DIFFERENCES IN ALUMINIUM CONTENT OF VARIOUS TEA POWDERS (BLACK, GREEN, HERBAL, FRUIT) AND TEA INFUSIONS

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Trace elements play an important role in human health. Some trace elements are essential, but some are harmful – especially in higher concentrations. Aluminum is not considered as an essential element for human beings, but has, in contrary, been correlated with various human pathologies for example Dementia, Parkinson and Alzheimer disease. Its uptake is mainly via food products for example tea, in the form of a food additive or via coming in contact with aluminium containing devices used during food processing and storage. The permissible daily dose for an adult is 60 mg of aluminium. Although no limit concentration for aluminium is given in the Codex Alimentarius Austriacus, the determination of the aluminium content in food and beverages is of great concern. In this study, different kinds of tea (black tea, green tea, fruit tea and herbal tea) were analyzed for their aluminium contents. The powders were brought into solution with a microwave assisted digestion unit at temperatures up to 220°C with diluted nitric acid as digestion medium. Furthermore, the aluminium concentrations have been determined in freshly prepared tea infusions in order to examine the extractable amount. The aluminium content in all solutions has been determined with ICP-OES (inductively coupled plasma-optical emission spectroscopy). Statistically significant differences between the different kinds of tea could be found, whereas the real tea types (green and black tea) contain more aluminium than fruit or herbal teas. The mean values of total concentrations of aluminium found were (0.91 ± 0.31) g/kg for green tea, (0.76 ± 0.38) g/kg for black tea, (0.23 ± 0.09) g/kg for herbal tea and (0.22 ± 0.08) g/kg for fruit tea. For the tea infusions (4.33 ± 0.35) mg/L for green tea, 4.40 mg/L for black tea, 0.52 mg/L for herbal tea and (0.12 ± 0.02) mg/L for fruit tea. These results are in good agreement with literature data.

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1. Introduction

Tea, originating from China, has become a very popular beverage in the last 2000 years.[1] Positive effects on heath have already been reported in Chinese and Japanese documents long ago.[2] As tea contains various trace elements, the attention to the biological functioning of tea beverages has rose during the last few years. Tea infusions are prepared by extracting the tea leaves with hot water. Extraction times are about 5 minutes. Hot water dissolves proteins, vitamins, fibres or carbohydrates and furthermore some essential dietary metals which are mostly bound to polyphenols.[3] By consuming tea regularly, essential elements may therefore be taken in sufficient amount.[4,5]

Under acidic conditions as in presence of citric acid in tea with lemon – the absorption of elements, for example aluminium, may be increased.[6]

The total metal content in tea or tealeaves varies in different tea types (e.g. black or green) and also in these classes in certain ranges between different brands. Because of the relation of aluminium to adverse health effects when absorbed in excess, focus has put on this investigation. For black tea concentrations of around 900 mg/kg aluminium have been found, for green tea slightly higher average concentrations of 1,000 mg/kg. Leaves harvested for human consumption contain 300 to 1,500 mg/kg.[7] But more than 1,000 mg/kg is only rarely found in commercial tea leaves.[12]

Influencing factors on the total metal content of tealeaves are soil properties[6], the age of the tealeaves and other environmental factors as for example rainfall or altitude of the growth area. Older tealeaves were reported to contain much more aluminium than young leaves[8] and the concentrations might even be as high as 2 to 3%.[7] Interestingly, it was also found that tea plants absorb aluminium from soils (for example Puerh tea plants)[9], accumulate aluminium[1] and show even increased growth through aluminium uptake.[10] Chenery was the first who reported in 1955 the accumulation of unusual and high levels of aluminium (5 to 16 g/kg) by tea plants.[8]

As a consequence, the varying metal contents in the tealeaves also influence the metal content in tea infusions. An additional influencing factor hereby is the preparation method of the tea infusions.[11] Also the water composition for the hot tea infusions plays a role.[21] In general, the aluminium concentrations in tea infusions are found between 1 and 6 mg/L[6], which was also found in other studies and in present investigation also. This makes tea infusions major sources for aluminium uptake.[12, 13]

Other ways of aluminium absorption in daily life are through food additives or via coming in contact with aluminium containing devices used during food processing and storage. On an average, a few milligrams of aluminium are the total dietary intake per day.[12]

Aluminium as trace element itself is not considered as essential element for human beings, but forms in contrast under certain conditions – for example acidic - potentially toxic species.[14] which can have harmful impacts on the human health. In the last decade aluminium has even been found to be responsible in Alzheimer´s disease[15] Parkinson´s disease and dialysis encephalopathy.[16]

Although no limit concentration for Aluminium is given in the Codex Alimentarius Austriacus, the determination of the aluminium content in food and beverages is because of its health risks at higher concentrations mentioned above, of great concern. In European countries the daily dietary exposure to aluminium was estimated on the average with 0.2 -1.2 mg/kg body weight per week; for highly exposed persons the value was as high as 2.3 mg/kg body weight per week.[17]

As tea counts to be an important source for aluminium uptake, different kinds of tea (black tea, green tea, fruit tea and herbal tea) were analyzed for their content of aluminium in this investigation. Total aluminium concentrations in tea powders from tealeaves as well as aluminium concentrations in freshly prepared tea infusions have been determined.

Experimental

Tea samples

Four different kinds of teas (black tea, green tea, fruit tea and herbal tea) have been taken for study under test. In these categories tea powders from various commercially available tea bags of different companies were used, as listed in Table 1. All samples were digested in duplicate. Samples without tea powders were also prepared as blank samples.

Table 1 Tea samples

Green tea	**Black tea**
G1	B1 (English Breakfast)
G2 with lemon	B2 (Irish cream)
G3	B3 (Earl grey)
G4	
G5	
G6	
G7	
G8 with lemon	
G9 w. lemongrass ingwer	
n=9	*n=3*
Herbal tea	**Fruit tea**
H1	F1 Pomegranate-Redcurrant
H2	F2 Strawberry
H3 (12 herbs)	F3 Strawberry Raspberry
	F4 Redcurrant-Cherry
	F5 Winter tea
n=3	*n=5*

Digestion of the tea samples

All samples were prepared in the fume hood so that gas emissions from nitric acid were removed quickly. For the digestion approximately 0.150 g of tea powders were weighed into the microwave digestion flasks. 5 mL HNO_3 (65 ww%, p.a, Merck) and 4 mL distilled water was added. The flasks were then closed and the microwave assisted digestion started. The instrument used for the digestion process was a "StarT" from the company MLS. The temperature programme for the digestion process is listed in Table 2. After heating a cool-down phase followed for 20 minutes.

Table 2 Digestion program

Time [min]	Max. power [W]	Temperature [°C]
00:03:00	700	85
00:12:00	500	145
00:16:00	1000	180
00:21:00	1000	220
00:35:00	1000	220

After the samples cooled down to room temperature the flasks were opened and the completely dissolved tea powder solutions were filled up to 10 mL with distilled water.

Preparation of tea infusions

One tea bag (approximately 1.5 – 2 g) and 100 mL of hot distilled water were used per tea infusion. The extraction time was 5 minutes.

Table 3 Tea sample masses [g] for digestion and preparation of the tea infusions

Green tea	***m* digestion [mg]**	***m* tea powder in tea bags for the infusions [g]**
G1	108.2; 108.0	2
G2	103.1; 103.3	
G3	118.2; 124.3	
G4	106.6; 118.3	
G5	107.9; 108.8	
G6	106.9; 98.7	
G7	121.8; 106.7	1.75
G8	103.5; 113.6	1.75
G9	112.7; 102.2	1.75
B1	100.8; 105.2	
B2	110.4; 109.2	
B3	113.6; 97.7	2
H1	114.8; 127.7	2
H2	108.6; 98.0	2
H3	98.7; 112.7	2
F1	109.8; 103.3	
F2	106.3; 107.1	
F3	100.6; 107.1	
F4	106.3; 112.4	
F5	116.2; 106.7	3

Determination of the aluminium concentration with ICP-OES

The aluminium content in all solutions (digestion solutions and tea infusions) has been determined with ICP-OES (inductively coupled plasma-optical emission spectroscopy) using an ICP spectrometer (Prodigy, Teledyne Leeman Labs, Hudson NH, USA) working in a simultaneous mode. The selected wavelength was $\lambda = 396.152$ nm. For the preparation of standards the ICP Multielement Standard IV, Merck, Darmstadt, FRG was used. All standards were diluted with nitric acid (1 mol/L). This solution was also used as rinsing agent between the samples.

Results and discussion

Aluminium concentrations in the tea powders

The results for the total aluminium concentrations in the tea powders tested are shown in Table 4.

Table 4 Total aluminium concentrations [g/kg] in the different tea powder samples

Type of tea	Sample	Content [g kg^{-1}]	(Mean content ± standard deviation) [g kg^{-1}]
green tea	G1	0.449 ± 0.016	
	G2	0.716 ± 0.009	
	G3	1.061 ± 0.002	
	G4	1.250 ± 0.151	
	G5	1.121 ± 0.023	0.912 ± 0.306
	G6	1.299 ± 0.090	
	G7	0.997 ± 0.052	
	G8	0.786 ± 0.006	
	G9	0.534 ± 0.016	
black tea	B1	0.385 ± 0.005	
	B2	0.745 ± 0.078	0.757 ± 0.379
	B3	1.142 ± 0.097	
herbal tea	H1	0.250 ± 0.004	
	H2	0.128 ± 0.037	0.226 ± 0.089
	H3	0.301 ± 0.029	
fruit tea	F1	0.181 ± 0.040	
	F2	0.348 ± 0.226	
	F3	0.217 ± 0.010	0.216 ± 0.077
	F4	0.181 ± 0.096	
	F5	0.154 ± 0.003	

It can be noticed that within the four tea types different brands show wide ranges of aluminium concentrations that induces relatively high standard deviations. Nevertheless the results show significant visible differences between the mean concentrations of the different kinds of tea. This is illustrated in Figure 1.

From literature a relative high content of aluminium in black or green teas was already known. Higher contents of aluminium in the real tea types (green and black teas) were also determined in this study. Fruit or herbal teas were in this investigation found to contain lower aluminium concentrations (only around ⅓ or ¼ of the concentrations in green or black teas).

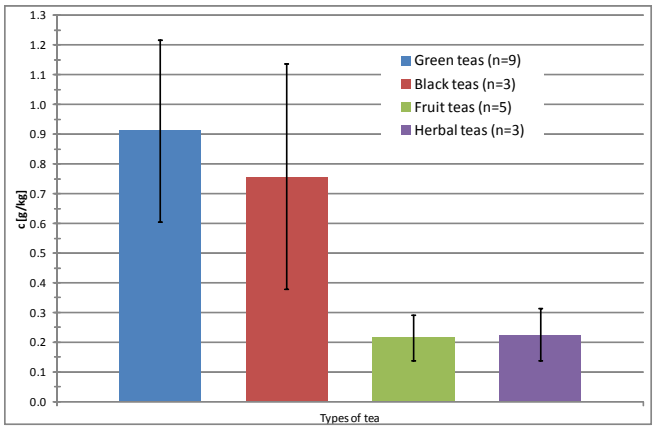

Figure 1 Aluminium contents in the four different kinds of teas

Aluminium concentrations in the tea infusions

Tea infusions were prepared for selected samples. The results for the aluminium concentrations in the tea infusions are shown in Table 5.

Table 5 Aluminium concentrations [mg/L] in the tea infusions from different kinds of tea

Type of tea	**Sample**	**Concentration [mg/L]**	**Mean concentration ± standard deviation, [mg L^{-1}]**
green tea	G1	4.34	
	G7	4.13	4.33 ± 0.35
	G8	4.92	
	G9	4.13	
black tea	B3	4.40	4.40
herbal tea	H1	0.10	
	H2	0.13	0.12 ± 0.02
	H3	0.13	
fruit tea	F5	0.52	0.52

The extractable amounts of aluminium are for black and green teas around 4.5 mg/L. Aluminium concentrations in tea infusions of fruit and herbal teas were found significantly lower than in the real tea types with 0.52 and 0.12 mg/kg in fruit and herbal tea, respectively.

Tea infusions have approximately 0.35% dry mass. Table 6 shows the extractable Aluminium concentrations for the four different tea types.

It can be noticed, that the amount of extractable aluminium is highest for green tea which brings this tea type - in despite of its otherwise very positive health effects because of its antioxidizing properties - in a negative context in terms of aluminium uptake through tea consumption and eventually possible adverse impacts on the human health. Black tea has the second highest extraction potential for aluminium and is therefore also very relevant in terms of possible health risks through uptake of aluminium. Aluminium is also quite extractable from tea powders for fruit tea infusions, but the average total content of aluminium in the tea powders in these two tea types is low

and so also the risk potential for aluminium uptake. Even less danger can be seen for herbal teas where only around 2% of the already low average total aluminium content is extracted.

Table 6 Aluminium concentrations [mg/L] in the tea infusions from different kinds of tea

Type of tea	Sample	Extractable Al [%]	Mean [%] ± standard deviation
green tea	G1	33.82	24.33 ± 8.17
	G7	14.49	
	G8	21.94	
	G9	27.06	
black tea	B3	13.48	13.48
herbal tea	H1	1.37	2.16 ± 1.25
	H2	3.61	
	H3	1.50	
fruit tea	F5	11.72	11.72

Comparison of the results with literature data

The determined concentrations ranges for the different tea types have been compared with literature data. In literature the focus for the determination of aluminium concentrations were mostly on green or black teas. This study extends the data also for fruit teas and herbal teas. Table 7 lists the data from this study and from literature.

Table 7 Comparison of aluminium concentrations from this study with literature data

Literature	Aluminium concentration [g kg^{-1}]	
	Green tea	Black tea
STREET, A. et al. (2007)[6]	1.340	1.070
Wrobel, K. et al. (2000)[18]	0.919 ± 0.03	0.759 ± 0.03
Matsuura, H. et al. (2001)[19]		0.807 ± 0.06
Odegard et al. (1997)[20]		0.90 ± 0.01
Mossion et al. (2008)[21]	0.4 – 1.0	0.4 – 1.0
study	0.912 ± 0.31	0.757 ±0.38

It can be observed, that the results of this study confirm the findings for black and green tea with literature data. This is also true for the results obtained for the aluminium concentrations in the tea infusions that are shown in Table 8.

Table 9 shows the percentage of the extractable aluminium content from the tea powders to the tea infusions. Comparable results could be found for the extractable amounts of aluminium from black and green tealeaves.

It can be seen in Table 8 that the determined extractable amounts of aluminium vary in the different studies but that all results of green and black teas are almost in the same range and are a higher than the extractable amounts in fruit or herbal tea.

The results so found by the present underline the comparison with literature data and advance the knowledge of aluminium concentrations for fruit and herbal tea powders and their infusions.

Table 8 Comparison of aluminium concentrations in tea infusions from this study with literature data

Literature	Aluminium concentration [mg L^{-1}] in tea infusions	
	Green tea	Black tea
STREET, A. et al. (2007)[6]	3.2	2.3
Matsuura, H. et al. (2001)[19]		5.54 ± 0.24
Flaten, T.P. (2002)[12]	1-6	1-6
Mossion et al. (2008)[21]	0.06 - 3.24	0.06 - 3.24
study	4.33 ± 0.35	4.40

Table 9 Comparison of the extractable aluminium from this study with literature data

Literature	Extractable Aluminium concentration [% dry mass]	
	Green tea	Black tea
STREET, A. et al. (2007)[6]	11.1	11.4
Wrobel, K. et al. (2000)[18]	18 - 29	17 - 45
Matsuura, H. et al. (2001)[19]		24.0
study	24.3 ± 8.2	13.5

Conclusions

The investigations of various tea types showed that significantly higher aluminium concentrations may be found in the real tea types (black and green), whereas the leaves of green tea contain the highest aluminium contents from all investigated types of tea which is about 0.9 g/kg. These results are in good agreement with aluminium concentrations in tealeaves reported in literature. The aluminium concentrations in black and green tea are three to four times higher than the investigated tea powder samples of fruit and herbal tea with around 0.2 g/kg in an average for both tea types. One reason for these findings is the significantly different organic matrix of real tea types and fruit or herbal teas. Also the real tea types are also known to be aluminium accumulators. Side by side with these results one may study the aluminium concentrations in the prepared tea infusions. Also here, significantly higher concentrations of aluminium could be found in green or black teas with 4.33 and 4.40 mg/L for green and black tea, respectively. As the aluminium uptake is reported with a few milligrams/day in literature, green and black teas can be a major source. On the other hand, fruit and herbal teas, only contain approximately 1/9 or even only 1/40 of the aluminium concentrations in tea leaves and therefore, the aluminium uptake from drinking tea is much lower than by drinking green or black tea.

The extractable amounts of aluminium found for green and black teas are also in the range reported in literature. Especially from green tea leaves that contain a higher total amount of aluminium compared to other tea types, the extraction potential is also the highest from the investigated tea types. From black tea leaves aluminium is also quite extractable. Fruit and herbal tealeaves contain only minor concentrations of aluminium and only small percentages are extractable so that these tea infusions do not count to major aluminium sources.

Although tea (black or green) counts to be the biggest aluminium sources of human food products, the aluminium concentrations in the tea infusions is still rather low and should not pose threats to the human health.

Further studies will advance and develop the data based on the metal concentrations in tea powders and tea infusions.

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