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ScienceDirect
Food Chemistry 101 (2007) 559–562
Food Chemistry
www.elsevier.com/locate/foodchem

Composition and availability of soluble and insoluble oxalates in raw and cooked taro (*Colocasia esculenta* var. Schott) leaves

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Received 10 February 2006; accepted 12 February 2006

Abstract

Taro (*Colocasia esculenta* var. Schott) is a major staple food crop in parts of Asia and the Pacific Islands and is grown as a minor crop in New Zealand. Soluble, insoluble and total oxalate content of young and older leaves were determined by HPLC following hot water (80 °C) and hot (80 °C) acid (0.2 mol/L HCL) extractions. Young taro leaves contained 589 ± 35.8 mg total oxalates/100 g fresh weight (FW) while older taro leaves contained (443 ± 15.0 mg total oxalates/100 g FW). Soluble oxalates were 74% of the total oxalate content of the young and old leaves.

Oxalate analysis was also carried out on leaves baked at 150°C for 1.5 h either alone or with 50 ml cows milk. The soluble oxalate content of the fresh baked tissue fell to a mean of 59% for both samples of leaves. Baking the young and old leaves with milk led to a further reduction of the soluble oxalate content in the cooked leaves (mean 21.4% of the total oxalates). The results from this study suggest that baked taro leaves should be regarded as a high oxalate food but baking with milk significantly reduces the amount of soluble oxalate that could be absorbed from the cooked leaves.

Keywords: Taro; *Colocasia esculenta*; Soluble oxalates; Calcium oxalate; Baking; Milk; Total calcium

1. Introduction

Taro is the common name for edible aroids which are important staple foods in many parts of the world. Within the family Araceae there is one ‘‘true taro’’ *Colocasia esculenta* var. Schott. This plant probably originates from the tropical region between India and Indonesia (Matthews, 2004) and has been grown in the South Pacific for hundreds of years (FAO, 1992). Taro produces edible corms (Chay-Prove & Goebel, 2004) and the leaves are also used as a vegetable (Aregheore & Perera, 2003). Taro is an important part of Pacific Island culture and it is imported into New Zealand and Australia for these people (Matthews, 2004). Attempts to grow taro leaves in New Zealand have met with some success (Busch, Vanhanen, & Savage, 2003).

Most taro cultivars taste acrid and can cause swelling of lips, mouth and throat if eaten raw (Bradbury & Nixon, 1998). This acridity is caused by needle-like calcium oxalate crystals, raphides, that can penetrate soft skin (Bradbury & Nixon, 1998). Thereafter an irritant present on the raphides, probably a protease, can cause discomfort in the tissue (Bradbury & Nixon, 1998; Paull, Tang, Gross, & Uruu, 1999). Both the root and the leaves can give this reaction (FAO, 1992) but this effect is reduced by cooking (Bradbury & Nixon, 1998).

Cooking can affect the soluble oxalate but not the insoluble oxalate content of the food. Boiling can reduce the soluble oxalate content of a food if the cooking water is discarded, while soaking, germination and fermentation will also reduce the content of soluble oxalates (Noonan & Savage, 1999). In contrast, baking a food will cause an effective concentration of oxalates in the food due to the loss of water from the baked food (Noonan & Savage, 1999).

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doi:10.1016/j.foodchem.2006.02.014

The bioavailability of the oxalates in food can be altered by the addition of extra calcium, for example, from milk and milk products. Brogren and Savage (2003) showed that when extra calcium was eaten together with spinach, an oxalate-rich food, the uptake of oxalates was reduced. This confirmed an earlier experiment where Albihn and Savage (2001) demonstrated that the bioavailability of oxalate could be reduced to zero if baked oca was eaten with sour cream.

Since taro is a staple food extensively eaten in the Pacific Islands and also has an emerging market in New Zealand, it is important to investigate whether the oxalate content of taro leaves poses a risk factor for hyperoxaluria and whether different methods of preparation and cooking with milk can reduce the risk of absorbing excess soluble oxalates when consumed as part of the diet.

2. Materials and methods

2.1. Harvesting

Leaves from Taro (*Colocasia esculenta* var. Schott) were harvested in the autumn (April 2005) from a greenhouse run by a Tongan Community Trust (Kahoa Tahoa Tauleva Christchurch Trust) situated at the Waio-ora Trust, Harewood, Christchurch, New Zealand. Young leaves (100–200 mm long) as well as older leaves (200–300 mm long) were chosen. The petioles were removed and the leaves were chopped into small pieces (5 × 5 mm) using a stainless steel knife. Triplicate samples of 2–3 g were taken. The samples were deep frozen at −20 °C for later analysis.

2.2. Cooking

Taro leaves (50 g), without petioles, were put into aluminium trays (140 × 200 mm), covered with aluminium foil and baked in a domestic fan bake oven (Simpson, Gemini, Australia) at 150 °C for 1.5 h. Additionally leaves were baked, as above, with 50 ml standard homogenised milk (Meadowfresh Family, Fontera, New Zealand). The cooking methods broadly followed the cooking and preparation of the Tongan dish, Lu pulu (Siale Faitotonu, Pers. Comm.) After cooking the leaves were homogenized with a household stick mixer (ZIP, New Zealand) and 2–3 g triplicate samples were taken from each treatment. The samples were deep frozen at −20 °C for later analysis.

2.3. Dry matter and calcium determination

The dry matter of all samples was determined, in duplicate, by drying them to constant weight in an oven at 105 °C for 24 h AOAC (2002) method 925.10. Calcium was determined following a nitric/perchloric digestion by inductively coupled plasma-mass spectrometry (Hill Laboratories, Hamilton, NZ).

2.4. Chemical extraction: total and soluble oxalates

Soluble and total oxalate contents of 3 g of finely chopped samples of raw, soaked and cooked taro leaves were extracted and measured as described in detail by Savage, Vanhanen, Mason, and Ross (2000). Insoluble oxalate content (calcium oxalate) was calculated by difference (Holloway, Argall, Jealous, Lee, & Bradbury, 1989). Each sample was analysed in triplicate and all data are presented as mg oxalate/100 g fresh weight (FM) as this is how this vegetable is normally consumed. A recovery study was carried out where 10 mg of oxalic acid was added to 3 g samples of mature leaves, 103 ± 1.9% of added oxalate was recovered in subsequent analysis.

2.5. Statistical analyses

Statistical analysis was performed using GenStat for Windows (Version 7, Laws Agricultural Trust, UK).

3. Results and discussion

3.1. Total oxalates

The mean dry matter content (12.6 g DM/100 g FW) of the fresh young and old taro leaves was very similar (Table 1). Young taro leaves contain 589 ± 35.8 mg oxalates/100 g FW and old leaves 443 ± 15.0 mg oxalates/100 g FW. Earlier studies have reported that taro leaves from Fiji contained 426 ± 110 mg of total oxalates/100 g FW (Holloway et al., 1989) and leaves grown in New Zealand were shown to contain 424 ± 6.6 mg total oxalates/100 g FW (Dubois & Savage, 2006). This is slightly lower than the content in both old and young leaves in this study, which could be attributed to natural variations caused by different growing conditions. The taro leaves studied in this work were harvested in autumn (April 2005) while the taro leaves studied by Dubois and Savage were harvested in early spring (August, 2004). Taro leaves should be considered a high oxa-

Table 1
Mean dry matter and oxalate composition (mg/100 g FW ± SE) of young and old taro leaves

Age of leaf	Dry matter (mg/100 g FW)	Total	Soluble (mg/100 g FW)	Insoluble
Young leaves	12.2 ± 0.6	589 ± 35.8	442 ± 35.8	147 ± 50.1
Old leaves	12.9 ± 0.7	443 ± 15.0	334 ± 14.7	110 ± 11.7
Level of significance[a]	NS	***	***	***
l.s.d	3.2	95.0	82.8	35.8

[a] Significance: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, NS = not significant, l.s.d. = least significant difference.

late food and should be compared with other green leafy vegetables such as spinach (330 ± 0.8 mg total oxalates/100 g FW) and Swiss chard (526 ± 13.0 mg total oxalates/100 g FW) (Savage et al., 2000).

The young leaves contained significantly ($p < 0.001$) more oxalates than the old leaves; a 24% reduction in total oxalate occurred as the leaves matured. However, in contrast Zindler-Frank, Hönow, and Hesse (2001) showed that the oxalate content of older *Phaseolus vugaris* leaves had a 75% increase in the insoluble oxalate content when compared to the young leaves. In a study on purslane (*Portulaca oleracea*) young leaves contained a mean of 482 mg total oxalate100 g FW while leaves from older plants were 29% lower (mean of 295 mg total oxalate/100 g FW). Palaniswamy, Bible, and McAvoy (2004) went on to recommend that young purslane leaves should not be harvested because of their higher oxalic acid content compared with older leaves.

3.2. Soluble and insoluble oxalates

The ratios between soluble and insoluble oxalates were similar in the young and the old leaves, with soluble oxalates contributing 74% of the total oxalates (Table 2). This was quite different from the study by Holloway et al. (1989) where the soluble oxalates were only 30% of the total oxalates. However, the taro leaves in this study were grown in a greenhouse in the South Island of New Zealand while the leaves analysed by Holloway et al. (1989) were grown in Fiji. The high ratio of soluble oxalates in taro leaves opens the possibility of reducing the oxalate content by pre-treatment since some soluble oxalates can be removed by leaching into water. Dubois and Savage (2006) showed that soaking the leaves in cold tap water for 18 h resulted in a 26% decrease in soluble oxalates. In the same study Dubois and Savage (2006) showed that boiling in water gave a 36% loss of soluble oxalates from taro leaves.

3.3. Baking

The dry matter contents of the baked young leaves was 23.1 g DM/100 g FW while the dry matter of the baked old leaves was 19.4 g DM/100 g FW. Baking the leaves at 150 °C for 1.5 h resulted in the soluble and insoluble oxalate content on a wet matter basis being significantly ($p < 0.001$) higher in the baked leaves than the raw leaves on a fresh weight basis. This is because during baking water is lost and a concentration of oxalates occurs in the baked tissue. In an earlier study when taro leaves were baked at 220 °C for 15 min, the oxalate concentration was only affected slightly as only a small amount of water was lost (Dubois & Savage, 2006).

The soluble oxalates fell from 73% of total oxalates to 45% when the leaves were baked. This effect could be due to disruption of the tissue caused by the heat, making it possible for free calcium in the young leaf tissue to combine with soluble oxalic acid to form insoluble oxalate in the cooked tissue. However, this effect was not observed in the older leaves.

3.4. The effect of baking taro leaves with milk

The mean dry matter of the young and old taro leaves baked with milk was very similar (mean 14.6 g DM/100 g FW). Baking the leaves with milk resulted in a decrease of soluble oxalate content of the cooked tissue (49% reduction in the young tissue, 73% in the old tissue) as the calcium in the milk bound with the soluble oxalate in the leaf tissue to form calcium oxalate. Baking the leaves with milk led to a significant ($p < 0.001$) reduction in the soluble oxalate content of both samples of cooked tissue when compared to the tissue cooked without milk.

3.5. Oxalate: calcium ratio

The young leaves contained 149 mg calcium/100 g FW while the older leaves contained 189 mg calcium/100 g FW (Table 3). These are similar to the values reported by Holloway et al. (1989) for leaves grown in Fiji but lower than the values reported for raw taro leaves (268 mg calcium/100 g) by Chay-Prove and Goebel (2004). Assuming that the insoluble oxalate in raw leaves is calcium oxalate then it is possible to calculate the amount of calcium bound into that molecule. In the young leaves 9.8% of the total calcium was bound as calcium oxalate while only 5.8% of

Table 2
Mean percent soluble and insoluble oxalate composition in young and old taro leaves baked with and without milk

Age of leaf and treatment		Soluble (%)	Insoluble (%)
Young leaves	Fresh	72.4 ± 4.68	27.6 ± 4.68
	Baked	45.1 ± 5.28	54.9 ± 5.28
	Baked with milk	23.7 ± 1.91	76.3 ± 1.91
Old leaves	Fresh	75.3 ± 2.37	24.7 ± 2.37
	Baked	72.1 ± 2.36	27.9 ± 2.36
	Baked with milk	19.3 ± 1.92	80.7 ± 1.92
Analysis of variance[a]	df		
Leaf age	1	*	*
Cooking	2	***	***
Leaf age × cooking	2	**	**
l.s.d		10.25	10.25

[a] Significance: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, NS = not significant, l.s.d. = least significant difference.

Table 3
Calcium content (mg/100 g FW) of young and old taro leaves (% of total calcium in parenthesis)

Age of leaf	Total calcium (mg/100 g FW)	Calcium bound as calcium oxalate (mg/100 g FW)	Calcium not bound to calcium oxalate (mg/100 g FW)	Oxalate/ calcium ratio
Young leaves	149	15 (10.1%)	134 (89.9%)	1.8
Old leaves	189	11 (5.8%)	178 (94.2%)	1.1

the total calcium was bound in the old leaves. Another way of presenting this is to calculate the oxalate:calcium ratio in the leaves. The oxalate:calcium molar ratio for the raw taro leaves in this study ranges from 1.8 for the young leaves to 1.1 in the older leaves. This confirms that raw taro leaves are a reasonable source of total calcium with only a small proportion bound to oxalates.

4. Conclusions

This study suggests that taro leaves should be included in the high oxalate food group and should be avoided by people who have an increased risk of calcium oxalate stone formation, or low calcium intake. Taro leaves particularly young leaves will supply a significant amount of oxalate in the diet if they are eaten regularly. Baking taro leaves effectively concentrates the oxalate content of the cooked dish. Baking at a higher temperature for a shorter period of time or boiling the leaves will reduce the oxalate content compared with traditional baking. Another option for at risk groups could be to consume cooked taro with milk as this decreases the amount of soluble oxalates that would be available for absorption in the small intestine.

Acknowledgements

The authors wish to thank Siale Faitotonu, a member of the Kahoa Tauleva Christchurch Trust for the supply of the taro leaves and our colleagues Leo Vanhanen, David Catherwood and Sue Mason for their assistance in many ways throughout this project.

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