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Session: Health effects of whole grains

Process-induced changes on bioactive compounds in whole grain rye

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Manufacturing of healthy wholegrain foods demands knowledge of process-induced changes in macro-, micro- and non-nutrients. The high content of dietary fibre is a challenge in relation to good product texture and sensory quality. The stability and bioavailability of bioactive compounds have a marked influence on the health effects of cereal foods. It was confirmed that sterols, folates, tocopherols and tocotrienols, alkylresorcinols, lignans, phenolic acids and total phenolics are concentrated in the bran layers of the rye grain, and are only present at low levels in the flour endosperm. The levels of folate and easily-extractable phenolic compounds increase in germination and sourdough baking, but there are negligible changes in the levels of sterols, lignans and alk(en)ylresorcinols. The levels of tocopherols and tocotrienols are reduced during the sourdough fermentation. In conclusion, many of the bioactive compounds in wholegrain rye are stable during food processing, and their levels can even be increased with suitable processing.

Whole grains: Rye: Food processing: Dietary fibre

Intake of wholegrain foods is increasingly reported to be associated with health benefits, including improved regulation of blood glucose levels and decreased risk of diabetes, cardiovascular disease and certain cancers (Jacobs *et al.* 1998*a,b*; Liu *et al.* 2000, Pereira *et al.* 2002). In addition to dietary fibre, grains contain a wide range of nutrients and bioactive compounds, which have been suggested to contribute to the positive health effects. These phytochemicals, such as lignans, phenolic acids, phytosterols, tocotrienols and other vitamins, are concentrated in the germ and in the outer layers of the kernel (Hegedüs *et al.* 1985; Nilsson *et al.* 1997*a*; Glitsø & Bach Knudsen, 1999).

Dietary guidelines recommend increasing the intake of wholegrain cereals, but there is a gap between recommendations and consumption (Adams & Engström, 2000). Despite

the growing consumer interest in health aspects of food, good sensory properties remain a key priority among consumer choice criteria. Processing is a prerequisite for consumption of whole grains. Processing must first turn the food into a suitable form and give it good sensory properties. With whole grains much work remains to be done in this area, as traditions for whole-grain consumption are limited on a global scale. Processing is also important in terms of both the content and bioavailability of nutrients and non-nutrients (Clydesdale, 1994). Whereas processing may increase the bioavailability of bioactive compounds in grains, a reduction in processing increases their levels, (for review, see Slavin *et al.* 2000). Processing may also be used to modify the bioavailability of carbohydrates, such as delaying the glycaemic responses (Holm *et al.* 1989; Björk *et al.* 1994) or enhancing

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the solubility and fermentability of dietary fibre components (Camire & Flint, 1991; Beer *et al.* 1997; Poutanen, 2001).

Milling and baking are the most common processes in grain processing for human food. If the extraction rate is approximately 100 %, wholemeal flour is obtained. With decreasing extraction rates in milling more and more of the outer grain layers are removed, accompanied by losses in dietary fibre and associated compounds (Hegedüs *et al.* 1985; Nilsson *et al.* 1997a; Glitsø & Bach Knudsen, 1999). During sourdough baking particularly, many biochemical changes occur which affect bread texture. Levels of phytate (Frölich *et al.* 1986; Larsson & Sandberg, 1991), alkyl-resorcinols (Verdeal & Lorenz, 1977) and tocopherols (Piironen *et al.* 1987) have been reported to decrease during the sourdough baking process, whereas levels of lignans show no marked change (Nilsson *et al.* 1997b).

Other important grain-processing methods include flaking, malting, extrusion and puffing. Process variables that also influence product bioactivity include the presence of enzymes (endogenous or added), the use of starter cultures, the amount of water and the amounts of thermal and mechanical energy used (Table 1). Literature about the influence of grain processing on levels of bioactive compounds is scarce. The aim of the present work was to study the effect of milling fractionation, sourdough fermentation and germination on the levels of bioactive compounds in rye. Rye is an important source of whole grain in the Nordic diet, because its traditional uses as various soft and crisp breads are based on wholemeal flour.

Materials and methods

Rye grains

Two rye cultivars, small-grained Akusti, and large-grained Amilo, harvested in summer 2000 in Finland were used in the present study. Akusti was used in sourdough baking and germination, and Amilo was used in milling fractionation.

Milling fractionation

Grains were milled at a moisture level of 16.5 % with a roller mill (Bühler MLU 202; Bühler, Uzwil, Switzerland) to give four streams: bran; shorts; C flour; B flour. Fraction B was the milling fraction from brake rolls and fraction C the milling fraction from reduction rolls. Part of the bran fraction was further cleaned by roller milling.

Table 1. Methods and important variables in the processing of wholegrain foods

Processing methods	Major variables
Milling	Heat
Flaking	Water content and distribution
Soaking	Shear
Malting	Enzyme activity (endo- and exogenous)
Extruding	Micro-organisms (natural and starter cultures)
Puffing	Presence of cell wall and aleurone particles
Fermenting	and large amount of cell-wall components (dietary fibre)
Baking	Presence of secondary metabolites

Sourdough baking

Rye sourdough was prepared by mixing 3036 g wholemeal rye flour and 5058 g water with baker's yeast (4 g/kg dough), with *Lactobacillus brevis* (4 g/kg dough), and with *Lactobacillus plantarum* (4 g/kg dough; Horsholmen CHR. Hansen a/s, Copenhagen, Denmark). Sourdough was fermented for 22 h at 30°C to obtain a pH value of 3.9 and total titratable acidity value of 15.2 (typical acidity values for industrial sourdough). After fermentation, sourdough (3217 g) was mixed with 3960 g wholemeal rye flour and 1980 g water with baker's yeast (9 g/kg dough), and with table salt (6 g/kg dough). After a floor time of 45 min at 28°C, the dough was divided into 600 g pieces that were moulded by hand and panned before proofing for 75 min at 35°C (relative humidity 70 %). Loaves were baked at 220–240°C for 40 min.

Germination

Germination was performed in commercial malting equipment (Joe White Malting Systems, Melbourne, Australia) at 5, 10 or 25°C. The grains were steeped for 8 h and allowed to stand in air for 16 h, and steeped a second time for 6 h. The samples were then germinated at a grain moisture content of approximately 42–46 %. The total germination time (including steeping) was 6 d. Samples were taken after 1, 2, 4, and 6 d. The samples were frozen and subsequently lyophilized.

Analysis of bioactive compounds

Sterols. Sterols were determined after acid and alkaline hydrolysis by GC (Piironen *et al.* 2002).

Folates. Folates were determined by a microbiological assay method including extraction and trienzyme treatment as described by Kariluoto *et al.* (2001).

Tocopherols and tocotrienols. Tocopherols and tocotrienols were determined after saponification by HPLC (M Rynänen, AM Lampi, P Salo-Väänänen and V Piironen, unpublished results).

Alk(en)ylresorcinols. Alk(en)ylresorcinols were determined after methanol extraction by HPLC (Hertog *et al.* 1992; Mullin *et al.* 1992).

Phenolic acids. Phenolic acids were determined as non-esterified, esterified, glycosylated and insoluble-bound fractions by HPLC (Hertog *et al.* 1992; Hatcher & Kruger, 1997).

Lignans. Lignans were determined by GC-MS. Samples were pre-treated using a modification of the original lignan method of Mazur *et al.* (1996). A new lignan method will be described in detail in a forthcoming methodological paper (T Nurmi, S-M Heinonen and H Adlercreutz, unpublished results).

Total phenolics and 1,1-diphenyl-2-picryl hydratsyl radical-scavenging activity. Methanolic extracts of freeze-dried and ground rye samples were obtained using an ultrasonication-assisted extraction procedure. The residue was further extracted in alkaline conditions. The content of total phenolic compounds (gallic acid equivalents) in methanolic and alkaline extracts was determined using the

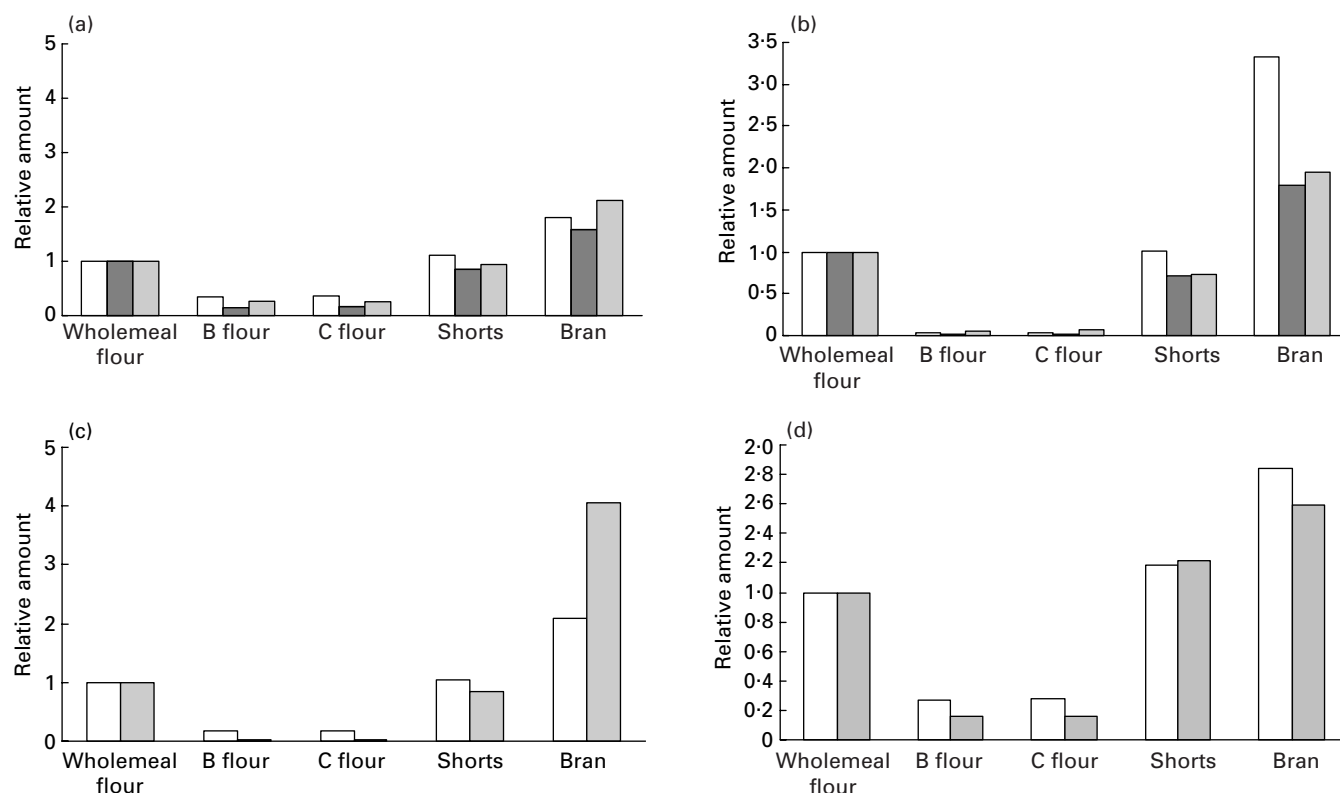


Fig. 1. Distribution of bioactive compounds in milling fractions of rye: (a) sterols (□), folates (■) and tocopherols and tocotrienols (▨); (b) alk(en)ylresorcinols (□), lignans (■) and phenolic acids (▨); (c) phenolic compounds after methanol extraction (□) and after alkaline extraction (▨); (d) 1,1-diphenyl-2-picrylhydratyl radical-scavenging activity after methanol extraction (□) and after alkaline extraction (▨). B flour, milling fraction from brake rolls; C flour, milling fraction from reduction rolls. For details of milling and analytical procedures, see p. 118.

Folin–Ciocalteu procedure (Singleton & Rossi, 1965). The assessment of the radical-scavenging activity of the samples was based on spectrophotometric detection of the absorbance at 517 nm caused by 1,1-diphenyl-2-picrylhydratyl radicals, which was decreased or inhibited by antioxidants capable of radical scavenging in the system. This assay was performed using a modification of the method of Goupy *et al.* (1999).

Results and discussion

Milling fractionation

In the milling of rye the yields of bran, shorts, C flour and B flour were 48, 16, 16 and 19 % respectively. Part of the bran fraction was further cleaned with a roller mill to give two bran fractions comprising 30 and 19 % of the original rye grains. The outer bran fraction contained 3.3–4.0 times more alk(en)ylresorcinols and alkaline-extractable total phenolics and 1.6–2.1 times more sterols, folates, tocopherols and tocotrienols, lignans, phenolic acids and easily-extractable (methanol-extractable) total phenolics than wholemeal rye flour (Fig. 1 (a, b, c)). Previous studies have already established the concentrations of bioactive compounds in the outer layers of rye grain (Verdeal & Lorenz, 1977; Otlés *et al.* 1996; Nilsson *et al.* 1997a; Andreasen *et al.* 2000; Lampi *et al.* 2002; Piironen *et al.* 2002).

In the shorts fraction, the relative amounts of bioactive compounds were very similar to those of the original

wholemeal rye flour. In the inner flour fractions (B and C) little or none of these compounds were present. The milling fractions of rye also exhibited varying amounts of antioxidant activity, i.e. radical-scavenging activity (Fig. 1 (d)). Bran showed the highest radical-scavenging activity, as also reported by Gray *et al.* (2000) for oats, whereas flours obtained from the inner parts of the grains exhibited the weakest activity. With the shorts fraction the same radical-scavenging activity was obtained as in wholemeal flour.

The results demonstrate that in addition to dietary fibre, most of the bioactive compounds suggested to play a role in the health benefits are concentrated in the outer layers of the grain, indicating the importance for utilizing the whole grain for human consumption.

Germination

During the 6 d germination of rye at 5, 10 or 25°C, the relative amounts of folates and easily-extractable phenolic compounds increased, whereas only very small changes were detected in the amounts of sterols, tocopherols and tocotrienols, alk(en)ylresorcinols, lignans and alkaline-extractable phenolic compounds (Fig. 2). The highest increase in the amounts of folates (Fig. 2 (a)) and easily-extractable phenolic compounds (Fig. 2 (c)) was observed at the germination temperature of 25°C. Despite the increase in the amount of extractable phenolic compounds, the anti-

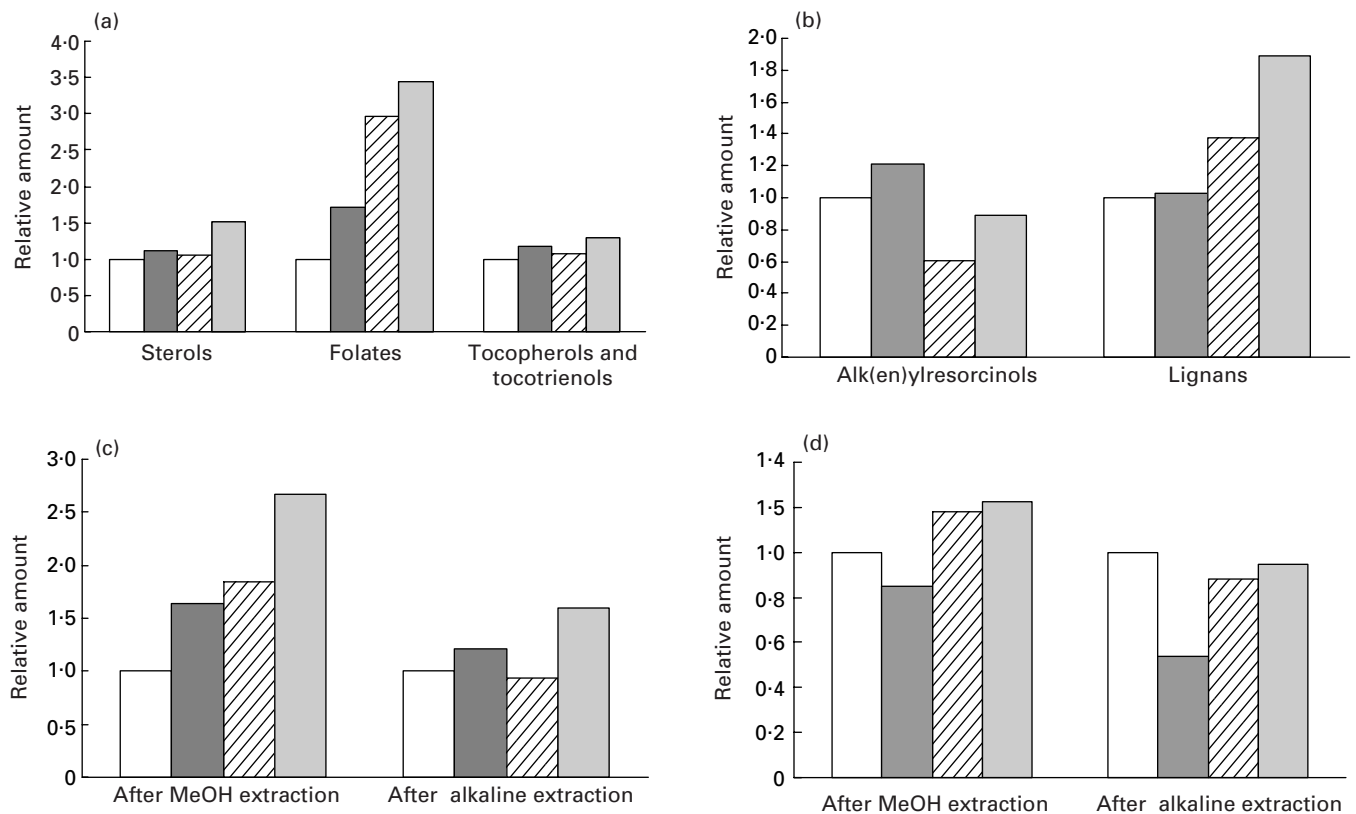


Fig. 2. Effects of 6 d germination of rye on levels of bioactive compounds: (a) sterols, folates and tocopherols and tocotrienols; (b) alk(en)ylresorcinols and lignans; (c) phenolic compounds after methanol (MeOH) extraction and after alkaline extraction; (d) 1,1-diphenyl-2-picrylhydrazyl radical-scavenging activity after MeOH extraction and after alkaline extraction. (□), Native grains; (■), germination at 15°C; (▨), germination at 25°C. For details of germination and analytical procedures, see p. 118.

oxidant activity of germinated rye grains remained very similar to that of the original ungerminated rye grains.

These results indicate that the bioactivity of rye can be increased by germination. In the studies of Walker *et al.* (2002) the folic acid content of green malt was higher than that of the corresponding unmalted barley, but it decreased during kilning. However, the folic acid concentration of kilned malt was still greater than that of unmalted barley. It has also been shown that the amount of phytate can be reduced by germination (Larsson & Sandberg, 1992, 1995). Germination is also an effective pre-treatment for whole grains to produce improved texture and change of flavour, as previously shown for oats (Heiniö *et al.* 2001; RL Heiniö, T Nikkola, K Latva-Kala, A Wilhelmson, K Katina, O Myllymäki, KH Liukkonen and K Poutanen, unpublished results). The major application of germination so far has been in the malting of barley for beer production. However, germination and hydrothermal treatments may also provide attractive processing methods for the production of new healthy and tasty wholegrain foods (Fredlund *et al.* 1997; Wilhelmson *et al.* 2001).

Sourdough baking

The sourdough baking process of rye included: (1) preparation of sourdough by mixing wholemeal rye flour, yeast

and *Lactobacillus* cultures and by fermenting for 22 h at 30°C; (2) addition of 'fresh' wholemeal rye flour; (3) proofing; (4) baking of the breads. The fermentation phase more than doubled the levels of folates and easily-extractable phenolic compounds, but the addition of 'fresh' unfermented wholemeal flour slightly diluted the effect (Fig. 3 (a, b, c)). The levels of tocopherols and tocotrienols decreased during the sourdough fermentation (Fig. 3 (a)), probably due to oxidation (Piironen *et al.* 1988), while the amounts of sterols, alk(en)ylresorcinols, lignans, phenolic acids and alkaline-extractable phenolic compounds changed very little (Fig. 3 (a, b, c)). The fermentation stage also increased the antioxidant activity (1,1-diphenyl-2-picrylhydrazyl radical-scavenging activity) in the methanol-extracted fraction (Fig. 3 (d)), probably due to increased levels of easily-extractable phenolic compounds. Losses of folates, tocopherols and tocotrienols during the baking stage at 220–240°C were surprisingly low.

After baking the amounts of all analysed bioactive compounds of the bread, except those of tocopherols and tocotrienols, were at the same or slightly higher than those of the wholemeal flour (Fig. 3 (a, b, c)). Antioxidant activity (radical-scavenging activity) of the bread was also very similar to that of the wholemeal flour (Fig. 3 (d)). However, the positive effects of the fermentation stage on the bioactivity of rye were mostly lost by 'fresh' flour addition.

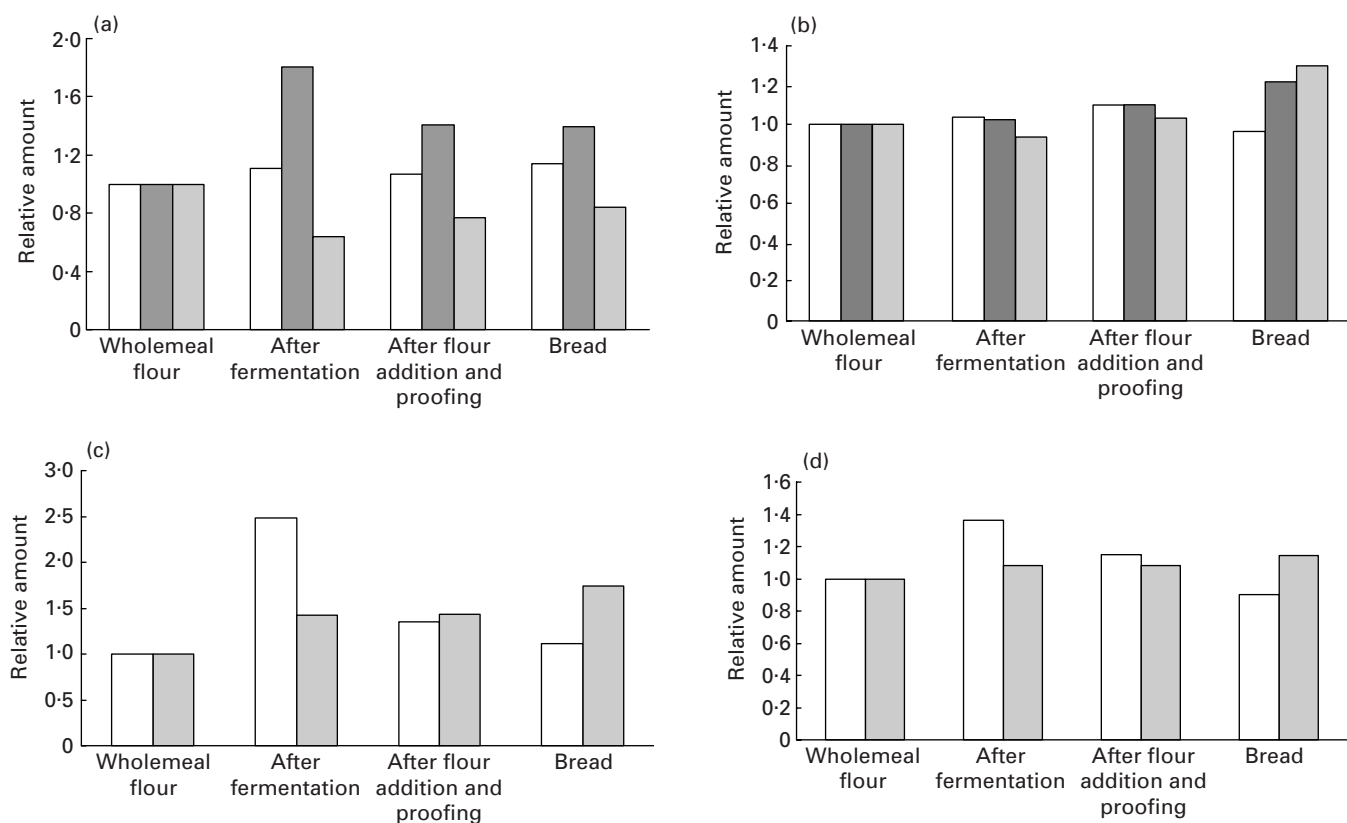


Fig. 3. Effects of sourdough baking of rye on levels of bioactive compounds: (a) sterols (□), folates (■) and tocopherols and tocotrienols (▨); (b) alk(en)ylresorcinols (□), lignans (■) and phenolic acids (▨); (c) phenolic compounds after methanol extraction (□) and after alkaline extraction (■); (d) 1,1-diphenyl-2-picrylhydratsyl radical-scavenging activity after methanol extraction (□) and after alkaline extraction (■). For details of baking and analytical procedures, see p. 118.

Conclusions

The profile and concentrations of bioactive compounds in rye can be modulated by milling fractionation, germination and sourdough baking. The use of milling fractionation concentrated the amounts of all the bioactive compounds studied in certain fractions. Germination and sourdough baking increased the amounts of folates and easily-extractable phenolic compounds in wholegrain rye. The amounts of other bioactive compounds, except those of tocopherols and tocotrienols, remained almost unchanged or slightly increased during germination and sourdough baking.

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References

Adams JF & Engström A (2000) A. Dietary intake of whole grain vs. recommendations. *Cereal Foods World* **45**, 75–78.

- Andreasen MF, Christensen LP, Meyer AS & Hansen Å (2000) Ferulic acid dehydromers in rye (*Secale cereale* L.). *Journal of Cereal Science* **31**, 303–307.
- Beer MU, Wood PJ, Weisz J & Fillion N (1997) Effect of cooking and storage on the amount and molecular weight of (1–3)(1–4)-β-D-glucan extracted from oat products by an in vitro digestion system. *Cereal Chemistry* **74**, 705–709.
- Björk I, Granfeldt Y, Liljeberg H, Tovar J & Asp N-G (1994) Food properties affecting the digestion and absorption of carbohydrates. *American Journal of Clinical Nutrition* **59**, Suppl., 699S–705S.
- Camire ME & Flint SI (1991) Thermal processing effects on dietary fibre composition and hydration capacity in corn meal, oat meal, and potato peels. *Cereal Chemistry* **68**, 645–647.
- Clydesdale FM (1994) Optimizing the diet with whole grains. *Critical Reviews in Food Science and Nutrition* **34**, 453–471.
- Fredlund K, Asp NG, Larsson M, Marklinder I & Sandberg AS (1997) Phytate reduction in whole grains of wheat, rye, barley and oats after hydrothermal treatment. *Journal of Cereal Science* **25**, 83–91.
- Frölich W, Drakenberg T & Asp N-G (1986) Enzymic degradation of phytate (myo-inositol hexaphosphate) in whole grain flour suspension and dough. A comparison between ³¹P NMR spectroscopy and ferric ion method. *Journal of Cereal Science* **4**, 325–334.
- Glitsø LV & Bach Knudsen KE (1999) Milling of whole grain rye to obtain fractions with different dietary fibre characteristics. *Journal of Cereal Science* **29**, 89–97.
- Goupy P, Hugues M, Boivin P & Amiot MJ (1999) Antioxidant composition and activity of barley (*Hordeum vulgare*) and malt

- extracts, and of isolated phenolic compounds. *Journal of the Science of Food and Agriculture* **79**, 1625–1634.
- Gray DA, Auerbach RH, Hill S, Wang R, Campbell GM, Webb C & South JB (2000) Enrichment of oat antioxidant activity by dry milling and sieving. *Journal of Cereal Science* **32**, 89–98.
- Hatcher DW & Kruger JE (1997) Simple phenolic acids in flours prepared from Canadian wheat: Relationship to ash content, colors, and polyphenolic oxidase activity. *Cereal Chemistry* **74**, 337–343.
- Hegedüs H, Pedersen B & Eggum BO (1985) The influence of milling on the nutritive value of flour from cereal grains. 7. Vitamins and tryptophan. *Quality of Plant Foods in Human Nutrition* **35**, 175–180.
- Heiniö RL, Oksman-Caldentey KM, Latva-Kala K, Lehtinen P & Poutanen K (2001) Effect of drying treatment conditions on the sensory profile of germinated oat. *Cereal Chemistry* **6**, 707–714.
- Hertog M, Hollman P & Venema D (1992) Optimization of quantitative HPLC determination of potentially anticarcinogenic flavonoids in vegetables and fruits. *Journal of Agricultural and Food Chemistry* **40**, 1591–1598.
- Holm J, Hagander B, Björk I, Eliasson A-C & Lundquist I (1989) The effect of various thermal processes on the glycemic response to whole grain wheat products in humans and in rats. *Journal of Nutrition* **119**, 1631–1638.
- Kariluoto SM, Vahteristo LT & Piironen V (2001) Applicability of microbiological assay and affinity chromatography purification followed by high-performance liquid chromatography (HPLC) in studying folate contents in rye. *Journal of the Science of Food and Agriculture* **81**, 938–942.
- Jacobs DR, Marquardt L, Slavin J & Kushi LH (1998a) Whole-grain intake and cancer: an expanded review and meta-analysis. *Nutrition and Cancer* **30**, 85–96.
- Jacobs DR, Meyer KA, Kushi LH & Folsom AR (1998b) Whole-grain intake may reduce the risk of ischemic heart disease death in post-menopausal women: the Iowa Women's Health Study. *American Journal of Clinical Nutrition* **68**, 248–257.
- Lampi AM, Kamal-Eldin A & Piironen V (2002) Tocopherols and tocotrienols from oil and cereal grains. In *Functional Foods. Biochemical and Processing Aspects*, vol. 2, pp. 1–38 [J Shi, G Mazza and M Le Maguer, editors]. Boca Raton, FL: CRC Press.
- Larsson M & Sandberg AS (1991) Phytate reduction in bread containing oat flour, oat bran or rye bran. *Journal of Cereal Science* **14**, 141–149.
- Larsson M & Sandberg AS (1992) Phytate reduction in oats during malting. *Journal of Food Science* **57**, 994–997.
- Larsson M & Sandberg AS (1995) Malting of oats in pilot plant process. Effects of heat treatment, storage and soaking conditions on phytate reduction. *Journal of Cereal Science* **21**, 87–95.
- Liu S, Manson JA, Stampfer M, Hu F, Giovannucci E, Colditz G, Hennekens C & Willett W (2000) A prospective study of whole-grain intake and risk of type 2 diabetes mellitus in US women. *American Journal of Public Health* **90**, 1409–1415.
- Mazur W, Fotsis T, Wähälä K, Ojala S, Salakka A & Adlercreutz H (1996) Isotope dilution gas chromatographic–mass spectrometric method for the determination of isoflavonoids, coumesterol, and lignans in food samples. *Analytical Biochemistry* **233**, 169–180.
- Mullin WJ, Wolynetz MS & Emery JP (1992) A comparison of methods for the extraction and quantitation of alk(en)ylresorcinols. *Journal of Food Composition and Analysis* **5**, 216–223.
- Nilsson M, Åman P, Härkönen H, Bach Knudsen KE, Mazur W & Adlercreutz H (1997a) Content of nutrients and lignans in roller milled fractions of rye. *Journal of the Science of Food and Agriculture* **73**, 143–148.
- Nilsson M, Åman P, Härkönen H, Hallmans G, Bach Knudsen KE, Mazur W & Adlercreutz H (1997b) Nutrient and lignan content, dough properties and baking performance of rye samples used in Scandinavia. *Acta Agriculturae Scandinavica* **47B**, 26–34.
- Otles S, Kose E, Fenwick GR, Hedley C, Richards RL & Khokhar S (1996) The influence of milling on the nutritive value of flour from rye – 1. Vitamins. In *Agri-food Quality: An Interdisciplinary Approach. Special Publication* no. 179, pp. 314–317 [GR Fenwick, C Hedley, RL Richards and S Khokhar, editors]. Cambridge: Royal Society of Chemistry.
- Pereira MA, Jacobs DR, Pins JJ, Raatz SK, Gross MD, Slavin JL & Sequist ER (2002) Effect of whole grains on insulin sensitivity in overweight hyperinsulinemic adults. *American Journal of Clinical Nutrition* **75**, 848–855.
- Piironen V, Toivo J & Lampi A-M (2002) Plant sterols in cereals and cereal products. *Cereal Chemistry* **79**, 148–154.
- Piironen V, Varo P & Koivistoinen P (1987) Stability of tocopherols and tocotrienols in food preparation procedures. *Journal of Food Composition Analysis* **1**, 53–58.
- Piironen V, Varo P & Koivistoinen P (1988) Stability of tocopherols and tocotrienols during storage of foods. *Journal of Food Composition Analysis* **1**, 124–129.
- Poutanen K (2001) Effect of processing on the properties of dietary fibre. In *Advanced Dietary Fibres*, part B, pp. 262–267 [B McCleary, editor]. London: Blackwell Science.
- Singleton VL & Rossi JA (1965) Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* **16**, 144–158.
- Slavin JL, Jacobs D & Marquardt L (2000) Grain processing and nutrition. *Critical Reviews in Food Science and Nutrition* **40**, 309–326.
- Verdeal K & Lorenz K (1977) Alkylresorcinols in wheat, rye and triticale. *Cereal Chemistry* **54**, 475–483.
- Walker CJ, Amblar S & Patel D (2002) Effects of the brewing process on the folic acid (vitamin B9) content in beer. *Brauwelt* **142**, 350, 352, 354.
- Wilhelmson A, Oksman-Caldentey KM, Laitila A, Suortti T, Kaukoviirta-Norja A & Poutanen K (2001) Development of a germination process for producing high β -glucan, whole grain food ingredients from oat. *Cereal Chemistry* **78**, 715–720.