contains only fructose chains with glucose end units or GF_n molecules. Both types of oligofructose contain $\beta(2—1)$ linkages between the fructose molecules, and they both carry essentially the same nutritional benefits (Roberfroid et al. 1998).

Functional properties

The differences in chain length between inulin and oligofructose account for their distinctly different functional attributes. Due to its longer chain length, inulin is less soluble than oligofructose and has the ability to form inulin microcrystals when sheared in water or milk. These crystals are not discretely perceptible in the mouth, but they interact to form a smooth creamy texture and provide a fat-like mouthfeel. Inulin has been used successfully to replace fat in table spreads, baked goods, fillings, dairy products, frozen desserts and dressings.

Oligofructose is composed of shorter-chain oligomers and possesses functional qualities similar to sugar or glucose syrup. It is actually more soluble than sucrose and provides ~30–50% of the sweetness of table sugar. Oligofructose contributes body to dairy products and humectancy to soft baked goods, depresses the freezing point in frozen desserts, provides crispness to low fat cookies, and acts as a binder in nutritional or granola bars, in much the same way as sugar, but with the added benefits of fewer calories, fiber enrichment and other nutritional properties. Oligofructose is often used in combination with high intensity sweeteners to replace sugar, provide a well-balanced sweetness profile and mask the aftertaste of aspartame or acesulfame k (Wiedmann and Jager 1997).

Both inulin and oligofructose are used worldwide to add fiber to food products. Unlike other fibers, they have no "off flavors" and may be used to add fiber without contributing viscosity. These properties allow the formulation of high fiber foods that look and taste like standard food formulations. It is an invisible way to add fiber to foods. Oligofructose is commonly used in cereals, fruit preparations for yogurt, frozen desserts, cookies and nutritional dairy products. The nutritional properties of inulin and oligofructose are similar; thus the decision to formulate with inulin vs. oligofructose is largely a function of the attributes desired in the finished product. For example, the use of high performance inulin would prove to be the method of choice when formulating a low fat table spread that has a creamy, fat-like mouthfeel with no added sweetness. Conversely, when formulating a low calorie fruit preparation for yogurts using high intensity sweeteners, oligofructose could enhance the fruit flavor, balance the sweetness profile and mask any undesirable aftertaste. Another added benefit of oligofructose that is often capitalized on in yogurt is the prebiotic effect, which may serve to reinforce or enhance the action of probiotic cultures typically added to yogurt.

Nutritional properties

Perhaps the most interesting and exciting aspects of inulin and oligofructose are their nutritional properties.

Caloric value. Inulin and oligofructose have been used in many countries to replace fat or sugar and reduce the calories of foods such as ice cream, dairy products, confections and baked goods. Inulin and oligofructose have lower caloric values than typical carbohydrates due to the $\beta(2—1)$ bonds linking the fructose molecules. These bonds render them nondigestible by human intestinal enzymes. Thus, inulin and oligofructose pass through the mouth, stomach and small intestine without being metabolized. This has been proven by many scientific studies (Kuppers-Sonnenberg 1952, Lewis 1912, Okey 1919, Nilsson et al. 1988, Rumessen et al. 1990, Ziesenitz and Siebert 1987), including studies on ileostomy volunteers (Ellegard et al. 1997, Knudsen and Hessov 1995). These studies indicate that almost all of the inulin or oligofructose ingested enters the colon where it is totally fermented by the colonic microflora. The energy derived from fermentation is largely a result of the production of short-chain fatty acids and lactate, which are metabolized and contribute 1.5 kcal/g of useful energy for both oligofructose and inulin. Other by-products of fermentation include bacterial biomass and gases that are eventually excreted. Due to the nondigestibility of inulin and oligofructose, they were found to be suitable for consumption by diabetics. Researchers found no influence on serum glucose, no stimulation of insulin secretion and no influence on glucagon secretion (Beringer and Wenger 1995, Sanno et al. 1984). Inulin has a long history of use by diabetics (Lewis 1912, Persia 1905) and in fact has been reported to benefit diabetic patients in high doses (40–100g/d) (McCance and Lawrence 1929, Root and Baker 1925, Strauss 1911, Wise and Hey 1931).

Dietary fiber. Another important nutritional attribute of inulin and oligofructose is their action as dietary fibers. Dietary fibers may be defined in two ways: by an analytical approach and a physiological one.

The analytical definition of dietary fiber used by the AOAC is "remnants of plant cells resistant to hydrolysis by the alimentary enzymes of man" (Trowel and Burkitt 1986). Inulin and oligofructose certainly fall under this definition and are now measured analytically with the use of the recently approved AOAC Fructan Method 977.08 (Hoebregs 1997). Although there is no official list of physiologic functions that a fiber should possess to meet the definition of fiber, generally accepted physiologic effects of fiber include an effect on intestinal function and the improvement of blood lipid parameters. Dietary fibers also typically have a reduced caloric value.

Inulin and oligofructose influence intestinal function by increasing stool frequency, particularly in constipated patients, (Gibson et al. 1995, Hidaka et al. 1986, Menne et al. 1997, Shimoyama et al. 1984) increasing stool weight (Gibson et al. 1995, Oku and Tokunaga 1984) as much as 2 g per gram of inulin or oligofructose ingested and decreasing fecal pH (Gibson and Roberfroid 1995, Menne et al. 1997), which has been linked to suppression of the production of putrefactive sub-

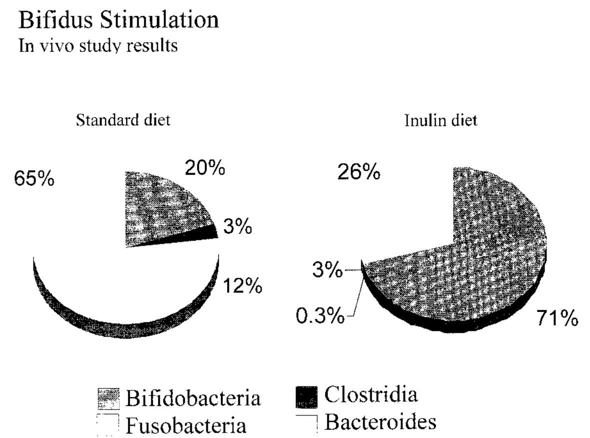

FIGURE 1 Shifts in the distribution of fecal microflora in humans provided a diet without and with supplemental inulin. Source: Gibson et al. (1995).

stances in the colon. Additionally, they reportedly decreased serum triglycerides and blood cholesterol levels in hypercholesterolemic patients (Brighenti et al. 1995, Fiordaliso et al. 1995, Hata et al. 1983, Hidaka et al. 1986, Kok et al. 1996, Mitsuoka et al. 1986, Sanno 1986, Yamashita et al. 1984).

From an analytical and a physiologic point of view, both inulin and oligofructose should be classed as fibers (Graham and Aman 1986, Knudsen et al. 1995, Lee and Prosky 1995, Nilsson et al. 1988, Roberfroid 1993).

Bifidus stimulation. Perhaps the best-known nutritional effects of inulin and oligofructose are their actions to stimulate bifidobacteria growth in the intestine. The colon is known to be a complex ecosystem with >400 different types of bacteria. Some strains have pathogenic effects such as the production of toxins and carcinogens, whereas others are considered to provide a health-promoting function. Among those bacteria that are thought to promote health are *Lactobacilli* and *Bifidobacteria*. Nourishing beneficial bacteria, such as *Bifidobacteria*, with inulin or oligofructose allows them to "outcompete" potential detrimental organisms and thereby potentially contribute to the health of the host. Health benefits ascribed to *Bifidobacteria* include the following: inhibiting the growth of harmful bacteria, stimulating of components of the immune system and aiding the absorption of certain ions and the synthesis of B vitamins. The bifidogenic effect of inulin and oligofructose has been well proven (Bouhnik et al. 1994, Djouzi and Andrieux 1997, Gibson et al. 1995, Gibson and Roberfroid 1995, Hidaka et al. 1986, Kleessen et al. 1994, Menne et al. 1997, Mitsuoka 1986, Mitsukoa et al. 1987, Roberfroid et al. 1998, Sanno 1986, Shimoyama et al. 1984, Takahashi 1986). Dramatic positive shifts in the composition of microflora have been shown through in vivo human studies at doses between 5 and 20 g/d, generally over a 15-d period (**Fig. 1**: Gibson et al. 1995), (Kleessen et al. 1994, Menne et al. 1997, Wang 1993, Wang and Gibson 1993). The bifidogenic effects of different forms of inulin and oligofructose are bifidogenic independent of chain length or GF_n and F_m type (Gibson et al. 1995, Roberfroid et al. 1998).

Inulin and oligofructose have been termed "prebiotics" (Gibson et al. 1995) because they are nondigestible food ingredients that selectively stimulate growth and/or activity of a number of potentially health-stimulating intestinal bacteria. They are often used in combination with "probiotics" or live bacteria that are added to the host's diet to promote health. The combinations of pre- and probiotics have synergistic effects, referred to as synbiotics, because in addition to the action of prebiotics that promote the growth of existing strains of beneficial bacteria in the colon, inulin and oligofructose also act to improve the survival, implantation and growth of newly added probiotic strains. The synbiotic health concept is being used by many European dairy drink and yogurt manufacturers in products such as Aktifit (Emmi, Switzerland), Probioplus (Migros, Switzerland), Symbalance (Tonilait, Switzerland), Proghurt (Ja Naturlich Naturprodukte, Austria), Fysiq (Mona, Netherlands), Vifit (Sudmilch/Stassano, Belgium, Germany, UK) and Fyos (Nutricia, Belgium) (Coussement 1997). Recent studies on bifidogenicity center on the effects of inulin and oligofructose in the treatment, prevention or alleviation of symptoms of intestinal diseases (Butel et al. 1997, Djouzi 1995, Gibson and Roberfroid 1995, Reddy et al. 1997, Roberfroid 1993, Roberfroid et al. 1995).

In addition to calorie and fat reduction, fiber effects, lipid modulation and bifidus stimulation, the results of studies have also indicated positive effects on calcium absorption in rats and humans and cancer prevention in animals. It has been shown in over 10 studies that inulin and oligofructose increase both the absorption and the deposition of calcium in the bones of rats and humans (Coudray et al. 1997, Delzenne and Roberfroid 1994, Lemort and Roberfroid 1997, Ohta et al. 1993, 1995 and 1997, Scholz-Ahrens et al. 1998, Shimura et al. 1991, Taguchi et al. 1995, Van den Heuvel et al. 1997). There are promising indications that inulin and oligofructose may contribute to the prevention of osteoporosis.

Results of recent studies that have been completed in animals suggest that inulin and oligofructose may also play a role in the prevention and inhibition of colon and breast cancer. These are early studies and further studies will be completed, but initial results look promising (Cooper and Carter 1986, Gallaher et al. 1996, Koo and Rao 1991, Reddy et al. 1997, Roland et al. 1994a, 1994b, 1995 and1996, Rowland et al. 1998, Taper et al. 1995 and1997).

Importance to the food industry today. Unquestionably, inulin and oligofructose have many interesting nutritional and functional attributes that are useful in formulating the foods of today and tomorrow. Today's consumers hold high standards for the foods they consume. They demand foods that taste great, are fat- and/or calorie-reduced, and they are interested in foods that provide added health benefits. Of course, it is expected that these foods will be convenient and affordable. The desire of consumers to look good and stay healthy in a fast-paced environment is becoming more difficult to fulfill. Quick fixes and shortcuts are attractive to the consumer, whether they refer to food preparation, weight loss or disease prevention. Time is a most precious commodity. Consumers are also more informed and more aware of the links between diet and health than ever before. Consequently they are looking for foods to provide multiple benefits as well as good taste.

America's leading health concerns are heart disease, cancer, stress, high cholesterol, weight control, osteoporosis and diabetes (Gilbert and Sloan 1998), and the number one health-related interest among food shoppers is "boosting the immune system" (Gilbert and Sloan 1998). This speaks to a strong focus on disease prevention and indicates that the time is right for optimizing health by the use of food components such as inulin and oligofructose.

In conclusion, inulin and oligofructose are widely used in functional foods throughout the world for their health-promoting and technological properties. They are ingredients of the future that meet the needs of the food industry today, and are on the leading edge of the emerging trend toward functional foods.

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