It is well known that the content of dietary fiber is higher in whole grain flour compared with refined endosperm flour, since dietary fiber is concentrated in the bran (pericarp/testa and aleurone layer). Cereals, particularly wheat, rye, and oats, are a major contributor to the dietary fiber intake in northern Europe where it accounts for up to 60% of the intake. The main reason is that whole meal oats and rye in the form of flakes, porridges, and soft and crisp breads are an inherent part of the culinary tradition, particularly in the Nordic and Baltic countries (34). The consumption of these traditional products has decreased over the last century, but the increased awareness of the health benefits, including intensified research, campaigning from health authorities, and product development within the cereal industry, now appear to be turning this trend.

In recent years, whole-grain-based products have regained attention due to a growing body of evidence of the health benefits of whole grains consumption. Just recently, the European HEALTHGRAIN consortium developed a definition, stating that “whole grains consist of intact, ground, cracked, or flaked kernel after the removal of inedible parts such as the hull and husk. The principal anatomical components—the starchy endosperm, germ, and bran—are present in the same relative proportions as they exist in the intact kernel. Temporary separation of whole grain constituents during processing for later recombination is acceptable” (2).

Whole grain cereals not only increase the intake of dietary fiber; a range of other nutrients and bioactive substances follow the fiber fraction. In the following article, emphasis will be devoted to the copassengers found in rye and oats with reference to the contents in wheat.

**Cereals as a Carbohydrate Source**

Cereal grains are primarily a carbohydrate source with a high content of starch and dietary fiber and a low content of simple sugars. The starch is concentrated in the endosperm, while the dietary fibers are concentrated in the bran fraction. During milling, there is a dramatic increase in the dietary fiber content at extraction rates above 80%. However, the germ and bran fraction also contain the major part of the cereal grains’ content of vitamins, minerals, and a range of other bioactive components. Approximately 87% of the rye kernel and 80% of the oat kernel consist of endosperm compared with 81–84% in wheat (9,26).

**The Copassengers in Whole Grain**

**Amino Acids and Peptides**

Aleurone cells have a high content of essential amino acids (e.g., lysine), but their availability may be restricted due to the surrounding thick aleurone cell walls (22).

Recently, it has been discovered that several cereal species contain a 43-amino acid peptide, lunasin. This peptide was first found in soy, and later in barley, wheat, the Solanum family, and amaranth, and just recently, it was also reported in 15 out of 21 cultivars of Korean rye (20). Lunasin is chemo-preventive and has also been suggested to have cholesterol-lowering effects (11). Of the rye varieties containing lunasin, the content was 45–150 ug/g of seed (20). In barley varieties, the corresponding contents were 14–22 ug/g of seed (19), while in wheat the content ranged from 211 to 290 ug/g of seed with an average of 249 ug/g of seed (18). So far, no information is available on the concentration of lunasin in different milling fractions.

**Minerals**

The minerals are concentrated in the outermost cell layers of the grain; the aleurone cells account for up to 60% of the ash content in wheat and presumably a similar proportion in other cereals. Therefore, whole grain flour has a much higher mineral content than refined flour (Fig. 1). However, the major part (87%) of phytic-bound phosphorus is concentrated in the...
aleurone cells, which will limit bioavailability (9). The decrease in mineral content at a lower degree of extraction is less dramatic in oats and rye compared to wheat (30,31). The reason is that the hulls of these grain species in contrast to wheat crack easily during milling. This brings a considerable amount of small-sized pericarp and testa into the flour, which also explains their darker color. For oats, some minerals even increase by milling due to removal of the hull (37).

**Lipids**

Most cereals have a fat content of 1.5–4%, but the contents in oats are considerably higher (3–9%). The lipids are concentrated in the germ, but there is also a high concentration in the aleurone cells (9). Oats have high lipid contents in the endosperm (38), so in contrast to the other cereals, where removal of the germ together with the bran during milling dramatically reduces the fat content, this effect is less pronounced in oats. Oleic acid accounts for 30–40% of the lipids in oats but only ~15% in the other cereals. On the other hand, oats have a much lower proportion of polyunsaturated fatty acids (primarily linoleic acid), accounting for 42–44% of the fat, while they account for 63–70% in other cereals. However, oats also have a high lipase activity, which is mainly associated with the aleurone layer (7). Therefore, hydrothermal treatment is mostly required to prevent rancidity and increase shelf life.

**Vitamins**

Cereals are particularly rich in the B vitamins thiamin (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), biotin (B7), and folic acid. The vitamins are concentrated in the aleurone cells and contains more than 80% of the niacin of wheat (9). According to previous analyses of different milling fractions of a range of cereals, whole grain rye contains slightly less thiamin and significantly less pyridoxine and niacin than whole grain wheat, but more riboflavin, folate, and biotin (Table II). At a decreasing extraction rate below 80%, there is a dramatic decrease in the content of B vitamins (Fig. 2), but the reduction is generally less in rye than in wheat. In fact, endosperm rye contains more riboflavin, folate, biotin, and niacin than wheat endosperm (Table II).

The contribution of B vitamins to the diet from whole grain is probably less important. In yeast-leavened bread, for instance, bakers’ yeast is a major contributor to the B vitamin intake, estimated to be approximately 70% of the folate in bread (29).

Vitamin E is another important vitamin, primarily due to its antioxidative effect toward lipid oxidation in biological membranes. α-Tocopherol has previously been considered the most effective antioxidant, but recent studies have shown that α-tocotrienol is at least three times more efficient in hampering free-radical chain reactions (27). The germ and aleurone layer are the main sources of vitamin E in the form of both tocopherols and tocotrienols. The content of the tocols is comparable in the different cereals, but there are variations in the contents of the different isomers. Oats and rye are characterized by having a high content of α-tocotrienol, while wheat (soft and durum), spelt, and triticale have high contents of β-tocotrienol. This is also reflected in bran, where the tocotrienols are concentrated. Rye bran has a higher level of α-tocotrienol than of β-tocotrienol, while the reverse is the case for wheat bran (21). Expressed as vitamin E equivalents, the content in oats (34 mg/kg of DM) is ~50% higher than in wheat (23–24 mg/kg of DM) (27) and twice as high in durum wheat and spelt (15 and 17 mg/kg of DM, respectively). There is not much information on the contents of tocols in the different milling fractions of cereals, but since the germ and bran are removed, the content of vitamin E in non-whole grain flour is lower than in whole grain flour (Table II).

![Image](image_url)

**Fig. 1.** Content of minerals in wheat and rye with varying extraction rates (%). Calcium (Ca) (●) and phosphorus (P) (■) in mg/g of DM, copper (Cu) (▲), zinc (Zn) (♦), and iron (Fe) (X) in mg/kg of DM (ppm) (30,31).

![Image](image_url)

**Fig. 2.** Proportional change in B vitamin content in flour, wheat, and rye with varying extraction rates (%). Thiamin (●), vitamin B6 (■), riboflavin (♦), folic acid (▲), biotin (●), and niacin (♦) (16).

**Table I.** Mineral content in whole grain and endosperm flour of rye and wheat

<table>
<thead>
<tr>
<th>Extraction rate (%)</th>
<th>Thiamin (µg/g)</th>
<th>Riboflavin (µg/g)</th>
<th>Vitamin B6 (µg/g)</th>
<th>Folate (µg/g)</th>
<th>Biotin (mg/g)</th>
<th>Niacin (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole grain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>100</td>
<td>5.8</td>
<td>0.95</td>
<td>7.5</td>
<td>0.57</td>
<td>116</td>
</tr>
<tr>
<td>Rye</td>
<td>100</td>
<td>4.2</td>
<td>1.35</td>
<td>3.9</td>
<td>0.65</td>
<td>145</td>
</tr>
<tr>
<td>Endosperm flour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>66</td>
<td>1.4</td>
<td>0.37</td>
<td>1.3</td>
<td>0.06</td>
<td>25</td>
</tr>
<tr>
<td>Rye</td>
<td>65</td>
<td>0.6</td>
<td>0.80</td>
<td>1.0</td>
<td>0.11</td>
<td>45</td>
</tr>
</tbody>
</table>

* Data from Hegedüs et al. (16).

**Table II.** Content of α-tocopheryl units (αTE) and α-tocopherol in different flour and grain products

<table>
<thead>
<tr>
<th></th>
<th>αTE</th>
<th>α-Tocopherol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley groats, raw</td>
<td>0.68</td>
<td>0.25</td>
</tr>
<tr>
<td>Barley flour</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Rolled oats</td>
<td>1.55</td>
<td>0.75</td>
</tr>
<tr>
<td>Whole wheat kernels</td>
<td>1.52</td>
<td>1.40</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>1.97</td>
<td>1.60</td>
</tr>
<tr>
<td>Whole meal flour</td>
<td>0.99</td>
<td>0.87</td>
</tr>
<tr>
<td>Bolled wheat flour</td>
<td>0.66</td>
<td>0.59</td>
</tr>
<tr>
<td>White wheat flour</td>
<td>0.46</td>
<td>0.43</td>
</tr>
<tr>
<td>Semolina</td>
<td>0.13</td>
<td>0.10</td>
</tr>
<tr>
<td>Wheat germ</td>
<td>11.00</td>
<td>11.00</td>
</tr>
<tr>
<td>Rye kernels</td>
<td>1.52</td>
<td>1.15</td>
</tr>
<tr>
<td>Whole rye flour</td>
<td>1.17</td>
<td>0.80</td>
</tr>
<tr>
<td>Rye flour, b. (extraction ~85%)</td>
<td>0.59</td>
<td>0.59</td>
</tr>
<tr>
<td>Rye flour, b. (extraction ~70%)</td>
<td>0.29</td>
<td>0.29</td>
</tr>
</tbody>
</table>

* Data from The Danish Food Composition Databank (35).
Phytosterols and Stanols

Germ and aleurone cells of the grain also contain phytosterols and stanols, which have important cholesterol-lowering properties. Whole grain flour of rye and wheat contain approximately twice as much sterols as white flour, and brans contain two to six times as much as whole grain flour. By milling rye, there is a less pronounced change in content with a change in extraction rate, while there is a clear gradient of increasing content of sterols toward the outer layers of the wheat kernel (26). Again, this is probably related to a poorer separation during the milling process. Sterols in cereals are mainly in the form of unsaturated sitosterol and campessterol and the saturated forms, stigmasterol and campesterol, although brassicasterol is the dominating compound in wheat bran. The sterols are either found in free form or bound as sterol glucosides or sterol ferulates (14). Hence, in spite of a considerably lower content of stanols than in oil seed, cereals contribute to approximately 40% of the daily intake (26).

Betaine and Choline

Cereals contain both betaine and choline, with much larger quantities of the former. Betaine (trimethyl glycine or glycine betaine) protects a variety of cells against osmotic stress and prevents an elevated level of homocysteine, a risk factor of chronic vascular disease. Choline is oxidized to betaine in the liver and kidney, but also to acetylcholine and phosphatidylcholine, which are essential for normal cell function. Increasing the extraction rate of wheat increases both the betaine and choline contents. There is almost four times as much betaine and twice as much choline in whole grain wheat compared with white wheat flour, and more than three times as much in wheat bran compared with whole grain wheat, indicating that both components are located in the bran fraction. Whole grain rye and rye bran contain levels of betaine and choline equivalent to the levels found in corresponding commercial wheat samples. Whole grain oats, on the other hand, contain only about one tenth of the level found in rye and wheat, and the content in oat bran is only 40 and 70% higher compared to the groats, respectively (4). While wheat bran contains slightly more betaine than the germ, the choline content of germ is twice the content of the bran (23).

Lignans (Phytoestrogens)

Lignans are diphenolic compounds that act as the plant’s natural defense (secondary metabolites). In the large intestine, the plant lignans are transformed by the microflora to enterolignans (enterodiol and enterolactone) that are absorbed and enter the blood stream. Lignans are biologically active and may protect against a range of diseases such as certain cancers (e.g., breast, prostate, and colon cancer) and cardiovascular disease (15). More than 20 different plant lignans have now been identified in the bran of different cereals (36). Rye is the cereal species with the highest content of plant lignans, both as whole grain and as bran. The highest content of lignans is found in the pericarp/testa, followed by aleurone, with the lowest content in the endosperm (12). Hence, the endosperm content of lignans in rye is only 30% of the content in whole grain rye. Whole grain oats have a higher content than whole grain wheat, but the content in wheat bran is higher than bran from oat and spelt (Table III).

The rapid development in the identification of new lignan precursors makes it difficult to get comprehensive table values for different cereal sources. While six lignans—secoisolariciresinol (Seco), og matairesinol (Mat), pinoresinol (Pin), lariciresinol (Lar) (17), medioresinol (Med), and syringaresinol (Syr) (32)—account for 77% of the plant lignans in rye, they account for only 35% of the lignans in normal wheat (Table III).

Avenanthramides

Oats are the only cereal source containing avenanthramides. They have gained interest due to their antioxidantic capacity (5) and their potential role in the prevention of inflammation of arteries, the development of atherosclerosis (13), and the inhibition of colonic cancer cell proliferation (25). The antipathogenic avenanthramides are substituted N-cinnamoylanthranilate alkaloids with anthranilic and hydroxyanthranilic acid linked to hydroxycinnamic acids. They are found in both hulls and groats (6), and the contents vary depending on the cultivar and environmental conditions. Oat fractions obtained by pearling indicate that the avenanthramides are concentrated in the aleurone layer (8), but concentrations that are twice as high have been reported in oat flakes when compared to oat bran (24).

Alkylresorcinols

Alkylresorcinols (ARs) are 1,3-dihydroxybenzen derivatives that are specific for certain cereals. ARs have antioxidative properties and possibly anticancer and antimicrobial effects (33). ARs are found in higher amounts in rye (260–3,200 µg/g of DM) than wheat/durum (310–1,080 µg/g of DM) and not at all in oats and rice. ARs are exclusively found in pericarp/testa and the aleurone layer. Fractionation of rye has shown almost double the concentration in the pericarp/testa fraction and four times as much in the aleurone fraction compared with whole grain rye. The ARs have different chain lengths with an uneven number of carbon atoms. The distributions of the homologous ARs differ among cereal species. Therefore, ARs have been suggested to be used as a marker of whole grain rye and wheat intake.

Table III. Content of lignans in whole grain flour and bran determined as the sum of matairesinol (Mat), secoisolariciresinol (Seco), pinoresinol (Pin), syringaresinol (Syr), lariciresinol (Lar), and medioresinol (Med) or all detected lignans according to Smeds et al. c

<table>
<thead>
<tr>
<th>Whole Grain Flour</th>
<th>Bran</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sum of Seco, Mat, Lar, Pin, Med, and Syr (µg/g)</strong></td>
<td><strong>Sum of Seco, Mat, Lar, Pin, Med, and Syr (µg/g)</strong></td>
</tr>
<tr>
<td>Rye</td>
<td>1891</td>
</tr>
<tr>
<td>Wheat</td>
<td>507</td>
</tr>
<tr>
<td>Spelt wheat</td>
<td>859</td>
</tr>
<tr>
<td></td>
<td>8,639</td>
</tr>
<tr>
<td>Triticale</td>
<td>2649&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Oats</td>
<td>2183&lt;sup&gt;v&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

| Contributions of Seco, Mat, Lar, Pin, Med, and Syr to all lignans (%) | 11,177 | 77 |
|---------------------------|------------------|
| All lignans<sup>c</sup> (µg/g) | 9,207 | 35 |
| Spelt | 3,220 | 82 |
| Triticale | 4,077 | 54 |
| Oats | 3,487 | 65 |

<sup>a</sup>Penalvo et al. (32).
<sup>b</sup>Kamal-Eldin et al. (21).
<sup>c</sup>Smeds et al. (36).
components may vary a great deal. Fur-
thermore, oats and rye contain bioactive
substances that are either unique (as a-
venanthramides in oats) or present in much
higher levels (such as lignans in rye) than
in wheat. Refining methods and emerging
technologies constantly leads to the dis-
covery of new components. To what extent
these newly discovered substances make
significant contributions to the health ef-
effects of these cereal sources is still far
from fully elucidated.

Other Phenolic Compounds

Overall, the bran fraction of cereals has a high content of antioxidative compounds that are primarily concentrated in the aleu-
rode layer of the grain. Benzoic acid de-
rivatives (p-hydroxybenzoic, gallic, and
syringic acid) and cinnamic acid deriva-
tives (ferulic, coumaric, and sinapic acid)
as well as flavonoids are located here, but
the content and composition of the pheno-
lcs in the outer cell layers of the kernel are
highly different (28). The biological im-
pact is not fully understood, but ap-
ppears to be associated with the antioxidative capacity, which has shown to
correlate highly with the content of pheno-
lc compounds. In a study of the antioxidative
effect of different rye fractions, extracts of rye bran had a higher activity than
whole grain rye and rye flour (1). This
supports information from wheat, where there is a progressive decrease in
phenolic content toward the inner parts of
the kernel and a very strong relationship
between the total phenolic content and antioxidative capacity (3). There are, how-
ever, conflicting reports on this issue. An-
other study has demonstrated that although
bran had higher contents of hydroxyl-cin-
namates, the oxidative capacity was lower
than other cereal fractions due to a low
solubility of the phenolics (10). In line
with this, it has been shown that the anti-
oxidative activity of extracts from oat
hulls was lower than in the grains in spite
of similar or higher total content of pheno-
lcs in the hulls.

Conclusions

Along with dietary fiber, the majority of vitamins, minerals, a range of sterols, phe-
nolics, and other bioactive substances are
found in the germ, bran fraction, and out-
nermost layer of the endosperm. Conse-
quently, the content of all these
cospassengers are significantly reduced in
flour with a low extraction rate when com-
pared to whole grain flour. Hence, milling
and separating bran from inner endosperm
not only reduces the amount of fiber that is
known to beneficially affect health, but als
a range of important nutrients and bioactive substances that may have poten-
tial health benefits. This is universal for all
cereals, but since separation during mill-
ing differs for the individual cereals, and
inherent content of bioactive substances
differ between species, the level of these
minor but potential health-promoting
components may vary a great deal. Fur-
thermore, oats and rye contain bioactive

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