# RYE AND HEALTH

1

# WELCOME IN THE WORLD OF RYE – THE GRAIN WITH A LONG HISTORY OF HUMAN CONSUMPTION AS WHOLE GRAIN FOOD!

*This rye site introduces you the rye grain, its various food uses, physiological effects and health relevance. We provide you in a nutshell a state-of-art in an easily accessible form. We wish to share with you our enthusiasm about the potential of rye for the modern consumer.*

*The site also wishes to serve as a worldwide noteboard for the scientists interested in rye. If you wish to present information about on-going research projects, recent new publications and other relevant rye information in this site, please send an e-mail to Ms. Paula Bergqvist, paula.bergqvist@vtt.fi.*

*The site has been established by the Nordic Rye Group, which has collaborated since 1994 in order to study especially the physiological responses and potential health effects of lignans in rye.*

*Editor of the Rye & Health site: Ms. Tarja Kujala*

**The Nordic Rye Group**

Collaboration for increased understanding on health effects of rye started in 1994. The project was funded by the Nordic Industrial Fund and Nordic cereal industry. Two separate projects, "Rye and health" (1994-1996) and "Rye phytoprotectants" (1997-2000) were carried out. In addition, several national projects have been carried out in Finland, Sweden and Denmark. The Nordic Rye Group has been active in organising meetings and discussing and disseminating research results.

**All the members of Nordic Rye Group welcome contacts regarding research on rye and health:**

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II

# HOW DOES DIET INFLUENCE OUR HEALTH?

## The Importance of Whole Grains and Dietary Fibre

*Cereals are the most important source of dietary fibre in the Nordic diet. The fibre in cereals is located mainly in the outer layers of the kernel, particularly in the bran. Rye is of special importance in contributing dietary fibre, because it is generally consumed as whole grain products, and has a high dietary fibre content in the starchy endosperm.*

Improved diet can help unlock the door to good health. People who lead a healthy lifestyle also pay attention to their nutritional habits. Good nutrition means adequately nourishing the body by choosing a variety of foods low in fat, salt and sugar and high in carbohydrates, especially starch and dietary fibre. Mortality is significantly lower in people consuming whole grain products (Jacobs et al. 1998).

In today's world people are increasingly aware of what they eat. As the level of education and the overall well-being of people increase, public awareness of the relationship between diet and health also grows. Knowledge of the nutritional content of foods increases among ordinary people. This leads to improved attitudes towards healthier eating habits. It can be expected that in the future people will make food choices based on what is beneficial for their health and well-being.

Whole grains are universally recommended as an integral part of the diet. Whole grains are an important source of nutrients that are in short supply in our diet, including digestible carbohydrates, dietary fibre, resistant starch, trace minerals, certain vitamins, and other compounds of interest in disease prevention, including phyto-oestrogens and antioxidants (Slavin et al. 1997).

**Physiological Effects of the Dietary Fibre Complex**

| Significance | Mechanism of Action | Potential Health Effect |
|---|---|---|
| Teeth | Requires more chewing.<br>Increases the secretion of saliva. | Protects against dental caries.<br>Keeps gums healthy. |
| Stomach | Increases the secretion of saliva and gastric juice.<br>Decreases the rate of evacuation of stomach contents into small intestine >> prolongs the feeling of satiety. | Enhances satiety >> prevents overeating and weight gain |
| Digestive tract | Shortens intestinal transit time.<br>Dilutes harmful substances.<br>Beneficial for the bacterial population in the large intestine.<br>Interrupts the enterohepatic circulation of estrogens, reducing estrogen levels. | Prevents constipation.<br>Decreases risk of breast and colon cancer.<br>Alters bile acid metabolism in the gut in a favorable way. |
| Cardiovascular system | Inhibits the absorption of dietary cholesterol.<br>Increases the release of bile acids into the intestine.<br>Influences the plasma triglyceride levels and blood clotting properties. | Lowers blood cholesterol levels.<br>Decreases the risk of heart disease and gallstones. |
| Blood glucose | Slows down the absorption of carbohydrates. | Stabilizes blood glucose levels, especially in diabetic individuals. |

## Recommendations for Dietary Fibre and Whole Grain Intake

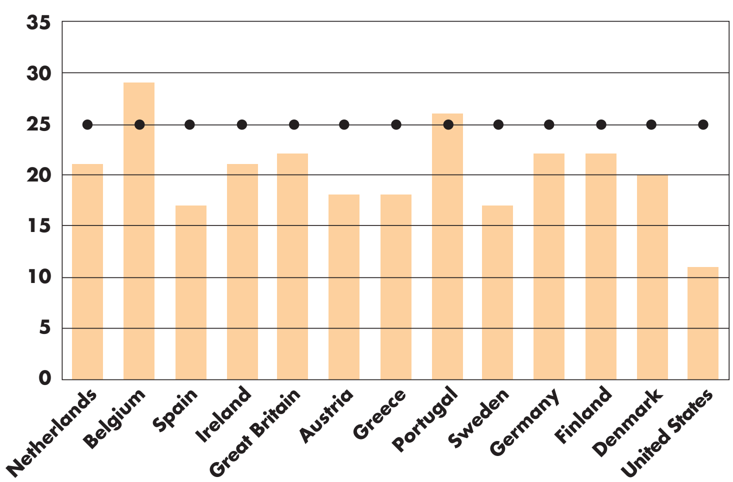
*Dietary fibre is the part of plant foods that is not digested and absorbed in the upper gastrointestinal tract in humans. It may be described as non-starch polysaccharides, enzyme-resistant starch and lignin. Non-starch polysaccharides and lignin mainly originate from the cell walls of plant foods.*

*In most countries the recommendation for dietary fibre intake is 25–35 g/day. Fibre intake should be increased, since in most countries, particularly in the Western Hemisphere, the intake today is clearly below the recommendation. Whole grain rye products, such as rye bread, crisp bread and rye flakes are excellent sources of dietary fibre.*

Though health experts may disagree on some aspects of nutrition, most agree on one important topic: dietary fibre. The general view is that we need to eat more of it, and by doing so we may prevent or possibly reverse many degenerative diseases.

In most western countries national nutrition committees recommend an adult intakes of 25-35 g/day of dietary fibres. The recommendation may be expressed in different ways, but generally it means an increase in fibre intake compared to the present situation (Cummings and Frolich 1993).

In the Nordic countries the recommended intake of dietary fibre is 25-35 g/day for adults or 3 g/MJ of energy. The average diet contains only about 70% of this amount. The most important source of dietary fibre is cereals, especially rye. In Finland over 40% of dietary fibre comes from rye, in Denmark over 30%, in Sweden about 20% and in Norway less than 10%.




Whole grain rye bread is an excellent source of dietary fibre contains about 10 g fibre/100 g bread. Crisp bread contains as much as 15 g fibre/100 g bread.

**Dietary Fibre Contents of some Foodstuffs**

| Foodstuff | Total dietary fiber (* | Soluble fiber (* | Insoluble fiber (* |
|---|---|---|---|
| Wheat bran | 55,0 | 1,8 | 53,2 |
| Rye bran | 39,0 | 2,4 | 36,6 |
| Flax seed | 28,4 | 1,2 | 27,2 |
| Oat bran | 17,9 | 2,9 | 15,0 |
| Thin crispbread | 14,9 | 2,7 | 12,2 |
| Rye crispbread | 14,9 | 2,7 | 12,2 |
| Whole grain rye flour | 13,6 | 2,2 | 11,4 |
| Oat flakes | 11,0 | 4,5 | 4,6 |
| Rye bread | 9,9 | 1,7 | 8,2 |
| Barley flakes | 7,6 | 1,0 | 6,6 |
| Corn flakes | 5,4 | 0,4 | 5,0 |
| Wheat bread | 3,5 | 0,8 | 2,7 |
| White rice, cooked | 0,8 | 0,1 | 0,7 |
| Raisins | 9,7 | 3,5 | 6,2 |
| Beans, brown | 6,7 | 3,2 | 3,5 |
| Muesli | 6,1 | 1,8 | 4,3 |
| Hazelnuts | 6,0 | 0,3 | 5,7 |
| Peas | 5,5 | 0,5 | 5,0 |
| Black currants | 4,9 | 1,9 | 3,0 |
| Blueberries | 3,1 | 0,5 | 2,6 |
| Carrot | 2,4 | 0,8 | 1,6 |
| Apple | 1,8 | 0,7 | 1,1 |
| Potato, cooked | 1,4 | 0,4 | 1,0 |
| Cucumber | 1,1 | 0,4 | 0,7 |

(National Public Health Institute, The Nutrient Content of Foodstuffs 1993 and Melia Ltd 1999)

*) g / 100 g

III

# DESCRIPTION AND COMPOSITION OF RYE AND OTHER CEREALS

## The Kernel

### - A Well-Organized Reserve of Nutrients

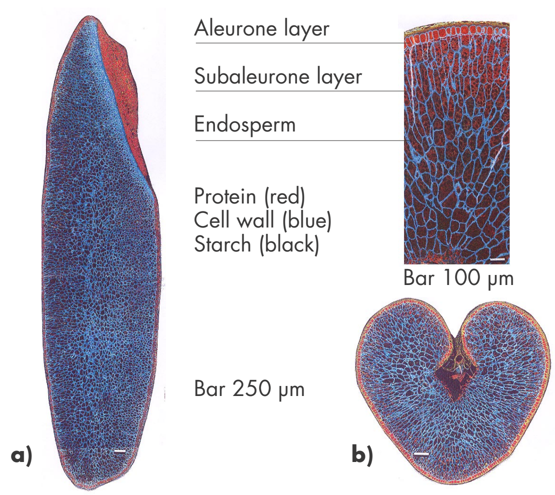
*The main components of cereal grains are the hull, pericarp, testa, aleuron, endosperm and the germ.*
*Rye is, in contrast to wheat, a special grain because it is mostly consumed as whole grain flour in breads and other cereal products. The grains may also be fractionated into different types of flour during the milling process.*

Before rye grains can be used in food production, the outer part of the grain, the hull, must be removed. After hulling, which generally occurs during threshing, the grains are used whole, cracked or flaked, or they are ground to make flakes or flour. The starchy endosperm constitutes about 80-85% of the weight of the whole kernel, the germ 2-3% and the outer layers about 10-15%.

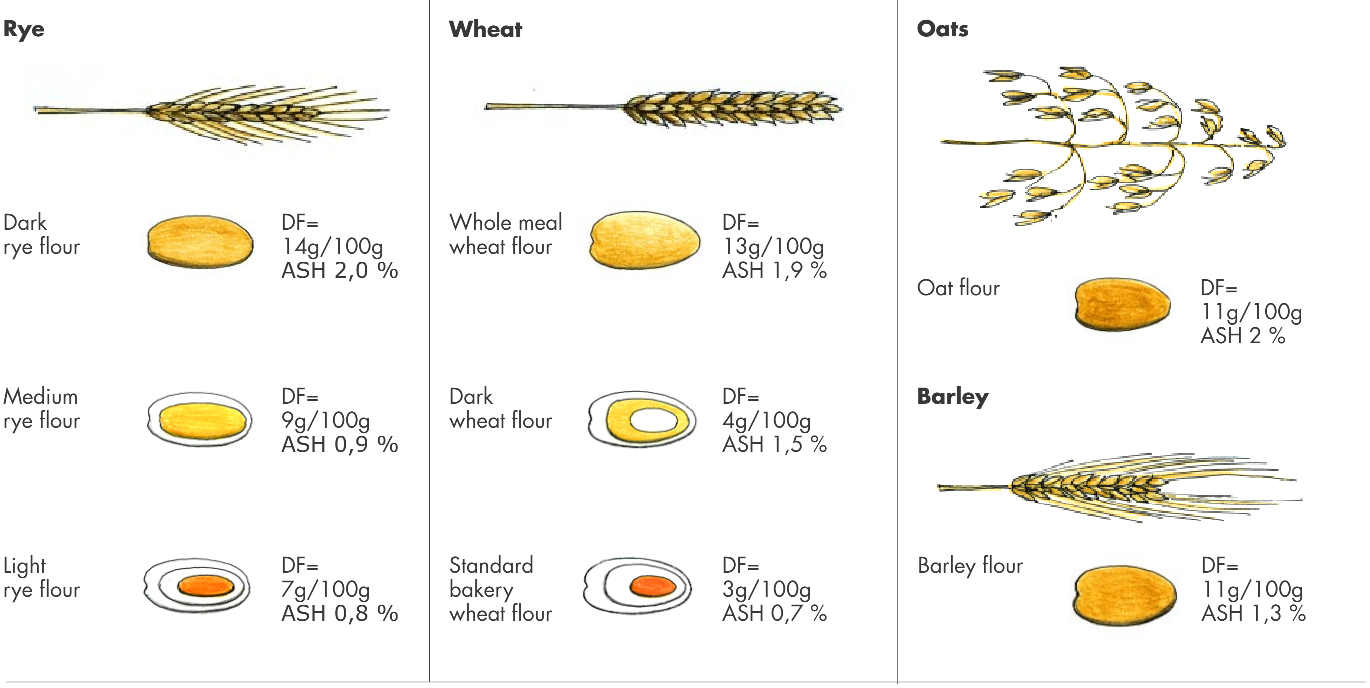
In the milling process the kernel can be ground and fractionated into different types of flour and bran. Ash content is a concept used to indicate the amount of inorganic minerals in food samples. Because the majority of minerals are located in the outer layers of the kernel, the ash content of flour indicates, how much of the outer layers have been included in the flour. In white wheat flour (ash content 0.7% or less), about 30% of the outer layers of the kernel have been removed. Traditional Nordic rye bread and crisp bread are made of whole grain rye flour (ash content about 2%), where all of the components of the kernel are present.

Cereals are the most important source of dietary fibre in many countries. The fibre in cereals is located mainly in the outer layers of the kernel, especially in the bran. Wheat and rye have similar bran content, but rye contains more cell walls within the endosperm, and thus has a higher fibre content (Nyman et al. 1984, Åman et al. 1997). Rye is also an exceptionally good source of dietary fibre because it is very often consumed as whole grain products.

**Microscopic picture of Rye Kernel**



### The Kernel and Different Flour Fractions Derived from it.




DF = Dietary Fiber
ASH = Ash Content

## Chemical Composition of Rye

### Down to the Molecular Level: What is Rye Composed of?

*A rye kernel contains large amounts of important dietary fibre components combined with other bioactive compounds, which have numerous positive functions for our health and well-being. Rye contains both soluble and insoluble dietary fibre. The main dietary fibre component in rye is the partly soluble arabinoxylan.*

*In bread making, the cell wall polysaccharides in rye have a profound effect on the rheological properties of dough and bread.*

The macronutrients in rye are the same as in other cereals: starch, dietary fibre, and protein. Rye generally contains less starch and crude protein than wheat, but more free sugars and dietary fibre. Of the free sugars, sucrose and fructo-oligosaccharides dominate.

The comparison between the chemical compositions of rye, wheat and oat grains are shown in the table below. All of these cereals are presented with an extraction rate of 100, which is comparable to whole grain or whole grain flour. The composition of wheat is also presented with an extraction rate of 66, which corresponds to white wheat flour. In Finland and Denmark, rye flour generally means whole grain rye with an extraction rate of 100 or close to it. In Sweden and Norway the most commonly used rye flour has an extraction rate of 80 or close to it.

#### The Chemical Composition of Rye, Wheat and Oats

| | % of dry matter | | | |
|---|---|---|---|---|
| **Component** | Rye 100 | Wheat 100 | Wheat 66 | Oat Groat |
| Protein | 10-15 | 12-14 | 13 | 13-16 |
| Fat | 2-3 | 3 | 1 | 6-7 |
| Starch | 55-65 | 67-70 | 84 | 54-64 |
| Ash | 2 | 2 | 0,5 | 2 |
| **Total dietary fibre** | 15-17 | 10-13 | 3 | 11-13 |
| of which soluble fibre | 3-4 | 1-2 | 0,9-2,0 | 3-5 |

(Åman et al 1997, Clydesdale 1994, Lasztity 1998, Härkönen et al 1997, Welch 1995, Andersson et al 1992 and Vollendorff et al 1991)
The number after the name of the cereal indicates the extraction rate.
Extraction rate is the propostion of flour derived from a known quantity of grain.
Extraction rate 100 = whole grain flour.
Extraction rate 66 = 66% of grain is milled in this flour.
Due to differences in analyzing methods the values are not totally comparable.

There are two types of dietary fibre, soluble and insoluble. Water-insoluble dietary fibre includes e.g. cellulose, and lignin, whereas xylans and β-glucan are partly insoluble, partly soluble. Soluble fibre, such as arabinoxylan and β-glucan, forms a viscous gel already at very low concentrations (0.5-2%). Rye contains more arabinoxylan and mixed-linked β-glucan than wheat, but similar amounts of cellulose and lignin.

Oats are widely known for their high β-glucan content. β-glucan has been shown to have a positive effect in reducing the risk of coronary heart disease. Whole-grain rye contains remarkable amounts of soluble arabinoxylan, which seems to have positive health effects similar to the β-glucan in oats.

The dietary fibre content of typical rye bread is about three times higher than that of white wheat bread. The reason for this is that rye bread is usually made of whole grain rye flour, while white wheat bread is typically made of wheat flour, where the outer layers of wheat grain have been eliminated during the milling process. However, even at the same extraction rate, rye flour would have a higher fibre content than wheat flour.

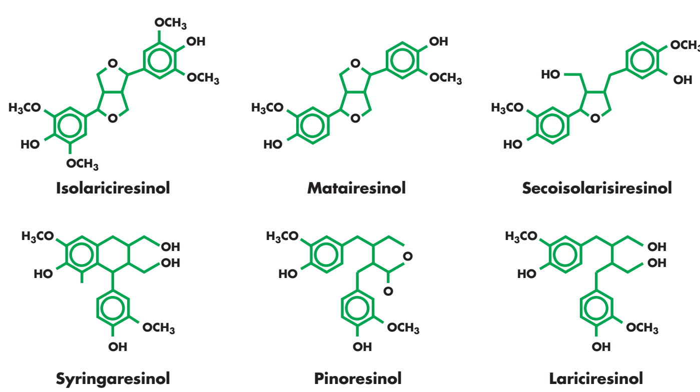
The outer layer of the endosperm, the aleurone layer, is rich in proteins, minerals and vitamins, especially B-vitamins. Rye is an especially good source of several minerals, e.g. manganese, iron, copper, zinc, selenium, magnesium and fluoride. The aleurone layer, i.e. the part of the grain very close to the surface, is difficult to separate from the bran (Clydesdale 1994, Åman et al. 1997).

**Mineral and Vitamin Content of Rye Bread and the Percentage of Recommended Daily Intake (RDI) that 100 grams (3 slices) of Whole grain Rye Bread Provides.**

| Nutrient | Amount in 100g Rye Bread | % RDI (for women) | % RDI (for men) |
|---|---|---|---|
| Vitamin E | 1,0 mg tocoph. | 14 | 10 |
| Thiamin | 0,18 mg | 16 | 13 |
| Riboflavin | 0,2 mg | 15 | 13 |
| Niacin | 1,2 mg | 8 | 6 |
| Folate | 3 µg | 14 | 14 |
| Iron | 2,7 mg | 18 | 27 |
| Zinc | 2,3 mg | 33 | 26 |
| Selenium | 3,2 µg | 8 | 6 |
| Calcium | 31 mg | 4 | 4 |
| Potassium | 0,4 g | 13 | 11 |
| Magnesium | 75 mg | 27 | 21 |
| Fiber | 9,9 g | 40 | 40 |

Rye grains are also a good source of non-nutrient bisphenolic lignans. 47 µg/100 g secoisolariciresinol (SECO) and 65 µg/100 g matairesinol (MAT) have been detected in whole grain rye, and the lignans were shown to be concentrated in the outer layers of the kernel (Nilsson et al. 1997 a,b). Recently, high concentrations of some new lignans were found in rye. These are pinoresinol, lariciresinol, isolariciresinol and syringaresinol. In the gut, the intestinal microflora converts the plant lignans into their mammalian derivatives, enterodiol and enterolactone, which may have a number of biological properties significant to human health. Of the new lignans all, except isolariciresinol, are converted to enterolactone and enterodiol (Heinonen et al. 2001). Rye grains also contain polyphenols, e.g. tannin (antioxidant which inhibits the activation of chemicals to mutagenic and carcinogenic derivatives and hastens chyme passage), phytic acid and vitamins and minerals (Adlercreutz and Mazur 1997 ). Ferulic acid is the major phenolic acid in rye, contributing to the antioxidative effects of rye (Andreasen et al. 2000, 2001).

**Structures of Plant Lingnans Identified in Rye**



IV

# METABOLISM OF DIFFERENT COMPONENTS OF RYE

## The Degradation of Dietary Fibre in the Intestine

### Small Intestine

The majority of nutrients in food are degraded and absorbed in the small intestine. Soluble fibre, such as β-glucan and soluble arabinoxylan, may slow down the gastric emptying rate and the absorption of nutrients from the lumen of the small intestine, possibly by increasing the viscosity of the food mass. This leads to the delayed hydrolysis of starch and absorption of nutrients, which results in lower and more stable blood glucose levels. This is beneficial e.g. with respect to prevention of development of type 2 diabetes.

Some minor degradation of non-starch polysaccharides may also occur in the small intestine of humans. The degradation depends on the type of polysaccharide. Rye has a higher arabinoxylan content than other cereals. The degradation of arabinoxylans and cellulose is much lower than that of the mostly soluble β-glucan (Bach Knudsen et al. 1997).

### Large Intestine

Most microbial degradation of dietary fibre occurs in the large intestine. Dietary fibre provides substrates for the complex ecosystem there, which consists of several hundred species of bacteria that are important for human health. The long term effects of the level of dietary fibre intake on the composition of human intestinal microflora have not been thoroughly investigated. It seems, however, that the microflora can be altered as early as after 2 weeks of increased intake of dietary fibre (Rao 1995). The intermediate and end products of fermentation also are partly determined by the composition of the polysaccharide substrate.

The fact that the gut microflora can be altered for the benefit of human health has motivated the development of new functional food ingredients. A probiotic is a live microbial food supplement, which beneficially affects the host by improving its intestinal microbial balance (Fuller 1989). A prebiotic is defined as a nondigestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improves host health (Gibson and Roberfroid 1995).

The most studied prebiotic food ingredients are oligosaccharides, which change the gut microflora in the favour of Bifidobacteria. The bifidogenic nature of fructo-oligosaccharides originating from chicory inulin has been well documented (Van Loo et al. 1999). There is also evidence that xylo-oligosaccharides increase the amount of Bifidobacteria in humans (Okazaki et al. 1990, Crittenden et al. 2002). The potential of rye arabinoxylan to selectively stimulate some groups of bacteria in the colon remains to be studied. Recently it was shown in pig experiments that whole grain rye is a much better stimulator of fermentation and enterolactone production than white wheat bread (Glitso et al. 2000).

It can be estimated that the amount of carbohydrates potentially available for fermentation in the large intestine is about 12 g/100 g of whole grain rye bread, of which about 80% is in the form of non-starch polysaccharides. This level is about three times higher than in white wheat bread. Moreover, whole grain rye bread provides 2 g of lignin per 100 g of dry matter, compared with 0.3 g in white wheat bread. The large amount of carbohydrates available for bacterial fermentation is beneficial for bowel physiology (Bach Knudsen et al. 1997, Gråsten et al. 2000).

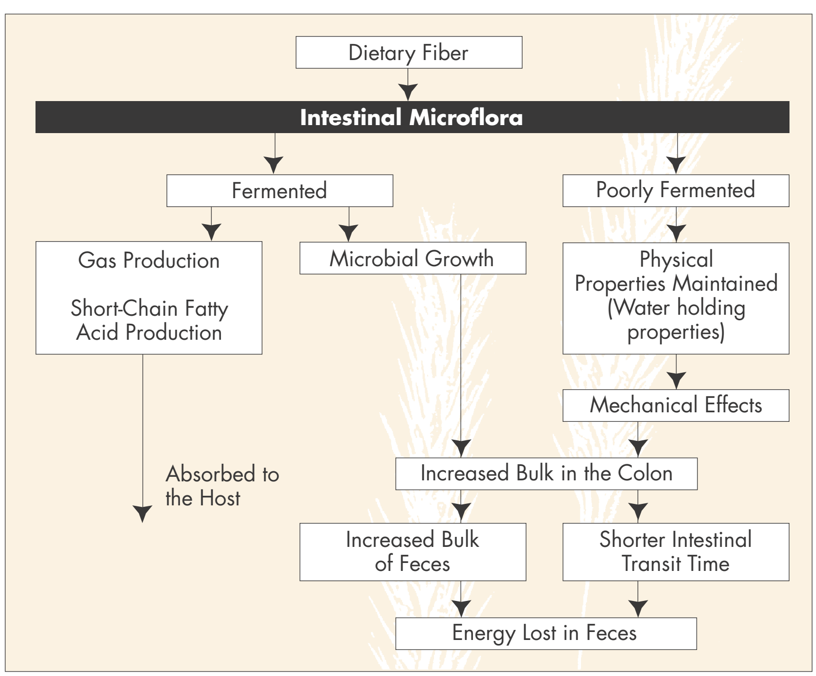
An increased intake of dietary fibre will inevitably influence bowel function because it stimulates microbial growth and short-chain fatty acid production, and lowers the pH in the gut, and also because of the mechanical action and the water holding properties of fibre (MacFarlane et al. 1991). All of these processes lead to increased bulk in the colon and a shorter feacal transit time, as also shown for high intake of rye bread (Gråsten et al. 2000)

The significance of the colonic fermentation lies mainly in the types of products that are formed and their fate in the body. Carbohydrates and proteins are broken down through a variety of intermediate products to short-chain fatty acids, various gases, branched-chain fatty acids and other organic compounds. The short-chain fatty acids generated supply the host with energy but have also specific metabolic roles with health implications. For example, butyrate has regulatory functions in cell proliferation and differentiation properties, which prevents cancer. Propionate has been proposed as a modifier of hepatic metabolism, and acetate is used as fuel for muscle tissues (Bergman 1990).

Studies have shown that the substrate available for fermentation influences the molar proportion of short-chain fatty acids. In vitro faecal fermentation studies indicated that rye bran and its fractions were good producers of butyrate and propionate (Karppinen et al. 2001). Results from animal experiments, obtained in the Nordic Industrial Fund funded project ”Rye Phytoprotectants”, point to rye dietary fibre as a good source of butyrate generation (Bach Knudsen et al., publication under preparation).

Whole grain rye bread lowers total bile acid concentration in faeces and reduces the concentration of free secondary bile acids, primarily because of a much higher concentration of saponifiable bile acids in faeces. The concentration of faecal litocholic acid, the most toxic of the bile acids, was significantly lower in a rye bread diet than in a wheat bread diet (Korpela et al. 1992, Gråsten et al. 2000). It is believed that saponifiable bile acids are less co-carcinogenic and comutagenic than free secondary bile acids.

**Mechanism of Action of Dietary Fibre and Unabsorbed Carbohydrates in Increasing Colonic and Faecal Weight and Bulk**



## Lignans in Rye and their Meatabolism

### Phyto-oestrogens: New Health Effects Revealed?

*Rye grains contain relatively high concentrations of plant lignans, which are converted to weakly oestrogenic mammalian lignans in the colon. The composition of the intestinal microflora and the availability of substrate in the diet influence the efficiency of this process.*

It has been found that a diet high in dietary fibre also contains certain amounts of biologically active compounds that may have significant physiological effects. These compounds are found in the same parts of the plant material as dietary fibre and they may be the cause of some of the health effects associated with fibre.

The lignans belong to the group of phyto-oestrogens, that display weak oestrogenic activities. Other phyto-oestrogens are isoflavones, mainly found in soy, and coumestrol, occurring in alfalfa. The isoflavones are more estrogenic than lignans but are still 1000 times less active than oestradiol. The lignans in plants probably have no oestrogenic activity, but plant lignans (pinoresinol, lariciresinol, syringaresinol, secoisolariciresinol and matairesinol) in the gut are converted to enterodiol and enterolactone. These s.c. mammalian lignans bind very weakly to the oestrogen receptor and exert oestrogenic effects of about 1/10000 to 1/100000 that of oestradiol. It is not possible to experience any oestrogen-related adverse effects by consuming a diet containing lignans. However, anti-oestrogenic effects have been described.

Phyto-oestrogens affect sex hormone metabolism and function by influencing some sex hormone metabolizing enzymes at the cellular level. They also stimulate the production of sex hormone binding globulin (SHBG) in the liver and in this way they favourably influence sex hormone levels in the body. In addition, they have a great number of other interesting biological activities, which appear to make them potential anti-cancer compounds. Many experimental and epidemiological studies support the theory that a diet high in phyto-oestrogens may inhibit the development and growth of hormone-dependent cancers, such as prostate and breast cancer, but no definite evidence has been found to date. Some evidence suggests that the inhibiting effect of enterolactone on breast cell proliferation may be due to growth factor action. Isoflavones inhibit vitamin D metabolism in the prostate and reduce androgen action at the receptor level. It is also possible that other components of such a diet may contribute to or even cause, the observed effects (Adlercreutz 2002).

**Phyto-oestrogens and Western Diseases: Potential Health Benefits**

- Hormone-altering
- Estrogenic/antiestrogenic
- Antioxidative
- Cancerprotective
- Anticarcinogenic
- Antiproliferative
- Cardioprotective
- Antiatherogenic
- Hypocholesterolemic
- Bone-maintaining
- Antiviral, antibacterial, insecticidal or fungistatic

Adlercreutz et al. 1997

In recent years scientists have been able to assess the phyto-oestrogen content in food and diet samples (Mazur et al. 1996, 1998). Flaxseed has been found to be the richest source of lignans. In flaxseeds, lignans are present in an oligomeric structure with secoisolariciresinoldiglucoside and 3-hydroxy-3-methyl glutaric acid as the main components. (Kamal-Eldin et al. 2001). Among grains rye has the highest content of lignans, while soy and a few other legumes are rich in isoflavones.

Rye contains the plant lignans pinoresinol (PINO), lariciresinol (LAR), isolariciresinol (ISOLAR), syringaresinol (SYR), secoisolariciresinol (SECO) and matairesinol (MAT), mostly as glycosides. To date, quantitative results are available only for SECO and MAT. Interestingly, wheat and barley are devoid of MAT. SECO and MAT undergo metabolic conversions in the gut. The intestinal microbes convert the plant lignans into the mammalian lignans enterodiol (END) and enterolactone (ENL). After the conversion, END is oxidized to ENL (Borriello et al. 1985). END and ENL are hormone-like compounds that have the ability to bind to oestrogen receptors with low affinity and with weak estrogen activity. (Adlercreutz and Mazur 1997).

The biotransformation of plant lignans to mammalian lignans has been studied in both human and animal experiments and in the laboratory. Experiments with ileostomy patients have shown that the entire enzymatic and fermentative activity of the intestine is needed for a complete bioconversion of rye lignans SECO and MAT to mammalian lignans END and ENL. Therefore, the ileostomy subjects were not able to complete the bioconversion (Petterson et al. 1996). In healthy humans, clearly higher plasma and urinary enterolactone levels were observed during the intake of whole grain rye bread than in a diet containing white wheat bread. (Juntunen et al. 2000).

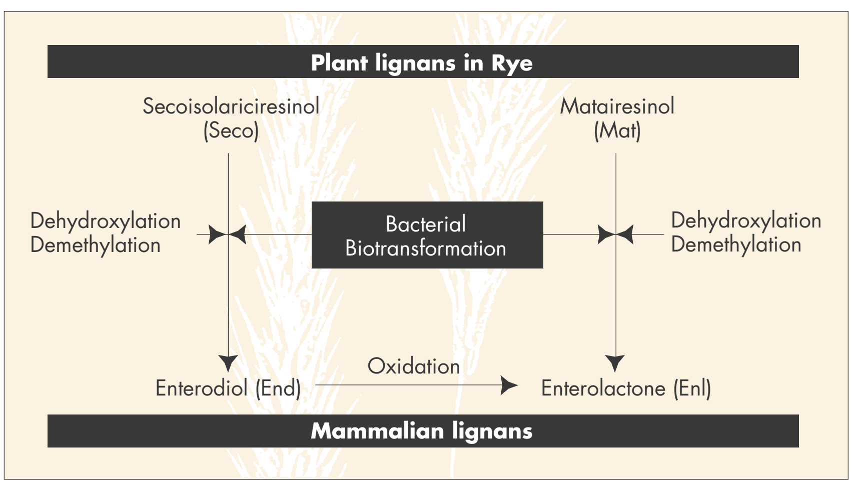
The biotransformation of plant lignans to mammalian lignans requires a suitable bacterial microflora in the gut. Some people are not able to convert the plant lignan precursors to enterolactone and enterodiol. This seems to be a consequence of frequent treatment with antibiotics, which destroys the microorganisms that perform the conversion from plant to mammalian lignans. After a course of antibiotics it may take more than a year before the microflora is again producing enterolactone normally. (Kilkkinen et al. 2002).

The ENL and END that are formed in the large intestine are absorbed by passive diffusion similar to what is seen for short-chain fatty acids. The most recent research carried out in the Nordic Industrial Fund project ”Rye Phytoprotectants” suggest that rye fibre not only stimulates the formation of butyrate but also the formation of ENL resulting in higher plasma levels of both metabolites. (Bach Knudsen et al. 2001).

## Alkylresorsinols

Alkylresorsinols are phenolic compounds present in the outer parts of rye and wheat kernels. They are considered to be inhibitory components responsible for lowering feed intake, feed conversion efficacy and growth rate in animals fed rye diets. As a result of this belief, selection programmes for rye cultivars with low levels of alkylresorcinols were started in an effort to increase the proportion of rye in animal feed. Interest in alkylresorsinols, however, continued and a wide range of activities, including antimicrobial, antiparasitic, antitumour and antioxidant effects, were attributed to them. (Ross et al. 2001, Kamal-Eldin et al. 2000).

**Biotransformation of Lignans in the Large Intestine**



V

# POTENTIAL HEALTH EFFECTS OF DIETS HIGH IN RYE

*In addition to helping in disease-prevention, a healthy diet may enhance the well-being of people on the shorter term. Diet high in fibre and low in fat reduces the risk of being overweight and of suffering from constipation, and helps maintain the desirable blood glucose levels.*

## Bowel Function and Constipation

### Avoid Constipation with Whole Grain Rye!

*Rye fibre increases faecal volume and reduces the intestinal transit time. This promotes proper bowel function and prevents constipation.*

Dietary fibre is not digested in the upper gastrointestinal tract of humans. Depending on the baking process, part of the starch in rye bread may also be resistant to digestion in the small intestine, and may reach the large intestine where it is fermented by the colonic bacteria. The amount of this so-called resistant starch is 1-2% and it increases the total amount of fermentable carbohydrates (Hansen et al. 1988). Rye fibre increases the faecal weight because the unfermentable residue maintains its water-holding property.

In a recent study two groups of people consumed rye bread or wheat bread in an amount equivalent to 20% of their daily energy intake. The fibre intake in the rye bread group was about 15 g/day more than in the wheat bread group. The consumption of rye bread improved bowel function. The faecal weight increased, the transit time became shorter and faecal evacuation frequency increased during the rye bread period. Intake of rye bread also decreased the levels of certain enzymes in faeces, which may reduce the formation of potentially carcinogenic compounds (Gråsten et al. 2000).

The preventive effect of rye fibre on constipation is due to the increased faecal weight, shorter intestinal transit time and softer faeces. High-fibre rye bread is recommended in the treatment of constipation. The simultaneous consumption of probiotic yoghurt relieves the possible adverse gastrointestinal effects associated with increased intake of dietary fibre (Niemi et al. 1998, MacFarlane et al. 1991).

## Weight problems? Whole Grain Rye May Help!

*Intake of rye fibre increases the excretion of energy. This may help to prevent the development of obesity.*

High fibre diets have several positive effects on human health. One of these is helping to control body weight. The most important mechanism is undoubtedly that whole grain food may increase the bulk of the food and probably long-term satiety. The effects on satiety are not scientifically proven but they can be tested individually by trial and error. The soluble fibre in rye is expected to increase the viscosity of food in the stomach, and thus delay the evacuation of stomach contents into the small intestine. This prolonged stay of food in the stomach increases the replete feeling, and thus helps in dieting (Hagander et al. 1987).

A second and possibly less-important but significant mechanism is that some factor in the whole grain fibre complex may decrease the availability of energy from a diet. There is an increase in the excretion of nitrogen, fat and energy from the small intestine in individuals eating a whole grain rye diet and this is highly correlated with the dry matter of the small intestinal content (Zhang et. al. 1994). In a follow-up experiment, they have confirmed the first results and further characterized the components of the excreted materials. In this study on ileostomy subjects the intake of high-fibre rye bran bread or wheat bread during different dietary regimes (nibbling - 7 meals/day, or gorging - 3 meals/day) was investigated with an emphasis on the excretion of energy and nutrients. The intake of rye bran bread increased the excretion of all nutrients (fat, protein and carbohydrates) and energy in all individuals. The excretion of nutrients and energy did not differ between the two eating regimes. During the high-fibre period the energy excretion was almost as much as twice the amount (2400 kJ/day) compared to the excretion during the wheat bread period (1400 kJ/day) as measured using a bomb calorimeter.

On the other hand, even though human enzymes cannot break down dietary fibre, part of the energy in dietary fibre can become available for humans following the microbial breakdown of the dietary fibre polysaccharides in the colon and the formation of short-chain fatty acids. Therefore, the energy obtained from dietary fibre depends largely on the extent of fibre fermentation (Wisker et al. 1996). The net effect of these processes of energy utilization has, however, not yet been clarified, but experiments are under way to study what is happening in the large intestine.

In animal experiments it has also been found that exogenous fibre-degrading enzymes added to the rye diet increase the amount of energy received from rye (Petterson et al. 1994, Boros 1995). From this it could be assumed that the fibre in rye restricts the uptake of energy from the small intestine.

## Reduced Insulin Levels and Preventation of Diabetes

*A high consumption of cereal fibre and whole grain is associated with a decreased risk of diabetes. Some factors in the dietary fibre complex in whole grain rye products seem to have favourable effects on insulin and glucose metabolism e.g. by increasing insulin sensitivity.*

The majority of nutrients are digested and absorbed in the small intestine. Soluble fibre, such as β-glucan and soluble arabinoxylan, may slow down the evacuation of stomach contents into the small intestine by increasing the viscosity of the food mass. This leads to the delayed hydrolysis of starch and the absorption of nutrients, which helps to slow down the changes in blood glucose levels (Hagander et al. 1987). Whole grain rye has a high content of soluble fibre, especially soluble arabinoxylans. In intervention studies in healthy subjects it was found that postprandial plasma insulin responses were significantly lower after the intake of a whole grain rye bread as compared to a wheat bread. No significant differences in plasma glucose levels were found (Leinonen et al. 1999). These results have been confirmed in a follow-up study where whole grain rye was used (Juntunen et al. 2002). In this study also a decrease was observed postprandially in the duodenal hormones GIP and GLP-1 after a whole grain rye meal intake.

Cross-sectional results from the Botnia Dietary Study show that the energy-adjusted intake of rye was directly related to insulin sensitivity in both sexes (Ylönen 2001). The consumption of other cereals, such as wheat, was not related to insulin sensitivity in this group of 555 high-risk individuals for type 2 diabetes. In an eight week cross-over study using an intravenous glucose tolerance test, insulin secretion (but not insulin sensitivity) was improved in 20 postmenopausal women when they were given a diet containing high-fibre rye bread compared with a diet containing white wheat bread (Juntunen 2001). In another study, wheat bran added to test meals had very little effect on short-term glucose, insulin and lipid metabolism (Jenkins 2001).

In a recent experiment on ileostomy subjects were given a wheat, low-fibre diet for 2 weeks, followed by a washout week, and a period of 2 weeks on a whole grain and rye bran supplemented high-fibre period (Lundin et al. 2001a). A cross-over design was used for meal frequency (three or seven times per day). During the seven meals per day period, the glucose and insulin peaks had clearly reduced at the end of the day during the whole grain rye period compared with the endosperm wheat control diet period. The daytime excretion of C-peptide was also decreased, which supports the results of decreased insulin secretion at the end of the day. C-peptide is a peptide, that is split off and secreted together with insulin. This delayed effect on glucose and insulin metabolism corresponds to similar effects on a morning meal as a result of a high fibre meal served during the previous evening (”over-night second meal effect”) observed in other studies using high fibre diets (Björk et al. 2001). It also corresponds to an increased insulin sensitivity, which has recently been observed associated with whole grain consumption (Pereira et al. 2002).

Rye bran and rye fibre have positive effects on the prevention of diabetes in experimental studies performed on both humans and animals. The effects of bread with a high content of rye bran were compared with those of either low-bran bread or a patients' usual bread in insulin-dependent diabetic patients (Nygren et al. 1984). When the bread with high rye bran content was included in the diet the glucose profile during the day improved and the insulin doses could be reduced.

The protective effects of rye bran on the diabetic syndrome were also found in rats and mice (Nygren 1981, Lundin 2001b). The diabetic rats fed the high-fibre bread lost less body weight, and exhibited lower blood glucose levels and lower urinary glucose excretion than the animals fed the low-fibre bread. Rye bran lowered blood glucose levels slightly and led to slower weight gain in normal rats and mice, and prolonged the survival of diabetic mice (Berglund et al. 1982). Obvious effects on the small intestinal morphology were also detected with an increased goblet cell volume and density in the ileum of hamsters (Lundin et al. 1993), broader ileal villi, a higher density of ileal microvilli, a thicker glycocalyx layer, and an abundance of filamentous microorganisms in the ileum of diabetic and control mice (Lundin 2001b). The morphological changes in the intestine of the diabetic animals were associated with a favourable weight development and a disappearance of urinary glucose excretion.

A clear association between a high intake of dietary fibre from cereal grain and a reduced risk of diabetes has been observed in two large-scale prospective studies in females. In one of the studies a low glycemic index was concomitantly associated with a decreased risk (Salmeron et. al. 1997) in comparatively younger women but not in the second more recent study (Meyer et al. 2000) on older women. The glycemic index is dependent on the food form and the way in which the food has been processed. Rye bread containing whole grains had a remarkably lower glycemic index than whole grain rye bread made of flour (Jenkins et al. 1986). The hypothesis that there may be differences

in the effects of whole grain diets and diets based on refined grain, but with a similar total fibre concentration, has recently been tested in postmenopausal women (Jacobs 2000). A 17% lower mortality rate was seen in women consuming a predominantly whole grain diet. It was considered that the effect was perhaps caused by phytochemicals in the whole grain complex. Residual confounding (other explanations are not accurately adjusted for) is an alternative explanation. More studies are obviously needed in order to determine the effect of diets on survival.

## Whole Grain is Associated with a Reduced Risk of Cardiovascular Disease (CVD)

*A number of prospective epidemiological studies clearly point to the protective effect of whole grain cereals on myocardial infarctions (MIs). A corresponding protective association with diabetes and ischaemic stroke (brain infarcts) has only recently been demonstrated. Many mechanisms have been put forward to explain the protective effects.*

There is a striking similarity between the risk factor pattern of the two major forms of cardiovascular disease (CVD), stroke and myocardial infarctions (MIs). For preventive purposes, it is important to focus on the control of diabetes, blood cholesterol, blood pressure, smoking cessation, and a reduction in weight, but also on some other risk indicators/factors such as insulin/proinsulin and fibrinolytic factors.

Many large-scale epidemiological studies strongly support the protective effect of dietary fibre rich food, especially whole grain products, on myocardial infarctions (Willet 1998). A study on whole grain rye consumption that covered nearly 22,000 middle-aged Finnish men showed an inverse association between the amount of dietary fibre in the diet and coronary heart disease (Pietinen et al. 1996). These men were followed over 6 years, and it was found that the intake of cereal fibre, to a large extent deriving from rye, was more strongly negatively associated with the risk of MI than was vegetable or fruit fibre. The positive effect of fibre was strongest for fatal events. The relative risk of fatal myocardial infarction was 0.45 among the men with the highest intake of fibre (median, 28.9 g/day) compared with the men with the lowest intake of fibre (median, 12.4 g/day).

Some recent studies have shown the same associations, where cereal fibre has been strongly associated with a protective effect on MI (Wolk et al. 1999, Liu et al. 2002). Similarly, the protective effects of whole grain food on ishaemic stroke have now also been shown in postmenopausal women, independent of other known CVD risk factors. There are probably several mechanisms behind the protective effects, including the effects on lipids and fibrinolysis.

Components in whole grain cereals, such as alkylresorcinols, phenols, lignans and phytic acid, can also act as antioxidants (Jacobs et al. 1998, Vanharanta et al. 2001). Some suggested mechanisms are:

### Insulin

In some prospective studies, a high insulin or proinsulin concentrations (Lindahl et al. 1999) has been associated with an increased risk of MI. There is a general agreement that insulin resistance with high insulin concentrations associated with an increased risk of MI. The effects of a rye bran bread-based high-fibre diet versus a wheat bread-based low-fibre diet have been studied experimentally (Leinonen et al. 2000, Lundin et al. 2001a).

### Cholesterol

The β-glucan in oats has been proven to reduce blood cholesterol concentration. In the United States, the following health claim is allowed in the marketing of oat products: The soluble fibre from oatmeal, as part of a low saturated fat, low cholesterol diet, may reduce the risk of heart disease (FDA 1997). Whole grain rye contains high amounts of soluble arabinoxylans, which theoretically may have a similar function in lowering cholesterol levels as the β-glucan in oats. A diet high in rye, especially rye fibre, has been shown to have positive effects in reducing serum total and LDL cholesterol in men with elevated serum cholesterol. The reduction of cholesterol was greatest among men that had consumed large amounts of rye bread (195-240 g rye bread/day). White wheat bread did not have a cholesterol-lowering effect (Leinonen et al. 2000).

In ileostomy studies, increased excretion of bile acids has been observed, with a slightly lowered (Lundin et al. 2001a) or no effect (Zhang et al. 1994) on the blood cholesterol concentration. An increased excretion of bile acids and cholesterol is believed to reduce the bloodcholesterol concentration. In earlier studies with rats, it was found that rye reduced serum cholesterol, probably due to reduced absorption of bile acids and cholesterol (Lund et al. 1993, Zhang et al. 1994). Rye bran also lowered blood cholesterol in hamsters (Zhang et al. 1994). The cholesterol lowering effect of rye bran has recently been evaluated by Asp and Åman (2000). They concluded that so far the evidence for a cholesterol-lowering effect associated with rye bran is insufficient, from health claim point of view.

More long-term experimental studies on humans are obviously needed to explore the possible association of a relevant cholesterol-lowering effect with a high intake of rye bran. In an epidemiological study from Finland, a high intake of rye products was associated with a decreased risk of MI, independent of the serum cholesterol concentration (Pietinen et al. 1996). This observation is consistent with results from other prospective studies. Thus, the major protective effect on MI associated with a high intake with whole grain cereals does not seem to be related to the blood cholesterol concentration.

### Prevention of blood clot (thrombosis) formation

The formation of a thrombosis is usually crucial for the MI event. An association has been observed between a high-fibre intake and a lowered concentration of variables associated with blood thrombosis dissolution (fibrinolysis) (Djoussé et al. 1998, Boman et al. 1994). Fibrinolysis can be defined as a breakdown of components (fibrin) that are an important part of a thrombosis. High concentrations of these fibrinolytic variables are associated with an increased risk of MI (Thogersen et al. 1998). The effect of whole grain diet/rye bran on the fibrinolytic system is a possible pathway for the protective effect of whole grain products. However, a diet high in rye did not show any significant changes in coagulation and fibrinolytic parameters in subjects with elevated blood cholesterol (Turpeinen et al. 2000). There is a very close relationship between high concentrations of insulin and high concentrations of one fibrinolytic factor (PAI-1). The two systems are linked together with insulin as the primary factor.

### Antioxidative or anti-inflammatory factors related to the whole grain complex

There are a large number of potential candidates with antioxidative and anti-inflammatory properties in the whole grain complex. The alkylresorcinols have the highest concentration of the substances with this potential in rye. From a theoretical point of view, anti-inflammatory effect of a factor present in the vessel wall may prevent ”plaque rupture” and subsequent thrombosis formation. A study on the absorption of alkylresorcinols in humans has recently been performed. Ten ileostomy-operated subjects were fed diets containing whole rye bread rich in alkylresorcinols or sifted wheat bread with no alkylresorcinols. Diet and ileostomy samples were analysed for alkylresorcinols and the apparent digestibility was calculated. The average absorption of alkylresorcinols in humans was between 50 and 70% for all major homologues (Ross et al. 2001). Alkylresorcinols may, therefore, be considered as good markers for whole cereal grain intake. Their biological effects and distribution in the body should be studied in the future.

In the field of cardiovascular disease, especially myocardial infarctions, there is a general agreement between prospective studies using biomarkers with antioxidative properties in blood such as enterolactone (Vanharanta et al. 1999) and ascorbic acid (Khaw 2001), and the results of prospective studies using dietary questionnaires. In a recent study from Finland, a high serum concentration of enterolactone was clearly associated with a decreased risk of myocardial infarction (Vanharanta et al. 1999). Thus, in this study, serum enterolactone was evaluated as a useful biomarker for the intake of lignan-rich foods. Like ascorbic acid and other antioxidants in blood a negative correlation may be expected to occur between enterolactone and markers of inflammation in blood, a hypothesis that has not yet been tested.

It is, however, unlikely that plasma enterolactone is confounded by the effect of a low-grade inflammation associated with advanced artherosclerocis. In fact in a very recent study by Vanharanta et al. (2001), serum enterolactone is associated with a decreased in vivo peroxidation. Also, after an adjustment for plasma antioxidative vitamins (alpha-tocopherol, beta-carotene, ascorbic acid) and dietary folic acid, the decreased peroxidation remained associated with enterolactone. It is thus suggested that enterolactone or some of its precursors may contribute to the antioxidative defence system in blood. Some other biomarkers/phytochemicals such as alkylrecorsinols, which also are absorbed in large amounts from rye, may of course be the active antioxidative agent.

### Diabetes

Diabetes is a well-established risk factor for CVD. A clear association between a high intake of dietary fibre from cereal grain and a reduced risk of diabetes has been observed as pointed out earlier. The outcome of the epidemiological and experimental studies suggest that substituting refined grain products with whole grain products may decrease the risk of both diabetes and CVD. It is probable that the protective effect is associated with some factor in the dietary fibre complex.

## Is There a Reduced Risk of Cancer Related to Whole Grain Intake?

*At present the aggregated results from studies on humans are insufficient to permit any conclusions indicating that rye, whole grain or phyto-oestrogens are cancer-protective. There are however some epidemiological studies, especially from the upper digestive tract, and intervention studies on prostate cancer, that point in that direction.*

The presence of phyto-oestrogens (isoflavones) in Asian diets and the comparatively low rates of so-called Western diseases, suggest that these plant chemicals may have protective effects. Numerous studies have evaluated this hypothesis and it has resulted in an intense discussion about the relationships between phyto-oestrogens and cancer. Most of the evidence regarding the effects of phyto-oestrogens in humans is epidemiological. The results of migration studies, as well as investigations on various dietary groups in the United States, Japan and Finland, suggest a protective role for phyto-oestrogens against the most common Western diseases (Adlercreutz et al. 1997). The two major forms of cancer in the two sexes, breast and prostate cancer, vary considerably between countries, and migration studies clearly show that the western lifestyle has adverse effects on their incidence. The overall picture regarding cancer is, however, very complex.

### Studies in animals:

In experiments with rats and nude mice, it has repeatedly been seen that rye bran and soy protein intake delay the early growth of hormone-sensitive prostate cancer. Rye bran and soy protein in the diet have been shown to delay the growth of transplanted hormone-sensitive prostate cancer in rats (Landström et al. 1998). Rye and soy diets markedly inhibit the prostate specific antigen (PSA) secretion of human LNCaP tumours transplanted to nude mice and these diets also increase tumour cell apoptosis (Bylund at al. 2000). The active component(s) of the dietary complex of rye bran may be lignans, but other substances and/or mechanisms may be involved such as effects on insulin and IGF-1. Addition of fat to a rye diet abolishes the beneficial effects on tumour take, tumour cell apoptosis and tumour growth. Fat also decreased the urinary excretion of enterolactone, which show that fat interacts with the formation of enterolactone in the gut, possibly by means of a reduced rate of fermentation or absorption (Hallmans et al., unpublished results).

The observation that the cancer-protecting effects of components in traditional diets can be reduced just by adding fat may be of considerable importance for the understanding of the geographical and temporal changes in the incidence of prostate cancer. The experimental studies also show that the effect of diet is transient on prostate tumour growth and that no effect is seen on aggressively growing tumours. The results are, however, supported by the effects of purified extracts of lignans on experimental breast- and colorectal cancer found by Thompsons group in Canada, as well as by results using purified lignans in experimental prostate cancer (Göran Hallmans, personal communication).

Rye bran has been shown to slow down adenoma growth in two different animal models. Rye bran supplementation decreased the frequency of colon cancer in azoxymethane-treated rats (Davies et al. 1999), and rye bran was beneficial against intestinal tumorgenesis in multiple intestinal neoplasia (Min) mice (Mutanen et al. 2000). Hydroxymatairesinol, which has a structure close to matairesinol in rye, also showed anticarcinogenic effects in Min mice model (Oikarinen et al. 2001). The mechanisms for the possible protective effects are, however, not yet revealed.

In general, the relationship between lignans and cancer is far from clear, but according to the emerging view, the anti-cancer effects are more likely due to a concerted action of many types of phenolic compounds including lignans and isoflavonoids, than to individual substances. The inhibitory effect of soy protein and rye bran on experimental tumour growth may also be related to several other mechanisms.

### Studies in humans:

***Breast cancer:***

Enterolactone is a biomarker for both the function of the intestinal microflora and the intake of lignan-rich food. In case control studies, a protective association has been observed between high enterolactone concentrations in blood (Pietinen et al. 1999) or urine (Ingram 1997) and breast cancer while the results so far from prospective studies on breast cancer have been inconclusive (den Tonkelaar 2001, Hultén 2001). In three studies, a low level of enterolactone was associated with a high risk of breast cancer. In Hultén's study, a low plasma concentration of enterolactone was associated with an increased risk in all women after stratification on pre- and post-menopausal status. Surprisingly, in this population, high plasma concentrations of enterolactone were also associated with a tendency towards an increased breast cancer risk. In three out of four studies a low enterolactone concentration in plasma or urine was associated with high breast cancer risk. In the study by Pietinen et al. (2001), the dietary studies showed that there was a significant positive association between plasma enterolactone and rye intake. Assuming that the hypothesis on the relationship between whole grain intake and breast cancer risk is true, it is not surprising that an association between enterolactone and breast cancer risk is not always found because in other populations the sources of lignans may be completely different. In the USA, the main sources of lignans are coffee, orange juice and fruit (Horn-Ross et al. 2000), which is very different from the sources (whole grain cereals, vegetables and berries) in the Nordic countries.

***Colorectal cancer:***

There has long been strong support of the concept that dietary factors, such as dietary fibre-rich food, may protect against cancer, e.g. cancer of the colon and rectum (World Cancer Research Fund 1997). During the last few years the concept of a protective effect of fruits, vegetables and whole grain cereals has been challenged, while no protective effect has been observed in some recent prospective studies using dietary questionnaires (Fuchs 1999, Pietinen 1999). No association has been detected between colorectal cancer risk and intake of plant sterols, with whole grain bread being an important source (Normén et al. 2001) or with enterolactone used as a biomarker for intake of dietary fibre-rich food (Lundin et al. 2001c).

To further increase confusion, support in a very recent prospective study was again given to the protective effect that fibre-rich food has on colorectal cancer. In a study by Terry et al. (2001), on a group of over 60,000 women, individuals with a very low intake of fruit and vegetables were at an increased risk.

The conflicting findings emphasize the potential usefulness of intervention studies, the identification of critical phytochemicals with adverse or protective effects on cancer, or the identification of biomarkers of food intake. Intervention trials have not been conclusive or negative, and in one study using a purified fibre fraction, ispaghula fibre, the treatment was even associated with an increased recurrence of colorectal adenomas. Neither was a low-fat, high-fibre diet effective for preventing recurrence of colorectal adenoma in a large-scale intervention study (Schatzkin 2001).

While so much evidence has previously been accumulated in support of the protective effect of fibre-rich food on colorectal cancer risk, follow-up studies on large prospective materials of colorectal cancers may be justified, using biomarkers fibre such as enterolactone for the dietary fibre complex, and perhaps, in the future, more specific biomarkers such as alkyresorcinols (for rye) (Ross 2001) and avenantramides (for oat).

***Other cancers:***

A number of prospective studies using enterolactone as a biomarker in blood are ongoing with regard to breast-, endometrial- and prostate cancer. The preliminary results of the first prostate cancer study have been presented. They were negative overall, with no clear associations observed (Stattin et al. 2002).

For stomach cancer, including cardia, a large number of case control studies strongly suggest a protective effect (World Cancer Research fund 1997). The results are almost completely consistent with a protective effect associated with whole grain cereals. Further strong support comes from recent study on cardia cancer, performed on a population-based material (Terry et al. 2001), where the protective association was strong for cardia cancer and somewhat weaker for adenocarcinomas of the lower oesophagus. Importantly, no indication of a protective effect was seen associated with oesophageal squamous cell carcinoma, which strongly supports the conclusion that recall bias has not been a significant bias-causing factor in this study. The most exciting mechanisms of a protection effect from whole grain cereals are connected with the binding properties of their N-nitroso compounds (Kurtz and Zhang 2001). Some preliminary data were presented by Jacobs at the Whole Grain and Human Health conference in Finland, in June 2001, based on the results of prospective studies. Surprisingly some results indicate a protective effect associated with the upper digestive tract and endometrial cancer.

A delay in clinical cancer onset may be very important from a public health perspective. Dietary intervention studies in humans, using various forms of endpoints such as apoptosis in tumours and changes in PSA concentration, are therefore required. Unfortunately, dietary intervention trials are costly and very time consuming. Nevertheless, they are needed in order to obtain final proof of the effects of diets.

## European Cancer Prevention (ECP) consensus panel statement on cereals, fibre and colorectal and breast cancers

*The European Cancer Organization held a meeting in Italy in October 1997. Twenty-two experts in the field of diet and cancer agreed on a consensus statement as follows:*

- A diet rich in high-fibre cereal is associated with a reduced risk of colorectal cancer.
- There is suggestive evidence that cereal fibre protects against breast cancer.
- There is good reason to examine the relationship between cereal fibre intake and risk of cancer at other sites.

The European Cancer Organization supported its statement by proposing a variety of mechanisms for the protective effect of cereal fibre.

The European Cancer Prevention Consensus Statement is, however, not supported by recent findings from some prospective studies where no protective effect of dietary fibre against colorectal cancer was found (Fuchs et al. 1999, Pietinen et al. 1999, Lundin et al. 2001c). In fact a significant positive association between the intake of vegetable fibre and colorectal cancer was unexpectedly observed in one study (Fuchs et al. 1999). The results show the complexity of the relationship between diet and cancer, and are expected to be followed up by large-scale prospective studies using questionnaires and biomarkers in blood, including studies on populations with a high consumption of cereal fibre. More dietary intervention studies with cancer or surrogate markers for cancer as endpoints are also needed.

European Cancer Prevention (ECP) consensus panel statement on cereals, fibre and colorectal and breast cancers

### The U.S. Health Claim for Whole Grain Foods

*The U.S. Food and Drug Administration (FDA) authorized a new health claim in July 1999 for foods that contain 51% or more whole grain ingredients:*

Diets rich in whole grain foods and low in total fat, saturated fat, and cholesterol may reduce the risk of heart disease and certain cancers.

This can be regarded as important proof for the health benefits of Nordic rye products, because most of them meet the requirements of the whole grain health claim. The results obtained recently about the various physiological functions of whole grain rye foods also very well support the whole grain health claim.

VI

# RYE CULTIVATION AND CONSUMPTION

## Rye Cultivation

### Rye: A Nordic Specialty

*Rye is a cereal with modest requirements regarding soil, fertilization and climate. The main cultivation area of rye is the north-western part of the Eastern Hemisphere. During the latest decade new rye varieties with better resistance and quality have been developed.*

Rye *(Secale cereale)* is a special cereal grown almost exclusively in the north-western part of the Eastern Hemisphere. Nearly 95% of the global production takes place in the northern part of the area between the Ural Mountains and the Nordic Sea.

Rye has been considered to be a primitive crop with low yield, long and weak straw, and problematic behaviour regarding sprouting in the ear. The positive features in cultivation practices include low requirements regarding soil and fertilization, as well as a relatively good overwintering ability. Therefore rye has gained popularity especially in areas with relatively poor soils such as the wide sandy ridges in Poland and some areas in Germany (Salovaara and Autio 2001).

The use of rye is mainly based on local traditional nutritional practices. Traditional rye bread is the dark sour bread known in Finland, the Baltics, Poland, Belarus and the Russian Federation. This tradition has somewhat changed the more westward one goes, for instance to Sweden, Denmark and Germany. There has been a steady decrease in the global total production of rye. The production has diminished even in the areas with long traditions in the use of dark bread.

The greatest rye producer used to be the former Soviet Union. Now this has been split in two main parts: the Russian Federation 3-4 million tonnes and Belarus about 1-2 million tonnes. Poland, which produces about 6 million tonnes, and Germany, with almost 5 million tonnes last year, are the largest producers (Salovaara and Autio 2001, Bushuk 2001).

The Nordic countries are relatively small rye producers, and the yearly production fluctuates depending on weather conditions at the time of sowing and, to some extent, on overwintering conditions.

The harvest of rye in Sweden has developed well in the last 15 years, with a good quality product for soft rye bread and rye crisp bread. Due to successful breeding Sweden is self-sufficient in rye, and in some good years, a surplus is also exported to other Nordic countries.

## Rye Consumption as Food

*Many different types of rye products are used daily in the Nordic countries. Today, after several decades of diminishing rye consumption, the increased knowledge of the relationship between diet and well-being has raised the consumers` interest toward rye. In addition, the cereal industry is actively developing new and innovative rye products especially in the Nordic countries.*

Although the total production of rye has diminished, its use as food for humans has increased slightly during the 1990s. In 1995, the food consumption of rye in the world was about 8 million metric tonnes, which is about 35% of total production. The rest was used as feed.

Generally, during the last few decades, rye consumption has decreased in countries, where its consumption has traditionally been high, and has increased in countries, where the consumption has been low. It can be assumed, though, that the growing public awareness of the role of diet for our well-being, the increased knowledge of the nutrient content of foods, and the improved attitudes toward healthy eating will change the situation.

The research on rye and its positive effects on health has already raised interest within the cereal industry. Several innovative rye products have become available, and the consumers' interest in rye is increasing.

**Annual Rye Consumption as Food in the World and in Some Individual Countries**

| Area/country | Rye Consumption in kilograms/capita | | | |
|---|---|---|---|---|
| | 1985 | 1990 | 1995 | 1999 |
| World | 1.77 | 1.08 | 1.38 | 1.08 |
| Poland | 57.0 | 32.5 | 36.4 | 35.2 |
| USSR | 8.4 | 3.8 | | |
| Former USSR | | | 21.3 | 10.2 |
| **Finland** | **20.4** | **17.7** | **15.8** | **16.0** |
| **Denmark** | **20.3** | **18.4** | **15.5** | **14.7** |
| **Sweden** | **14.8** | **11.7** | **12.4** | **12.3** |
| **Norway** | **8.9** | **9.2** | **7.2** | **9.00** |
| Germany | 21.4 | 13.8 | 11.5 | 11.5 |
| Canada | 0.5 | 0.5 | 1.6 | 0.5 |
| USA | 0.2 | 0.4 | 0.3 | 0.3 |
| China | 0.7 | 0.5 | 0.2 | 0.2 |

## Different Rye Products

*Nutritionists world wide recommend an increased consumption of whole grain products and dietary fibre. Rye is an excellent raw material for healthy and tasty foods and it has a high fibre content.*

Rye bread has in the past been the most important source of energy, protein, and carbohydrate in the diet of Finnish and German farmers. As wheat, fat and sugar became readily available, the consumption of rye declined considerably. Now that consumers are increasingly interested in health, balanced diets, variation, and ethnic tastes of food, rye has the potential to gain interest and popularity. In particular, educated women have adopted rye as part of their regular diet (Prättälä et al. 2000). This may be a symptom of changing eating habits; the consumers are more often seeking healthy and tasty new foods. In addition, the cereal industry has responded to the growing demand, and the number of new rye products is increasing.

### Rye bread

*A wide variety of different types of rye breads are available in the Nordic countries and the field is growing. The traditional whole grain sourdough rye bread and rye crisp bread have gained new dimensions due to active research and product development in bakeries. Attention has been paid to health aspects, like low sodium content and high amounts of dietary fibre. In addition, new types of user-friendly breads have been developed.*

The flavour and the structure of rye bread are quite different from those of wheat bread, and they vary depending on flour type, other ingredients, the process, baking conditions and time, as well as the size and shape of the bread.

The most typical rye bread in Finland, Denmark, Russia, and the Baltic countries is whole grain rye bread made using a sourdough method. In this method the main ingredients, whole grain rye flour, water and starter culture are mixed and fermented for about 8-18 hours. During the fermentation period the lactic acid bacteria and the sourdough yeast grow, and due to the microbial activity and the enzymatic reactions of the microflora, flavour compounds are formed.

The main components formed are lactic acid and acetic acid. After fermentation more flour, water, and other ingredients are mixed to the sourdough to make the dough. The dough is left to rise for a short period, after which the breads are shaped, left to rise again and baked.

Today, in Finland, a wide variety of different types of whole grain sourdough breads are available. Small rye breads torn in half and used as a bun have gained popularity. Breads baked slowly at low temperature have a thick tasty crust, and they are available in different varieties, low-sodium or normal sodium, and made of organic rye. A number of pre-sliced rye loaves are also available with different textures and acidity profiles. The popularity of rye bread with whole grain kernels is increasing rapidly.

Taste is the most important quality criteria when food selections are made. The identity of rye bread is closely related to the bread's acidity and the whole meal rye flour content of the bread. Several studies have shown that acidity enhances perceived saltiness in rye bread. Thus it is possible to reduce sodium chloride levels in sour rye breads.

Rye bread in Sweden is consumed as traditional whole grain rye bread and as the popular loaf bread. One-third of bread consumption in Sweden involves the loaf bread type with about 40% rye flour at an extraction rate of about 80%. This type of bread has a long tradition. During the last five years new types of loaf breads with increased fibre content and whole rye kernels have been developed. These types of breads have been well accepted by consumers.

Another popular type of rye bread is crisp bread, originating from Sweden, which is eaten throughout the world. It has its greatest popularity in the Nordic countries. The annual consumption of crisp bread in Sweden is 4.5 kg per person, in Finland 2.5 kg and in Norway 2.0 kg. The basic ingredients in most of the crisp bread variants are the same as in most rye breads: whole grain rye flour, water, yeast and salt.

There are three different types of rye crisp bread: normal yeast fermented, sourdough fermented and cold bread crisp bread. Most of the crisp bread produced in Scandinavia is produced following 3-4 hours of fermentation. Sourdough versions are used in Finland and Germany. The third type of crisp bread is the so-called cold bread crisp bread, which is baked without the addition of yeast. The dough gets the right texture from a foaming process, where air is incorporated into the cooled dough, which also leads to the almost white colour of the finished bread. Crisp bread has a long shelf life due to its very low water content (5-7%).

## Rye Milling Products

*The variety of rye cereal products is growing. In addition to the traditional use of different types of rye flour, various types of rye flakes, breakfast cereals, etc. are also available.*

Whole grain rye is the most popular flour type for baking rye bread, especially in Finland. Rye flour with an extraction rate of about 80% is also widely used.

Different types of rye groats and flakes are available for baking, cooking porridges and for breakfast cereals. These products are generally made of whole grain rye. In the Nordic countries, several new types of rye products have been developed. Breakfast cereals containing rye have gained popularity. Different types of breakfast cereals are available with rye contents of up to 55%. The rye in these products is flaked and precooked, and sometimes even extruded to increase crispiness and taste.

## Other Traditional Rye Products

*In the Nordic countries rye has been a widely used raw material for many other traditional foodstuffs besides bread.*

In addition to bread and breakfast cereals, rye has always been consumed in variety of ways, in regions where it is popular.

Rye porridge is traditionally made of rye flour, but nowadays rye flakes are also available for a good and tasty porridge. A typical Finnish breakfast dish or dessert is rye-lingonberry or rye-blueberry porridge. Traditional baked rye berry pies still appeal to today's consumer.

Edible coatings are part of modern food technology, but they were already in use long ago in Eastern Finland, where fish, vegetables, and meat were baked inside a rye shell in order to make a shelf-stable product with a delicious edible coating.

A traditional Finnish pastry (Karelian pastry) is made with a very thin coating containing rye and wheat flour. The filling is made of cooked mashed potatoes, rice or barley pudding. Karelian pastries have always been popular in Finland, but during the last few decades, new technology in their production has made them more easily available. Today Karelian pastries could be called "Finnish pizza", a traditional convenience food.

”Mämmi”, the Finnish Easter pudding, is made of rye malt, rye flour, and water that are allowed to sweeten naturally and are then baked in the oven for several hours. The roots of this cereal-based dish go back hundreds of years in time, but it is still a common Easter dish, although nowadays enjoyed most often with cream and sugar.

### Novel Rye Products

*The possibilities for developing and producing new tasty and healthy rye products are limitless. Rye is an excellent raw material for new types of functional foods. The Nordic cereal industry is enthusiastically taking advantage of the results of rye research and new technologies, and developing novel rye products for the market.*

Increased consumer awareness and interest in the health-improving effects of foods have induced the Nordic cereal industry to research the benefits of whole meal rye products and improved processing. Rye is an excellent raw material for a variety of products; it may even be utilized as a major ingredient in many functional foods.

Rye bread mix with sourdough is an interesting new innovation, which makes baking traditional rye bread easier both at home and in catering kitchens. Rye bread mix contains sourdough in a dried form, and sourdough rye bread can be baked in a couple of hours, thus omitting the long fermentation of traditional sourdough.

Interesting rye novelties are pasta products that contain both wheat and rye. In addition, a mixture of rice and steel-cut rye is available to be served as a side dish, or used as an ingredient in casseroles and salads. Rye adds colour and taste in a similar way to wild rice. In Finland, two fast-food chains offer hamburger buns made of a wheat and rye flour mixture, ”rye burgers”.

Bakeries have developed new breads and buns that contain, in addition to whole grain flour, crushed rye grains and groats. The amount of added salt may be reduced, because the sourdough acids increase the perceived intensity of saltiness (Heiniö et al. 1997). Taste continues to be the number one priority when food selections are made (Clydesdale 1994). Also, the interest in ethnic recipes is increasing. Both of these trends provide opportunities for the development of new and revised rye products.

Karelian pastries are now available deep frozen, and oven-ready, which makes their use at home and at catering kitchens easy and popular. Prebaked rye bread is also available to be used in bake-off facilities.

Cereal-based snack products are a growing business area. Rye could be utilized to add flavour and taste in this area as well. Crispbread sandwiches with tasty fillings are already available, and a demand for these types of products is clearly emerging.

Today’s busy consumers utilize more and more ready-to-eat -products. Home meal replacement is a major trend in the United States supermarket industry, and it is also emerging in Europe. Supermarkets try to find new ways to attract customers to buy value-added products from supermarkets instead of buying take-out-meals from restaurants. To meet this demand, rye processors could find new solutions by developing ready-to-eat rye sandwiches, puddings, salads with rice-rye, etc.

Weight Watchers® in Finland have ”freed” whole meal rye bread in their diet. This means that a person following a Weight Watchers’ diet in order to lose weight is allowed to eat rye bread during breakfast, lunch and dinner as an extra dish, which does not count in the basic diet. This is a very interesting new utilization of rye bread, and it will no doubt change attitudes towards rye bread in the diets of those watching their weight.

#### Rye-based Consumer Products

**Milling Products**
- Whole grain rye
- Steel cut rye
- Crushed rye grains
- Malted and crushed rye grains
- Precooked rye kernels
- Malted rye kernels
- Whole grain rye flour
- Sifted rye flour (variations in ash content)
- Rye bran
- Rye flakes
- 4-grain flakes with rye
- Toasted rye flakes
- Breakfast cereals (muesli, others)
- Sourdough rye bread mix

**Bread Products**
- Rye bread
- Crispbread
- Thin crispbread
- Rye rolls and buns
- Rolls, buns and breads containing wheat/ rye-mixture
- Parbaked rye products

**Other Rye Products**
- Rye porridge
- Berry pastries
- Karelian pastries
- ”Kalakukko” - rye-dough-covered baked dish containing fish, meat and/or vegetables
- ”Mämmi” - Finnish Easter pudding
- Rye pasta
- Rice-rye-mixture
- Snack products
- Crispbread sandwich
- Rye Hamburger

VII

# VOCABULARY

### Antioxidant
Antioxidant is a substance that delays the onset or slows down the rate of oxidation of oxidizable substrates. Whole grains contain a number of antioxidants such as vitamins (e.g. vitamins E and b-caroten) and trace elements essential for enzymes performing antioxidant functions (e.g. Se, Mn, Mg), and nonnutrients such as phenolic compounds (e.g. lignans) and antinutrients (e.g. phytic acid).

### Arabinoxylan
Arabinoxylan, a polysaccharide composed of xylose and arabinose, is part of the soluble and insoluble fibre in cereals. Rye is a good source of arabinoxylan (pentosan).

### Ash content
Ash content is the amount of inorganic minerals in food samples. The ash content of flour indicates how much of the outer layers of the kernel have been ground to flour. In white wheat flour (ash content 0.7% or less) about 30% of the outer layers of the kernel have been removed. The ash content of whole meal rye flour is about 2%.

### Biomarker
It is not always possible to establish a quantitative measurement of the benefits or risks between diet and health and disease. Biomarker in the diet is a compound that can be measured, and its presence is related to the potential benefits or risks to health.

### β-glucan
β-glucan is a component of soluble fibre in cereals. Oat is very rich in β-glucan.

### Dietary fibre
The plant polysaccharides and lignin which are resistant to hydrolysis by the digestive enzymes of man.

### Dietary Fibre Complex
In addition to indigestible polysaccharides and lignin, minor components, such as phenolic compounds (e.g. lignans) or strongly associated cell wall proteins also may be included in the dietary fibre concept. The presence of such minor constituents, as well as structural variations in the dietary fibre components, can be of great importance for the functional and/or physiological properties of dietary fibre.

### Epidemiological Study
Epidemiological study seeks the potential associations between aspects of health (such as cancer, heart disease, etc.) and diet, lifestyle, habits or other factors within populations. Epidemiological studies may suggest relationships between two factors, but do not provide the basis for conclusions about cause and effect. Possible associations inferred from epidemiological research can turn out to be coincidental.

### Extraction rate
Flours are characterised by the rate of extraction. Extraction rate is the proportion of flour, derived by milling, from a known quantity of grain. Extraction rate is used to define various types of flours. White wheat flour has an extraction rate of 75 - 78% or less. Whole grain flour has an extraction rate of 100%.

### Gluten
Gluten is the water-insoluble part of cereal proteins. Gluten is especially important in wheat baking processes because of its effect in the structure of wheat breads.

### Glycemic index
The glycemic index is a method of classifying the blood glucose raising potential of foods in which the blood glucose responses of test foods are expressed as a percent of the response to the same amount of carbohydrate from a standard food, white bread.

**Ileostomy subject**
The large intestine and a part of the small intestine of the subject are removed and a loop or end of the small intestine is brought out through an opening in the abdominal wall of the subject for ”defecation”.

**Lignan**
Lignans are diphenolic phyto-oestrogens, which in the colon are converted to estrogen-like mammalian compounds.

**Phenolic compound**
Phenolic compounds are chemical compounds that contain carbo-aromatic rings.

**Phyto-oestrogen**
Phyto-oestrogens are steroid-like plant compounds consisting mainly of two groups of biphenols, isoflavones and lignans, which after consumption by animals or man have been shown to have oestrogenic activities.

**Prebiotic**
A prebiotic is a nondigestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improves host health.

**Probiotic**
A probiotic is a live microbial feed supplement, which beneficially affects the host animal by improving its intestinal microbial balance.

**Prospective study**
Epidemiological research that follows a group of people over a period of time to observe the potential effects of diet, behaviour and other factors on health or the incidence of disease. In general, this is considered a more valid research design than a retrospective research.

**Rheology**
Rheology encompasses the mechanical properties of solids, semisolids and liquids. In rheological experiment, one imposes a force and measures the deformation of sample. Under the same force, softer material will be deformed more than harder one.

**Synbiotic**
A mixture of probiotics and prebiotics that beneficially affects the host by improving the survival and implantation of live microbial dietary supplements in the gastrointestinal tract, by selectively stimulating the growth and/or by activating the metabolism of one or a limited number of health-promoting bacteria, and thus improving host welfare.

**Western diseases**
Breast cancer, prostate cancer and endometrial cancer belong to the group of hormone-dependent cancers which in addition to colon cancer, coronary heart disease and some other diseases are called Western diseases because their incidence and mortality are high in the Western world compared to countries in Asia and South and East Europe. An increased risk for Western diseases has been found to be related to a change towards a diet high in fat and low in fibre.

**Whole Grain Product**
The whole grain has been used for making the product.

VIII

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