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Food Chemistry 98 (2006) 220–224

Food Chemistry

www.elsevier.com/locate/foodchem

Oxalate contents of species of the Polygonaceae, Amaranthaceae and Chenopodiaceae families

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Received 21 March 2005; received in revised form 20 May 2005; accepted 25 May 2005

Abstract

A high dietary oxalate intake influences mineral and trace element absorption in humans and may lead to calcium oxalate stone formation due to the ability of oxalate to form insoluble complexes with divalent cations in the gastrointestinal tract. The soluble and total oxalate contents of species in the Polygonaceae, Amaranthaceae and Chenopodiaceae families were measured using an HPLC-enzyme-reactor method. Polygonaceae, Amaranthaceae and Chenopodiaceae include most of the foods with excessively high oxalate concentrations. Amaranth is a specie of the Amaranthaceae family, Polygonaceae include buckwheat, rhubarb, and sorrel, whereas beetroot, mangold, spinach, and quinoa are species of the Chenopodiaceae family. Obviously, oxalate is accumulated in these plant families in each plant tissue, i.e., in leaves, stems, hypocotyl-root and nuts. The highest oxalate content was found in leaves and stems of plants in these families. Soluble oxalate ranged from 59 to 131 mg/100 g in roots and nuts, and from 258 to 1029 mg/100 g in leaves and stems. Total oxalate ranged from 143 to 232 mg/100 g in roots and nuts, and from 874 to 1959 mg/100 g in leaves and stems. Patients with calcium oxalate stone disease should be advised to avoid these oxalate-rich foods.

Keywords: Dietary oxalate; Vegetables; Pseudocereals; Calcium oxalate stone disease

1. Introduction

Oxalate is a toxic substance and an important health risk. A high dietary oxalate intake plays a key role in secondary hyperoxaluria, a major risk factor for calcium oxalate stone formation. About 75% of all urinary stones are composed mainly of calcium oxalate (Hesse & Siener, 1997). An excessive dietary oxalate intake has been reported to result in acute renal failure (Chen, Fang, Chou, Wang, & Chung, 2001). Dietary oxalate further reduces the intestinal absorption of calcium and magnesium and is expected to impair the bioavailability of a number of trace elements due to the formation of insoluble complexes (Bohn, Davidsson, Walczyk, & Hurrell, 2004; Heaney, Weaver, & Recker, 1988; Kelsay & Prather, 1983; Weast, 1989).

Oxalate is an ubiquitous constituent of plants, where it is involved in several metabolic processes. Most fruits and vegetables in a typical Western diet contain low or moderate concentrations of oxalate (Hönow & Hesse, 2002). A normal dietary intake of oxalate is estimated to be in the range of 50–200 mg daily (Holmes, Goodman, & Assimos, 1995; Siener & Hesse, 2002; Siener, Schade, Nicolay, von Unruh, & Hesse, 2005). Spinach, beetroot and rhubarb, species in the Chenopodiaceae and Polygonaceae families, respectively, have been clearly identified as high-oxalate containing plants (Hodgkinson, 1977; Hönow & Hesse, 2002; Massey,

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0308-8146/$ - see front matter
doi:10.1016/j.foodchem.2005.05.059

Table 1
Nutrient content of pseudocereals and vegetables in the Polygonaceae, Amaranthaceae and Chenopodiaceae families (100 g edible portion) (according to Souci et al., 2000)

	Protein (g/100 g)	PUFA[a] (g/100 g)	Potassium (mg/100 g)	Calcium (mg/100 g)	Magnesium (mg/100 g)	Iron (mg/100 g)	Zinc (mg/100 g)	Vitamin B1 (μg/100 g)
Amaranth, nuts	14.6	4.1	484	214	308	9.0	3.7	800
Buckwheat, nuts	9.1	0.6	392	20	142	3.5	2.7	240
Quinoa, nuts	13.8	2.6	804	80	276	8.0	2.5	170
	Potassium (mg/100 g)	Calcium (mg/100 g)	Magnesium (mg/100 g)	Iron (mg/100 g)	Vitamin K (μg/100 g)	Retinolequiv. (μg/100 g)	Folic acid (μg/100 g)	Vitamin C (mg/100 g)
Rhubarb, stems	287	66	11	0.4	11	10	3	10
Sorrel, leaves	287	58	33	2.1	n.a.[b]	231	n.a.[b]	117
Beetroot, root	407	17	21	0.9	n.a.[b]	2	83	10
Mangold, leaves	376	103	n.a.[b]	2.7	n.a.[b]	588	30	39
Spinach, leaves	554	117	60	3.8	307	795	145	51

[a] Polyunsaturated fatty acids.
[b] Not available.

2003). Leafy vegetables and pseudocereals in the Chenopodiaceae, Amaranthaceae and Polygonaceae families, namely mangold, sorrel, beetroot, spinach, rhubarb, amaranth, buckwheat and quinoa, are rich sources of essential amino acids, polyunsaturated fatty acids, vitamins, minerals and trace elements (Table 1) (Souci, Fachmann, & Kraut, 2000) and are common components of vegetarian diets. Moreover, the gluten-free pseudocereals, buckwheat, amaranth and quinoa, are recommended for patients with celiac disease. However, reliable oxalate values of most of these foods are currently not available.

The results of a study in healthy individuals revealed that dietary oxalate may contribute up to 50% of urinary oxalate excretion (Holmes, Goodman, & Assimos, 2001). 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, revealed an increased oxalate absorption in 34% of patients with calcium oxalate stone disease (Hesse, Schneeberger, Engfeld, von Unruh, & Sauerbruch, 1999).

The ratio of soluble and insoluble oxalate seems to have a prominent effect on bioavailability and intestinal absorption of oxalate in the gut (Chai & Liebman, 2004). Oxalate occurs in plant tissues as insoluble calcium oxalate crystals, as well as water-soluble oxalate, including sodium hydrogen oxalate, potassium hydrogen oxalate and free oxalic acid. Weakly soluble compounds consist of magnesium salts.

The purpose of this study was to examine the soluble and total oxalate contents of species in the Polygonaceae, Amaranthaceae and Chenopodiaceae families for the construction of dietary guidelines for calcium oxalate stone-formers.

2. Materials and methods

2.1. General

For the determination of oxalate in foods, a selective and sensitive method has been developed using an HPLC-enzyme-reactor (Hönow, Bongartz, & Hesse, 1997). This method combines enzymatic conversion and chromatographic separation of oxalate with amperometrical detection.

2.2. Sample preparation

All food samples were investigated raw. All values refer to the 'edible portion' of the particular food, which is calculated as follows: raw product as purchased minus waste (Souci et al., 2000). Samples were shredded or milled and mixed before preparation. Each sample was analysed in double. The number of samples of different origin or growing seasons is indicated in Table 2.

2.3. 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 N hydrochloric acid (p.a.; Merck, Darmstadt, Germany) and subsequently stirred for 15 min at 21 °C (Hönow & Hesse, 2002).

Soluble oxalate was extracted by suspending 2.0 g of the homogenized samples in 4.0 ml distilled water (J.T. Baker Water; HPLC-reagent, Deventer, The Netherlands). The filtrates were acidified with hydrochloric acid (50 μl 2 N HCl/ml) to stabilize ascorbic acid (Hönow & Hesse, 2002).

Table 2
Oxalate contents of species of the Polygonaceae, Amaranthaceae and Chenopodiaceae families (100 g edible portion)

Food	Kind of sample	Oxalate content (mg/100 g)					
		n	Range soluble	*n*	Range total	Mean soluble	Mean total
Amaranthaceae							
Amaranth *Amaranthus caudatos*	Nuts	2	55.5–106.5	2	228–236	81.0	232
Polygonaceae							
Buckwheat *Fagopyrum esculentum*	Nuts	3	56.7–104.9	3	119–178	82.2	143
Buckwheat *Fagopyrum esculentum*	Whole-meal flour	1	86.0	1	155	86.0	155
Rhubarb *Rheum rhabarbarum*	Stems, raw	1	380	2	570–1900	380	1235
Sorrel *Rumex acetosa* L var. *hortensis*	Leaves, raw	1	258	1	1391	258	1391
Chenopodiaceae							
Quinoa *Chenopodium quinoa*	Nuts	2	123–138	2	183–185	131	184
Beetroot *Beta vulgaris* L. ssp. *vulgaris* var. *conditiva*	Root, raw	1	59.3	1	160	59.3	160
Mangold *Beta vulgaris* L. ssp. *vulgaris* var. *vulgaris*	Leaves, raw	6	134–501	6	436–1614	327	874
Spinach *Spinacia oleracea*	Leaves, raw	2	800–1257	2	1634–2285	1029	1959

2.4. HPLC-enzyme reactor method (all equipment Gynkotek, Germering, Germany)

Analysis of filtrates was performed by the HPLC-enzyme-reactor method. Oxalate was separated by an anion-exchange column (AS4A-DIONEX, Sunnyvale, CA). The mobile phase consisted of 2.0 g EDTA/l (p.a.; Merck, Darmstadt, Germany), distilled water adjusted to pH 5.0 by adding 15 μl 0.3 N NaOH (Merck, Darmstadt, Germany). The enzyme reactor contained 5 U of immobilized oxalate oxidase (oxalate oxidase: EC 1.2.3.4.; Sigma Diagnostics, St. Louis, USA) (carrier: VA Epoxy Biosynth, Riedel-de-Häen, Seelze, Germany) which oxidized oxalate to hydrogen peroxide and carbon dioxide. Resulting hydrogen peroxide was analyzed with an amperometric detector (Pt: 0.5 V) (Hönow et al., 1997).

3. Results

The most important plants in the Polygonaceae, Amaranthaceae and Chenopodiaceae families that accumulate oxalate are listed in Table 2. Amaranth *Amaranthus caudatos* is a specie of the Amaranthaceae family, Polygonaceae include buckwheat *Fagopyrum esculentum*, rhubarb *Rheum rhabarbarum,* and sorrel *Rumex acetosa* L var. *hortensis*, whereas beetroot *Beta vulgaris* L. ssp. *vulgaris* var. *conditiva*, mangold *Beta vulgaris* L. ssp. *vulgaris* var. *vulgaris*, spinach *Spinacia oleracea,* and quinoa *Chenopodium quinoa* are species of the Chenopodiaceae family. Soluble oxalate ranged from 59 to 131 mg/100 g in roots and nuts, and from 258 to 1029 mg/100 g in leaves and stems. Total oxalate ranged from 143 to 232 mg/100 g in roots and nuts, and from 874 to 1959 mg/100 g in leaves and stems.

4. Discussion

An excessive dietary oxalate intake may lead to renal insufficiency. Acute oxalate nephropathy, associated with the ingestion of large quantities of pure fresh star fruit (carambola) juice, a high oxalate food in the Oxalidaceae family, has been reported by Chen et al. (2001). A high dietary oxalate intake plays a key role in secondary hyperoxaluria, a major risk factor for calcium oxalate stone formation. The consumption of oxalate-rich foods can induce hyperoxaluria already in healthy subjects without disturbances in oxalate metabolism (Hesse, Siener, Heynck, & Jahnen, 1993). Treatment of diet-dependent hyperoxaluria begins with the restriction of oxalate-rich foods. Without adequate knowledge of food oxalate content, dietary guidelines can not be established.

A number of plants accumulate high concentrations of oxalate. Polygonaceae, Amaranthaceae and Chenopodiaceae include most of the species with excessively high oxalate concentrations. The results of the analyses demonstrate that oxalate is accumulated in these plant families in each plant tissue, namely in leaves, stems, hypocotyl-root and nuts. The soluble and total oxalate contents are considerably higher in leaves and stems than in roots and nuts. The relationship between species and tissues suggests that similar biosynthetic pathways and functional roles for oxalate exist within these families. A recent analysis of the oxalate content of other plant orders revealed low to medium oxalate concentrations in species of the Brassicaceae and Solanaceae families (Hönow & Hesse, 2002). In radish, kohlrabi, broccoli, brussels sprouts, cauliflower, cress, sauerkraut, and savoy cabbage, plants of the Brassicaceae family, total oxalate concentration was very low (<10 mg/100 g), ranging from below detection limit to 7.1 mg/100 g. In potatoes, tomatoes, and aubergine, plants of the Solanaceae family, total oxalate content was low to medium (<50 mg/100 g), ranging from 8.5 to 17.1 mg/100 g.

In Asian, North and South American countries, quinoa leaves are ingested as vegetable, and the leaves of amaranth are consumed as vegetable or salad (“Chinese salad”). Moreover, the leaves of buckwheat are used for the preparation of medical tea and tablets. From the results of the present study, it is suggested that these foods and preparations have high oxalate concentrations.

A study in growing rats demonstrated that a minor addition of amaranth leaves (*Amaranthus gangeticus*) significantly reduced the fractional calcium absorption and utilization (Larsen, Thilsted, Biswas, & Tetens, 2003). Although oxalate content of the leafy vegetable amaranth *Amaranthus gangeticus,* an Asian foodstuff and member of the Amaranthaceae family, was unfortunately not measured, the availability of calcium was probably limited by the oxalate content. A recent study in human subjects demonstrated that magnesium absorption was significantly lower from a meal served with spinach than a meal served with kale which is attributed to the difference in oxalic acid content between the two vegetables (Bohn et al., 2004). The results clearly reveal that the formulation of a recommendable diet cannot be based only on the nutrient content values of foods due to interactions between nutrients and antinutrients in the diet, especially oxalate. Although most of the species of the Polygonaceae, Amaranthaceae and Chenopodiaceae families contain considerable amounts of minerals and trace elements, it is suggested that bioavailability of micronutrients from these foods is low.

The relative amount of soluble and insoluble oxalate in food seems to have a major effect on oxalate absorption (Chai & Liebman, 2004). However, at the present time, it is not clear to what extent insoluble calcium oxalate dissolves in the gastric juice and whether calcium oxalate could be absorbed as an intact complex in human intestine (Hanes, Weaver, Heaney, & Wastney, 1999). Moreover, the effect of different doses of ingested oxalate-rich foods on oxalate absorption is currently unknown.

The reduction of dietary calcium increases intestinal absorption and urinary excretion of oxalate (von Unruh, Voss, Sauerbruch, & Hesse, 2004). To limit intestinal absorption of oxalate, calcium oxalate stone patients with hyperoxaluria should be on a normal calcium diet (800–1000 mg/day). Dietary calcium should be ingested with the meals to maximize the oxalate binding effect of calcium in the gut. In healthy subjects, the consumption of foods rich in oxalate requires an adequate supply of calcium, especially with lean milk or milk products.

In the present study, vegetables and pseudocereals were analysed raw, because food processing and food preparation lead to different degrees of oxalate losses. Boiling has been found to be an effective strategy for reducing the oxalate content of foods by leaching soluble oxalate into the cooking water (Savage, Vanhanen, Mason, & Ross, 2000). However, the percentages of reduction in soluble and insoluble oxalate by different cooking methods, such as boiling, steaming, blanching and baking, have not been compared to date. Moreover, the amount of oxalate present in a plant may vary over a wide range, depending on the growth conditions, season, climate and developmental stage of the plant.

The determination of the oxalate content of foods is required as important precondition for the accurate assessment of dietary oxalate intake in calcium oxalate stone patients, as well as for the modification of the oxalate content of the diet. The results from the present study demonstrate, that the oxalate content in foods varies, mainly depending upon the plant families and the plant organ. Patients at risk for calcium oxalate stone formation should be advised to avoid foods rich in oxalate, taking the average serving sizes of different foods into account.

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