Oat Soluble Fibers (β-Glucans) as a Source for Healthy Snack and Breakfast Foods

R. DUSS
CreaNutrition AG
Zug, Switzerland

L. NYBERG
Skånemejerier
Malmö, Sweden

Oat (Avena sativa L.) is a typical northern cereal. As such, it prefers a wet, cold climate, with rain during the growing phase and sunshine and long hours of daylight during the harvest season. For approximately 2,000 years, oats and barley were staples of the diet in Nordic countries. Only at the beginning of the 19th century were oats partially replaced by other cereals and potatoes. Today, interest in oats is increasing, and it retains a strong image as a nutritious, health-promoting ingredient in food applications due to its high bioactive and functional component contents.

Significant positive health effects have been attributed to oat products, including cholesterol control, modulation of glucose and insulin responses, weight management, and improved gastrointestinal function. Probably the most well-recognized health-promoting ingredient from oats is β-glucans, a soluble fiber (25,40).

Chemistry of Oat β-Glucans

Oat β-glucans are nonstarch polysaccharides. Like starch, they are composed of glucose molecules in long chains, but the binding between glucose monomers differs from starch. In starch, the glucose monomers are connected by α-bonds: amyllose has α-(1→4) bonds, whereas amyllopectin, in addition to long glucose chains with α-(1→4) bonds, also has α-(1→6) bonds that initiate side chains. The two α-bonds in starch are easily digested by enzymes in the intestine.

Cellulose is also a polysaccharide and is composed of long chains of glucose molecules bound by β-(1→4), which produces a straight molecule. The intestine does not contain enzymes that can digest these β-(1→4) links. Cellulose is a nonsoluble fiber, because the long, straight chains are closely packed and water molecules cannot penetrate and dissolve the fibers.

Oat β-glucans, like cellulose, are linear glucose polymers, but oat β-glucans have both β-(1→4) and β-(1→3) links, creating a cellulose chain with β-(1→4) links interrupted by β-(1→3)-linked glucose units. Approximately 70% of the links are β-(1→4), and the rest are β-(1→3). The distribution is not random: the (1→3) linkages always occur singly, and most of the (1→4) linkages occur in groups of three or four. The intestine does not contain enzymes that can digest oat β-glucans, so they are by definition a fiber (38).

Physical Properties of Oat β-Glucans

The mixed linkages that form oat β-glucans are important for their physical properties, such as viscosity and solubility. The presence of two types of linkages prevents compact folding of oat β-glucan chains, making them soluble in water. The (1→3)–linked residues result in kinks in the otherwise ribbon-like shape of the molecule, allowing water to penetrate and solubilize the fiber (11). The longer (1→4) sequences are believed to be responsible for the partial water insolubility properties of oat β-glucans, because they provide surfaces that are capable of forming junction zones (39). Oat β-glucans are asymmetric molecules that assume an extended conformation in aqueous solution, best described as worm-like chains (16). One theoretical model (10) describes β-glucans in solution as an extended random coil.

Oat β-glucans are large molecules. Available data on molecular weight distribution vary between 2.68 × 10⁴ and 3 × 10⁶ g/mol (32,34). These variations probably depend on differences in raw materials, processing, and methods of determination (13,36). Even at low concentrations in water solutions, oat β-glucan molecules interact, causing marked resistance in water flow and creating a viscous solution. If the concentration is high enough, a gel is formed through associations between molecules.

Increased viscosity is a fundamental characteristic of oat β-glucans solutions and has an important impact on their physiological behavior in the intestine and, thus, their physiological function. Viscosity plays an important role in cholesterol-lowering effects and glycemic response. Solubilization and the molecular weight of β-glucans influence viscosity and bioavailability (2,3,6,42) (Figs. 1 and 2). Viscosity is mainly determined by molecular weight but also by molecular structure, resulting from the distribution of (1→3) and (1→4) links.

To maintain functional attributes, it is important that the processing of oat kernels into oat bran, which has an elevated concentration of oat β-glucans, does not destroy the β-glucan structure. These large macromolecules are mechanically sensitive and can be broken at high shear rates, requiring careful attention to mechanical treatment in processing. Figure 3 shows the distribution of β-glucans in oat bran containing 22% β-glucans.

Effects of Oat β-Glucans on Glycemic Response

Rapidly Digested Carbohydrates.

Many of the foods we eat today contain carbohydrates that are digested and absorbed very rapidly from the intestine into the blood stream, causing a high glycemic response or glycemic index (GI) and rapid secretion of insulin from the pancreas. Increased insulin levels are believed to be a key factor in the development of several diseases.

Studies show positive metabolic effects of diets containing carbohydrates that are slowly digested in the intestine and have a low GI. Epidemiological data suggest that a low-GI diet may help prevent type II diabetes.
(36,41), cardiovascular disease (22), and metabolic syndrome (27) and may reduce insulin resistance (27).

The World Health Organization (WHO) and Food and Agriculture Organization (FAO) recommend that people in industrialized countries base their diets on low-GI foods in an effort to reduce some of the diseases associated with high-GI diets, such as coronary heart disease, diabetes, and obesity (12).

**Soluble Fiber.** Fibers can be classified into two groups based on water solubility. In contrast to insoluble fibers, which have no significant effect on viscosity in the small intestine, water-soluble oat β-glucans exert their effects mainly by increasing viscosity in the small intestine.

In the intestine, oat β-glucans absorb fluids and contribute to viscosity during digestion, resulting in an extended digestion period. When digestion is delayed, blood sugar increases more slowly, causing a low insulin response. The effect has been established (5,9,17), but the course of events causing the effect is not fully understood. One hypothesis is that in the intestine food is “incorporated” in the viscous oat β-glucan solution making it more difficult for enzymes in the intestine to degrade the food components and causing digestion to take longer. Another hypothesis is that oat β-glucans form a protective layer along the intestinal wall that acts as a viscous barrier, slowing food uptake from the intestine.

**Blood Cholesterol and Oat β-Glucans**

Substantial clinical evidence from the last 30 years has documented that oat β-glucans have an effect on blood cholesterol levels and control of lipoprotein metabolism (8,21,33,37). Oat β-glucans are believed to favorably affect blood cholesterol and lipoprotein metabolism mainly by increasing viscosity in the small intestine.

There are different theories concerning the mechanisms of the blood cholesterol lowering effect of oat β-glucans. One theory (26) proposes that the viscous oat β-glucans encapsulate bile acids, resulting in their excretion in the feces. Bile acids generally are recycled, i.e., they are taken up in the lower part of the intestine and used again. Through excretion in feces, the body loses bile acids and has to synthesize new ones, which is done in the liver. The building block for bile acids is cholesterol, which the liver extracts from the blood, decreasing blood cholesterol levels. Another hypothesis (20) is that fermentation of soluble fiber by bacteria in the large intestine produces propionate. The propionate is then absorbed by the colon cells and goes to the liver, where it is thought to have an effect on cholesterol synthesis. A third theory is

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**Fig. 1.** Molecular weight (MW) and solubility of β-glucans extracted by digestive enzymes at 37°C and hot water from oat bran containing 22% β-glucans, oat bran, and rolled oats. *, Data from Beer and coworkers (6); **, MW and solubility (2,3,6,32). β-Glucans were analyzed according to AACC Approved Method 32-33 and AOAC Official Method 995.16.

**Fig. 2.** Apparent viscosity of soluble fiber extract (physiological extract after in vitro digestion [2,6]) from oat bran containing 22% β-glucans at increasing β-glucan concentration in the extract.
that oat β-glucans interfere with the absorption of lipids, probably by reducing or delaying the emulsification and lipid hydrolysis process.

**Oat β-Glucans as Prebiotics**

The lower part of the intestine, the colon, has been identified as a key organ affecting general health. The growth and metabolism of the many individual bacterial species inhabiting the colon depend primarily on the substrates available to them, most of which come from the diet. Oat β-glucans, which are indigestible in the small intestine but are fermented by bacteria in the colon, are prebiotics (24).

Prebiotics are nondigestible food ingredients that selectively stimulate the growth or activities of bacteria in the colon. They beneficially affect a series of intestinal functions by modulating the structure, composition, and metabolic activity of mucosa and microflora in the colon. The end products created from prebiotic fermentation in the colon are short-chain fatty acids, e.g., butyric acid, that serve as nutrients for mucosal cells.

**Oat β-Glucans and Weight Management**

Satiety is a complex bodily sensation that signals that the stomach is full and it is time to stop eating. When consumed 20–30 min before eating a meal, oat β-glucans form a thick viscous fluid in the stomach and small intestine that stimulates the sensation of satiety and helps limit appetite. By reducing the desire for food intake, the effect can help in weight control when combined with a healthy, balanced diet and adequate exercise. As a result of the extended period of digestion, nutrients are utilized by the body over a longer period and, thus, may contribute to a longer period of satiety in weight management programs (23,35).

**Oat-Based Ingredients**

Because of the cool, wet climate and long hours of daylight during the harvest season, high-quality oats are grown in Scandinavia and Canada. Highly selective technology and careful processing controls are used to produce natural, consistent oat bran ingredients with high total dietary fiber (44%) and β-glucan (up to 22%) contents (15). The level of oat β-glucans is significantly higher compared with other oat and oat bran products. Viscosity and molecular weight are important production control parameters. β-Glucans with a very high molecular weight are important for viscosity (1,3,6).

Over the last 10 years, numerous clinical trials have proven the physiological effect of oat β-glucans on cholesterol reduction and blood sugar response (5,7,8,14,17,19,21,30,31,36,43). Applications for the functional attributes of oat β-glucans include fiber applications for cardiovascular

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Fig. 3. A and B show a typical fragment of oat bran containing 22% β-glucans. The substantial portions of β-glucan–rich endosperm cell walls are distinct (A [arrow], the primary source of the soluble fiber in these products), as are the intact aleurone layer and adjacent coverings (B, arrow). A sample of oat flour with significantly reduced (as expected) evidence of endosperm cell walls and aleurone/pericarp structures is shown for comparison (C) (15,28,29). Analysis performed by R. Gary Fulcher, University of Minnesota.
health, energy enhancement, moderation of GI, and weight management.

Innovative Uses for β-Glucans in Food Applications

A new product has been introduced to the Swedish market, a 200-mL cup of low-fat yogurt with müsli in a top cup. The müsli contains 4 g of oat β-glucans per serving. The effect of yogurt and müsli containing oat β-glucans on blood sugar and insulin responses to a mixed breakfast meal was determined in clinical studies performed at Lund University (Sweden) (7). The test meal significantly lowered blood sugar and insulin responses compared with a reference meal without oat β-glucans. The difference was 36% and 44%, respectively.

Products such as yogurt and müsli containing β-glucans eaten together with high GI-foods, like white bread, produce a favorable blood sugar response to the whole meal. The effect of oat β-glucan–containing products on cholesterol and other blood parameters also were tested in a clinical study by Öresund Diabetes Team (Lund). The results showed a significant lowering of both total cholesterol (9.4%) and LDL (10.8%) compared with a control product (14).

The primary target group for the yogurt and müsli product is health-conscious consumers. The secondary target group is diabetics. The third target group is persons with elevated levels of blood cholesterol and, therefore, an increased risk for cardiovascular disease.

There is an increasing frequency of type II diabetes worldwide. In Sweden, 350,000 people have type II diabetes, and if current trends prevail, in 10 years this number will increase to 500,000 (in a population of 9 million). There is an urgent need to delay or reverse this development and to educate consumers.

Health Claims for Products with Oat β-Glucans

Approved Health Claims in Sweden

Sweden was the first country in Europe to grant permission to use health claims on food products. Today, both generic and product-specific claims are allowed (4,7). Currently, generic claims can be used for nine well-established diet–health relationships. In 2001 regulatory guidelines were established (4) that allow product-specific claims. Product-specific claims must be based on scientific studies, the quality of which is guaranteed through a review process involving international experts.

In the Swedish market, a product-specific claim, that the product balances or even out blood glucose levels after a meal, has been approved for the yogurt and müsli containing β-glucans. A generic claim in two steps about the blood cholesterol-lowering effect of oat fibers has also been approved. The following statement is used on the product: “Soluble fibers may, as part of a healthy diet, contribute to healthy cholesterol levels. This product is rich in soluble oat fibers.”

Approved Health Claims in the United Kingdom

A scientific dossier was submitted to the U.K. Joint Health Claims Initiative (JHCI) on behalf of CreaNutrition–Swedish Oat Fiber concerning the use and application of oat β-glucans in oat-based products and their association with reduced risk of cardiovascular disease. The JHCI Expert Committee and the JHCI Council confirmed that the totality of the evidence substantiated a health claim: whole oats, oat bran, rolled oats, and whole-oat flour, as a part of a diet low in saturated fat and a healthy lifestyle, can reduce cholesterol. The soluble oat fiber, β-glucans, may serve as a marker for oat products that are the subject of the claim. Products carrying the claim should contain at least 0.75 g of soluble oat fiber (β-glucans per serving), which is one-quarter of the suggested daily intake of 3 g (18).

Approved Health Claim in the United States

In 1997, the U.S. Food and Drug Administration (FDA) reviewed 37 clinical studies concerning the effect of oat β-glucans on blood cholesterol, especially the significance and dose-response of the effect. Based on the findings, the FDA approved the first food-specific claim for oat bran, authorizing the use of a health claim that states “Soluble fiber from foods such as oat bran, as part of a diet low in saturated fat and cholesterol, may reduce the risk of coronary heart disease.” The claim is based on a daily intake of 3 g of oat β-glucans, and the food product must contain at least 0.75 g per serving (13).

Summary

Oat products have a strong image as nutritious, health-promoting ingredients in food applications due to their high bioactive and functional component contents. Probably the most well recognized health-promoting ingredient from oats is β-glucans, a soluble fiber.

Significant positive health effects have been attributed to oat β-glucans, including cholesterol control, modulation of glucose and insulin responses, weight management, and improved gastrointestinal function. As a component of oats, β-glucans can be incorporated into a wide variety of innovative food products.

A significant lowering of plasma LDL cholesterol may be achieved with daily consumption of approximately 3 g of β-glucans. A 30–50% reduction in blood glucose peak can be achieved when β-glucans constitute 8–10% of the carbohydrates in a food product.

Scientific evidence supports health claims for oat β-glucans. Approved claims differ from country to country but are now permitted in the United States, the United Kingdom, and Sweden.

References

Hulmi, eds. MTT Agrifood Research Finland, Helsinki. In press.


The Authors

Ruedi Duss is the managing director of CreaNutrition Inc., based in Switzerland, a subsidiary of SOF Swedish Oat Fiber AB. SOF AB, based in Våröbacka, Sweden, has developed unique and proprietary technologies relative to the processing of natural oat β-glucans, creating value-added ingredients for the functional nutrition market. During the past decade, numerous clinical trials have proven the functional properties of OatWell® oat bran β-glucans. CreaNutrition, a worldwide sales and marketing organization, is seeking to expand current marketing efforts for ingredient sales and product applications through its distribution network (with a primary focus on the United States, the European Union, Japan, and Australia). Market opportunities and applications of specific interest include extruded cereals, drinks, bars, bakery goods, and confectionery products, as well as nutraceutical, supplement, and personal care applications.

Lena Nyberg has a M.S. degree in food technology and Ph.D. degree in medical science. She wrote her Ph.D. thesis on “Digestion and Absorption of Sphingo-myelin from Milk.” Since 1999 she has been employed at the Swedish dairy company Skane Dairy, where she works in the R&D department, mainly with health-related projects. Skane Dairy is the second largest dairy company in Sweden and is situated in the southern part of the country. It is owned by 900 dairy farmers and processes 380 Mkg of milk per year. The turnover is approximately US$350 million. Milk and dairy products are the basis of the Skanet product range, in addition to traditional products and health products with added value, e.g., Proviva®, a probiotic fruit drink, and Primaliv®, a yogurt with müsli containing β-glucans.