



Short Communication

Composition of oxalates in baked taro (*Colocasia esculenta* var. Schott) leaves cooked alone or with additions of cows milk or coconut milkG.P. Savage^{a,*}, L. Mårtensson^b, J.R. Sedcole^a^a Food Group, Agriculture and Life Sciences, Lincoln University, Canterbury, New Zealand^b Department of Food Science, Swedish University of Agricultural Science, Uppsala, Sweden

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ABSTRACT

Taro (*Colocasia esculenta* var. Schott) is a major staple food crop in parts of Asia and the Pacific Islands and two different cultivars of taro plants Taro Tonga (*C. esculenta*) and Taro Futuna (*Xanthosoma sagittifolium*), known respectively as Maori and Japanese, are grown as a minor crop in New Zealand. The leaves are either boiled or baked before they are consumed. In this experiment the leaves were baked at 150 °C for 1.5 h either alone or with additions of cows milk and coconut milk prior to baking. Oxalate contents of both cultivars of leaves were determined following extraction by either hot distilled water (80 °C) to give soluble oxalates or hot (80 °C) acid (0.2 mol/l HCl) to give total oxalates. The extracted oxalates were then determined by HPLC chromatography. Baked Maori-type taro leaves contained 719.3 ± 12.0 mg total oxalates/100 g fresh weight (FW) and 365.9 ± 11.4 soluble oxalates/100 g FW while baked Japanese-type leaves contained 533.9 ± 14.9 mg total oxalates/100 g FW and 352.6 ± 8.4 mg soluble oxalates/100 g FW. The total and soluble oxalate content of the baked leaves was considerably reduced when the leaves were baked with cows milk, coconut milk or mixtures of these two (mean % reduction of total oxalates was 43.2 ± 3.8% while the mean % reduction of soluble oxalates was 58.7 ± 1.8%).

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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 (Busch et al., 2003). There are, however, many plants which are also referred to as taro some of which are found in other families such as cyrtosperma and xanthosoma (Busch et al., 2003). True taro 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 and Goebel, 2005) and the leaves are also used as a vegetable (Aregheore and Perera, 2003). Taro is an important part of Pacific Island diet (Matthews, 2004) and taro leaves and corms are imported into New Zealand and Australia usually for Pacific Island people who eat taro regularly. Four main varieties of taro are grown in Tonga, Kul, Tea, Tonca and Taro Futuna (Smit, 1989). Taro Tonga (*C. esculenta*) and Taro Futuna (*Xanthosoma sagittifolium*) are the most commonly grown in the Islands and they

are respectively known as Maori and Japanese in New Zealand (Siale Faitotonu, 2007, pers. com.). These two types of taro plants, Maori and Japanese can be identified by differences in their leaf shape (Mårtensson, 2006) and are grown for solely their leaves in New Zealand.

Most taro cultivars taste acrid and can cause swelling of lips, mouth and throat if eaten raw (Bradbury and Nixon, 1998). This acidity is caused by needle-like calcium oxalate crystals, raphides, that can penetrate soft skin (Bradbury and Nixon, 1998). Thereafter an irritant present on the raphides, probably a protease, can cause discomfort in the tissue (Bradbury and Nixon, 1998; Paull et al., 1999). Both the root and the leaves can give this reaction (FAO, 1992) but this effect is reduced by cooking (Bradbury and 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 and Savage, 1999). In contrast, baking a food will cause a concentration of oxalates in the food due to the loss of water during baking (Noonan and Savage, 1999).

Plants containing oxalate usually have the highest concentration in the leaves; taro is no exception (Busch et al., 2003). In the

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Pacific Islands taro leaves are frequently boiled or baked and the leaves are often cooked with either coconut milk or cows milk (Siale Faitotonu, 2007, pers. com.) as these additions tend to reduce the sharp taste of the leaves. The sharp taste is referred to as *fifisi* in Tongan. In the Pacific Islands coconut milk is a readily available, relatively inexpensive food product and as its taste is highly regarded it is added to many foods. Dried cows milk is often used in cooking and food preparation as fresh milk is both expensive and often unavailable. Coconut milk contains 20% oil and relatively low levels of calcium while in contrast dried cows milk contains much higher levels of calcium and very low levels of milk fat (0.5%).

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 Albiñ and Savage (2001) demonstrated that the bioavailability of oxalate could be reduced to zero if baked oca was eaten with sour cream. More recently, Mårtensson and Savage (submitted for publication) showed that the addition of non-fat cows milk or the addition of a 50/50 milk and coconut milk mixture to baked taro leaves was almost equally effective at reducing the mean urinary oxalate output following the consumption of standard test meals by volunteers. This suggested that both additions, already widely used in the Pacific Islands, effectively reduced the absorption of soluble oxalates during passage of the test meal down the small intestine from the baked taro leaves when eaten as a test meal. The reduction of soluble oxalates in the baked mixtures resulted from the combination of calcium supplied by the additions of cows milk or coconut milk to the baked taro leaves with soluble oxalates released from the taro leaves during baking. 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 baking with cows and coconut milk or their mixtures can reduce the risk of absorbing excess soluble oxalates when taro leaves are consumed as part of the diet.

2. Materials and methods

2.1. Harvesting

Leaves from two cultivars of taro, Maori (*C. esculenta* (L.) Schott) and Japanese (*X. sagittifolium* (L.) Schott), were harvested in spring (November 2005) from a greenhouse run by a Tongan Community Trust (Kahoa Tahoā Tauleva Christchurch Trust) situated at Pukekohe, south of Auckland, New Zealand.

2.2. Cooking

115 g of taro leaves without petioles (a standard serving, Alhar et al., 2006), were put into 600 ml round mixing bowls (Pyrex, Corning, Reston, USA), covered with aluminium foil and baked in a domestic fan bake oven (Simpson, Gemini, Australia) at 150 °C for 1.5 h. In addition, leaves were baked, as above, with 115 ml non-fat cows milk made from milk powder (Pam's Products Ltd., Mt. Roskill, Auckland, NZ, 115 ml non-fat milk contains 11.5 g milk powder), 115 ml coconut milk (Sincere, Sun Tan Holdings Ltd., Christchurch), 57.5 ml cows milk and 57.5 ml coconut milk and finally 115 ml coconut milk with 11.5 g cows milk powder dissolved in it. The cooking methods broadly followed the cooking and preparation of the Tongan dish, Lu Pulu (Siale Faitotonu, pers. com.) After cooking the leaves were homogenized with a household stick mixer (ZIP, New Zealand) representative samples were

taken from each treatment and deep frozen at –20 °C for later analysis.

2.3. Chemical extraction: total and soluble oxalates

Soluble and total oxalate contents of 3 g of homogenized samples of raw leaves and baked leaves with and without additions of cows milk and coconut milk were extracted and measured as described in detail by Savage et al. (2000). Insoluble oxalate content (which is predominantly calcium oxalate) was calculated by difference (Holloway et al., 1989). Each sample was analysed six times and all data are presented as mg oxalate/100 g fresh weight (FW) as this is how this vegetable is normally consumed.

2.4. Statistical analyses

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

3. Results and discussion

Maori and Japanese (also called Futuna) taro plants have a very similar appearance except for the difference in the shape of the leaves where they connect to the petiole (Mårtensson, 2006). The plants are commonly grown together and when they are harvested for food the leaves are often mixed before they are cooked. The dry matter (DM) content and the mean amount of total, soluble and insoluble oxalates on a fresh weight basis (FW) of the two cultivars of taro leaves are shown in Table 1. The DM and the oxalate contents of the two cultivars were very similar except for a lower insoluble oxalate content in the Japanese taro leaves ($P < 0.005$). Baking led to an increase in dry matter content of the baked leaves (mean of 14.3 mg/100 g FW) compared to the fresh leaves, which contained 13.4 g dry matter/100 g FW (Table 1). The total oxalates in the baked Maori and Japanese leaves were 719.3 ± 12.0 and 533.9 ± 14.9 mg/100 g FW, respectively. These were significantly different from each other ($P < 0.01$). The mean total oxalate of the baked tissue increased when compared to the concentration in the fresh raw leaves. The total oxalate content of the Maori and Japanese taro leaves baked with the addition of cows milk or coconut milk were significantly reduced ($P < 0.01$). The soluble oxalate contents of the Maori and Japanese taro leaves were very similar but the soluble oxalate contents of the mixes prepared from the addition of cows milk or coconut to the leaves were significantly reduced ($P < 0.01$) by each treatment. The proportion of soluble oxalates in the baked leaves (mean 57%) was very similar to the amounts found in the raw tissue (mean 55%). This is in contrast to an earlier study by Oscarsson and Savage (2007) who showed that baking young and old taro leaves significantly reduced the proportion of soluble oxalates from 73.9% in the fresh leaves to 21.5% in the baked leaves.

Addition of cows milk and coconut milk led to an increase in both the added calcium and the resulting dry matter content of the baked mixtures (Table 1), except when 115 ml of milk was added to the leaves. Addition of cows milk or coconut milk, and mixtures of the two products, led to an overall reduction in total oxalates of 43.2% when compared to the plain baked Maori and Japanese leaves. This reduction occurred due to the dilution effect from the addition of dry matter to the mixtures. However, reduction in soluble oxalate contents in the baked mixes occurred not only from simple dilution effects of the mixtures but also from the binding of added free calcium (from addition of cows or coconut milk) with soluble oxalates released from the baked taro leaves being formed into insoluble oxalates in the final cooked mix. The three mixes milk, coconut milk and a 50/50 mix of cows milk and coconut milk were equally effective at reducing the overall soluble oxalate of the

Table 1Mean total, soluble and insoluble oxalate composition (mg/100 g FW \pm S.E.) of Maori and Japanese taro leaves baked with cows milk and coconut milk additions.

Cultivar	Treatment	Calcium added to test mix from either cows milk or coconut milk (mg)	Dry matter (mg/100 g WM)	Total oxalate (mg/100 g FW)	Soluble oxalate (mg/100 g FW)	Insoluble oxalate (mg/100 g FW)
Maori	Raw leaves	–	10.8	524.2 \pm 21.3	241.1 \pm 20.9	283.0 \pm 27.7
Japanese	Raw leaves	–	11.2	525.6 \pm 19.9	330.4 \pm 28.3	195.1 \pm 19.2
Maori	Baked	–	14.4	719.3 \pm 12.0	365.9 \pm 11.4	353.4 \pm 21.3
Japanese	Baked	–	14.2	533.9 \pm 14.9	352.6 \pm 8.4	181.4 \pm 21.7
Maori	Baked with cows milk	140.3	11.9	381.0 \pm 26.0	159.7 \pm 11.0	221.3 \pm 24.5
Japanese	Baked with cows milk	140.3	11.2	298.8 \pm 6.7	143.9 \pm 8.1	154.9 \pm 5.5
Maori	Baked with coconut milk	33.4	19.1	387.2 \pm 35.6	156.8 \pm 3.7	230.5 \pm 35.2
Japanese	Baked with coconut milk	33.4	17.9	347.2 \pm 12.6	157.7 \pm 8.6	190.9 \pm 13.2
Maori	Baked with 50/50 cows milk and coconut milk	86.8	17.3	387.7 \pm 14.7	131.0 \pm 12.0	256.7 \pm 13.8
Japanese	Baked with 50/50 cows milk and coconut milk	86.8	18.4	408.7 \pm 13.0	175.5 \pm 16.9	233.2 \pm 9.3
Maori	Baked with milk powder dissolved in coconut milk	173.7	22.4	364.3 \pm 24.5	124.6 \pm 3.8	239.7 \pm 25.5
Japanese	Baked with milk powder dissolved in coconut milk	173.7	21.4	317.4 \pm 6.6	136.3 \pm 22.8	181.2 \pm 15.9
Analysis of variance	d.f.			Significance		
Cultivar	1			*	NS	**
Treatments	5			**	**	*
Raw \times cooked	1			*	NS	NS
Baked \times calcium added	1			**	***	**
S.E.M.				30.3	18.0	13.6

mixtures (mean reduction compared to the plain baked leaves was 58.7%). A mean 63.6% reduction in the soluble oxalate content was achieved when 11.5 g non-fat cows milk powder was dissolved in 115 ml coconut milk. This mix contained the highest content of added calcium of all the test meals. One way analysis of variance using a contrast showed that the significant difference ($P < 0.001$) in the levels of total and soluble oxalates in the baked mixes resulting from the addition of different levels of calcium was entirely due to the differences between the two leaves-baked-alone mixes and all the other mixes, where cows or coconut milk or combinations were added to the leaves prior to baking. A paired t -test showed that there was a highly significant difference ($P < 0.01$) between the mean reduction of the total oxalates in the four mixes where cows or coconut milk was added (mean % reduction 43.2 ± 3.8) compared with the mean reduction in the soluble oxalate content of the same mixes (mean % reduction 58.7 ± 1.8). The difference between these values confirms that calcium from the added cows milk or coconut milk was effective at reducing the soluble oxalate content of the cooked mix as the reduction in total oxalate was the result of simple dilution from the added materials. It is most interesting to note that the addition of only 33.4 mg calcium from the coconut milk was effective and that addition of much larger amounts of calcium from the milk-based diets had very little increased effect in reducing the soluble oxalate content of the final cooked mix.

The Maori taro leaves had a significantly higher proportion of the total oxalate as insoluble oxalate than the Japanese leaves. It is generally assumed that insoluble oxalate in the leaves is predominantly calcium oxalate and that would make Maori plants more resistant than Japanese plants against herbivores and micro organisms since calcium oxalate is assumed to be connected with the plant's defence system (Noonan and Savage, 1999).

Taro leaves are commonly either boiled or baked. Earlier experiments have shown that soaking taro leaves for 18 h or boiling for 2 min can significantly reduce the soluble oxalate content of the leaves by 26 and 36% respectively (Savage and

Dubois, 2006). When the leaves are baked there is no possibility of losses of soluble oxalates by leaching but the soluble oxalate content of the leaves could be reduced by combination with soluble minerals, such as calcium, from within the leaves or from materials cooked with the leaves such as cows or coconut milk. However, taro leaves are seldom eaten alone and are often consumed after being baked in cows milk or coconut milk. The results shown in Table 1 suggest that the addition of cows milk or coconut milk are equally effective at reducing the soluble oxalate content of the final baked mix even though the coconut milk contained relatively low levels of calcium compared to cows milk. These results may be confounded by differences in the availability of calcium in the coconut and cows milk and the fact that the coconut milk contained 20% fat while the non-fat milk powder contained 0.1% fat. Addition of more than 33.4 mg Ca (supplied by the addition of coconut milk) to the test mixes did not incrementally reduce the soluble oxalate of the final baked mixes.

In a similar trial, Brogren and Savage (2003) showed that when spinach was baked with different calcium sources there was a decrease in the urinary excretion of total oxalate after the test meals were consumed. Spinach eaten alone gave 14.0 ± 3.7 mg of mean urinary oxalate/6 h. Spinach baked with sour cream and cows milk gave the best result (8.1 ± 2.2 mg/6 h), followed by spinach and sour cream (11.7 ± 4.2 mg/6 h). In contrast, baking spinach with olive oil gave an even higher result than for the plain baked spinach (16.0 ± 6.9 mg/6 h). Therefore, in their study, adding fat to a test meal increased the absorption of oxalate from the digestive tract. In contrast, Liebman et al. (1999) observed that addition of fat or olestra (a fat substitute that is not absorbed in the gastrointestinal tract) to a potato diet depressed the oxalate absorption (10.5 and 12.2%, respectively) compared to the potato diet alone (13.2%). Also, Finch et al. (1981) noted that higher fat containing foods like peanuts and chocolate appeared to have a higher relative absorption of oxalate when compared to spinach (8.5 and 9.0% compared to 1.5%).

In a recent experiment reported by Mårtensson and Savage (submitted for publication), addition of non-fat cows milk or the

addition of 50/50 milk and coconut milk to baked taro leaves was almost equally effective at reducing the mean urinary oxalate output following the consumption of standard test meals. This suggested that both additions, already widely used in the Pacific Islands, effectively reduced the absorption of soluble oxalates from the baked taro leaves.

The standard serving size of cooked taro leaves is a cup full (250 ml) which is 115 g FW (Alhar et al., 2006). Consumption of this amount of baked taro leaves would mean that 359.3 mg soluble oxalate (mean value of Maori and Japanese leaves) would be consumed in one meal. Assuming that people would eat the same amount of the baked taro leaf mixes, consumption of the leaves baked with cows milk, coconut milk, 50/50 cows milk and coconut milk and cows milk powder dissolved in coconut milk would lead to the consumption, respectively, of 151.8, 157.3, 153.3 and 130.5 mg soluble oxalate per serving. The overall mean value from the cows milk and coconut milk additions was 148.2 mg soluble oxalate per serving which is an overall $58.7 \pm 1.8\%$ reduction in soluble oxalate content of the standard 115 g serving.

This study confirms that the baked taro leaves should be included in the high oxalate food group, as defined by Noonan and Savage (1999). Taro leaves baked with cows milk or coconut milk combinations; although they contain much lower levels of soluble oxalates, still remain in the high oxalate group of foods.

4. Conclusions

This study confirms 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. Baked taro 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. Another option for at risk groups could be to consume cooked taro leaves with cows milk or coconut milk as this decreases the amount of soluble oxalates that would be available for absorption in the small intestine but this option does not completely eliminate the soluble oxalate content of the mixtures.

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