Original Article

Total and soluble oxalate contents in Thai vegetables, cereal grains and legume seeds and their changes after cooking

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Abstract

This study was conducted to determine soluble and total oxalate contents in common vegetables, cereal grains and legume seeds and the effect of household cooking on these substances. Each food sample was randomly purchased from three main representative markets in metropolitan area of Bangkok, Thailand. Soluble and total oxalates were determined by high-performance liquid chromatography (HPLC). The limit of quantitation for the oxalates was 3 mg/100 g.

All studied vegetables contained relatively small amounts of total oxalate (<100 mg/100 g), except chinese convolvulus (*Lpomoea reptans*), acacia pennata (*Acacia pennata*), and cultivated bamboo shoot (*Bambusa* spp.), contained total oxalate more than 150 mg/100 g which can be significantly reduced after cooking by boiling. Among the legume seeds, soybeans (*Glycine max* (L.) *Merrill*) and peanuts (*Arachis hypogaea* L.) contained highest and moderate amounts of total oxalate, 204±14 mg and 142±35 mg/100 g, respectively. Rice contained negligible amount of total oxalate (<3 mg/100 g). There was significant reduction ($P<0.05$) in total oxalate due to cooking by boiling, percentage loss ranged form 18% in coconut heart top stems (*Cocos nucifera* Linn.) to 76% in *A. pennata*. Similar findings appeared in soluble oxalate, significant loss ($P<0.05$) ranged from 30% in cooked white stems swamp morning glory (*Lpomoea aquatica*, Forsk) to 83% in cooked cultivated bamboo shoot (*Bambusa* spp.). Loss of oxalates in various foods is likely due to their leaching loss in cooking water.

Keywords: Total oxalate; Soluble oxalate; Vegetables; Cereals; Legume seeds; Effect of cooking

1. Introduction

Oxalate is widely distributed in plant foods in a readily water-soluble form as potassium, sodium and ammonium oxalates and as insoluble calcium oxalates (Holloway et al., 1989). Oxalate forms strong chelates with dietary calcium, thus rendering the complex unavailable for absorption and assimilation. It precipitates as insoluble salts accumulating in the renal glomeruli, and contributes to the development of renal disorder. While other factors have to be considered in the development of renal disorder, it is being recommended to limit the intake of oxalate-rich foods, specifically for individuals at risk for kidney stone formation (Noonan and Savage, 1999).

Several methods have been published for the determination of oxalic acid using amperometric (Leon et al., 1990), chemiluminescence (Perez-Ruiz et al., 1999), fluorometric (Perez-Ruiz et al., 1994), spectrophotometric (Infantes et al., 1991), polarographic (Koolstra et al., 1987; Rodrigues and Barros, 1993) and gas chromatography (Gelot et al., 1980). The oxalate determination by AOAC (1984) method was based on calcium oxalate precipitation. It has some limitation in terms of sensitivity, precision and time consumption. The high-performance liquid chromatography (HPLC) method was shown to be accurate and reliable for determinations of oxalic acid in plant materials (Holloway et al., 1989; Utzman, 1993; Brega et al., 1992; Savage et al., 2000). Thus, in this study the soluble and total oxalic acid contents were determined by HPLC.

Vegetables are commonly consumed among Thai people as sources of vitamins, minerals, antioxidants and dietary fibre. Some plant foods are well known to contain oxalates (Savage et al., 2000) which are recognized as inhibitors of mineral bioavailability. However, data on oxalate content in commonly consumed plant foods are limited; especially no published data in a journal are available on oxalate content in Thai foods. Data in the form of thesis (Promboon, 1977; Liammongkolkul, 1992) were obtained by precipitating method. The method determines the amount of total oxalate which has limited precision for foods containing small amount of oxalates. Data in the literature on the forms of oxalates in plant foods are very scarce. In addition, less is known on the effect of cooking on oxalate content in foods. This study was, therefore, conducted to generate data on soluble, insoluble and total oxalate in commonly consumed Thai foods and to investigate the effect of household cooking on these substances.

2. Materials and methods

2.1. Food sampling

Thirty common Thai foods—vegetables, cereals and legume seeds—were selected to be studied as shown in Table 1. Nine samples for each food item, 1–3 kg, were purchased randomly from three representative markets

Table 1
English name, scientific name and edible portion of studied foods

English name	Scientific name	Edible portion (%) ($n = 3$)[a]
Leafy vegetables		
Cabbage	*Brassica oleracea* Linn. Var. *capitata* Linn.	40.7 ± 5.0
Kale, Chinese	*Brassica oleracea* var. *alboglabra*, *Bail.*	44.3 ± 1.1
Acacia pennata	*Acacia pennata*, L *Willd. Subsp.*, *Insuavis Nielsen*	24.1 ± 3.8
Ivygourd	*Coccinia grandis* Voigt./*C. indica*, Wight & Am.	33.3 ± 2.9
Cabbage, Chinese/flowering white cabbage	*Brassica napus*, L. var *chinensis*	49.0 ± 3.1
Cabbage, Chinese, white	*Lactuca sativa*, var. *capitata*	53.8 ± 2.3
Chinese convolvulus	*Lpomoea reptans*, Poir.	36.8 ± 2.3
Swamp morning glory, white stems	*Lpomoea aquatica*, Forsk	28.1 ± 3.3
Swamp morning glory, red stems	*Lpomoea aquatica*, Forsk	33.6 ± 3.1
Flower or fruit-consumed vegetables		
Cauliflower	*Brassica oleracea* Linn. Var, *botrytis*, Mill.	30.9 ± 4.5
Yard long bean, green	*Vigna sesquipedalis*, Fruwirth	46.1 ± 1.0
Winged bean, pods	*Psophocarpus tetragonolobus*, (L) DC	39.0 ± 7.5
Tomato	*Lycopersicon esculentum*, Mill.	95.0 ± 2.1
Eggplant/brinjal	*Salonum xanthocarpum*	42.1 ± 2.4
Eggplant/aubergine, green, long	*Salonum melongena*, L.	48.4 ± 1.8
Gourd/cucumber, bitter, Chinese variety	*Momordica charantia*, L.	42.1 ± 1.5
Papaya, raw	*Carica papaya*, L.	36.5 ± 4.5
Other vegetables		
Carrot	*Dancus carota*	38.2 ± 3.6
Coconut heart, top stem	*Cocos nucifera* Linn.	43.1 ± 2.3
Bamboo shoot, cultivated	*Bambusa* spp.	26.0 ± 5.9
Bamboo shoot, pickled	*Bambusa* spp.	43.2 ± 4.3
		($n = 3$)[a]
Cereal grains		
Rice, whole grain	*Oryza sativa*	100
Rice, jusmin, polished	*Oryza sativa*	100
Rice, glutinous, polished	*Oryza glutinosa*	100
Job's tears, seeds	*Coix lachryma-jobi*, L.	100
Legumes, nuts and seeds		
Cowpea, seeds	*Vigna unguiculata*	100
Mungbean, seeds	*Phaseolus aureus* Roxb.	100
Peanut/groundnut, seeds	*Arachis hypogaea* L.	100
Red kidney bean/princess bean, seeds	*Phaseolus vulgaris* L.	100
Soybean, seeds	*Glycine max* (L.) *Merrill*	100

[a] Three composite samples, each prepared from 3–5 single samples from three representative markets.

in metropolitan areas of Bangkok, Thailand. Three samples from each market were pooled as a composite sample. After purchasing, the samples as such were transported as soon as possible to Food chemistry laboratory at the Institute of Nutrition, Mahidol University.

2.2. Sample preparation

Samples of vegetables were cleaned once with tap water, and twice with deionized (DI) water. The inedible portions of each vegetable were recorded and discarded. Rice samples and legume seeds were used as purchased. The edible parts of each composite sample were divided into two portions: one for analysis as raw, and another for cooking before analysis. Weight before and after cooking was recorded.

Before cooking by boiling, rice samples were washed twice with DI water whereas those of legume seeds, except peanuts, were washed twice with tap water and soaked overnight in 1:5 seeds to DI water. The amount of water used for cooking was as necessary to cover the amount of each raw food studied. The ratio of raw foods: DI water varied from 1:2 to 4. Peanuts were cooked by roasting raw peanuts in a hot pan with low-to-medium heating and then peeled by hand. The percentage edible portion (EP) for various foods was shown in Table 1. Raw and cooked samples were homogenized using a food processor (Tefal® Kaleo Blender, France), kept in an acid-washed screw-capped plastic bottle, and stored at −20 °C until analysis. For oxalate determination, a portion of the homogenized samples was dried at 60 °C and ground to be fine particles, then stored in a sealed plastic bag in desiccators at room temperature. All foods were analysed in both raw and cooked state, except tomato and soybean seeds were analysed in raw form.

2.3. Moisture determination

Moisture in fresh and cooked food samples was determined, according to the AOAC (2000, 925.45D), by drying 2–5 g sample in an oven (Memmert®, Schwabach, Germany) set at 100 ± 5 °C until constant weight.

2.4. Oxalate determination

Oxalate content in various foods was determined by HPLC method (Savage et al., 2000). In a 250-mL beaker with a cover glass, total oxalate was extracted from 1 g of finely ground-dried sample with 50 mL HCl (2 M) in a water bath at 80 °C for 15 min. Soluble oxalate was extracted by the same method but with 50 mL DI water. Upper layer was collected after centrifugation for 15 min at 3000 rpm and filtered through a 0.45 μm cellulose acetate membrane. A 20 μL sample was injected into HPLC system (Waters® chromatography system, Milford, USA) with UV detector (Waters® 486), set at 210 nm. The chromatographic separation was carried out on a 300 × 7.8 mm Biorad Aminex ion exclusion column (HPX-87H), using an isocratic elution at 0.5 mL/min with 0.0125 M sulphuric acid as a mobile phase. The amount of oxalic acid in each sample was determined against a standard calibration curve of oxalic acid (100–500 μg/mL) and expressed as mg oxalate in 100 g sample. All samples were extracted and analysed in duplicate.

2.5. Percentage of oxalate loss

Percent retention is defined as the amount of oxalate remained in the food after cooking. It was calculated using the following formula (Murphy et al., 1975). Percent loss of oxalate was calculated as 100−% true retention (TR):

$$\%\mathrm{TR} = \frac{\text{Oxalate content per g of cooked food} \times \text{g of food after cooking} \times 100}{\text{Oxalate content per g of raw food} \times \text{g of food before cooking}}.$$

2.6. Quality control

Cha-moung (*Garcinia cowa* Roxb.) leaves were dried at 50 °C overnight. They were ground to be fine particles and used as an in-house quality control (QC) sample. The assigned values of total and soluble oxalate were developed from duplicate analysis of 10 single samples of the in-housed QC samples on 10 different days. The QC sample was then analysed along with the unknown samples in each run to monitor the precision of the total and soluble oxalate measurement over time. Recoveries of standard added (10 mg of oxalic acid/1 g of sample) prior to sample extraction were performed in both an in-house QC sample and dried food samples.

2.7. Statistical analysis

Effects of cooking on oxalate contents in various foods were analysed by Wilcoxon signed ranks test (non-parametric statistic), using SPSS (version 11.0, SPSS Inc. Chicago, IL, USA).

Table 2
Oxalates and moisture contents in various Thai foods

Foods	Status	Moisture[a]	Oxalate[a] (mg/100 g)			% Soluble
		(g/100 g)	Total	Soluble	Insoluble[b]	Oxalate
Leafy vegetables						
Acacia pennata	Raw	82.4±1.1	161±38	110±15	51±30	68
(Cha-om)	Boiled	87.6±0.7	75±23	41±16	34±19	55
Cabbage	Raw	94.5±0.3	7±2	<3[c]	7±2	NC[d]
	Boiled	95.0±0.4	5±1	4±1	<3	80
Cabbage, Chinese	Raw	95.0±0.5	6±1	<3	6±1	NC
	Boiled	94.6±0.4	17±10	<3	16±8	NC
Cabbage, Chinese,	Raw	96.7±0.4	<3	<3	<3	NC
White	Boiled	95.9±0.1	<3	<3	<3	NC
Chinese convolvulus	Raw	94.8±0.6	156±17	21±16	135±32	13
	Boiled	94.8±0.5	135±13	7±2	128±15	5
Ivygourd	Raw	92.5±1.9	36±5	10±6	29±5	28
	Boiled	92.4±1.1	24±7	5±1	19±7	21
Kale, Chinese	Raw	91.9±2.3	23±13	<3	22±15	NC
	Boiled	92.8±0.8	7±2	<3	7±2	NC
Swamp morning glory, red stems	Raw	93.1±0.4	94±18	61±7	33±25	65
	Boiled	93.6±0.6	59±9	23±18	36±22	39
Swamp morning glory, white stems	Raw	93.6±0.2	79±8	58±10	21±10	73
	Boiled	94.4±0.5	56±2	40±9	16±10	71
Flower or fruit-consumed vegetables						
Cauliflower	Raw	90.8±0.2	27±18	<3	27±18	NC
	Boiled	92.3±0.5	8±3	<3	6±3	NC
Eggplant/brinjal	Raw	91.0±0.7	96±41	47±6	49±36	49
	Boiled	91.0±0.5	65±9	25±3	40±11	38
Eggplant/aubergine, green, long	Raw	93.1±0.8	55±6	45±1	10±7	82
	Boiled	93.7±0.4	38±9	19±3	19±11	50
Gourd/cucumber, bitter	Raw	95.0±0.2	71±8	57±6	14±5	80
	Boiled	95.9±0.4	56±9	22±4	34±6	39
Papaya, raw	Raw	94.0±1.8	5±2	<3[c]	<3	NC[d]
	Boiled	94.1±0.3	11±6	<3	8±6	NC
Tomato	Raw	93.6±0.8	11±2	7±3	4±3	64
Winged bean, pods	Raw	91.1±0.4	7±1	<3	4±2	NC
	Boiled	92.6±0.4	5±1	<3	5±2	NC
Yard long bean,	Raw	91.9±0.6	38±4	9±6	29±6	24
Green	Boiled	90.8±1.4	29±3	3±2	26±4	10
Other vegetables						
Bamboo shoot,	Raw	91.9±1.4	222±41	163±23	60±22	73
cultivated	Boiled	94.7±1.7	93±39	51±42	42±15	55
Bamboo shoot,	Raw	93.6±0.7	71±14	23±10	47±13	32
pickled	Boiled	94.0±1.4	51±10	10±4	41±11	20
Carrot	Raw	88.7±0.7	29±7	24±6	5±1	83
	Boiled	91.1±1.9	12±6	7±3	5±3	58
Coconut heart,	Raw	89.8±1.4	120±32	<3	117±31	NC
Top stem	Boiled	92.2±0.5	109±24	<3	105±29	NC
Cereal grains						
Rice, whole grain	Raw	11.9±0.4	<3[c]	<3	<3	NC[d]
	Boiled	65.9±2.1	<3	<3	<3	NC

Table 2 (*continued*)

Foods	Status	Moisture[a] (g/100 g)	Oxalate[a] (mg/100 g)			% Soluble Oxalate
			Total	Soluble	Insoluble[b]	
Rice, jusmin, Polished	Raw	12.2±0.3	<3	<3	<3	NC
	Boiled	59.3±1.2	<3	<3	<3	NC
Rice, glutinous, polished	Raw	12.6±1.0	<3	<3	<3	NC
	Boiled	39.9±3.8	<3	<3	<3	NC
Job's tears, seeds	Raw	10.4±0.8	66±2	64±2	<3	97
	Boiled	62.6±1.9	18±8	15±8	<3	83
Legume seeds						
Cowpea, seeds	Raw	12.5±0.2	<3	<3	<3	NC
	Boiled	65.3±5.2	5±1	<3	5±1	NC
Mungbean, seeds	Raw	11.7±0.6	24±4	12±3	12±2	50
	Boiled	70.8±2.5	5±0	<3	4±1	NC
Peanut, seeds	Raw	8.4±0.9	142±35	118±24	24±17	83
	Roasted	2.4±1.2	160±40	108±9	53±49	68
Red kidney bean, seeds	Raw	11.3±0.2	91±10	26±17	65±7	29
	Boiled	64.4±1.0	32±12	10±6	27±15	31
Soybean, seeds	Raw	8.2±1.0	204±14	58±7	145±20	28

[a] Mean±s.d. of values obtained from duplicate analysis of three composite samples.
[b] Insoluble oxalate = total oxalate−soluble oxalate.
[c] Value below limit of quantitation (3 mg/100 g) reported as <3 mg/100 g.
[d] NC = not calculated due to negligible amount of oxalates.

3. Results and discussion

The average EP of the studied foods ranged from 24% in acacia pennata (*Acacia pennata*) to 95% in tomato (*Lycopersicon esculentum*, Mill.) as purchased whereas 100% was presented in cereal and legume seeds (Table 1). Oxalate (soluble, insoluble and total) and moisture contents in all food items are shown in Table 2 and their losses after cooking are shown in Table 3. The data were presented as the mean±s.d. of three individual composite samples.

3.1. Oxalate content

Total oxalate content in the samples and standards was measured by HPLC from the acid extract (2 M HCl, pH 1.0) whereas soluble oxalate content was measured from the water extract (pH 5.5). The selected HPLC conditions show the linear relationship ($r^2 = 0.997$) between the peak areas and the concentrations of oxalic acid (both acid and water extract) in the studied ranges of 0–500 μg/mL. The limit of quantitation for the oxalates was 3 mg/100 g.

Cha-moung (*Garcinia cowa* Roxb.) leaf, which was used as the in-house QC sample, contained high levels of total and soluble oxalates, 875+48 and 574±48, respectively. The oxalate values of the in-house QC sample within ±2s.d. were achieved for each set of analysis, with the relative standard deviation of less than 9%. This indicated the good performance of all measurements. The percent recoveries of total oxalate and soluble oxalate, obtained from standard adding to the in-house QC and to individual samples, were 97±10% and 72±14%, respectively ($n = 40$), which agreed well with the findings of Savage et al. (2000).

As shown in Table 2, most studied vegetables, contained small amounts of total oxalates (less than 100 mg/100 g EP) except those of top stem coconut heart (*Cocos nucifera*, Linn.), Chinese convolvulus (*Lpomoea reptans*, Poir.), *A. pennata*, and cultivated bamboo shoot (*Bambusa* spp.) which contained total oxalates ranged from 112 to 222 mg/100 g. The level found in these vegetables was about 13% of the spinach (*Tetragonia expansia*) (1765 mg/100 g) studied by Savage et al. (2000). Cereal grains contained trace amount of total oxalate (<3 mg/100 g) except that of Job's tears seeds (*Coix lachryma-jobi*, L.) (66±2 mg/100 g). The descending order of the oxalate content in the legume seeds studied is soybean > peanut > red kidney bean > mungbean > cowpea (ranged from 204±14 to <3 mg/100 g).

Low level of total oxalate contents found in Brassica vegetables was in accordance with those reported by Promboon (1977), Benway and Weaver (1993), Mosha et al. (1995), Savage et al. (2000) and Kamchan et al. (2004). However, most of the total oxalate data in various vegetables reported by the US Department of Agriculture and Agricultural Research Service (1984) were higher than the levels obtained from this study.

Table 3
Effect of cooking[1] by boiling on soluble and total oxalates (Mean ± S.D.) in various foods

English name	Food:water used for cooking	Cooking time (min.)	Oxalate (mg/total weight)				% Loss in oxalate[2]	
			Before cooking		After cooking		(Mean ± S.D.)	
			Soluble	Total	Soluble	Total	Soluble	Total
Leafy vegetables								
Acacia pennata	1:4	2–3	484 ± 57^{a}	703 ± 122^{a}	226 ± 84^{b}	407 ± 96^{b}	53 ± 16	42 ± 13
Chinese convolvulus	1:2	2–5	69 ± 58^{a}	496 ± 61^{a}	16 ± 4^{b}	343 ± 110^{b}	67 ± 18	21 ± 2
Ivygourd	1:3.5	2–3	48 ± 36^{a}	166 ± 48^{a}	20 ± 7^{b}	96 ± 39^{b}	56 ± 18	42 ± 15
Kale, Chinese	1:2	5	12 ± 8^{a}	168 ± 136^{a}	0 ± 0^{b}	47 ± 26^{b}	NC[3]	76 ± 1
Swamp morning glory, red stems	1:3	2–5	427 ± 83^{a}	651 ± 96^{a}	165 ± 138^{b}	406 ± 72^{b}	64 ± 23	37 ± 10
Swamp morning glory, white stems	1:2	3–6	321 ± 77^{a}	454 ± 168^{a}	220 ± 82^{b}	308 ± 91^{b}	30 ± 23	30 ± 8
Flower or fruit-consumed vegetables								
Cauliflower	1:3.5	5–7	0 ± 0^{a}	139 ± 69^{a}	10 ± 7^{b}	42 ± 8^{b}	NC	64 ± 17
Eggplant/brinjal	1:2	5–12	350 ± 13^{a}	699 ± 232^{a}	179 ± 32^{b}	468 ± 42^{b}	48 ± 11	38 ± 16
Eggplant/aubergine, green, long	1:2	7–10	331 ± 25^{a}	408 ± 86^{a}	135 ± 22^{b}	275 ± 88^{b}	59 ± 6	34 ± 7
Gourd/cucumber, bitter	1:3	10	394 ± 71^{a}	486 ± 80^{a}	143 ± 33^{b}	367 ± 83^{b}	64 ± 2	25 ± 5
Winged bean, pods	1:3	3–5	10 ± 6^{a}	39 ± 6^{a}	4 ± 4^{b}	27 ± 9^{b}	NC	32 ± 13
Yard long bean, green	1:2	5–10	43 ± 17^{a}	223 ± 126^{a}	20 ± 15^{b}	159 ± 60^{b}	58 ± 32	24 ± 14
Other vegetables								
Bamboo shoot, cultivated	1:3	30	1014 ± 110^{a}	1375 ± 99^{a}	278 ± 202^{b}	518 ± 155^{b}	83 ± 7	63 ± 8
Bamboo shoot, pickled	1:3	25–30	183 ± 83^{a}	561 ± 167^{a}	81 ± 34^{b}	409 ± 123^{b}	59 ± 2	27 ± 1
Carrot	1:2	10	196 ± 61^{a}	237 ± 72^{a}	49 ± 26^{b}	85 ± 45^{b}	76 ± 8	71 ± 13
Coconut heart, top stem	1:2	10–12	18 ± 9^{a}	916 ± 293^{a}	5 ± 4^{b}	745 ± 218^{b}	NC	18 ± 5
Cereal grains and legume seeds								
Job's tears, seeds	1:4	48 (30–65)	809 ± 279^{a}	843 ± 313^{a}	340 ± 100^{b}	410 ± 107^{b}	53 ± 15	50 ± 13
Mungbean, seeds	1:3.5	46 (35–60)	72 ± 43^{a}	138 ± 71^{a}	0 ± 0^{b}	85 ± 34^{b}	NC	44 ± 3
Red kidney bean	1:4	60	111 ± 54^{a}	434 ± 138^{a}	93 ± 45^{b}	360 ± 199^{b}	19 ± 6	21 ± 1

[1] Different letters between values of oxalate content before and after cooking of each food show significant difference ($P < 0.05$).
[2] Mean ± standard deviations of three individual experiments, calculated as 100 − % true retention.
[3] NC = not calculated due to negligible amount of oxalates.

US Department of Agriculture and Agricultural Research Service (1984) analysed the total oxalate by calcium oxalate precipitation AOAC method. The discrepancy in these levels is likely due to the differences in analytical methods, varieties and growing location of plant foods. Although the total oxalate content in raw soybean seeds (*Glycine max* (L.) *Merrill*) was high (204 ± 14 mg/100 g), the level in the cooked seeds (by boiling) reported by Kamchan et al. (2004) was markedly low (5.5 mg/100 g, with moisture content 61.1 g/100 g). The total and insoluble oxalate contents should be concerned since some vegetables are sometimes consumed as raw, i.e., cabbage, white Chinese cabbage, swamp morning glory, eggplant, raw papaya, tomato, winged bean pods, yard long bean, pickled bamboo shoot and carrot. Among these vegetables, swamp morning glory and eggplant contained medium level of total oxalate (about 95 mg/100 g). Nevertheless, 50–65% of the total oxalate was found to be soluble. It was expected that soluble oxalate will be easily reduced by leaching loss during cooking. For the foods consumed as cooked only, soluble oxalate varied from 13% of total oxalate in Chinese convolvulus (*L. reptans*, Poir.) to 97% of total oxalate in Job's tear seeds (*C. lachryma-jobi*, L.). Although the cultivated bamboo shoot (*Bambusa* spp.) contained the highest amount of total oxalate content (222 ± 41 mg/100 g), its soluble oxalate was considerably high (70% soluble). On the other hand, Chinese convolvulus (*L. reptans*, Poir.), contained medium level of total oxalate (156 ± 17 mg/100 g) but its contained highest level of insoluble oxalate (135 ± 32 mg/100 g).

3.2. *Effect of cooking on oxalate*

Percent reduction of oxalate due to cooking (Table 3) was calculated as 100 − % TR. Murphy et al. (1975) found that apparent retention overestimated the TR. To avoid the bias, they recommended reporting TR whenever data on weights of food before and after cooking are available. Therefore, the effect of cooking on oxalates content as TR was calculated in this study. For food contained insignificant amount of total oxalate less than 10 mg/100 g as raw (Table 2), the effect of cooking was not evaluated.

In vegetables, there was significant reduction ($P < 0.05$) in total oxalate due to cooking by boiling, percentage loss ranged from 18% in coconut heart top stems (*C. nucifera* Linn.) to 76% in *A. pennata* (Table 3). Wanasundera and Ravindran (1992) reported 40–50% loss of total oxalates when two kinds of yam tubers (*Dioscorea alata* and *D. esculenta*) were boiled compared to steamed (20–25%). Similar findings appeared in soluble oxalate, significant loss ranged from 30% in cooked white stems swamp morning glory (*Lpomoea aquatica*, Forsk) to 83% in cooked cultivated bamboo shoot (*Bambusa* spp.). Savage et al. (2000) showed that boiling resulted in significant loss of soluble oxalates of some New Zealand foods such as spinach (*Spinacia oleracea*), silverbeet (*Beta vulgaris* v. *cicla*) and rhubarb (*Rheum rhaponticum*). Loss of oxalates in various vegetables is likely due to their leaching loss in cooking water.

Losses of soluble (19–53%) and total oxalate (21–51%) were also found in Job's tears seeds (*C. lachryma-jobi*, L.) (about 50%) and red kidney bean (*Phaseolus vulgaris* L.) (about 20%) which could be due to leaching loss during soaking and boiling. As expected, roasting has negligible effect on changing of oxalate content in roasted peanut (7% reduction of total oxalate). Since roasted peanut was analysed without skin, minute amount of oxalates might be present in the removed skin.

4. Conclusion

Commonly consumed plant foods contain relatively small amounts of oxalate (<100 mg/100 g). Levels of total oxalate more than 150 mg/100 g were found only in 4—cultivated bamboo shoot (*Bambusa* spp.), soybeans (*G. max* (L.) *Merrill*), *A. pennata*) and chinese convolvulus (*L. reptans*, Poir.)—out of 30 foods studied which can be significantly reduced after cooking by boiling. According to Noonan and Savage (1999), the adverse effect of oxalates on calcium bioavailability may be pronounced when the oxalate/calcium mole ratio is 9:4. The studied foods which contain the highest level of total oxalate—222 mg/100 g in raw cultivated bamboo shoot (*Bambusa* spp.) which contains 37 mgCa/100 g (Puwastien et al., 1999)—has oxalate/calcium mole ratio of 10.7:4 which reduced to 7.1:4 after cooking. The ratios of the other foods as raw were less than 7:4 and changed to less than 5:4 after cooking. Therefore, all common foods studied should not have any adverse effect of oxalate on minerals bioavailability especially when they are consumed as cooked. However, oxalate content and oxalate: calcium ratio in mixed plant foods which are commonly consumed as raw and cooked among vegetarians, should be investigated.

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References

AOAC, 1984. Association Official of Analytical Chemistry, 974.24.

AOAC, 2000. Association Official of Analytical Chemistry, 925.45D, 991.43.

Benway, D.A., Weaver, C.M., 1993. Assessing chemical form of calcium in wheat, spinach and kale. Journal of Food Science 58 (3), 605–608.

Brega, A., Quadri, A., Vitta, P., Prandini, P., Wei, J.Q., Lucarelli, C., 1992. Improved HPLC determination of plasma and urine oxalic acid in the clinical diagnostic laboratory. Journal of Liquid Chromatography 15 (3), 501–511.

Gelot, H.A., Lover, G., Belleville, F., Nabet, P., 1980. Determination of oxalic acids in plasma and urine using gas chromatography. Clinica Chimica Acta 106 (3), 279–285.

Holloway, W.D., Argall, M.E., Jealous, W.T., Lee, J.A., Bradbury, J.H., 1989. Organic Acids and Calcium Oxalic acid in Tropical Root Crops. Journal of Agricultural and Food Chemistry 37, 337–341.

Infantes, J.A., Luque de Castro, M.D., Valcarcel, M., 1991. Kinetic–enzymatic determination of oxalic acid in urine by flow-injection analysis with double stopped flow. Analytica Chimica Acta 242, 179–183.

Kamchan, A., Puwastien, P., Sirichakwal, P.P., Kongkachuichai, R., 2004. In vitro calcium bioavailability of vegetables, legumes and seeds. Journal of Food Composition and Analysis 17, 311–320.

Koolstra, W., Wolters, B.G., Hayer, M., Elzerga, H., 1987. Development of a reference method for determining urinary oxalic acid by mean of isotope dilution-mass spectrometry (ID-MS) and its usefulness in testing existing assays fir urinary oxalate. Clinica Chimica Acta 170 (2–3), 227–235.

Leon, L.E., Rois, A., Luque de Castro, M.D., Valcarcel, M., 1990. Use of photochemical reactions in flow injection: determination of oxalic acid in urine. Analyst 115 (12), 1549–1552.

Liammongkolkul, S., 1992. Relationship of nutrient intake renal stone and distal renal tubular acidosis (dRNA) in the North-East of Thailand. Thesis in Master of Science of Mahidol University, Thailand.

Mosha, T.C., Gaga, H.E., Pace, R.D., 1995. Effect of blanching on the content of antinutritional factors in selected vegetables. Plant Foods for Human Nutrition 47 (4), 361–367.

Murphy, E.W., Criner, P.E., Gray, B.C., 1975. Comparisons of methods for calculating retentions of nutrients in cooked foods. Journal of Agricultural and Food Chemistry 23, 1153–1157.

Noonan, S.C., Savage, G.P., 1999. Oxalic acid content of foods and its effect on humans. Asia Pacific Journal of Clinical Nutrition 8 (1), 64–74.

Perez-Ruiz, T., Matinez-Lozano, C., Casajus, R., 1994. Flow injection spectrofluorimetric determination of oxalic acid based on its enhancing effect on the oxidation of rhodamine B by dichromate. Analyst 120 (8), 2111–2114.

Perez-Ruiz, T., Matinez-Lozano, C., San, A., Val, O., 1999. HPLC determination of oxalic acid using tris(1,10-phenanthroline)ruthenium(II) chemiluminescence application to the analysis of spinach. Food Chemistry 65 (4), 543–546.

Promboon, Y., 1977. A study of the oxalic acid content of some vegetable from Northern and Southern parts of Thailand. Thesis Graduate School of Kasetsart University, Thailand.

Puwastien, P., Raroengwichit, M., Sungpuag, P., Judprasong, K., 1999. Thai Food Composition Tables. Institute of Nutrition Mahidol University (INMU), Thailand.

Rodrigues, J.A., Barros, A.A., 1993. Development of a method for oxalic acid determination by differential-pulse polarography after derivatization with *o*-phenylenediamine. Analytica Chimica Acta 273, 531.

Savage, G.P., Vanhanen, L., Mason, S.M., Ross, A.B., 2000. Effect of cooking on the soluble and insoluble oxalic acid content of some New Zealand foods. Journal of Food Composition and Analysis 13, 201–206.

US Department of Agriculture, Agricultural Research Service, 1984. USDA Composition of Foods: Vegetables and Vegetable Products, Agriculture Handbook Number 11. Human Nutrition Information Service, Washington, DC 11pp.

Utzman, S., 1993. Improved analysis of process liquors for the pulp and paper industry by ion chromatography. Journal of Chromatography 640 (1–2), 287–292.

Wanasundera, J.P.D., Ravindran, G., 1992. Effects of cooking on the nutrient and antinutrient contents of yam tubers (*Dioscorea alata* and *Dioscorea esculenta*). Food Chemistry 45, 247–250.