

Functional Oat Ingredients—Opportunities and Challenges for Food Technology

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Oats are a well-known health-promoting cereal crop. Yet, oats are a minor crop when compared to wheat, corn, and rice. The global production of oats was 25.8 million tons in the 2007–2008 crop season (10). The main producers are the European Union, Russia, and Canada. The two largest producers of oats in the European Union are Poland and Finland, with Finland being the largest exporter. Even though there are well-documented health effects related to the intake of oat bran, it is estimated that, globally, only 25% of oats are used for food, seed, or industrial products. The proportion of oats used for food varies a lot among countries—30% in the United States, but less than 10% in many European countries (10).

Oats for Health

Whole Grain and Dietary Fiber

Compared with other cereals, oats have several nutritional advantages. Several physiological responses have been linked to the intake of oat products (34). Unlike wheat, which is consumed mainly as refined flour, oats are typically used as a whole grain or a bran-enriched product. After the harvest, typically only the unpalatable lignocellulose-rich hull is removed from oats. This process yields oat groats, retaining the germ and aleurone cell layers intact. Cell walls, located in the oat aleurone layer and partially in the endosperm, have a high concentration of (1–3)/(1–4)- β -D-glucan, generally referred to as β -glucan. Typically, in whole grain oat flakes, the β -glucan concentration is between 2 and 6% and in oat bran products between 6 and 12%. Even higher β -glucan concentrations are available in products usually referred to as β -glucan or oat bran concentrates.

Specific Health Effects of β -Glucan

Besides the generic benefits related to the intake of cereal dietary fiber, β -glucan is strongly linked to two specific physiological responses: a) a small reduction of serum cholesterol levels in people with elevated cholesterol levels; and b) an attenuation of postprandial glycaemic response. The cholesterol-lowering effect of oat β -glucan is evaluated in two meta-analyses (1,26). These analyses concluded that β -glucan has a dose-dependent effect on cholesterol so that the intake of approximately 3.2 g of β -glucan per day is capable of lowering cholesterol from -0.13 to -0.16 mmol/L. Reviews by Truswell (31) and Butt et al. (2)

highlighted that the cholesterol-lowering effect was more evident in hypercholesterolemic subjects than in subjects with normal cholesterol levels.

The data on oat β -glucan and the postprandial glycaemic response is reviewed by Wood (34). In patients with type 2 diabetes, Jenkins et al. (11) found attenuation of the glycaemic response by β -glucan with two functional foods tested. It is evident that the viscosity of the food product has a central role in controlling the effect of β -glucan on glycaemic response (35). Viscosity, in turn, is strongly dependent on the molecular weight of β -glucan. During bread making, for example, the molecular weight of β -glucan can easily be reduced unintentionally due to the action of β -glucan-hydrolyzing enzymes (4,29). Thus, in order to deliver the effect of β -glucan on glycaemic response, the careful control of processing conditions and raw material is required. In particular, raw materials should be carefully analyzed for potential β -glucan-hydrolyzing enzyme activities.

There is also an increasing interest in the effect of cereal fibers on gastrointestinal health and their influence on gut microbiota. β -glucan intake has been linked to a slower gastric emptying, enhanced gut fill, and slower absorption of nutrients (21). Recent data indicates that the gastrointestinal behavior of β -glucan is at least partially determined by its viscosity (12). However, the data concerning β -glucan's molecular weight and the health properties of oats is inconsistent and is complicated by the complex viscosity and gelling properties of β -glucan solutions. Furthermore, it has been suggested that the oat bran is digested by the gut ecosystem and that it increases the population of beneficial bacteria in the indigenous gut microbiota (14).

Health Claims

Several national authorities have acknowledged the health benefits of oat β -glucan. The U.S. FDA has allowed a heart-healthy claim on the label of the products that provide at least 0.75 g of β -glucan per serving (13). In Finland, Sweden, and the United Kingdom, national-level authorities have also approved health claims related to oat products. Currently, the European Union is harmonizing the use of health claims and the European Food Safety Authority (EFSA) is reviewing the health claims suggested by various nations. Several oats-related health claims are included in this review, which aims to deliver a set of acceptable health claims at the beginning of 2010 (Table I).

Current Oat Products

Ingredients Enriched with β -Glucan

There are several oat β -glucan-containing food ingredients available on the market (Table II). Oat bran is a conventional milling product obtained by removing starch from dehulled or naked oat groats. The relatively low β -glucan content of regular bran makes it suitable only for a limited number of functional food products. The β -glucan concentrates, with significantly higher β -glucan concentration than in oat bran, are produced by different dry- or wet-fractionation processes. Based on the available patents and patent applications, the processes that are used in the manufacturing of β -glucan concentrate ingredients are reviewed below.

The process developed by USDA is based on α -amylase-aided hot water extraction (9). After extraction, the β -glucan-containing solid particles are separated and dried. The product can be further modified into a soluble fiber. This is done by extracting β -glucan in high-temperature water using mechanical shear forces. From this, nonsoluble fibers are removed by filtration or centrifugation. The liquid is then dried to produce the soluble β -glucan concentrate (8).

Mälkki et al. (20) have developed a dry fractionation process based on two or more subsequent millings and air classifications. The final product is characterized by a β -glucan concentration of 11–25%. Apparently, this process involves only dry fractionation steps, which makes it unique among the processes for β -glucan concentrates.

Weightman (33) and Vasanthan and Temelli (32) described an industrial process where the milling and air-classification steps are used to obtain a bran product that is treated with ethanol to reduce lipid content. Due to ethanol treatment, the lipid content of these bran concentrates is slightly lower than in other prod-

ucts. This process is apparently not patented and only limited information about the process is available.

The University of Alberta has developed an aqueous ethanol extraction in combination with enzymatic treatment, which permits hydrolysis of starch and protein, but prevents solubilization of β -glucan. The β -glucan concentrate is recovered from the slurry by screening or filtering (32).

Kvist & Lawther (16,17) developed a β -glucan-enrichment method based on enzymatic treatment and wet milling, followed by sequential centrifugation and ultrafiltration or a freezing/thawing step and a precipitation step.

Potter et al. (23) described an entirely aqueous method for β -glucan enrichment. In this method, milled oat bran is slurried with cold water and screened to remove starch. The material, which does not pass through the screen, is extracted with alkaline solution to solubilize the β -glucan. Protein can be precipitated from the solution following acidification. The remaining solution can either be evaporated or microfiltered to collect the β -glucan concentrate (23).

Table I. Health claim proposals related to oats included in the evaluation for inclusion in the list of accepted health claims in the European Union

Ingredient	Suggested Health Relationship
Oat grain fiber	Weight control
Oat oil fatty acids	
Oat beta-glucan	Blood cholesterol
Oat bran and oat bran products	Contribution to the maintenance of healthy blood cholesterol levels
Oat grain fiber	Carbohydrate metabolism and insulin sensitivity Gut health
Oat shoot extract	Mental state and performance
Oat (<i>Avena sativum</i>)	Satiety and weight control/skin health Constipation/intestinal health Relaxing effect Helps induce sleep Invigoration of body
Green oat (<i>Avena sativa</i>)	Urogenital system Digestive system, metabolism

Table II. Examples of commercial oat-containing food products

Year	Company	Country	Product Name or Brand	Product Type and Its β -Glucan Concentration (If Available)
1995	Bioferme	Finland	Yosa	A nondairy oat product made from oats and oat bran. The oats are fermented with a combination of probiotic bacteria.
1996	Ceba AB	Sweden	Oatly	A range of dairy products made of oats instead of milk. The product contains oats, water, and rapeseed oil.
2001	Nestlé	France and Germany	Nesvital	Cereal bar (25 g) containing 0.75 g of β -glucan.
2002	Skåne Dairies	Sweden	PrimaLiv	A yogurt with a lid filled with muesli that contains a high concentration of β -glucans.
2003	Allied Bakeries	United Kingdom	Burgen	Oat bran and honey bread; two slices provides 0.75 g of β -glucan soluble fiber.
2005	Albert Heijm (retailer)	The Netherlands	Vitaalbroot Pró-Fit	Multigrain bread with oat bran; four slices contain 3.0 g of β -glucan.
2006	Raisio	Finland	Elovena	Single-packed snack biscuits with berries; 2.9 g of β -glucan per 100 g.
2006	Tesco (super market chain)	United Kingdom	Own label	White bread with oat bran; three slices contain 0.75 g of β -glucan.
2006	Kellogg's	United Kingdom and Spain	Optivita	Bars and breakfast cereals. A 40-g bowl provides at least 1 g of β -glucan
2007	Nutritech International	Sweden	Activ Everyday	Muesli breakfast cereals rich in β -glucans.
2007	Barilla	Italy	Alixir	Bread and brioche with GraceLinc's Glucagel (concentration of β -glucan not mentioned).
2008	Fazer Bakeries	Finland	Fazer Kauraihme, Oululainen Kaurakorppu	Bread and cracker with added oat bran (concentration of β -glucan not mentioned).
2008	Raisio	Finland	Elovena Snack Drink	Snack beverage with 11.3% of dietary fiber in a portion (270 ml); contains 10% oat flakes.

In the process of Redmond and Fielder (24,25), oat bran is purified with air classification or sieving, and then extracted at alkaline conditions (pH: 9–10). The solids are removed by centrifugation and a flocculant or coagulant is added to the solution to precipitate proteineous material. Amyolytic enzymes can be used to hydrolyze starch from the solution. Finally, β -glucan is recovered from the solution by ethanol precipitation, followed by centrifugation.

Food Applications Based on β -Glucan

The most important traditional oat products are oat porridge and different types of muesli and other breakfast products. The use of oats in breads has been mainly limited to wheat breads supplemented with less than 20% oats. However, a novel oat-baking technology has been developed that enables the production of oat breads without wheat or wheat gluten (4). Extruded oats are also well suited for different types of snack or bakery products, where they can be used to improve nutritional status or to enhance cereal flavor. Oat-containing pasta products are also available. In these products, oats are often used to replace wheat to some extent.

Despite the technical difficulties related to the production of liquid oat products, there are several commercial oat beverages available. The level of beta-glucan in these beverages is often below the level that is expected to deliver β -glucan-specific health claims. The molecular weight of β -glucan is in the central role in controlling technical usability of β -glucan in beverages. High molecular weight β -glucan produces a high viscosity even at very low concentrations, whereas low molecular weight β -glucan-containing products are prone to time-dependent gelling during the storage (18).

Only a limited set of clinical studies have been carried out with β -glucan-containing consumer products. Liatis et al. (19) demonstrated that β -glucan delivered in regular wheat bread was able to improve the lipid profile and insulin resistance in patients with type 2 diabetes. Another example of β -glucan action in a food matrix was provided by Tosh et al. (30). They reported that oat bran muffins, containing 8 g of β -glucan per serving, caused a significant reduction of the glycemic response. Also, in beverages, the cholesterol-lowering properties of oat β -glucan have been reported. Naumann et al. (22) demonstrated that 5 g of β -glucan delivered in 500 ml of fruit juice was able to reduce total and LDL cholesterol in healthy individuals. It is remarkable that the β -glucan used in this study was very low in molecular weight, approximately 80 kDa.

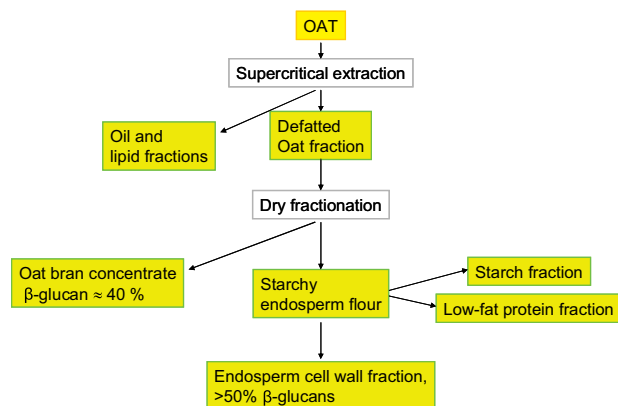


Fig. 1. Fractionation process for oats. Developed by A. Kaukovirta-Norja et al. (13).

Opportunities for Oat β -Glucan

New Fractionation Technology

A novel fractionation scheme, based on lipid removal and subsequent dry fractionation, was developed in 2007 by Kaukovirta-Norja et al. (13). This process is based on the extraction of oat lipids by supercritical CO_2 before the sequential milling and dry-bran separation processes. Recent data has shown that the lipids in oat endosperm are fused with protein and starch (5,6). The removal of this lipid phase enables the use of conventional milling and dry fractionation technologies in a much more efficient way than when normal, lipid-containing oats are used as raw material. This enables the handling of oat-milling products without clogging or lump formation in the milling chambers, air-classifier wheels, and screens.

This process yields a β -glucan concentrate with up to 40% beta-glucan with a mass yield of 8–10% of the raw material (Figs. 1 and 2). The β -glucan concentrate originates mainly from the aleurone layer and contains also around 10% of the other cell wall component, arabinoxylan, and 24% protein. Besides the aleurone β -glucan, the process yields starchy endosperm fractions with a total mass yield of approximately 80% of the raw material. In order to fully exploit the potential of oats, this starch material was further fractionated to yield a) endosperm cell wall concentrate (1–5% raw material); and b) protein concentrate (5–8%); and c) oat starch (>50%). If a similar milling and fractionation scheme was performed without the lipid removal step, it would have been impossible to separate endosperm components.

Oats for Celiac Patients

There is increasing clinical data supporting the view that oats can be included in a gluten-free diet (27). This increases the interest toward developing oat-based breads and other products where oats are used to replace wheat. This would make it possible to diversify the diet of celiac patients by providing cereal character and high-fiber content foods. The contamination of oats with gluten-containing cereals, such as wheat, barley, or rye, is common in regular commercial oat products (28). Active efforts have been made to develop “clean oat” production chains that are certified to have an extremely low level of contamination with other cereals. Thus, these types of product lines are suitable for celiac disease patients who can tolerate oats.

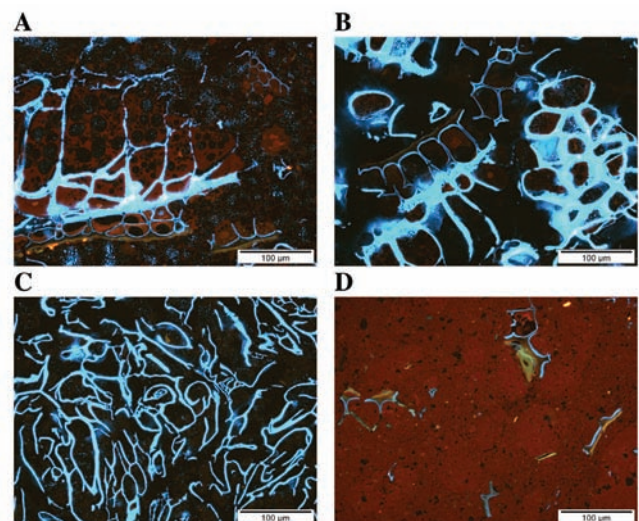


Fig. 2. Micrographs of different oat fractions stained with Acid Fuchsin and calcofluor dyes. Cell walls appear as blue and protein as red. A) defatted oat flour; B) β -glucan concentrate from defatted oat flour; C) endosperm cell wall fraction from defatted oat flour; and D) protein concentrate from defatted oat flour.

In addition, children with celiac disease have been reported to tolerate uncontaminated oats (2). Children are very pleased to use oat-containing products, as oat delivers a typical cereal character into food products and enables the use of typical cereal foods, such as bakery products, porridges, and snacks. The development of whole-oat baking technology further improves the quality and acceptability of traditional-style soft breads. A selection of oat breads for celiac patients is already commercially available.

New Insight into Health Effects

The health effects of oat β -glucan are well documented for oat bran. However, the literature regarding the effect of oat processing and β -glucan properties on health is very limited. During processing, the molecular weight of beta-glucan can be easily reduced from more than 1 million to a few hundred thousand. This has an inevitable effect on the viscosity behavior of β -glucan. The current view is that the effect of oats on glycemic and insulin responses is at least partially viscosity dependent. However, recent data suggests that the molecular weight and/or viscosity of β -glucan may have less of an influence on blood lipid response than previously thought (15,36). The literature describing clinical trials has so far largely omitted aspects related to the state of β -glucan, the presence of other bran components, and the effects of food matrices. In the future, we are hoping to see more clinical data with extensive analysis also on the raw material properties. This would enable future R&D work to focus on providing oat products that can be used as a part of nutritional therapy and prevention of hyperglycemia and hyperlipidemia.

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Olavi Myllymäki has significant experience in process and product development of food and feed materials. He has applied basic unit operations into production processes from the dewatering of fish to the dry fractionation of vegetable material, especially for cereals like oat. He has extensive experience in HTST processes (extrusion) and he has applied it to develop cereal-based, commercially available functional products. He is the coinventor of 15 patents, mostly from the cereal and oilseed field, some of which have found industrial applications. Myllymäki can be reached at olavi.myllymaki@vtt.fi.



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