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Oxalate Content of Cereals and Cereal Products

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Detailed knowledge of food oxalate content is of essential importance for dietary treatment of recurrent calcium oxalate urolithiasis. Dietary oxalate can contribute considerably to the amount of urinary oxalate excretion. Because cereal foods play an important role in daily nutrition, the soluble and total oxalate contents of various types of cereal grains, milling products, bread, pastries, and pasta were analyzed using an HPLC-enzyme-reactor method. A high total oxalate content (>50 mg/100 g) was found in whole grain wheat species *Triticum durum* (76.6 mg/100 g), *Triticum sativum* (71.2 mg/100 g), and *Triticum aestivum* (53.3 mg/100 g). Total oxalate content was comparably high in whole grain products of *T. aestivum*, that is, wheat flakes and flour, as well as in whole grain products of *T. durum*, that is, couscous, bulgur, and pasta. The highest oxalate content was demonstrated for wheat bran (457.4 mg/100 g). The higher oxalate content in whole grain than in refined grain cereals suggests that oxalic acid is primarily located in the outer layers of cereal grains. Cereals and cereal products contribute to the daily oxalate intake to a considerable extent. Vegetarian diets may contain high amounts of oxalate when whole grain wheat and wheat products are ingested. Recommendations for prevention of recurrence of calcium oxalate stone disease have to take into account the oxalate content of these foodstuffs.

KEYWORDS: Dietary oxalate; cereals; cereal products; calcium oxalate stone disease

INTRODUCTION

Calcium oxalate is the major constituent of ~75% of all urinary stones (*1*). Hyperoxaluria is a primary risk factor in the development of calcium oxalate stone disease. Because the oxalate/calcium molar ratio in urine is normally 1:10 (*2*), even slight changes in urinary oxalate concentration exert much larger effects on crystallization and stone formation than comparable changes in calcium concentration. Urinary oxalate is predominantly derived from endogenous production of oxalate from ingested or metabolically generated precursors and from the diet (*3*). It has been suggested that dietary oxalate contributes up to 50% of urinary oxalate excretion (*4*). Estimates of normal dietary oxalate intake are in the range of 50–200 mg daily (*2*, *5*, *6*). The consumption of foodstuffs rich in oxalic acid can induce hyperoxaluria already in healthy individuals without disturbances in oxalate metabolism (*7*). Moreover, intestinal hyperabsorption of oxalate, defined as an absorption exceeding 10%, can make a considerable contribution to urinary oxalate, even in the absence of gastrointestinal disorders. A recent study using [$^{13}C_2$]-oxalate reported an increased oxalate absorption in 46% of patients with calcium oxalate stone disease (*8*).

Detailed knowledge of food oxalate content is of essential importance for dietary treatment of recurrent calcium oxalate urolithiasis. Most fruits and vegetables in a typical Western diet contain low or moderate concentrations of oxalate (*9*). Cereals and cereal products play an important role in daily nutrition. Recently, the total oxalate concentration of a few flours has been published (*10*). However, comprehensive data on the oxalate content of cereals and cereal products are lacking. Therefore, the aim of the present study was to determine the soluble and total oxalate contents of various types of cereal grains, milling products, bread, pastries, and pasta.

MATERIALS AND METHODS

For the determination of oxalate in foods a selective and sensitive HPLC-enzyme-reactor method has been developed (*11*). This method combines enzymatic conversion and chromatographic separation of oxalate with amperometrical detection.

Sample Preparation. All cereals and cereal products were purchased from local establishments in Bonn, Germany. Samples were milled and then mixed before analysis. Each sample was analyzed in duplicate. The numbers of samples of different origin or growing seasons (*n*) are indicated in the tables.

Extraction. For the determination of total oxalate content in foods, portions of 2.0 g of the homogenized food samples were suspended with 4.0 mL of 2 N hydrochloric acid (p.a.; Merck, Darmstadt, Germany) and subsequently stirred for 15 min at 21 °C (*9*).

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Table 1. Oxalate Content of Various Types of Cereal Grains (Milligrams per 100 g)

grain/cultivar	sample	soluble oxalate *n*	soluble oxalate mean	soluble oxalate SD	total oxalate *n*	total oxalate mean	total oxalate SD
wheat, *Triticum aestivum*	whole grain	2	44.1	0.7	2	53.3	12.5
wheat, *Triticum sativum*	whole grain	1	48.9		1	71.2	
durum wheat, *Triticum durum*	whole grain	1	40.0		1	76.6	
spelt, *Triticum spelta*	whole grain	2	31.2	0.3	2	36.2	2.9
unripe spelt, *Triticum spelta*	whole grain	1	18.2		1	46.6	
kamut, *Triticum turgidum*	whole grain	2	28.4	13.9	2	46.5	1.4
rye, *Secale cereale*	whole grain	1	32.1		1	32.2	
oats, *Avena sativa*	whole grain	1	13.8		1	16.3	
naked oats, *Avena nuda*	whole grain	1	25.8		1	35.6	
naked barley, *Hordeum vulgare*	whole grain	2	15.5	8.4	2	27.3	7.2
millet, *Panicum miliaceum*	hulled grain	1	19.2		1	21.0	
brown rice, *Oryza sativa indica*	long-grain, unpolished	1	13.8		1	13.8	
brown rice, *Oryza sativa japonica*	round-grain, unpolished	1	9.8		1	12.6	
rice, *Oryza sativa*	long-grain, parboiled	1	3.2		1	3.6	
red rice, *Oryza sativa*	unpolished	1	6.5		1	12.7	
basmati rice, *Oryza sativa*		1	3.9		1	17.2	
arborio rice, *Oryza sativa*		1	3.8		1	5.9	
maize, *Zea mays*	whole grain	1	38.6		1	38.6	

Table 2. Oxalate Content of Various Types of Cereal Milling Products (Milligrams per 100 g)

milled product/ cereal cultivar	sample origin	soluble oxalate *n*	soluble oxalate mean	soluble oxalate SD	total oxalate *n*	total oxalate mean	total oxalate SD
wheat flakes, *T. aestivum*	whole grain	2	17.3	5.7	2	75.6	10.7
spelt flakes, *T. spelta*	whole grain	4	6.6	3.4	4	44.1	7.2
rye flakes, *S. cereale*	whole grain	1	12.5		1	44.0	
oat flakes, *A. sativa*	whole grain	6	6.2	1.2	6	22.0	6.5
barley flakes, *H. vulgare*	whole grain	3	8.2	3.3	3	25.3	12.3
millet flakes, *P. miliaceum*	hulled grain	2	3.6	0.5	2	7.6	1.3
rice flakes, *O. sativa*	whole grain	2	4.2	1.3	2	12.2	2.8
four-cereal flakes (oats, wheat, barley, rye)	whole grain	1	17.7		1	47.7	
pearl barley, *H. vulgare*		1	11.6		1	12.0	
wheat, *T. aestivum*	semolina	2	2.6	3.5	2	12.5	6.2
spelt, *T. spelta*	semolina	2	3.4	1.5	2	18.4	6.2
bulgur, *T. durum*		2	15.7	0.3	2	59.4	13.9
couscous, *T. durum*		1	11.5		1	65.2	
polenta, *Z. mays*		1	3.5		1	4.2	
wheat, *T. aestivum*	wholemeal flour	2	34.0	0.9	2	70.0	8.0
wheat, *T. aestivum*	flour, type 1050	1	12.9		1	45.0	
wheat, *T. aestivum*	flour, type 550	2	3.0	0.1	2	18.7	0.9
wheat, *T. aestivum*	flour, type 405	6	2.4	0.6	6	16.8	2.8
spelt, *T. spelta*	wholemeal flour	2	17.5	9.7	2	40.1	3.8
spelt, *T. spelta*	flour, type 1050	2	6.1	1.1	2	20.3	4.5
rye, *S. cereale*	wholemeal flour	1	22.6		1	27.9	
rye, *S. cereale*	flour, type 1150	2	10.7	2.3	2	19.2	4.5
wheat, *T. aestivum*	bran	4	131.2	71.1	4	457.4	192.6
wheat, *T. aestivum*	germs	1	27.3		1	44.1	
oats, *A. sativa*	bran and germs	1	11.0		1	32.0	
maize, *Z. mays*	starch	1	0		1	0	

Soluble oxalate was extracted by suspending 2.0 g of the homogenized samples with 4.0 mL of distilled water (J. T. Baker water; HPLC-reagent, Deventer, The Netherlands). To stabilize ascorbic acid, the filtrates were acidified with hydrochloric acid (50 μL of 2 N HCl/mL) (*9*).

HPLC-Enzyme-Reactor Method (All Equipment from Gynkotek, Germering, Germany). Filtrates were analyzed by the HPLC-enzyme-reactor method. Oxalate was separated from matrix substances by an anion exchange column (AS4A-Dionex, Sunnyvale, CA). The mobile phase consisted of 2.0 g of EDTA/L (p.a.; Merck) of distilled water adjusted to pH 5.0 by adding 15 μL of 0.3 N NaOH (Merck). The enzyme reactor contained 5 units of immobilized oxalate oxidase (oxalate oxidase: EC 1.2.3.4.; Sigma Diagnostics, St. Louis, MO) (carrier: VA Epoxy Biosynth, Riedel-de-Häen, Seelze, Germany), which oxidized oxalate to hydrogen peroxide and carbon dioxide. The resulting hydrogen peroxide was detected amperometrically (Pt: 0.5 V) (*11*).

RESULTS

The soluble and total oxalate contents of various types of cereals and cereal products are listed in **Tables 1−5**. All values refer to the fresh weight of the particular food. A high total oxalate content (>50 mg/100 g) was found in whole grain wheat species *Triticum durum* (76.6 mg/100 g), *Triticum sativum* (71.2 mg/100 g), and *Triticum aestivum* (53.3 mg/100 g) (**Table 1**). Total oxalate content was comparably high in whole grain milling products of *T. aestivum*, that is, wheat flakes and wholemeal flour, as well as in whole grain products of *T. durum*, that is, couscous and bulgur (**Table 2**). The highest soluble and total oxalate contents were demonstrated for wheat bran (131.2 and 457.4 mg/100 g, respectively). Total oxalate ranged from 11.8 to 49.5 mg/100 g in bread (**Table 3**). Total and soluble oxalate contents were higher in wholemeal wheat toast bread (37.6 and 24.8 mg/100 g, respectively) than in white wheat toast

Table 3. Oxalate Content of Various Types of Bread (Milligrams per 100 g)

food	soluble oxalate *n*	soluble oxalate mean	soluble oxalate SD	total oxalate *n*	total oxalate mean	total oxalate SD
wholemeal wheat toast bread	1	24.8		1	37.6	
white wheat toast bread	1	6.7		1	11.8	
white wheat rolls	2	7.3	1.1	2	20.3	11.1
wheat and rye bread	3	10.9	3.8	3	24.8	3.3
wheat and rye bread with sunflower seed	1	14.7		1	19.3	
wholemeal wheat crispbread	1	27.7		1	41.8	
wholemeal wheat crispbread with sesame seed	1	24.6		1	46.1	
spelt bread	1	3.7		1	19.2	
wholemeal rye bread	3	10.3	3.6	3	32.2	5.6
rye and wheat bread	1	9.5		1	16.8	
wholemeal rye crispbread	1	24.2		1	49.5	
rye rolls	1	7.8		1	16.6	
multigrain bread	2	9.1	6.0	2	19.7	1.4
rusk	1	10.2		1	15.4	

Table 4. Oxalate Content of Various Types of Pastries and Bakery Products (Milligrams per 100 g)

food	kind of sample	soluble oxalate *n*	soluble oxalate mean	soluble oxalate SD	total oxalate *n*	total oxalate mean	total oxalate SD
waffles	baked	1	1.8		1	6.5	
cake with nuts	baked	1	8.8		1	13.7	
puff pastry	baked	1	4.5		1	14.2	
biscuit flan base	baked	1	1.3		1	14.3	
wholemeal biscuit bar with nuts		1	10.4		1	55.1	

Table 5. Oxalate Content of Various Types of Pasta (Milligrams per 100 g)

food	kind of sample	soluble oxalate *n*	soluble oxalate mean	soluble oxalate SD	total oxalate *n*	total oxalate mean	total oxalate SD
wholemeal spaghetti	raw	1	24.8		1	65.1	
spaghetti	raw	1	13.1		1	38.4	
pasta made with eggs	raw	2	6.0	2.0	2	32.1	10.0

bread (11.8 and 6.7 mg/100 g, respectively). Crispbreads were found to have the highest total and soluble oxalate levels among breads, ranging from 41.8 to 49.5 mg/100 g and from 24.2 to 27.7 mg/100 g, respectively. With the exception of the wholemeal biscuit bar, total and soluble oxalate concentrations were low in pastries, ranging from 6.5 to 14.3 mg/100 g and from 1.3 to 8.8 mg/100 g, respectively (**Table 4**). The soluble and total oxalate contents of pasta are given in **Table 5**. The values for total and soluble oxalate of wholemeal spaghetti were ∼2 times higher than that in spaghetti from refined flour. Among whole grain cereals, the lowest soluble and total oxalate values were found in rice.

DISCUSSION

Treatment of diet-dependent hyperoxaluria starts with the restriction of foods rich in oxalate. Comprehensive data on the oxalate content of foods are therefore essential for the construction of dietary guidelines for calcium oxalate stone patients. According to a recent study, the oxalate content in foods varies mainly depending upon the plant families and the plant organ (*12*). The cereals analyzed in the present study are all species of the Poaceae family. Total oxalate concentration was highest in whole grain wheat compared to the other whole grain cereals. The higher oxalate content in whole grain than in refined grain cereals suggests that oxalic acid is primarily located in the outer layers of cereal grains. Accordingly, the highest soluble and total oxalate contents were found in wheat bran.

For wheat species *T. aestivum*, total oxalate content was higher in whole grain flakes or wholemeal flour than in whole grain. Moreover, the oxalate pattern (soluble/total) was different among these three samples. Although the oxalate content of plants is mainly a species characteristic, considerable variations can occur within the same species depending on the age of the plant, maturity, season, and soil conditions during growth. Variations in the oxalate content are sometimes reflected in the soluble and insoluble fractions (*13*). However, the total oxalate content obtained for wholemeal wheat flour (70 mg/100 g) was close to the 67 mg/100 g reported by Chai and Liebman (*10*). Because the flour is the major determinant of the oxalate content of bread, pastries, and pasta, it is assumed that similar products from different countries have similar oxalate values.

Because soluble oxalate in foods seems to have a major effect on oxalate absorption (*14*), cereals and cereal products were further analyzed for soluble oxalate. The soluble oxalate content of whole grain wheat species was between 18.2 and 48.9 mg/100 g, which is ∼40−90% of the total oxalate. At present, it is not clear to what extent insoluble calcium oxalate dissociates in the gut prior to absorption and whether calcium oxalate could be absorbed as intact salt in the human intestine (*15*). Moreover, the percentage of oxalate may vary depending on the intake of oxalate and the composition of the diet.

A low intake of calcium increases intestinal absorption and urinary excretion of oxalate (*16*, *17*). To limit intestinal absorption of oxalate, a normal calcium diet (1000 mg/day) should be recommended for calcium oxalate stone patients with hyperoxaluria. An adequate supply of calcium should be obtained with lean dairy products. Dietary calcium should be ingested with oxalate-containing meals to maximize the oxalate binding effect of calcium in the intestine.

Cereals and cereal products contribute to the daily oxalate intake to a considerable extent. Vegetarian diets may contain high amounts of oxalate when whole grain wheat and wheat products are ingested. Recommendations for the prevention of recurrence of calcium oxalate stone disease have to take into account the oxalate content of these foodstuffs. Further research should determine the oxalate bioavailability of cereals and cereal products.

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