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Aluminum Concentrations in Selected Foods Prepared in Aluminum Cookware, and Its Implications for Human Health

N. Fimreite, O. Ø. Hansen, H. C. Pettersen

Department of Environmental Sciences, Telemark College, 3800 Bø, Norway

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There is evidence, although conflicting, that aluminum is a factor in the development of serious brain disorders like Alzheimers disease since abnormal accumulations of aluminum have been identified within neurons derived from patients suffering from such diseases (Perl 1985). Abnormal accumulations apparently result from ingestion of aluminum derived from different sources, of which increased intake of aluminum in drinking water caused by acid rain has been much in focus the last years. Stressing side effects like anaemia, osteomalacia, and a neurologic syndrome known as dialysis encephalopathy have been observed in patients with chronic kidney disease. Such patients are exposed to higher aluminum levels than normal from large volumes of water used in dialysis (Precott 1989). It is also well known that high dosages of medicaments like antacids containing aluminum hydroxide contribute to the body burden of aluminum (Spencer 1982). Other important sources are foodstuffs prepared and/or stored in aluminum utensils. However, the latter has attracted little attention and has often been dismissed as trivial compared to other sources (Trapp and Cannon 1981, Lione et al. 1989), despite it having been known for more than half a century that aluminum pots or foils are vulnerable to degradation by acidic or alkaline foods (Glaister and Allison 1913, Campbell et al. 1957, King et al. Will 1981). For example Lione (1983) has shown that an aluminum pot used to prepare tomato sauce can add up to 4 mg aluminum to each serving. Lione et al. (1984) found that coffee brewed in aluminum percolators contained considerable amounts of aluminum, and Aikoh and Nishio (1996) documented significant concentrations of aluminum in beverages stored in aluminum cans.

The present study was carried out with the aim of documenting levels of aluminum in selected acid foods and tea cooked in aluminum cookware, still used extensively in many households.

Correspondence to: N. Fimreite

MATERIALS AND METHODS

The aluminum cookware applied in the experiment consisted of 3 ordinary cooking pots and a special cooker used for boiling juice out of berries (juice boiler). A steel pot was used as a control. Relevant information regarding make, volume, age etc. is given in Table 1.

Table 1. Data on cookware used in the experiment

Pot no.	Material	Volume (L)	Manufact.	Age (yr)	Remarks
1	Aluminum	2	Høyang	30	Heavy eroded
2	Aluminum	1	Høyang	10	Slightly eroded
3	Aluminum	5	Høyang	0	Brand new
4	Steel	2.5	Polaris	0	Brand new
5	Aluminum	4	Høyang	10	Juice boiler

The following products were examined for aluminum content: black currant juice, stewed rhubarb , and tea. They were prepared as follows.

The black currant juice was cooked following two different recommended procedures. 1) Four litres of fresh black currants, 1 kg of sugar, and 500 mL of water were mixed and brought to a boil in the aluminum juice boiler (Table 1). The first samples were collected after boiling for 30 min, after which samples were collected every 10 min for the next 60 min. 2) The same procedure as above except that the sugar was added after the water and currants were brought to a boil and the mixture then reboiled. For comparison, juice squeezed from the currants in a cloth was also sampled for analysis.

Tea manufactured by Lipton and Twinning, both in portion bags of 2 grams, were tested. Two different pots were used, one made of aluminum (Table 1, no. 2) and the other of steel (Table 1, no. 4). The tea bags were put in 200 mL of distilled, boiling water and kept hot. Samples were collected after 5 and 10 minutes. The tea leaves were also analyzed for aluminum.

The stewed rhubarb consisted of 700 grams of fresh rhubarb, 400 mL water, and 100 grams sugar. This mixture was boiled for 10 minutes, after which potato starch was added and the mixture reboiled. The stew was cooked in 4 different pots, three made of aluminum (Table 1, nos. 1, 2, and 3 , respectively), and one of steel. (Table 1, no. 4). Samples were collected after 5, 10 and 12 minutes cooking.

The aluminum concentrations were determined by atomic absorption spectrophotometry using the graphite furnace techniques. We used a Perkin Elmer 460 with HGA 400. Detection limit is 0.005 mg/kg. We corrected for background levels in water and acids used in the experiment. They were 0.01 mg/L for $HN0^3$ and distilled water, and 0.04 mg/L for tap water. Standard procedures were followed. Three parallel samples were collected for analysis. For statistical correlation and regression analysis we followed Sokal and Rohlf (1969).

RESULTS AND DISCUSSION

Aluminum accumulations in black currant juice increased linearly with the cooking time (Figure 1, $p < 0.01$). The cooking procedure had a marked influence on the final concentration. In juice added sugar (the sugar contained 0.1 mg Al/kg) before the initial boiling it reached 23 mg/L in contrast to 50 mg/L with sugar added following the initial boiling. Since sugar has no alkaline or acid neutralizing properties a possible explanation can be that the sugar may have formed a sort of coating that reduced the contact between the acids in the juice and the aluminum surface. The juice squeezed from the currants using a cloth contained only 0.05 mg/L.

The aluminum concentrations in the stewed rhubarb prepared in the alumimum pots reached 15 -23 mg/kg after 12 minutes of cooking and were approximately proportional to the cooking time (Figure 2). The levels in the stew prepared in the steel pot averaged 0.8 mg/kg and did not increase with cooking time, indicating that the aluminum originated largely from the aluminum pots. There were differences among the aluminum pots as the oldest one (30 years) released more aluminum than the others, but no appreciable difference was observed between the 10 years old pot and the new one. The increase in the concentrations after addition of potato starch (10 minutes from start) can be due to aluminum content of the starch but is not likely since no such increase took place in the steel pot. The more elevated levels in the stew made in pot no. 1 is not surprising as this old pot was much eroded with deep excavations in the bottom and therefore had a larger surface area.

The aluminum concentrations in the brewed tea increased with brewing time and reached concentrations between 4 and 5 mg A1/L after 10 minutes. There was no noticable difference between the two types of tea and, surprisingly, the levels did not depend on which kind of pot was used, whether made of aluminum or stainless steel (Figure 3). This indicates that practically the whole content of aluminum in the beverage

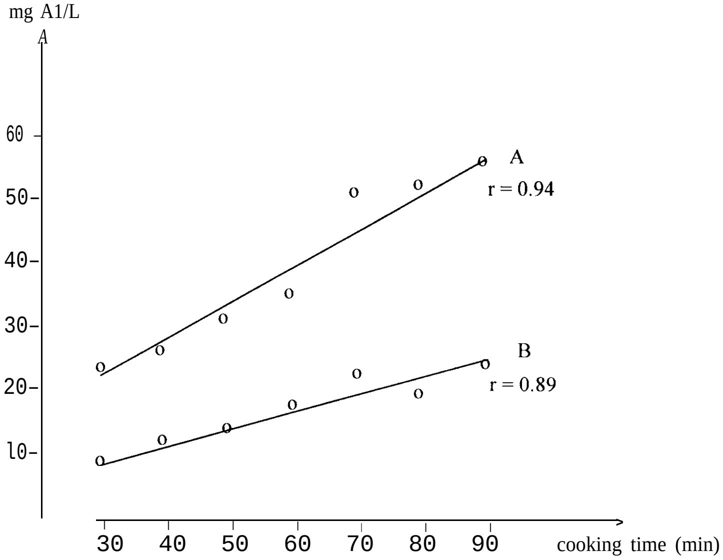

Figure l. Aluminum concentrations in black currant juice.
A. Sugar added to currants and water before boiling.
B. Sugar added after the currants and water were brought to boil, and the mixture reboiled.
Each point represents the average of 3 replicates.

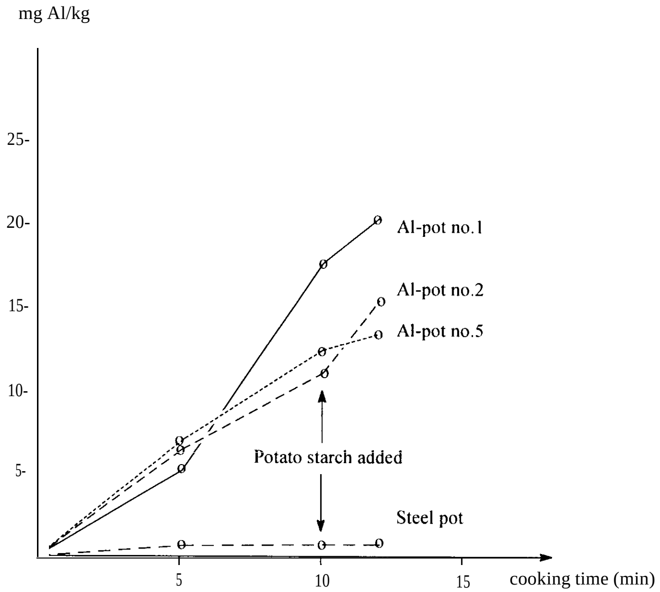

Figure 2. Aluminum concentrations in stewed rhubarb.
Each point represents the average of 3 replicates.

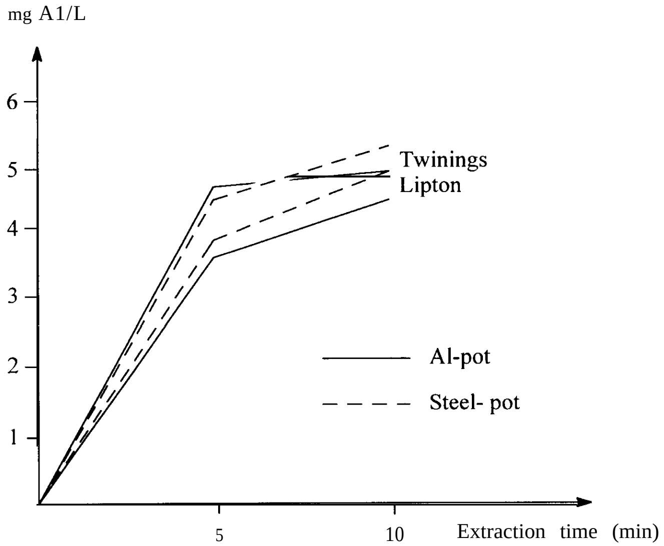

Figure 3. The aluminum concentrations in the tea.Each point represents the average of 3 replicates. The extraction time zero shows the aluminum content of distilled, boiled water, which was negligible (< 0.01 mg Al /L)

had to originate from that in the tea leaves. The tea plant *(Camellia sinensis)* is known to be a strong aluminum accumulator, as is the case with many other tropical and subtropical plant species, and mature leaves may contain up to 20000 ug/g (Sivasubramaniam and Talibudeen 1971, Jones and Bennet 1986). Our analyses also revealed considerable concentrations in tea leaves, 515 ug/g (Lipton) and 526 ug/g (Twinning). This is identical to 1.04 mg per 2 gram bag, meaning that 96 % (5.0/5.2) of the aluminum had been extracted from the tea leaves when prepared in the steel pot and 94 % when brewed in the aluminum pot. From Figure 3 it appears that the leaching from tea leaves occurs very fast as 70% of the final concentration was reached after 5 minutes of extraction.

The erosion of aluminum from aluminum pots induced by the acid products of black currant juice and stewed rhubarb was substantial and may have toxic implications. Martyn et al. (1989) and Michel (1990) associated an intake of drinking water containing 0.11 ppm with increased risk for Alzheimers disease. The present levels were up to 500 times higher. The juice from black currants is usually diluted with water before use, but even when diluted by a factor of 5, as is common, the concentration is 5 ppm. A glass (200 ml) of such diluted juice contains about 1 mg Al, that is 10 times higher than that found in 1 litre of the aforementioned drinking water. The latter are probably realistic intakes of juice and water, respectively, and therefore comparable in evaluating the toxic risks.

Also the consumption of stewed rhubarb may contribute considerably to the body burden of aluminum. A dessert consisting of 200 grams of stew is equivalent to an intake of about 4 mg Al and therefore, if used frequently, a most significant source of aluminum intake. The tea contained about the same amount of aluminum as the diluted black currant juice, but since tea is a more common drink its potential as a source of contamination deserves special scrutiny.

There is no doubt that the present foodstuffs prepared in aluminum cookware increase the intake of aluminum substantially if used frequently. Alfrey (1986) suggests that a normal daily intake is 3 to 5 mg. The effects, however , are dependent upon whether the aluminum is absorbed or not. According to Prescott (1989) between 75 and 95 % of the aluminum we eat or drink is egested as insoluble material in the feces. The rest is absorbed and may accumulate in various organs such as bones and lungs, or is excreted in the urine. The bioavailability of aluminum, however, is unclear as the present evidence is conflicting. Kawachy and Pearce (1991) and Martyn et al. (1989) suggested that aluminum is more bioavailable when dissolved in water than in foodstuffs. Other researchers have observed that some patients may consume up to 1 gram of aluminum daily in the form of antacids, apparently without any signs of dementia or other aluminum related diseases (Aikoh and Nishio 1996) while Spencer et al. (1982), on the other hand reported that only small amounts of Al-containing antacids affect calcium and phosphorus metabolism. Corrodible aluminum cookware may be a significant source of aluminum intake, but the link between this source and possible biological effects is still unclear. In the meantime, we should avoid using such utensils, at least for preparing strong acidic foods and beverages.

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