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Leaching and bioavailability of aluminium, copper and manganese from tea (*Camellia sinensis*)

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Abstract

To assess human exposure to Al, Cu and Mn from tea drinking, eight tea samples were analysed for their 'total' and soluble elemental content. From this data, the percentage of 'available' element to the human system was calculated. Results for the samples showed that, compared to background levels for plants, concentrations of Al were highly elevated. The solubility of Al, Cu and Mn in infusions at 2, 5 and 10 min with boiling water showed that the solubility in the first infusion was the highest followed by the second and the third infusions in decreasing order. Calculation of percentage 'available' Al, Cu and Mn to the human system showed that tea is a rich source of dietary Mn, contributes towards our dietary copper intake, and is of no cause for concern in terms of Al toxicity in healthy individuals.

Keywords: *Camellia sinensis*; Availability; Leaching; Tea infusions

1. Introduction

The tea bush, *Camellia sinensis*, is a perennial shrub, which is grown commercially in a large number of countries, the northernmost being Georgia in the former Soviet Union, and the southernmost being South Africa and Argentina. Although India, China and Sri Lanka are the three major producers, significant quantities are also grown in Java, Sumatra, Japan and in parts of Africa. The major tea exporting countries of the world are Kenya, China, India, Indonesia and Sri Lanka (The Tea Council, 2004).

Cultivation of tea crops requires a high annual rainfall and air humidity. Air temperatures in the range of 18–30 °C and soil temperatures between 20 and 25 °C are optimal for plant growth and high yield. Tea is grown in a wide variety of soil types, such as alluvial soils, drained peat, sedimentary soils derived from gneiss and granite, and soils derived from volcanic ash. Its growth is favoured in acidic conditions, with pH values ranging between 5.0 and 5.6. Although it will grow in soil pH as low as 4.0, soil pH only marginally higher than 5.6 is considered unsuitable without pH adjustment of soils. Soils with pH values higher than 6.5 are not amenable to treatment for commercial tea growing (Varnam & Sutherland, 1994).

The technology of tea processing is determined by the kind of tea that is being produced. The different kinds of tea which are consumed are: black, semi-fermented, green, pickled, decaffeinated and instant tea. Black tea involves the processing stages of plucking, transport, indoor withering, leaf disruption, fermentation, drying and packing. Differences in the intensity of the fermentation stage result in semi-fermented teas. Green tea differs technologically and chemically from black tea, where the fermentation stage is completely omitted from its processing and enzymic activity in the leaves is inhibited by heating as soon as possible after plucking. The character of green tea is thus largely determined by the endogenous components of the leaves at the time of plucking, rather than by compounds formed in the processing stages (Varnam & Sutherland, 1994). Pickled tea is made from fresh tea leaves which are steamed and then allowed to ferment, by burying in a pit or packing it in bamboo cylinders or baskets, where

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microorganisms acting on it are responsible for its sour and flowery flavour. Decaffeinated tea is produced by mixing black or green tea with an organic solvent, which dissolves the caffeine, which is removed. Instant tea may be made from black, semi-fermented or green dried tea leaves, and the manufacturing technology can vary from one manufacturer to another. However, the basic technology is common and involves the processing stages of extraction, clarification, aroma stripping, tea cream processing, concentration, drying (spray or freeze) and packaging.

In the context used by most consumers, tea is a beverage consisting of an infusion of the processed and dried tea leaves. It is one of the most popular beverages in the world (Graham, 1984; Mondal, Bhattacharya, Laxmikumaran, & Ahuja, 2004; Ruan & Wong, 2001) and is a rich source of some essential dietary metals (Souci, Fachmann, & Kraut, 1986; The Tea Council, 2004) and metal-binding polyphenols (Powell, Burden, & Thompson, 1998). On average, 1 l of tea is consumed per person per day in the UK (Nas, Gokalp, & Sahin, 1993), which as a percentage of average daily dietary intake, can provide 58.8% of Al, 2% of Cu and 115% of Mn (Powell et al., 1998). Studies by Wang, Su, and Wang (1994) show that of the daily dietary intake of 9–12 mg Al by Chinese population, tea contributes 0.2–1.1 mg Al, assuming that an adult drinks 1–5 g of tea per day. Al was affirmed as a food contaminant in 1989 by the Joint FAO/WHO Expert Committee on Food Additives (JECFA, 1999) who suggested a Provisional Tolerable Weekly Intake (PTWI) for Al of 7 mg kg^{-1} body weight (equivalent to 1 mg kg^{-1} body weight day^{-1}). Various studies have been conducted, to evaluate the daily dietary intake of Al from a number of food products. Studies on dietary intake of Al show an average intake of 23 mg day^{-1} for Indian population (Rao, 1994), 9–12 mg day^{-1} for Chinese population (Wang et al., 1994), 2–25 mg day^{-1} for American population, 2.2–8.1 mg day^{-1} for Japanese adult males and 0.6–33.3 mg day^{-1} for Dutch adults (Greger, 1992). The contribution of tea drinking to mineral absorption is not certain, as the bioavailability of many of these metals with tea is not known (Powell et al., 1998).

Jackson (1983) reports that tea which contains a substantial amount of Al may present health hazards (kidney weakness) for consumers. Moreover, high Al content in the human body has been hypothesized to have possible links with various diseases, such as encephalopathy dementia, oestomalacia, fractures and/or high levels of bone Al (Stewart, 1989) and Alzheimer's disease (Edwardson et al., 1989; Martyn, 1989; McLachlan, 1995). Although tea leaves and leaf infusions contain high concentrations of Al, only a small proportion of it is available for absorption in the gastro-intestinal tract (Flaten & Lund, 1997; Powell et al., 1998) and the renal excretion of Al is fairly effective (Wills & Savory, 1988). It has been observed that tea, ingested alongside food, inhibits the absorption of inorganic and some forms of organic iron, contributing to iron deficiency, mainly in women on a vegetarian diet of low iron content (Varnam & Sutherland, 1994). Studies by Powell et al. (1998) show that tea drinking may marginally decrease the availability of divalent metals, such as Cu and Zn. Moreover, apart from Mn, where a single serving of tea contributes about 10% of the average daily dietary intake of the metal in a potentially bioavailable form, tea drinking is not a rich source of essential metals in humans (Powell et al., 1998). Although some concern regarding tea consumption and caffeinism has been raised, it is markedly less common amongst tea drinkers than among coffee drinkers (Varnam & Sutherland, 1994).

The present study aims to assess our exposure to Al, Cu and Mn from tea drinking. This is achieved by: (a) determining 'total' Al, Cu and Mn contents in tea samples from different regions of the world; (b) determining the leaching of Al, Cu and Mn in infusions from these tea samples; and (c) calculating the percentage 'available' content of these elements to the human system.

2. Materials and methods

Eight tea samples produced in different parts of the world were purchased from a local supermarket and their details are given below.

Indian teas. India is the world's largest producer of tea, with more than 480,000 ha under cultivation, and exports more than 28% of the world's tea (The Tea Council, 2004). Teas from different regions of the country vary in characteristics and flavour according to the soil and climatic conditions of the growing area. The two main teas produced in India are Assam tea and Darjeeling tea, which are both black teas and were included in this study along with a third green tea from India, the Kashmir Green.

Sri Lankan teas. Sri Lanka has more than 240,000 ha under tea cultivation. Tea growing accounts for approximately 12% of the land use and provides 10.4% of the world's total tea (The Tea Council, 2004). The main Sri Lankan teas are the Ceylon Blend, Dimbula and Uva. Dimbula and Uva teas are both used in Ceylon Blend, although they can also be purchased in speciality shops as single estate teas. Ceylon and Ceylon decaffeinated were used as tea samples in the present study.

Chinese teas. Although China is as a major tea producer, producing 23.3% of the world's tea, it is predominantly known for its speciality teas (The Tea Council, 2004). The main Chinese black teas are Lapsang Souchong and Keemun, green tea is Gunpowder, semi-green tea is Oolong and flavoured tea is Jasmine tea. The Chinese teas used in the present study were Lapsang Souchong and Gunpowder Green.

Tetley teas. Tetley teas are a blend of teas from different countries. Their teas may come from up to 35 different countries and from some 10,000 different estates and each blend can contain up to 30 different teas (Tetley GB Limited, 1999). Tetley tea bag tea was used in the present study.

2.1. Treatment of samples

2.1.1. 'Total' metal analysis

Tea samples were oven dried at 70 °C for 4 h, cooled to room temperature and then Tema milled to 100 μm. Milled samples (0.5 g) were digested by nitric and perchloric acids (Thompson & Wood, 1982) and analysed for elemental composition by inductively coupled plasma–atomic emission spectrometry (ICP–AES). Quality control of results was carried out using sample replicates (10%), reagent blanks (10%) and replicate analysis of the certified reference material (CRM) for tea (GBW 07605, Institute of Geophysical and Geochemical Exploration, China).

2.1.2. Tea infusions and elemental leaching

Several studies have used different tea w/v ratios and infusion times (Flaten & Lund, 1997; Fung, Zhang, Wong, & Wong, 2003; Jackson & Lee, 1988; Koch, 1990; Muller, Anke, & Illing-Gunther, 1997; Ozdemir & Gucer, 1998; Powell et al., 1998; Rao, 1994; Wong, Zhang, Wong, & Lan, 1998; Zhou et al., 1996). Tea (5 g) was added to 200 ml of boiling distilled water (Powell et al., 1998) and allowed to infuse for 2 min. After filtering under vacuum (using a 0.45 μm cellulose nitrate membrane filter), the liquor was collected as the first infusion. The same tea samples were used for making a second and then a third infusion, using 200 ml of boiling distilled water each time and allowing to infuse for a further 3 and 5 min, respectively. Liquors from the first, second and third infusions were analysed for Al, Cu and Mn content by ICP-AES. All samples were prepared and analysed in triplicate. Comparison of elemental concentrations in tea infusions over different time periods was carried out by single factor analyis of variance.

3. Results and discussion

3.1. Quality assurance

Analysis of sample replicates showed that the coefficient of variation of the results were within ±10%. Analysis of reagent blanks showed that there was no contamination or interference from the reagents. The CRM percentage recovery for Cu and Mn were $98.0 \pm 5.7\%$ and $95.1 \pm 2.2\%$, respectively, indicating a good accuracy of the sample data generated. The Al certified value for the CRM GBW07605 is only a proposed reference value with no associated relative uncertainty values. The Al percentage recovery of $87.4 \pm 2.6\%$ for the CRM indicated that, although there was good precision in the data generated, the results obtained for Al in the tea samples may be approximately 10% lower than the actual values. However, this could not be proved from the results of the CRM alone, as these were only proposed values. Therefore, during sample analysis, Al calibration solutions were run at regular intervals between the samples, to check both the accuracy and precision of the data generated.

3.1.1. 'Total' metal concentrations

Elemental concentrations of Al, Cu and Mn in the different tea samples analysed are given in Table 1. On comparing these results with typical concentrations in vegetation (Alloway, 1990; Kabata-Pendias & Pendias, 2001; and Markert, 1993), Al concentrations in all the tea samples analysed are relatively high. Cu and Mn concentrations in the different tea samples are comparable to their typical values in plants, with the exception of a higher Cu content in the Ceylon decaffeinated tea and a higher Mn content in the Gunpowder Green and Tetley tea.

A high Al content in most of the tea samples analysed is not surprising, as the tea plant is known to be an Al accumulator. Similar Al concentrations have been reported in tea leaf samples from India (Rajwanshi et al., 1997; Rao, 1994), Sri Lanka (Koch, 1990), China (Ruan & Wong, 2001; Wong et al., 1998; Zhou et al., 1996) and different regions of the world (Fung et al., 2003; Koch, 1990; Muller et al., 1997). Moreover, concentrations as high as 23,000 mg kg^{-1} (Coriat & Gillard, 1986) and 30,000 mg kg^{-1} (Matsumoto, Hirasawa, Morimura, & Takahashi, 1976) have been reported in tea leaves, which are extremely high.

Concentrations of Cu and Mn in the tea samples in the present study (Table 1) generally compare well with literature values reported for tea samples from India, Sri Lanka, China and from various parts of the world (Koch, 1990; Ozdemir & Gucer, 1998; Rajwanshi et al., 1997; Rao, 1994; Zhou et al., 1996; Wong et al., 1998). However, analysis of Cu content in tea samples from nine tea-growing regions of the world by Lepp and Dickinson (1985) showed that eight of the nine samples exceeded the normal range of 2–20 mg kg^{-1} and samples produced from China had the highest content of 78 mg kg^{-1}. In the present study the Chinese tea sample, Lapsang Souchong, showed only marginally higher values for Cu (23 mg kg^{-1}), as compared to the typical plant concentrations (Alloway, 1990;

Table 1
'Total' mean elemental concentrations (mg kg^{-1}) in tea samples ($n = 3$)

Tea sample	Al	Cu	Mn
Indian			
Assam	458	19.8	549
Darjeeling	495	20.9	300
Kashmir Green	605	18.2	361
Sri Lankan			
Ceylon	712	23	409
Ceylon decaffeinated	1092	34	640
Chinese			
Lapsang Souchong	1053	23	582
Gunpowder Green	1307	16.6	1141
Tetley	845	15.7	1147
All samples			
Range	458–1307	15.7–34	300–1147
Mean	821	21	641
SD	307	5.8	331

Kabata-Pendias & Pendias, 2001; Markert, 1993). Moreover, Cu content of all tea samples in the present study are below the upper limits imposed in tea by various countries: Germany 40, China 60, Japan 100 and Australia, UK and USA 150 mg kg^{-1}, respectively (Chen, 1984).

Comparison of concentrations of Al, Cu and Mn between Ceylon and Ceylon *decaffeinated* tea (Table 1) showed a marked variation, and in all cases the elemental content was higher in the decaffeinated product (higher by 53.4% for Al, 47.8% for Cu, and 56.5% for Mn). Both products were produced by Whittards, but as Ceylon teas are generally blends from a number of tea estates, it is not possible to know if the source plantation was the same in both cases. The difference in metal concentrations may therefore be attributed to the tea products being produced in different tea estates with varying metal concentrations in the soils resulting in variation in elemental uptake by the tea leaves. Moreover, differences in methods used in processing and storage could be contributory factors for this difference. During the decaffeination process, tea is mixed with an organic solvent which dissolves the caffeine and is separated from the tea (Varnam & Sutherland, 1994). Therefore, elemental concentrations in mg of metal for every kg of tea product will be higher in the decaffeinated tea samples.

On comparing black tea (Assam, Darjeeling from India; Lapsang Souchong from China) with green tea samples (Kashmir Green from India; Gunpowder Green from China) (Table 1), it can be seen that Al concentrations are higher in the green teas (Kashmir Green higher than Assam by 32.1%, and Darjeeling by 22.2%; Gunpowder Green higher than Lapsang Souchong by 24.1%). This may be attributed to the processing of the green teas being different from black tea, which results in green tea being different both technologically and chemically from black tea (Varnam & Sutherland, 1994). However, no definite trend was observed for Cu and Mn content in black and green teas.

3.1.2. Tea infusions

Concentrations of Al, Cu and Mn in the tea infusions in the first, second and third infusions are given in Fig. 1. These results show that the solubilities of metals in the first infusion were significantly (Al, Cu: $P < 0.01$; Mn: $P < 0.05$) higher than in the second infusion and the solubilities in the second infusion were also significantly higher than in the third infusion (Al, Cu: $P < 0.01$; Mn: $P < 0.05$). Similar findings have been reported by Wong et al. (1998), where the solubilities of Al, Cu and Zn in the first infusion were significantly higher than in the second infusion, and by Zhou et al. (1996) where 75% of the extracted Al was contained in the first tea infusion.

The percentage transfer of elements in tea infusions in individual tea samples in the first, second and third

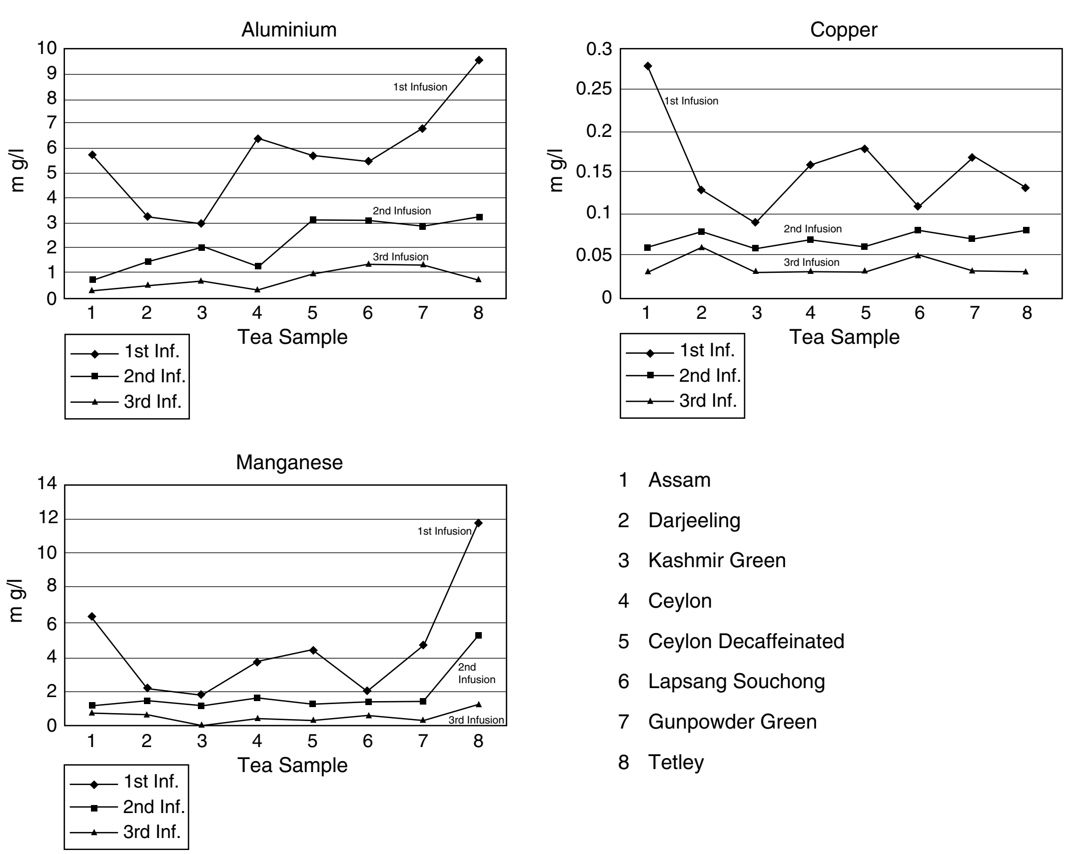

Fig. 1. Al, Cu and Mn concentrations (mg l^{-1}) in the first, second and third tea infusions.

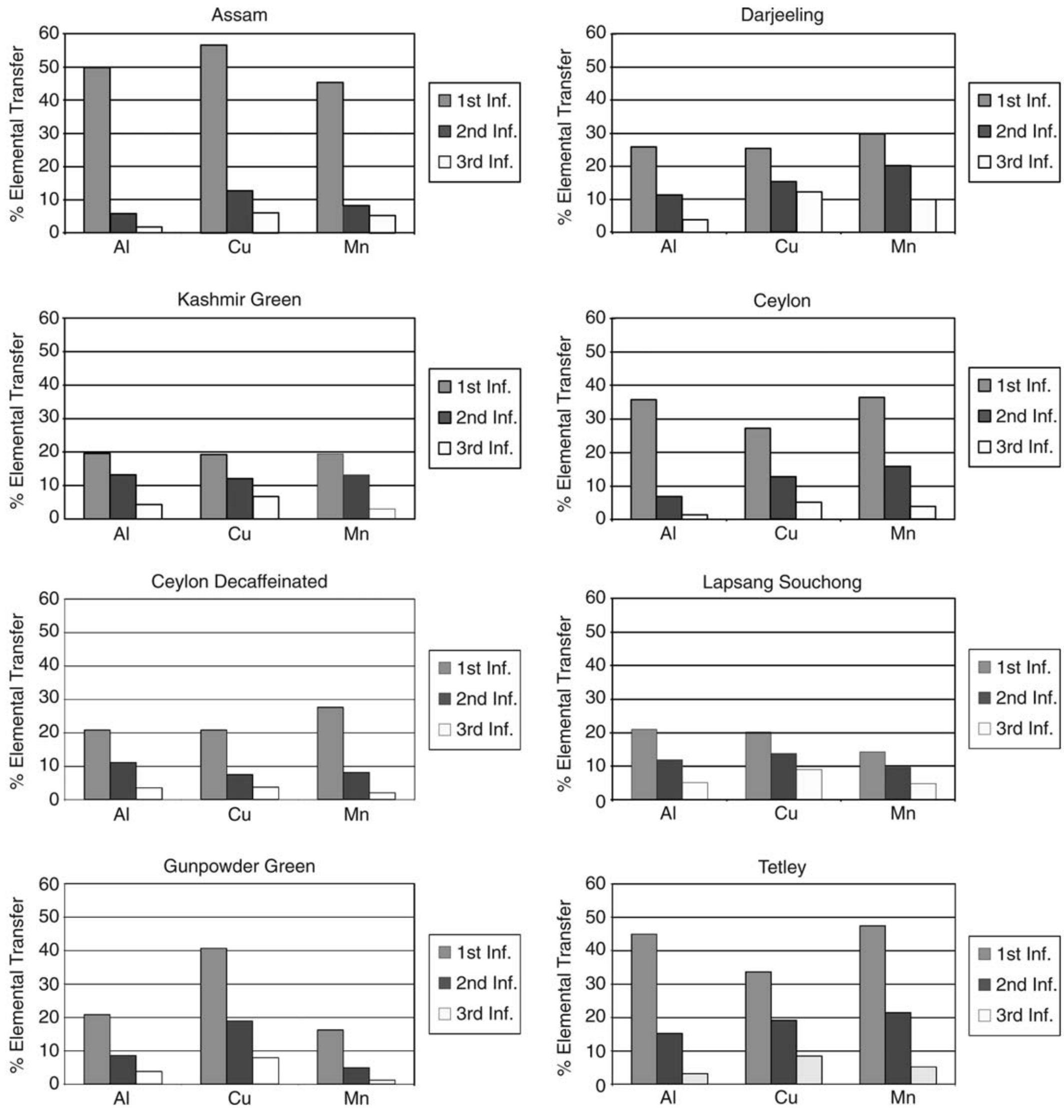

Fig. 2. Percentage transfer of Al, Cu and Mn in the first, second and third tea infusions.

infusions are shown in Fig. 2, and the mean percentage transfers for each element given in Table 2. These results show that the percentage of elements transferred into the tea liquor varied widely for the different tea samples used, specially in the first infusions as shown by the standard deviation values (Table 2). Percentage transfer of Al in the first infusion was >40% for Assam and Tetley tea samples (Fig. 2), which can be a cause for concern in terms of Al intake from tea drinking.

Table 2
Mean ($n = 8$, all tea samples) percentage transfer of elements in the first, second and third infusion

Element	First infusion	Second infusion	Third infusion
Al			
Mean	29.7	10.4	3.3
SD	12.1	3.2	1.2
Cu			
Mean	30.4	13.9	7.3
SD	12.9	3.8	2.6
Mn			
Mean	29.5	12.6	4.3
SD	12.7	6.0	2.7

Cumulative percentage elemental transfers into tea infusion over 2 min (first infusion), 5 min (first + second infusion) and 10 min (first + second + third infusion) for the different tea samples are given in Table 3 and the order of elemental transfers (see Table 3) is given below.

- Elemental transfer of Al at:
  2 min: Assam > Tetley > Ceylon > Darjeeling > Lapsang Souchong > Ceylon decaffeinated = Gunpowder Green > Kashmir Green
  5 min: Tetley > Assam > Ceylon > Darjeeling > Lapsang Souchong > Kashmir Green > Ceylon decaffeinated > Gunpowder Green

Table 3
Cumulative percentage elemental transfer in tea infusions at 2, 5 and 10 min

	Assam	Darjeeling	Kashmir Green	Ceylon	Ceylon decaffeinated	Lapsang Souchong	Gunpowder Green	Tetley
2 min								
Al	49.7	25.7	19.5	35.7	20.8	20.9	20.8	44.9
Cu	56.5	25.3	19.2	27.1	20.8	20.1	40.6	33.6
Mn	45.3	29.7	19.4	36.3	27.6	14.2	16.2	47.4
5 min								
Al	55.3	36.9	32.6	42.5	31.9	32.8	29.4	60.2
Cu	68.9	40.5	31.2	39.7	28.3	33.8	59.6	52.7
Mn	53.4	49.9	32.5	52.1	35.7	23.8	21.2	68.8
10 min								
Al	56.9	40.7	36.7	43.8	35.4	37.8	33.2	63.3
Cu	74.8	52.7	37.8	44.8	32.0	42.7	67.6	61.1
Mn	58.5	59.8	35.4	55.9	37.8	28.5	22.4	73.9

10 min: Tetley > Assam > Ceylon > Darjeeling > Lapsang Souchong > Kashmir Green > Ceylon decaffeinated > Gunpowder Green

- Elemental transfer of Cu at:
  2 min: Assam > Gunpowder Green > Tetley > Ceylon > Darjeeling > Ceylon decaffeinated > Lapsang Souchong > Kashmir Green
  5 min: Assam > Gunpowder Green > Tetley > Darjeeling > Ceylon > Lapsang Souchong > Kashmir Green > Ceylon decaffeinated
  10 min: Assam > Gunpowder Green > Tetley > Darjeeling > Ceylon > Lapsang Souchong > Kashmir Green > Ceylon decaffeinated
- Elemental transfer of Mn at:
  2 min: Tetley > Assam > Ceylon > Darjeeling > Ceylon decaffeinated > Kashmir Green > Gunpowder Green > Lapsang Souchong
  5 min: Tetley > Assam > Ceylon > Darjeeling > Ceylon decaffeinated > Kashmir Green > Lapsang Souchong > Gunpowder Green
  10 min: Tetley > Darjeeling > Assam > Ceylon > Ceylon decaffeinated > Kashmir Green > Lapsang Souchong > Gunpowder Green

These results show that elemental transfers for Al and Mn in the tea infusions are higher from Tetley tea bags compared to the loose teas, with the exception of Assam tea, which leached out the most Al in the 2 min infusion. This is of importance to the consumer, as the use of tea bags is very popular world wide. For example in the UK, 85% of all cups of tea are brewed from tea bags (The Tea Council, 2004) and data from a Hot Beverages Report issued by Nestle (1998) showed that tea use in Great Britain for 1997 was 77.8% tea bags, 5.1% tea leaf, 3.2% instant tea, 2.4% herbal tea and 11.4% speciality tea. However, transfer of Cu into the tea infusion does not follow the pattern for Al and Mn and here the Assam and Gunpowder Green tea leaves transfer higher amounts of Cu into the liquor than the Tetley tea bag.

Although comparison of 'total' elemental content in Ceylon and Ceylon decaffeinated teas showed that concentrations of Al, Cu and Mn were considerably higher in the decaffeinated product (Table 1), infusion studies show that the percentage elemental transfer of these elements into solution over time was lower for the decaffeinated tea (Table 3). However, neither of these relationships was statistically significant ($P > 0.05$). It is possible that in the decaffeination process, the organic solvent used to remove the caffeine (Varnam & Sutherland, 1994) from tea may also leach out the elements to some extent, resulting in lower percentage elemental leaching in tea infusions from decaffeinated tea.

On comparing elemental transfers into solution from black (Assam, Darjeeling from India; Lapsang Souchong from China) and green teas (Kashmir Green from India: Gunpowder Green from China) (Table 3) it can be seen that the percentage elemental transfer of Al and Mn (in most cases) for green teas was lower than that of black teas for all infusion times. However, transfer of Cu into solution did not follow a similar trend. Gunpowder Green tea showed higher percentage transfer of Cu than many of the black teas investigated (Fig. 2, Table 3). Wong et al. (1998) reported that the highest percentage metal solubility was observed in green tea followed by Oolong tea, black tea and Puerh tea. It is to be noted that the study by Wong et al. (1998) was carried out on various Chinese teas, whereas the present study investigated teas from different parts of the world. Shaw (1996) has shown that teas from different locations in the world can be significantly different in terms of their components associated with trace metals, thus affecting the solubility of metals from these teas. Hence, the difference in observations between the study of Wong et al.'s (1998) and the present findings may be attributed to the speciation of the metals in the different tea infusions. Black tea contains predominately polymeric polyphenols (Varnam & Sutherland, 1994) which may form soluble and insoluble complexes with the different metals.

3.1.3. Percentage 'available' metals from tea in the daily human dietary intake

The contribution of tea drinking to mineral absorption is ill-defined (Powell et al., 1998), as the bioavailability of

Table 4
Percentage 'available' element from the daily dietary intake

	Average daily dietary intake mg day^{-1} (range) (Powell et al., 1998)	Elemental concentrations in 2 min infusion mg l^{-1} mean (mg l^{-1} range)	% average daily dietary intake from 1 l tea drinking	% element 'available' at intestinal pH (Powell et al., 1998)	'Available' element from 1 l tea drinking as a% of the average daily dietary intake
Al	5 (2–10)	Loose tea: 5.16 (2.96–6.79) Tea bag: 9.51	103.2 190.2	4.8	Loose tea: 4.96 Tea bag: 9.13
Cu	2.5 (2–3)	Loose tea: 0.16 (0.08–0.28) Tea bag: 0.13	6.40 5.28	45.3	Loose tea: 2.88 Tea bag: 2.39
Mn	4 (2–5)	Loose tea: 3.58 (1.76–6.24) Tea bag: 11.61	89.5 290.3	39.8	Loose tea: 35.5 Tea bag: 115.5

many of the metals in tea is uncertain. Powell et al. (1998) studied the bioavailability of a range of metals in tea under simulated intestinal conditions and found that although the percentage of the average daily dietary intake from 1 l tea was 58.8% for Al, 2.0% for Cu and 115% for Mn, the percentage of 'available' elements as a percentage of the average daily dietary intake was reduced to 2.82% for Al, 0.91% for Cu and 45.8% for Mn. They attributed this to the 'availability' of the elements at the intestinal pH, the average percentage 'available' element at intestinal pH being 4.8% for Al, 45.3% for Cu and 39.8% for Mn. Using the average percentage 'available' metal in tea infusion at intestinal pH from the data of Powell et al.'s (1998) the 'available' element from 1 l tea as a percentage of the average daily dietary intake from the tea samples used in the present study is calculated for the 2 min infusion as a minimum elemental transfer time (Table 4).

From Table 4 it can be seen that although 1 l of tea can provide >100% of the daily dietary intake of Al, the percentage 'available' for absorption in the intestine is only 4.96% for loose tea and 9.13% for tea bag samples. This shows that there is a marked difference between the 'intake' and 'uptake' of Al in the human body. According to Duffield and Williams (1988), Al represents a classical example, used by nutritionists to emphasise the differences between 'intake' and 'uptake', as Al ions in the diet are completely non-bioavailable from the small intestine and unable to pass into the bloodstream. If small amounts of Al do enter the blood plasma, they tend to be rapidly excreted. Pennington and Jones (1989) have also reported that only a small percentage of ingested Al is absorbed by the intestines of healthy people and this is readily eliminated from the body by the kidneys. This is based on the fact that total body Al is quite low and does not increase with ageing (Alfrey, 1989). Therefore, from our findings we can suggest that it is unlikely that moderate amounts of tea drinking can have any harmful effects on humans. However, it must be stated that tea drinking may contribute towards Al toxicity in individuals with impaired absorption or excretion of Al in their systems.

Manganese is an essential element that is incorporated into a number of metalloenzymes. However, high doses of dietary manganese can be associated with long-term toxicity. Hence an estimated safe and adequate daily dietary intake is 2–5 mg (Powell et al., 1998). Results from the present study (Table 4) show that loose tea provides 35.5% of 'available' manganese, as a percentage of the average daily dietary intake. Hence, tea drinking may be regarded as a major source of essential dietary manganese. A deficiency of manganese in the diet may lead to degenerative bone changes and altered pancreatic function. However, 115.5% 'available' manganese from the Tetley tea bag sample (which is different from the findings of Powell et al. (1998) of 45.8%, also in Tetley tea bag tea) is of some concern' as high manganese in the diet can lead to long-term toxicity. As this finding is based on only one tea bag sample, further studies are needed to confirm the finding and its related consequences.

Copper is an essential element, with both deficiencies and excesses being associated with impaired health (Alloway & Ayres, 1993). Copper deficiency may lead to anaemia and bone abnormalities (Uauy, Olivares, & Gonzalez, 1998), whereas excess may lead to liver damage, weakness and nausea (Medeiros & Percival, 2004). Table 4 shows that 'available' Cu from drinking 1 l of tea per day provides 2.88% (loose tea) and 2.39% (tea bag tea) of the average daily dietary intake. Compared to Al and Mn, contribution of tea towards the daily dietary intake of Cu is low, which may be attributed to low concentrations of Cu in tea (Table 1). It is also important to note that unlike Al and Mn, the difference in percentage 'available' Cu between loose and tea bag tea is minimal.

In the present study, tea infusions were prepared using distilled water. However, tea for consumers may be prepared with water from various sources containing different elemental concentrations and this may affect elemental concentrations in the tea infusion.

4. Conclusions

The present study suggests that tea is a rich source of dietary manganese, contributes towards our dietary copper intake, and is of no cause for concern for Al toxicity in healthy individuals. Further studies need to be carried out to confirm whether or not tea bag tea provides toxic doses of manganese in the daily diet.

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