Rye is a cereal with modest requirements regarding soil, fertilization, and climate. It is a staple food in Northern and Eastern Europe and adds variety to the bread and breakfast cereal markets in these regions. Beneficial health effects of insoluble and soluble dietary fibers have gained interest among consumers, the agro-industrial sector, and food authorities. Increased intake of dietary fiber has been associated with, for example, reduced intestinal disorders, reduced appetite, improved blood glucose control, and reduced serum cholesterol levels. A diet rich in dietary fiber may therefore reduce the risk of chronic diseases, such as obesity, diabetes, cardiovascular diseases, and certain cancers. Rye is among the cereals with the highest content of dietary fiber and therefore the search for new applications of this cereal in healthy foods has increased in the Nordic countries as well as around the world. For example, the Department of Food Science at the Swedish University of Agricultural Sciences (SLU) is involved with rye projects in China within the Sino-Swedish R&D Centre for Food Safety, Nutrition, and Health at Fudan University in Shanghai.

Insulin is a key factor that has been related to several mechanisms involved in the development of diseases related to metabolic syndrome. Postprandial insulin, glucose-dependent insulinotropic polypeptide, and C-peptide responses to rye bread intake were significantly lower than to wheat bread (7). However, the effect could not be related to the total content of dietary fiber in the products but possibly to the structure of the breads, which is at least partly related to the dietary fibers. The Department of Food Science at SLU has been involved in studies regarding the satiating effects of rye breakfasts (6). Rye breakfasts resulted in a suppressed appetite before lunch compared to a control breakfast with wheat bread. It is interesting to note that for the rye breakfasts, after the intake of a standardized lunch, decreased hunger and desire to eat were also noted in the afternoon. Furthermore, in a small, randomized, controlled, and short-term intervention, the effect of rye bran intake on subjects with prostate cancer was studied (4). Results suggested, in accordance with animal studies, that rye bran bread intake might induce an increase in tumor cell apoptosis and thereby a slower tumor growth. However, endogenous hormone levels were essentially unchanged.

Rye contains about 20% dietary fiber, mainly arabinoxylan, fructan, cellulose, and β-glucan, and among commonly used cereals is the one with the highest fiber content.

In rye, approximately 40% of the dietary fiber, mainly arabinoxylan and fructan, is extractable; rye is therefore an outstanding source of this type of fiber.

During food processing, such as baking, the molecular weight and properties of rye dietary fibers may be modified.
and no significant alteration was seen in plasma levels of prostate-specific antigen and markers of fibrinolytic activity. Within this area, ongoing studies will show the potential of these findings.

Nordic and Baltic researchers and industry are collaborating to improve and promote rye foods in the Grainity Project (www.ryeandhealth.org). In this feature paper, the term dietary fiber will be discussed, and the content of dietary fiber and dietary fiber components in rye and rye milling fractions and finally the effects of food processing on dietary fiber will be presented.

The Rye Kernel
Rye, like other cereals, has a single-seeded fruit called caryopsis, with multiple outer layers derived from the fruit wall and seed coat. At maturity, the outer layers are dry and rich in dietary fiber, minerals, and certain phytochemicals (8). Inside these layers are the germ and the endosperm—the storage tissue of the caryopsis.

During milling, the outer parts of the grain (bran) as well as the germ are removed, resulting in severe depletion of many components with established health benefits such as dietary fiber, minerals, vitamins, and certain phytochemicals (9). Due to a different behavior during the milling process, rye bran generally contains more starchy endosperm compared to wheat bran.

What Is Dietary Fiber in Europe?
Dietary fiber as a term was first used by E. H. Hipsley in 1953. Potential health benefits of dietary fiber—a plant food constituent, mainly present in the cell walls—were rediscovered about 50 years ago by Denis Burkitt and Hugh Trowell. Since then, intensive research around the globe has been devoted to support or reject many of their hypotheses. The lack of a universal definition for dietary fiber has severely hampered the research in obtaining an evidence-based association between the intake of dietary fiber and its beneficial health effects. Legislation and health claims require a precise and harmonized definition, and dietary fiber was recently defined in Europe (Commission Directive 2008/100/EC, October 28, 2008). According to this definition, dietary fiber includes carbohydrate polymers/oligomers with three or more monomeric units that are neither digested nor absorbed in the human small intestine. These edible carbohydrates can be naturally occurring in foods, isolated from food raw materials, or synthetic polymers. The latter two should have documented physiological effects. It is known that carbohydrate polymers in plant foods may be closely associated with noncarbohydrate components such as lignin and other phenolic constituents. When these components are analyzed together with the carbohydrate polymers they can be regarded as dietary fiber and included in the dietary fiber value. If isolated and added back to the food, they should not be considered dietary fiber. Today, work is ongoing in the European Union in order to advise suitable analytical methods for the components included in the new definition.

Content of Dietary Fiber and Its Components in Rye
The dry rye caryopsis (kernel or grain) contains about 20% (range of 19–22%) dietary fiber, determined as nonstarch polysaccharides, and Klasson lignin (Table I) (2). This is the highest content among common cereals. For example, rice contains only about 3% dietary fiber and wheat contains about 12%. A main difference between rye and wheat is that the starchy endosperm of rye contains twice as much cell wall components. Arabinose (about 3.3%) and xylene residues (about 5.6%), mostly from different types of arabinoxylans, dominate, followed by glucose residues (4.4%), mainly from cellulose and β-glucan, and fructan (4.1%). Smaller amounts of mannose, galactose, and uronic acid residues (together about 1.2%) are also present in different polysaccharides. The content of Klasson lignin (about 1.1%) includes lignin as well as other resistant constituents often attached to the cell-wall polysaccharides and is sometimes denoted as the noncarbohydrate part of dietary fiber.

Detailed analysis of a rye sample (cv. Kaskelott) showed that it contained 9.0% arabinoxylan of which 36% was extractable, 0.2% extractable arabinogalactan- peptide, 1.5% partly extractable β-glucan, 3.5% insoluble cellulose, when assuming that unprocessed rye kernels contain no resistant starch, and 5.0% extractable fructan (including fructooligosaccharides) (Table II) (2). It is interesting to note that as much as 39% (8.8 g/100 g of dry rye kernels) of the dietary fiber in rye is extractable with fructan and arabinoxylan as dominating constituents.

Table I. Content of dietary fiber and dietary fiber components in different rye varieties grown in Sweden (n = 18)a,b

<table>
<thead>
<tr>
<th>Component</th>
<th>Average Content</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arabinose residues</td>
<td>3.3 (28)</td>
<td>2.9–5.9</td>
</tr>
<tr>
<td>Xylene residues</td>
<td>5.6 (27)</td>
<td>4.7–6.2</td>
</tr>
<tr>
<td>Mannose residues</td>
<td>0.6 (29)</td>
<td>0.6–0.7</td>
</tr>
<tr>
<td>Galactose residues</td>
<td>0.4 (24)</td>
<td>0.3–0.5</td>
</tr>
<tr>
<td>Glucose residues</td>
<td>4.4 (11)</td>
<td>3.9–5.1</td>
</tr>
<tr>
<td>Uronic acid residues</td>
<td>0.2 (29)</td>
<td>0.2–0.3</td>
</tr>
<tr>
<td>Klasson lignin</td>
<td>1.1 (0.0)</td>
<td>0.9–1.4</td>
</tr>
<tr>
<td>Fructan/fructooligosaccharides</td>
<td>4.1 (100)</td>
<td>3.6–4.4</td>
</tr>
<tr>
<td>Total</td>
<td>19.9 (37)</td>
<td>18.7–22.2</td>
</tr>
</tbody>
</table>

a Results are given as percent of dry matter, and extractability of the different analytes are given within parentheses (2).

b Carbohydrate residues and Klasson lignin were analyzed with the Uppsala method (12) and fructan and fructooligosaccharides with the Megazyme kit K-fruc.

Table II. Content of main extractable and unextractable dietary fiber polysaccharides of whole grain rye floura,b

<table>
<thead>
<tr>
<th>Component</th>
<th>Extractable</th>
<th>Unextractable</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arabinofuranose</td>
<td>2.4</td>
<td>6.6</td>
<td>9.0</td>
</tr>
<tr>
<td>Arabinogalactan</td>
<td>0.2</td>
<td>-</td>
<td>0.2</td>
</tr>
<tr>
<td>β-glucan</td>
<td>naa</td>
<td>naa</td>
<td>1.5</td>
</tr>
<tr>
<td>Cellulose and resistant starch</td>
<td>-</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Fructan and fructooligosaccharides</td>
<td>5.0</td>
<td>-</td>
<td>5.0</td>
</tr>
<tr>
<td>Total</td>
<td>8.8</td>
<td>13.0</td>
<td>20.6</td>
</tr>
</tbody>
</table>

a cv. Kaskelott, percent of dry matter (2).
b Carbohydrate residues and Klasson lignin were analyzed with the Uppsala method (12) and fructan and fructooligosaccharides with the Megazyme kit K-fruc.
c Not analyzed.
Distributions of extractable β-glucan (10), arabinoxylan (2), and fructan (5) in cereals and cereal foods.

Recently, content, extractability, and molecular weight distributions of major extractable dietary fiber components in milling fractions of rye were examined (11). The sifted flour (inner endosperm) contained 12% dietary fiber with arabinoxylan (4.4%), β-glucan (1.5%), cellulose (1.2%), and fructan (3.4%) as major components. The intermediate fraction (outer endosperm) contained 21.8% dietary fiber, including 9.3% arabinoxylan, 3.4% β-glucan, 2.1% cellulose, and 4.6% fructan, and the bran fraction contained 38% dietary fiber, including 18% arabinoxylan, 4.4% β-glucan, 4.3% cellulose, and 5.0% fructan. The molecular weight distributions of extractable β-glucan covered the range from 10^4 (lower limit for analysis) to 10^7 g/mol for all three fractions. The bran fraction contained a higher proportion of low-molecular weight β-glucan compared to the other two fractions, and weight average molecular weights of the extractable β-glucan were 1.3 × 10^6 g/mol for the sifted flour and intermediate fractions and 0.86 × 10^6 g/mol for the bran fraction. For extractable arabinoxylan, molecular weights covered the range of around 10^5 to 10^7 g/mol for all three fractions. Extractable arabinoxylan in sifted flour and an intermediate fraction had weight average molecular weights of about 1.1 × 10^6 g/mol and in the bran fraction about 1.4 × 10^6 g/mol. During breadmaking, it is known that the molecular weight of extractable β-glucan can be highly reduced (1.3), while the extractable arabinoxylan seems to be more resistant to degradation (2).

The degree of polymerization (DP) of fructan was similar in all three milling fractions studied. About 50% of the molecules had a DP below 9 and less than 20% had a DP below 4. About 30% of the fructan had a DP between 10 and 15 and about 20% had a DP greater than 15. It is well established that food processing of cereals, such as baking, can reduce content and molecular weight of cereal fructan (11).

Rye bran is thus a dietary-fiber-rich product that can be used in different applications. Some industrial rye brans from the Nordic countries were studied and compared with wheat bran (9). A relatively large variation in dietary fiber content (41–48%) and composition was found among the six brans studied, which calls for standardization of this commodity, especially if it will be used as a food ingredient for its health effects. The content of dietary fiber was comparable in rye and wheat bran. However, the relative proportion of the dietary fiber components differed, and rye bran contained less cellulose but more β-glucan and fructan.

**Dietary Fiber in Rye Products**

Rye is generally consumed as whole grain, including all parts of the naked kernel, or bran. During processing of cereals, the content of dietary fiber may change. Common changes include an increased content of resistant starch, especially retrograded amylose (RS 3) and Klason lignin (including also some Maillard products) during hydrothermal treatment and reduced content of more soluble fiber components, such as fructan, β-glucan, and arabinoxylan during hydrolysis with endogenous or added enzymes or during fermentation (e.g., with yeast). Recently, the content and properties of dietary fiber in rye foods, including crisp and soft breads, as well as extruded products were studied.

In the collected crisp breads, the content of dietary fiber ranged from 13 to 20%, while the soft breads were lower (8–18%) due to a higher incorporation of wheat flour (11). Arabinxylan and fructan were generally the major dietary fiber components in the product, followed by cellulose and resistant starch, beta-glucan, Klason lignin, and arabinoogalactan. Cellulose and resistant starch were higher in the soft breads than in the crisp breads due to a higher formation of resistant starch (RS 3). The molecular weight of extractable beta-glucan was highly reduced during breadmaking while the molecular weight of extractable arabinoxylan was more resistant to degradation (Fig. 1). The extruded products had the highest extractability and the extracted beta-glucan retained its molecular weight best. The crisp bread products produced without yeast had the highest dietary fiber and fructan contents and the highest proportion of low-molecular-weight fructan. These results indicate that, during breadmaking, the low-molecular-weight fraction of fructan was the most available for degradation by yeast or by endogenous enzymes present in the ingredients.

**Conclusion**

It is now well established that rye is a unique cereal with a very high content of dietary fiber and an interesting dietary fiber composition. Rye bran cell walls are rich in unextractable dietary fiber with cellulose and different xylans as important components. Xylans are often cross-linked with phenolic constituents making them relatively resistant to fermentation. The content of extractable dietary fiber is high in rye with both easy, fermentable components such as fructan and β-glucan and more slowly fermentable components such as arabinxylan. Both extractable β-glucan and arabinoxylan are high-molecular-weight polymers with profound...

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**Fig. 1.** Molecular weight distribution of extractable β-glucan (dotted line) and arabinoxylan (solid line) in whole grain rye flour, rye crisp bread, rye breakfast cereal, and rye soft bread (11).
effects on the rheological properties in dough or digesta.

References

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