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ORIGINAL PAPER

EFFECT OF INFUSION TIME AND ADDITION OF LEMON JUICE ON THE MOBILITY OF SELECTED MACROELEMENTS AND ALUMINIUM DURING AQUEOUS EXTRACTION OF QUALITY BRANDS OF LEAF TEA*

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Abstract

In view of the growing tea consumption and the variety of tea brands available on the market, the aim of the study was to determine the content of selected minerals (K, Ca, P, Mg and Al) in black, white and green teas as well as to estimate the influence of brewing time and the addition of acid (lemon juice) during the process of tea brewing on the mobility of selected elements. The brands of fine quality leaf tea selected for the study included three brands of black tea (Assam Dagapur, Darjeeling Jungpana, Ceylon Uva), three brands of white tea (Pai Mu Tan, Ya Bao Yesheng, China White Snow Buds) and three brands of green tea (Pi Lo Chun, Gyokuro, Hojicha). The tea infusions were brewed for 5 or 15 minutes. The procedure was repeated using dry tea leaves with the addition of acid, i.e. 5 ml of lemon juice. The contents of mineral elements in tea infusions were examined with an ICP-OES Thermo iCAP Dual 6500 spectrometer, using a 3-point calibration curve for each element, as well as optical adjustment applied via the method of internal models provided by yttrium and ytterbium ions. Certified Reference Material, characteristic for the relevant matrix, was used to verify selected lengths of the measurement lines. Generally, the mineral content in decreasing order was K>Ca>P>Mg>Al, the one exception being white tea (Ya Bao Yesheng). Longer boiling time and the addition of lemon juice caused a higher mineral content in tea infusions. Among the macroelements tested, calcium content increased the most after the addition of lemon juice (2-3 times higher in black and green teas, 3.5-4 times higher in white teas). However, potassium extraction decreased by about 10% after

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the addition of lemon juice. The aluminium content, which is associated with human neurodegenerative diseases, increased from 19 to 50% in black teas, from 56 to 200% in white teas and from 27 to 41% in green teas.

Keywords: leaf tea, water extraction, lemon juice, macroelements, aluminium.

INTRODUCTION

Tea ranks among the most popular beverages worldwide. Various kinds and types of tea are obtained as a result of technological processes subjecting leaves, buds and delicate stalks of *Camellia sinensis* L. to different treatments. The basic classification of tea types takes into account the degree of fermentation. We can distinguish fermented tea, including black, red and yellow; non-fermented green tea, and minimally fermented white tea (Alma-jano et al. 2008, Plust et al. 2011).

Tea leaves, and consequently their infusions, contain a number of compounds affecting the human body in various ways. Concentrations of bioactive compounds in tea infusions depend on such factors as: the plant variety, ripening conditions and the method of technological processing (Rusinek-Prystupa et al. 2016). Of critical importance are also such environmental factors as cultivation methods, weather conditions and harvest time (Okinda et al. 2008). Furthermore, the quality of tea infusions may be affected by anthropogenic or natural contaminations contained in the leaves, such as heavy metals, pesticide residues as well as natural constituents, e.g. oxalates (Jabłońska-Ryś 2012). The main compounds contained in tea include tannins, purine alkaloids, essential oils, proteins, pigments, vitamins and minerals (Stańczyk et al. 2010).

The content of inorganic compounds (the so-called total ash) in tea is in the range of 4-7% and largely depends on the type and composition of soil. Dry tea leaves are a good source of compounds of chromium, calcium, magnesium, aluminium, manganese, iron, copper, zinc, molybdenum, sodium, phosphorus, strontium, cobalt, potassium, nickel, boron, fluorine, selenium, silicon and iodine (Jędra et al. 2003). Among the mineral compounds and trace elements, the content of calcium, sodium, potassium, magnesium and manganese in tea leaves is at a level of g kg^{-1}, while the contents of chromium, iron, cobalt, nickel, copper, and zinc are found at a level of mg kg^{-1} (Street et al. 2006). What is more important, however, from the viewpoint of health and dietary benefits, is the content of these mineral compounds in tea infusions ready for consumption (Cabrera et al. 2006, Wierzejska 2014). Aluminium is a controversial chemical element, which in recent years has been widely discussed. Aluminium may occur in the environment as a result of human activities, air pollution due to gas or dust emissions, and the operation of aluminium foundries, as well as the chemical, glass and enamelling industries. A typical example of aluminium accumulation would involve the element being absorbed by tea shrubs from underground water and from soil (Czernicka et al. 2015). It is also known that tea is one of the main sources of aluminium in the human diet (Flaten 2002). In the majority of its forms, aluminium is harmless to living organisms, yet in some conditions, at low pH values, it may have a tendency to create toxic compounds, in particular aluminium citrates. Research has shown that aluminium may be involved in some increasingly common diseases such as Alzheimer's disease, Parkinson's disease and dialysis encephalopathy (Exley, Korchazhkina 2001).

Large contents of macro- and micro-elements in dry tea leaves correspond to their concentrations in tea infusions. It should be emphasized that the age of tea leaves as well as the method of preparing tea infusions, i.e. the duration of brewing, temperature, and tea/water ratio, also play a significant role in the diffusion of elements from dry tea leaves to solution (Street et al. 2006). Furthermore, the mobility of elements may be also significantly promoted by adding lemon juice or milk during the tea brewing process. These additives lead to changes in the pH of the solution, which affects the bioavailability of various forms of aluminium (Fanni et al. 2014).

Taking into account the above facts, as well as the growing tea consumption and the variety of tea brands available on the market, the authors of the present study decided to determine the content of selected minerals (K, Ca, P, Mg and Al) in black, white and green teas as well as to estimate the influence of brewing time and the addition of acid (lemon juice) during the process of tea brewing on the mobility of selected elements.

MATERIALS AND METHODS

The research material included fine quality leaf teas purchased in Poland. The analyses took into account aqueous infusions obtained from the dry tea leaves of the following brands, which were marked with symbols for easier identification: black – Assam Dagapur (B1), Darjeeling Jungpana (B2), Ceylon Uva (B3); white – Pai Mu Tan (W1), Ya Bao Yesheng (W2), China White Snow Buds (W3) and green – Pi Lo Chun (G1), Gyokuro (G2), and Hojicha (G3) – Table 1.

The tea infusions were prepared in conical flasks, in which 2 g samples of tea were placed. To these we added 100 ml of demineralised water at a temp. of 100°C. The mixture was covered and brewed for periods of 5 or 15 minutes. The procedure was repeated using dry tea leaves with the addition of acid, i.e. 5 ml of lemon juice, with a pH of 2.24. After 5 and 15 min, respectively, the infusions were trickled via filter paper to measuring flasks and left to cool down. The experiment was repeated three times and the results are presented as mean values. Adjustments were made to the results, showing the contents of minerals in the infusions containing lemon

Table 1

Types of tea used in the experiment

Type of tea	Degree of fermentation	Country of origin	Name	Symbol
Black	Fully fermented	India	Assam Dagapur	B1
			Darjeeling Jungpana	B2
		Sri Lanka	Ceylon Uva	B3
White	Minimally fermented	China	Pai Mu Tan	W1
			Ya Bao Yesheng	W2
			China White Snow Buds	W3
Green	Non-fermented	China	Pi Lo Chun	G1
		Japan	Gyokuro	G2
			Hojicha	G3

juice to take account of the mineral content determined in the additive applied.

The infusions, cooled down to room temperature, were examined for pH using a Nahita – 907 pH-meter. Then, 10 ml samples of tea infusions were subjected to spectral measurements in a Thermo iCAP Dual 6500 ICP-OES apparatus with horizontal plasma and the capacity to detect elements both along and across the plasma flame (i.e. both radial and axial one). Before measuring each batch of 10 samples, calibration was performed using certified (Merck) models, with concentrations of 10 000 ppm for Ca, Mg, K, P and 1000 ppm for Al.

In each case, a 3-point calibration curve was used for each element, with optical adjustment used to apply the method of internal models, provided by yttrium and ytterbium ions at concentrations of 2 mg L^{-1} and 5 mg L^{-1} respectively. The analytical methods were validated with two independent tests. Certified Reference Material (INCT-TL-1 tea leaves and NIES CRM No. 7 Tea Leaves) was used and the recovery obtained for specific elements is shown in Table 2. In order to identify the relevant measurement lines and avoid possible interferences, the method of adding a model with a known concentration was applied (Environmental Analysis, Method 200.7, US EPA, Drinking water).

The detection limit for each element was determined at a level which was not lower than 1 μg L^{-1}.

Multi-way ANOVA was applied to compare means of mineral contents in the types of tea being studied. Three factors were taken into account: brand of tea, duration of infusion, and whether lemon juice was added. The detailed comparisons were done using the Tuckey test, which also allows one to assess the interaction between these three factors. This procedure was repeated separately for each kind of tea. The level of significance was $p \leq 0.05$.

Table 2

Lengths of measurement lines and recoveries obtained for the specific elements examined

Element	Measurement line (nm)	Recovery according to CRM (%)	Recovery according to known addition method (%)
Ca	317.933	101	99
Mg	279.533	102	101
K	766.490	102	98
P	177.495	101	99
Al	167.079	98	100

RESULTS AND DISCUSSION

Tea is one of the most popular beverages in Poland and in the world. In Poland, the average tea consumption is around 1 kg per person, which places Poland among the top ten consumers of tea in the world (Samolińska et al. 2017). Moreover, lemon juice is very often added to tea in Poland. Because of these facts, we wanted to analyse the influence of the duration of infusion, and addition of lemon juice on the mineral content in different kinds of tea infusion.

pH

The pHs of the tea infusions are presented in Table 3. Black teas were found to be more acidic than green ones. Similar results were observed by

Table 3

pH values in different kinds of tea infusion depending on infusion time and addition of lemon juice

Type (colour)	Symbol	Factor*			
		5	15	5 + L	15 + L
		pH			
Black	B1	4.91	4.87	2.76	2.83
	B2	5.12	5.10	2.80	2.81
	B3	4.94	4.88	2.79	2.83
White	W1	5.35	5.28	2.77	2.8
	W2	4.66	4.63	2.45	2.48
	W3	5.52	5.5	2.82	2.81
Green	G1	5.69	5.69	2.81	2.87
	G2	5.77	5.75	2.88	2.94
	G3	5.09	5.10	2.75	2.83

* infusion time (min), L – addition of lemon juice

Street et al. (2006). Brewing time generally has no influence on pH, but the addition of lemon juice decreases the pH to a value range from 2.45 to 2.88.

Mineral content

Of the macroelements analysed, potassium and calcium were present in the greatest quantities in all of the herbal tea infusions selected for study. Generally, the mineral concentration in black, white and green teas was in descending order K>Ca>P>Mg>Al, the one exception being white tea (W2) which contained 10-fold less potassium than the other teas. This tea is special in that it only contains buds, and no leaves, which may explain the significantly lower contents of the macroelements examined. The content of potassium determined in black teas after 5 min. of brewing was from 306 to 395 mg L^{-1}, in white teas it ranged from 26 to 250 mg L^{-1} and in green teas it varied from 294 to 446 mg L^{-1} (Tables 4, 5, 6). The lowest potassium concen-

Table 4

Contents of selected macroelements and aluminium in black teas, relative to infusion time and addition of lemon juice

Type (colour)	Symbol	Factor*	Ca	K	Mg	P	Al
			(mg L^{-1})				
Black	B1	5	57.13^{b}	306.35^{b}	18.73^{e}	36.07^{a}	5.62^{c}
		5+L	148.42^{g}	344.13^{c}	24.61^{a}	33.76^{j}	6.70^{f}
		15	67.41^{c}	366.01^{d}	24.41^{a}	40.90^{c}	6.37^{e}
		15+L	185.01^{i}	377.04^{e}	29.94^{b}	37.60^{b}	7.58^{h}
	B2	5	49.74^{a}	307.41^{b}	17.00^{d}	32.60^{i}	3.93^{a}
		5+L	160.31^{h}	336.80^{c}	24.09^{a}	30.57^{h}	5.97^{d}
		15	73.70^{d}	367.41^{d}	23.76^{a}	39.97^{c}	4.72^{b}
		15+L	219.54^{k}	390.34^{a}	31.94^{f}	36.64^{ab}	7.58^{h}
	B3	5	105.03^{e}	395.61^{a}	29.96^{b}	24.07^{e}	8.26^{i}
		5+L	190.91^{j}	399.51^{a}	35.33^{c}	22.52^{d}	10.24^{k}
		15	119.01^{f}	411.55^{f}	34.45^{c}	28.80^{g}	9.42^{j}
		15+L	257.40^{l}	436.30^{g}	44.36^{g}	25.73^{f}	11.35^{l}

* infusion time (min), L – addition of lemon juice;
According to the LSD test, means with the same Arabic letter are not significantly different with $p \leq 0.05$.

tration was observed in white teas, being higher in black and green teas. However, it must be stated that the K content also strongly depended on a tea sample. According to Dambiec et al. (2013), concentrations of macroelements in black tea infusion are relatively high and differ significantly between tea brands. The author states that the most abundant element among the researched macroelements was potassium. The content of calcium ranged from 49.74 to 105.03 mg L^{-1} for black teas, and from 42.53 to 63.76 mg L^{-1} for

Table 5

Contents of selected macroelements and aluminium in white teas, relative to infusion time and addition of lemon juice

Type (colour)	Symbol	Factor*	Ca	K	Mg	P	Al
			(mg L^{-1})				
White	W1	5	63.76^{b}	219.53^{f}	9.62^{a}	24.85^{f}	3.26^{g}
		5+L	212.01^{g}	264.11^{h}	14.29^{b}	23.88^{e}	5.11^{j}
		15	70.56^{c}	285.11^{a}	13.79^{b}	35.38^{k}	4.82^{i}
		15+L	246.91^{h}	350.51^{k}	20.60^{c}	33.75^{j}	7.07^{k}
	W2	5	59.61^{b}	26.34^{b}	1.92^{d}	1.90^{b}	0.44^{b}
		5+L	269.91^{i}	71.91^{d}	7.21^{f}	1.42^{b}	1.27^{d}
		15	89.94^{d}	40.71^{c}	3.05^{e}	2.79^{c}	0.73^{c}
		15+L	287.70^{j}	97.97^{e}	10.20^{a}	2.03^{a}	1.94^{a}
	W3	5	42.53^{a}	250.01^{g}	16.07^{g}	26.66^{g}	1.56^{e}
		5+L	168.52^{e}	271.11^{i}	20.51^{c}	22.94^{d}	3.16^{f}
		15	44.93^{a}	286.61^{a}	18.95^{h}	32.34^{i}	1.91^{a}
		15+L	189.11^{f}	334.78^{j}	28.56^{i}	29.28^{h}	4.28^{h}

* infusion time (min), L – addition of lemon juice;
According to the LSD test, means with the same Arabic letter are not significantly different with $p \leq 0.05$.

Table 6

Contents of selected macroelements and aluminium in green teas, relative to infusion time and addition of lemon juice

Type (colour)	Symbol	Factor*	Ca	K	Mg	P	Al
			(mg L^{-1})				
Green	G1	5	85.47^{a}	294.82^{a}	16.42^{c}	27.39^{ae}	1.74^{a}
		5+L	260.30^{c}	303.35^{b}	23.10^{a}	23.64^{e}	2.46^{c}
		15	77.37^{a}	352.34^{c}	22.02^{a}	31.68^{abc}	1.97^{b}
		15+L	277.77^{c}	346.74^{c}	29.18^{f}	28.50^{ae}	2.98^{d}
	G2	5	86.49^{a}	446.90^{h}	34.96^{h}	41.06f^{g}	6.54^{e}
		5+L	171.41^{b}	471.24^{i}	39.12^{b}	34.80^{bcd}	8.32^{h}
		15	96.32^{a}	501.11^{d}	38.34^{b}	43.96^{g}	7.08^{f}
		15+L	174.64^{b}	503.48^{d}	46.12^{j}	37.97^{df}	9.79^{k}
	G3	5	75.66^{a}	299.61^{ab}	20.51^{d}	31.49^{abc}	7.06^{g}
		5+L	184.61^{b}	370.11^{f}	33.70^{g}	30.67^{ab}	9.51^{j}
		15	97.71^{a}	333.60^{e}	26.88^{e}	37.72^{df}	9.17^{i}
		15+L	249.61^{c}	411.61^{g}	43.74^{i}	36.05^{cd}	12.42^{l}

* infusion time (min), L – addition of lemon juice;
According to the LSD test, means with the same Arabic letter are not significantly different with $p \leq 0.05$.

white teas, and from 75.66 to 85.49 mg L^{-1} for green teas. The phosphorus content in all the samples tested was from 24.07 to 41.06 mg L^{-1} with the one exception being one sample of white tea where the P concentration was 1.9 mg L^{-1}. The Mg concentration was dependent on the tea sample and ranged from 9.62 to 34.96 mg L^{-1} with the lowest value being found in one white tea sample (1.92 mg L^{-1}). Aluminium content was lower in the white tea samples than in the black and green tea sample. In these teas the Al content ranged from 1.74 to 8.26 mg L^{-1}. The finding that the highest concentration of K was extracted following infusion of green teas was also observed by other authors (Olivier et al. 2012, Dambiec et al. 2013, Brzezicha-Cirocka et al. 2016) and in black teas (Olivier et al. 2012, Tayfur et al. 2013). Kumar et al. (2005) suggested that such high concentrations of K might be explained by the specific incorporation of K within a binding ligand in the tea leaves. The differences observed in the content or range of some elements may be due to differences in the geographic characteristics, origin and nature of soils, and the agronomic and cultural practices between the various tea-producing areas (Tayfur et al. 2013).

Influence of infusion time on mineral content

We could observe that infusion time positively influenced the mineral content in tea infusions irrespective of tea types. In almost all cases, the content of the minerals analysed increases after a longer infusion time. Generally, the increase in the mineral content for black teas is around 15-20% in comparison with the infusion time of 5 minutes. There are some exceptions: in two samples of the black teas tested (B1 and B2) the Mg content was about 30-39% higher, and in one sample the Ca content was also higher by about 48%. In general, the content of all minerals depended on the duration of infusion. In some cases, there was no difference between the brands of tea as the content of K did not differ after 5 minutes of brewing and P and Mg levels were the same after 15 min of brewing between brands B1 and B2 (Table 4). Statistical analysis revealed that the content of minerals in white tea depended on the duration of infusion. One of a few cases is the content of Ca in W3. Among the white teas tested, the content of Mg, P and Al in two samples was about 42 to 65% higher when compared to the samples after 5 min of brewing. The Ca and K concentrations were generally about 13-19% higher, with some exceptions (one sample had a 48% higher Ca content, and one had an Mg content that was only 4% higher) – Table 5. In one sample of green tea (G2), the concentration of the minerals analysed increased by about 7-12% for the first K sample, by about 13-17% for P and Al, and by about 48% for the Mg content. In the third sample (G3), the Ca, Mg and Al content was about 30% higher, K – 11% and P – 19% (Table 6). In the case of green tea, the Ca content did not depend on brewing duration and brand (homogeneous group *a* in Table 6). It can be stated that the longer infusion time has an influence by producing a higher mineral content in tea infusions.

The longer extraction time during tea brewing results in efficient release of minerals from tea leaf cell structures and, according to the law of diffusion, spontaneous components penetrate from one phase of the system into the other phase. The mineral extraction process is also dependent on the degree of development of the surface exchange rate, which arises for example from the degree of fragmentation of leaves, and on the solubility of minerals in the aquatic environment. The longer the extraction time, the better the degree of moistening of the extracted material and its intensity penetration (Karak, Bhagat 2010). It is known that the degree of extraction of minerals into the infusions is modified by many factors, and is determined *inter alia* by the method of preparation of the infusion and brewing time (Samolińska et al. 2017). Some authors have noticed a lower mineral content after prolonged infusion time. Street et al. (2006) observed decreased concentration of Cu, Mn, Pb and Cd after changing the infusion time from 5 to 10 min. On the other hand, they noticed higher levels of Fe and Zn in these teas. Olivier et al. (2006) attributed the lower mineral content obtained in their research than in studies of other authors to shorter infusion time. This suggests that longer infusion time produces the highest mineral content in tea infusions.

The influence of the addition of lemon juice on mineral content

Addition of lemon juice influences the pH of teas, which plays an important role in mineral mobility and the ability to solubilise in water (Yalcin Gorgulu et al.2014). The addition of the lemon juice caused a higher concentration of Ca, K, Mg and Al. We revealed the interaction between two factors: the duration of infusion and the addition of lemon juice for all type and brand of teas. The P content in tea infusions was lower than without the lemon juice. Also the interaction among grouping factors were demonstrated with only one exception- the addition of lemon juice did not influence the P content in 5- minutes infusion (Tables 4, 5, 6) which may be explained by the formation of complexes with phosphorus ions in the presence of aluminium compounds. As it is well known, tea is one of the very few plants that accumulate Al. Aluminium salts present in tea garden soils dissociate at $pH < 5.5$ and produce Al^{3+} in soil solution and form complexes with phosphate (Karak, Bhagat 2010). Al stimulates the growth of tea plants possibly through improvement of the absorption and utilisation of phosphorus and perhaps other essential elements. Tea leaves also contain a large number of compounds that are able to complex Al (Flaten 2002). Most aluminium-containing food additives are sulphates, phosphates or silicates. Aluminium phosphate is reported to be insoluble, although when it is consumed in large quantities, urinary excretion of aluminium is elevated (Rogers, Simon, 1999). The relative distribution of Al between its various organic and inorganic complexes influences its mobility in the environment, bioavailability and toxicity. Among the four minerals with increased content, the greatest increase was observed for calcium. It may be due to greater Ca solubility in an acidic pH and by the formation of complexes of calcium ions with the citric acid contained in the juice (Spiro et al. 1996). Its concentration was 2-3 times higher in black and green teas and 3.5-4 times higher in white teas. P extraction was decreased by about 10% in comparison with the infusions without the addition of lemon juice. Kipcak et al. (2012) also observed that the addition of lemon increased the K and Mg content of the black tea and decreased the phosphorus content. A number of studies have reported high levels of Al in traditional tea infusions. Because high levels of Al have been associated with neurodegenerative diseases such as Alzheimer's and Parkinson's, tea consumption may be a cause for concern (Exley, Korchazhkina 2001). Al content, which is the most important because of its possible toxicity, increased from 19 to 50% in black teas, from 56 to 200% in white teas and from 27 to 41% in green teas (Tables 4, 5, 6). "Aluminium production" has been classified as carcinogenic to humans by the International Agency for Research and Cancer (IARC). Oral Al bioavailability from water has been reported to be 0.1 to 0.4% and is increased by citrate, acidic pH (Krewski et al. 2007), which are the conditions in tea infusions with lemon juice. The World Health Organization (WHO) limits the Al content in drinking water to 200 µg L^{-1} (i.e. 0.2 mg L^{-1} or 0.05 mg/cup of 250 ml), and in 2011 the WHO established a provisional tolerable weekly intake (PTWI) for food of 2 mg Al kg^{-1} body mass. The Al concentrations of 1.48 and 1.91 (after lemon addition) mg/cup in black tea and 1.28 and 1.69 (after lemon addition) mg/cup of green tea should be taken note of by people with low body mass who consume a large number of cups of tea per day. The excessive consumption of black and green tea by young children should be discouraged. The lowest content of Al was observed in white tea at 0.44 mg/cup and 0.8 mg/cup (for tea with added lemon juice). A similar Al content was observed by Olivier et al (2012) at a level of 1.25 mg/cup of black tea and 0.9 mg/cup of green tea.

Recommended dietary intake

The RDAs (*Recommended Dietary Allowances*) for the different elements were calculated for infusions according to the Polish (Jarosz 2012) recommendations (Table 7). One litre (4-5 cups of tea) per day provides approximately 5-7% of Ca, 3-7% of K, 2-8% of Mg and 2.5-4.8% of P. The addition of lemon juice enhances the RDAs of Ca from 2.5 to 4 times, slightly enhances K and Mg RDA, and decreases the RDA of phosphorus. According to Brzezicha-Cirocka et al. (2016), one cup of green tea (200 ml) provided approximately 1% of the RDA for Ca, K, Mg and P. Our results are similar for Mg and P, and slightly higher (around 1.5%) for Ca and K. Although K has a high content in the infusions of the teas analysed, as many as seven cups (250 mL each cup) of tea infusion need to be consumed to provide a source of 10% of the daily value of this mineral, which is comparable to the results of Islam and Ebihara (2017) for Japanese green tea infusions. The provisional tolerable weekly intake of Al delivered with tea may be calculated depending on

Table 7

Percentage contribution to recommended dietary intake through the consumption of 1 L of tea beverage

Element	Recommended daily allowance (RDA) (mg/day/person)		Average content (mg L^{-1})		Contribution to the RDA through consumption of 1 L of infusions (%)	
			without lemon juice	with lemon juice	without lemon juice	with lemon juice
Ca	1000	B	70.63	166.55	7.06	16.65
		W	55.30	216.81	5.53	21.68
		G	82.54	205.44	8.25	20.54
K	4700	B	336.46	360.15	7.16	7.66
		W	165.29	202.38	3.52	4.31
		G	347.11	381.57	7.39	8.12
Mg	420M/320F	B	21.90	28.01	5.21/6.84	6.67/8.75
		W	9.20	14.00	2.19/2.88	3.33/4.38
		G	23.96	31.97	5.71/7.49	7.61/9.99
P	700	B	30.91	28.95	4.42	4.14
		W	17.80	16.08	2.54	2.30
		G	33.31	29.70	4.76	4.24
Al	-	B	5.94	7.63	-	-
		W	1.75	3.18		
		G	5.11	6.76		

M – males, F – females, B – black tea, W – white tea, G – green tea, RDA according to Jarosz (2012).

the age and body weight of people, which can be divided into 3 groups: 1-6 year old (young children), 7-14 (children), >15 (adolescents and adults). According to the Polish Central Statistical Office (2009), the mean body weight of each age group is 18.0 kg for young children, 40 kg for children, and higher than 56 kg for the last group. The PTWI is 36, 80, more than 112 mg of Al per week, for each group, respectively. Because the most popular tea in Poland is black tea with lemon juice, with average consumption of 1l per day, the weekly Al intake can reach the level around 49 mg per week, which might be very dangerous, especially for young children with low body weight, where level of Al exposure can exceed the PTWI of about 36%. It must be also remembered that other food products can be the source of Al. Moreover, some food additives such as sodium aluminum phosphate and sodium aluminum silicate are approved for use as food additives in the USA and the EU countries (Bratakos et al. 2012, Sato et al. 2014) and cooking utensils and food packaging can contribute to Al intake (Fekete et al. 2013).

CONCLUSIONS

It can be concluded that the mineral content in tea infusions depends on the tea type, time of boiling and addition of lemon juice. Both the two latter factors, in most cases, caused a higher mineral content in tea infusions (the highest for calcium) but with one exception – phosphorus extraction decreased after the addition of lemon juice. Among the macroelements tested, the calcium content increased the most after the addition of lemon juice (2-3 times higher in black and green teas, 3.5-4 times higher in white teas). However, potassium extraction decreased by about 10% after the addition of lemon juice. The aluminium content, which is associated with human neurodegenerative diseases, increased from 19 to 50% in black teas, from 56 to 200% in white teas and from 27 to 41% in green teas. Generally, the mineral concentration in black, white and green teas was of the order of (in descending sequence) K>Ca>P>Mg>Al. The content of aluminium in teas should be examined, and its concentration should be taken into account during tea consumption, especially among young children, for which the Al intake can exceed the provisional tolerable weekly intake.

REFERENCES

Almajano P., Carbo R., Lopez Jimenez J.A., Gordon M.H. 2008. *Antioxidant and antimicrobial activities of tea infusions*. Food Chem., 108: 55-63.

Bratakos S. M., Lazou A.E., Bratakos M.S., Lazos E.S. 2012. *Aluminium in food and daily dietary intake estimate in Greece*. Food Addit. Contam., 5: 33-44.

Brzezicha-Cirocka J., Grembecka M., Szefer P. 2016. *Monitoring of essential and heavy metals in green tea from different geographical origins*. Environ. Monit. Assess., 188:183.

Cabrera C., Artacho R., Giménez R. 2006. *Beneficial effects of green tea - A review*. J. Am. Call. Nutr., 25: 79-99.

Central Statistical Office, Krakow, Poland, 2011. *The health of children and adolescents in Poland in 2009*. (in Polish)

Czernicka M., Zaguła G., Puchalski Cz., Cebulak T., Kapusta I. 2015. *Assessment of the nutritional value of high-grade leafy white and green teas based on the analysis of the content of fluorides, caffeine and minerals* Bromat. Chem. Toksykol., 48(4): 667-676. (in Polish)

Dambiec M., Polechońska L., Klink, A. 2013. *Levels of essentials and non-essential elements in black teas commercialized in Poland and their transfer to tea infusion*. J. Food Comp. Anal., 31: 62-66.

Exley C., Korchazhkina O.V. 2001. *Promotion of formation of amyloid fibrils by aluminium adenosine triphosphate (AlATP)*. J. Inorg. Biochem., 84(3-4): 215-224.

Fanni D., Ambu R., Gerosa C., Nemolato S., Iacovidou N., Van Eyken P., Fanos V., Zaffanello M., Faa G. 2014. *Aluminum exposure and toxicity in neonates: practical guide to halt aluminum overload in the prenatal and perinatal periods*. World J. Pediatr., 10(2): 101-107.

Fekete V., Vandevijvere S., Bolle F., Loco J.V. 2013. *Estimation of dietary aluminum exposure of the Belgian adult population: evaluation of contribution of food and kitchenware*. Food Chem. Toxicol., 55: 602-608.

Flaten T.P. 2002. *Aluminium in tea – concentrations, speciation and bioavailability*. Coord. Chem. Rev., 228(2): 385-395.

ISLAM M.A., EBIHARA M. 2017. *Elemental characterization of Japanese green tea leaves and tea infusion residue by neutron-induced prompt and delayed gamma-ray analysis*. Arab. J. Chem., 10: 677-682.

JABŁOŃSKA-RYŚ E. 2012. *Effect of brewing method of various tea types on content of soluble oxalates therein*. Żywność. Nauka. Technologia. Jakość, 1(80): 187-195. (in Polish)

JAROSZ M. 2012. *Nutrition standards for the Polish population – amendment*. Warsaw, IŻŻ. (in Polish)

JĘDRA M., URBANEK-KARŁOWSKA B., GAWARSKA H., SAWILSKA-RAUTENSTRAUCH D., BADOWSKI P. 2003. *Fluorine content in teas, beverages and beverages concentrates with tea extract*. Bromat. Chem. Toksykol., 36: 41-45. (in Polish)

KARAK T., BHAGAT R. M. 2010. *Trace elements in tea leaves, made tea and tea infusion: A review*. Food Res. Int., 43(9): 2234-2252.

KIPCAK A.S., OZDEMIR D., MOROYDOR DERUN E., PISKIN M.B. 2012. *Lemon effect on some elements in Turkish teas*. Int. J. Chem. Mol. Nucl. Materials and Metallurgical Engineering., 6(7): 606-609.

KREWSKI D., YOKEL R.A., NIEBOER E., BORCHELT D., COHEN J., HARRY J., KACEW S., LINDSAY J., MAHFOUZ A.M., RONDEAU V. 2007. *Human health risk assessment for aluminium, aluminium oxide, and aluminium hydroxide*. J. Toxicol. Environ. Health B Crit Rev., 10(Suppl 1): 1-269.

KUMAR A., NAIR A.G.C., REDDY A.V.R., GARG A.N. 2005. *Availability of essential elements in Indian and US tea brands*. Food Chem., 89: 441-448.

OKINDA OWUOR P., OBANDA M., NYIRENDA H.E., MANDALA W.L. 2008. *Influence of region of production on clonal black tea chemical characteristics*. Food Chem., 108: 26-271.

OLIVIER J., SYMINGTON E.A., JONKER C.Z., RAMPEDI I.T., VAN EEDEN T.S. 2012. *Comparison of the mineral composition of leaves and infusions of traditional and herbal teas*. S. Afr. J. Sci., 108(1/2).

PLUST D., CZERNIEJEWSKA-SURMA B., DOMISZEWSKI Z., BIENKIEWICZ G., SUBDA R., WESOŁOWSKI T. 2011. *Quality of selected white tea types*. Żywność. Nauka. Technologia. Jakość, 3(76): 90-97. (in Polish)

ROGERS M.A., SIMON D.G. 1999. *A preliminary study of dietary aluminium intake and risk of Alzheimer's disease*. Age Ageing., 28(2): 205-209.

RUSINEK-PRYSTUPA E., SEMBRATOWICZ I., MARZEC Z., SAMOLIŃSKA W., KICZOROWSKA B. 2016. *The content of some minerals in YERBA MATE teas and ROOIBOS*. Biol. Treace Elem. Res., 172(1): 266-75.

SAMOLIŃSKA W., KICZOROWSKA B., KWIECIEŃ M., RUSINEK-PRYSTUPA E. 2017. *Determination of minerals in herbal infusions promoting weight loss*. Biol. Trace Elem. Res., 175: 494-502.

SATO K., SUZUKI I., KUBOTA H., FURUSHO N., INOUE T., YASUKOUCHI Y., AKIYAMA H. 2014. *Estimation of daily aluminum intake in Japan based on food consumption inspection results: impact of food additives*. Food Sci. Nutrit., 2(4): 389-397.

SPIRO M., CHONG Y.Y., JAGANYI D. 1996. *Kinetics and equilibria of tea infusion*. Part 13. *Further studies on tea scum: the effects of calcium carbonate, lemon juice and sugar*. Food Chem., 57(2): 295-298.

STAŃCZYK A., ROGALA E., WĘDZISZ A. 2010. *Determination of the contents of tannins and selected minerals in green tea*. Bromat. Chem. Toksykol., 43(4): 505-508. (in Polish)

STREET R., SZÁKOVÁ J., DRÁBEK O., MLÁDKOVÁ L. 2006. *The status of micronutrients (Cu, Fe, Mn, Zn) in tea and tea infusions in selected samples imported to the Czech Republic*. Czech J. Food Sci., 2(24): 62-71.

TAYFUR M., KARAAGAOGLU N., BASOGLU S., MERCANLIGIL S.M. 2013. *Influence of brewing pots on mineral content of black tea infusions*. Turk. J. Biochem., 38(1): 57-62.

WIERZEJSKA R. 2014. *Tea and health – A review of the current state of knowledge.* Prz. Epidemiol., 68: 595-599. (in Polish)

Joint FAO/WHO Expert Committee on Food Additives. 2011. *Evaluation of certain food additives and contaminants*. WHO Tech. Rep. Ser., 966: 7-17.

YALCIN GORGULU T., KIPCAK A.S., DERE OZDEMIR O., MOROYDOR DERUN E., PISKIN S. 2014. *Examination of the lemon effect on risk elements concentrations in herbal and fruit teas.* Czech J. Food Sci., 32(6): 555-562.