

Intake of alkylresorcinols from wheat and rye in the United Kingdom and Sweden

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(Received 19 November 2004 – Revised 7 April 2005 – Accepted 21 April 2005)

Alkylresorcinols, phenolic lipids present in high amounts in whole-grain wheat and rye but not present in appreciable amounts in other foods, are candidates as biomarkers of whole-grain intake from these cereals. We estimated the intake of alkylresorcinols in Sweden and the UK using two different methods: food supply data (FSD); food consumption data (FCD; based on individual and household survey data). The average *per capita* intake of alkylresorcinols in Sweden was 17.5 mg/d (FSD) and 22.9 (SD 16.6) mg/d (FCD), while in the UK it was 11.9 mg/d (FSD) and 11.8 (SD 18.62) mg/d (FCD). Ninety-six per cent of all Swedes consumed some alkylresorcinols, compared with 50% of British people surveyed. Both women and men over the age of 40 years had a higher alkylresorcinol intake than younger people. The average results from the two methods were similar, but the FCD data provided more detail about the range of alkylresorcinol intake, and indicate that because the intake of alkylresorcinols varies so widely, they may be good markers of diets rich or poor in whole-grain wheat/rye products.

Alkylresorcinol: Whole grains: Food supply: Dietary intake: Sweden: United Kingdom

Consumption of whole-grain cereals has been linked to many health effects, including a reduction in the risk of CHD, diabetes, obesity and some cancers (Slavin, 2004). However, this evidence is based largely on results from epidemiological studies, where the uncertainties in diet estimation using food frequency questionnaires (Bingham *et al.* 2003) are compounded by the difficulties that consumers have in identifying whole-grain foods (Slavin *et al.* 2001) and the different definitions of whole-grain foods used by different researchers (e.g. 25% whole grains by weight used in many epidemiological studies *v.* 51% whole grains by weight as defined by the US Food and Drug Administration; Kantor *et al.* 2001; Smith *et al.* 2003). The uncertainty surrounding actual whole-grain cereal intakes could be improved by the use of a biomarker of whole-grain cereal intake. A biomarker of whole-grain cereal intake would allow non-subjective estimation of whole-grain cereal intake. This, in combination with self-reported intake data, could strengthen the evidence for the health benefits of whole-grain cereals by removing those subjects who may have incorrectly reported their intake of whole-grain cereals. Alkylresorcinols have been proposed to be biomarkers of whole-grain wheat and rye intake (Ross *et al.* 2004a; Linko *et al.* 2005).

Alkylresorcinols are phenolic lipids present in high amounts in the outer layers of wheat and rye, but are not present in the endosperm or germ of these cereals, nor in significant amounts in other plant foods (Ross *et al.* 2003c, 2004a). Alkylresorcinols may have some bioactive effects (Kozubek & Tyman, 1999; Ross *et al.*

2004a) and do not appear to be harmful in animal models (Ross *et al.* 2004a,c). They are absorbed by rats, pigs and man (Ross *et al.* 2003a,c), and can be detected in intact form in human plasma (Linko *et al.* 2002) and erythrocytes (Linko & Adlercreutz, 2005) and in metabolised form in human urine (Ross *et al.* 2004b). Initial studies suggest that there is a good correlation between consumption of whole-grain rye bread and plasma and erythrocyte alkylresorcinol levels (Linko & Adlercreutz, 2005; Linko *et al.* 2005).

To date there are no data on the intake of alkylresorcinols in man. Such data would be useful to judge expected levels of alkylresorcinols in bodily fluids and estimate what is a 'normal' intake for human volunteers in any future bioactivity/biomarker studies. To estimate alkylresorcinol intake, in the present study we used food supply data (FSD) and food consumption data (FCD; based on both individual and household survey data) on the intake of whole-grain wheat and rye in the UK and Sweden. These two countries have different types of cereal intake, with the UK having a 'white' wheat bread culture, similar to the USA (Slavin, 2004), while Sweden has a 'dark' rye bread culture, akin to other Northern and Eastern European countries.

Methods

Alkylresorcinols are present in significant amounts in the bran of wheat and rye. They are also present in barley and triticale (Ross *et al.* 2003c), but these cereals represent a minute amount of the

Abbreviations: FCD, food consumption data; FSD, food supply data.

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total cereals consumed in the countries included in the present study. Thus data only for products containing wheat or rye bran, brown wheat flour, sifted rye flour, or whole-grain wheat or rye were included herein. Sifted (white) wheat flour does not contain alkylresorcinols (Ross *et al.* 2003c).

Calculation of alkylresorcinol intake

From food supply data. Wheat and rye milling data for the Nordic countries (Denmark, Finland, Norway and Sweden) for the year 1995, and wheat and rye milling data for the UK for the year 1999, were obtained from Nordic milling industry organisations and the National Association of British and Irish Millers (Anon., 2003), respectively. As milling data were available for the other Nordic countries, FSD on their alkylresorcinol intake are also presented, assuming that their wheat and rye has the same alkylresorcinol content as Sweden's. The majority of all wheat and rye milled in these countries is used for baking bread or making other cereal foods. The amount of rye milled each year in the UK is low (National Association of British and Irish Millers, personal communication), and so was not included in the calculations. Similarly, the amount of whole-grain wheat flour used for food in Denmark, Finland and Sweden is very low (I Börjesson, personal communication), and is excluded for these countries. Bran consumption was low in all countries studied, and not included in the intake calculations. The amounts of rye/wheat flour milled (sifted rye, whole-grain rye, brown wheat, whole-grain wheat) in a given year were converted to *per capita* amounts (kg/d).

The alkylresorcinol content of the flours was obtained by direct analysis using the GC method of Ross *et al.* (2001) and previously published data for cultivars of wheat and rye commonly used by the baking industry (Ross *et al.* 2001, 2003c; Chen *et al.* 2004). The averaged flour alkylresorcinol contents used for the calculations are the means of at least three different samples for each category, and were (all dry weights): sifted rye flour (Nordic countries), 0.141 mg/g; whole-grain rye flour (Nordic countries), 0.888 mg/g; whole-grain wheat flour (Nordic countries), 0.412 mg/g; brown wheat flour (UK), 0.378 mg/g; whole-grain wheat flour (UK), 0.945 mg/g. The average *per capita* intake of each type of flour was multiplied by the alkylresorcinol content to give the average *per capita* alkylresorcinol intake (mg/d).

From food consumption data. FCD for Sweden were from Riksmaten 1997–98 (Becker & Pearson, 2002) and for the UK, from the National Food Survey 1999 (Ministry of Agriculture, Fisheries and Food & Office for National Statistics, 2001). In the Riksmaten study, subjects recorded their food and drink consumption during 1 week using a pre-coded record book. In the case of the National Food Survey 1999, each household

recorded food acquired during 1 week. Data for 1 month (January) were used for the analysis. The Swedish survey involved 1215 subjects, while the UK survey involved 1381 subjects (584 households). Alkylresorcinol intake data from the Swedish dietary survey were also estimated for the different sexes and age groups. This was not possible for the UK dietary data, which were based on household intake rather than individual intake. Food categories that were likely to contain whole-grain wheat or rye were selected for analysis in the present study. The alkylresorcinol content for each category was determined using a basic 'recipe' representing the amount of whole-grain wheat or rye present and the previously published alkylresorcinol levels for wheat and rye cultivars commonly used for the food industry (Ross *et al.* 2001, 2003c; Chen *et al.* 2004). Alkylresorcinol concentrations used for the recipes were the mean of at least ten different local wheat or rye samples. This approach was used to account for the variability of alkylresorcinol content in wheat and rye grains, rather than using the more limited data available for individual products. Alkylresorcinol concentrations calculated in this manner were in general agreement with food products that had been analysed directly (Ross *et al.* 2003c; Chen *et al.* 2004).

Fresh weight amounts of foods reported in the surveys were corrected for the alkylresorcinol concentrations reported in dry weights using average values from many previous cereal and cereal product analyses (Department of Food Science, Swedish University of Agricultural Sciences, Sweden).

The alkylresorcinol concentrations (mg/g fresh weight) used for the different food categories are listed in Table 1. Two categories in the UK national food survey ('specialty bread' and 'muesli') included some products that may have contained alkylresorcinols, but the majority of products (e.g. bagels, croissants, oat muesli) included in these categories were made from cereals that do not contain alkylresorcinols. Because most foods in these groups did not contain alkylresorcinols, it was difficult to calculate an appropriate alkylresorcinol content without over-estimating alkylresorcinol intake, so they were not included in the present study.

FCD were statistically analysed using Minitab version 14.0 (Minitab Inc., State College, PA, USA) using one-way ANOVA with Tukey's pairwise comparisons, and analysis of covariance to test for the effect of sex, age and BMI. Results were considered significant if $P < 0.05$.

Results and discussion

Results for the average intake of alkylresorcinols in the UK, Sweden and the other Nordic countries are presented in Table 2.

Table 1. Alkylresorcinol concentrations used to calculate intake from food consumption data*

Sweden†	Alkylresorcinol concentration (mg/g fresh weight)	UK‡	Alkylresorcinol concentration (mg/g fresh weight)
Crispbread	0.62	Sliced brown bread	0.27
Soft whole-grain rye bread	0.35	Un sliced brown bread	0.27
Soft light rye bread	0.21	Sliced wholemeal bread	0.33
Thinbread	0.03	Un sliced wholemeal bread	0.33
Other breads	0.03	Crispbread	0.77
		High-fibre breakfast cereal	0.50

* Alkylresorcinol concentrations based on data from Ross *et al.* (2001, 2003c) and Chen *et al.* (2004).

† Riksmaten 1997–98 (Becker & Pearson, 2002).

‡ UK National Food Survey 1999 (Ministry of Agriculture, Fisheries and Food & Office for National Statistics, 2001).

Table 2. Average *per capita* intake of alkylresorcinols (mg/d) calculated from food supply data (FSD) and food consumption data (FCD)*
(Values are means and standard deviations)

	UK		Sweden		Norway	Finland	Denmark
	Mean	SD	Mean	SD			
FSD	11.9		17.5		18.5	39.8	37.1
FCD	11.8	18.6	22.9†	16.6	—	—	—

* For details of calculations, see p. 497.

† Mean intake was significantly different from the UK intake ($P < 0.0001$).

From the FSD, the UK had the lowest, Sweden and Norway had moderate, while Finland and Denmark had the highest intake of alkylresorcinols. The UK had less than one third of the alkylresorcinol intake of Finland and Denmark, emphasising the differences in bread-eating culture between the Nordic countries and the UK (Prättälä *et al.* 2001; Lang *et al.* 2003).

FCD for both Sweden and the UK gave similar average results to FSD (Table 2), even though FSD tend to overestimate actual consumption because factors such as wastage and changes due to food processing are not accounted for (Kantor *et al.* 2001). The amount of error introduced into this estimation may have been reduced by the fact that alkylresorcinols are present in only a limited number of foods, and are not destroyed by normal baking and extrusion processes (Ross *et al.* 2003c; Chen *et al.* 2004). Fig. 1 shows that, in spite of the similar mean intakes for Sweden and the UK, they were significantly different ($P < 0.0001$) and the pattern of consumption in Sweden and the UK differs markedly. Around 50% of all UK consumers surveyed ate no food categories that contained alkylresorcinols, while only 3% of the Swedes surveyed ate no alkylresorcinol-containing foods. Most people in Sweden and the

Table 3. *Per capita* intake of alkylresorcinols, calculated from food consumption data, in a Swedish population according to age and sex*

	Alkylresorcinol intake (mg/d)		<i>n</i>
	Mean	SD	
Males	26.4 ^b	19.9	585
Females	19.6 ^a	11.9	626
Males and females			
< 30 years	17.0 ^a	13.6	244
30–39 years	19.8 ^a	13.8	275
40–49 years	24.6 ^b	17.8	286
50–59 years	26.9 ^b	20.1	205
> 60 years	28.0 ^b	14.9	195
Males			
< 30 years	18.7 ^{ac}	16.0	122
30–39 years	22.8 ^{bc}	15.7	136
40–49 years	29.4 ^{de}	21.3	139
50–59 years	33.7 ^e	26.1	88
> 60 years	31.2 ^{de}	16.8	95
Females			
< 30 years	15.4 ^a	10.4	122
30–39 years	17.0 ^{ab}	10.9	140
40–49 years	20.1 ^{abc}	12.1	147
50–59 years	21.8 ^{bc}	12.0	117
> 60 years	25.0 ^{cd}	12.2	100

a,b,c,d,e Mean values with unlike superscript letters were significantly different ($P < 0.001$).

* For details of calculations, see p. 497.

UK consumed bread on a regular basis, but the differences in alkylresorcinol intake came from the fact that bread containing at least some whole-grain rye is commonly eaten by almost all consumers in Sweden, whereas white bread is most popular in the UK and wholemeal wheat bread is still mostly eaten by more elderly

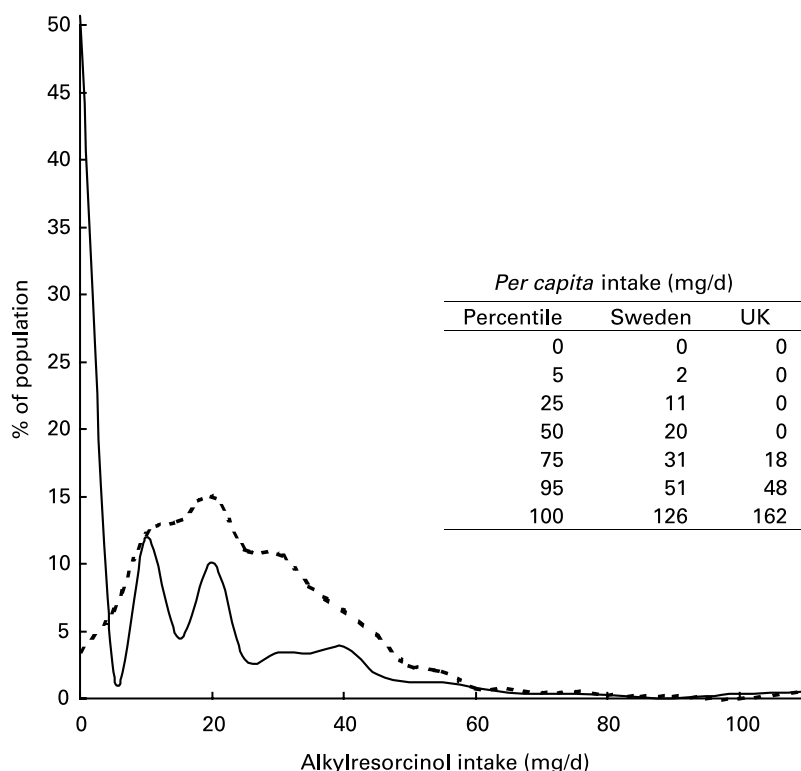


Fig. 1. *Per capita* intake of alkylresorcinols in Sweden (---) and the UK (—) estimated from food consumption data.

consumers (Lang *et al.* 2003). A similar trend is apparent in Sweden, where consumers over 40 years old had a significantly higher intake of alkylresorcinols than consumers under 40 years old ($P < 0.001$; Table 3). This was evident for both sexes, although men had a consistently higher intake of alkylresorcinols than women in the same age group. The difference between men and women may be due to the greater total energy intake by men, although energy intake decreased with age in this study (Becker & Pearson, 2002). Differences in BMI were not associated with alkylresorcinol intake. Whether this difference in consumption of alkylresorcinols (and therefore of whole-grain rye in this case) is due to age (older people change their diet to contain more whole-grain cereals), or a general change in dietary habits from a more traditional Swedish diet high in whole-grain rye to a more cosmopolitan diet, is not clear. As a similar trend is seen in the UK (Lang *et al.* 2003), this is of concern for those wishing to increase consumption of whole-grain foods to improve public health.

Because a number of categories that may have included alkylresorcinol-containing foods were not analysed due to the 'broadness' of these categories, it is probable that there was an underestimation of the number of people consuming alkylresorcinols and the amount of alkylresorcinols consumed. FSD estimations normally overestimate intake compared with FCD, as they do not take into account losses due to wastage and non-food uses. However, in the present study, FCD average values were higher than FSD values. A possible explanation could be that the recipes for the various products in each food category varied widely, along with the level of alkylresorcinols in the raw wheat and rye grains, which can differ by up to 40% for the same cultivar grown at different locations (Ross *et al.* 2001; Chen *et al.* 2004) and much more between different cultivars. While these sources of variation may have had some impact on the final results, they are unlikely to have greatly changed the overall range of alkylresorcinol intake estimated here.

In conclusion, the present study demonstrates that there are differences in alkylresorcinol intake both within populations and between countries. Because of these large differences in intake, it should be possible to use alkylresorcinols/alkylresorcinol metabolites measured in biological samples to estimate whether a person is a non-consumer, occasional consumer or regular consumer of whole-grain wheat and/or rye products.

Acknowledgement

The authors thank Carl-Erik Albertsson for the Nordic milling data.

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