



Elemental composition of green tea infusions depending on the method of their brewing

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Abstract

Green tea infusions are a source of many bioactive compounds as well as elements, both nutrients and toxic ones. In this study, we assessed the content of elements in green tea infusions depending on the brewing time and their pH values. In instrumental analysis we used atomic absorption spectrometry. Elements such as Ca (calcium), Cu (copper), K (potassium), Mg (magnesium), Na (sodium), Fe (iron), Mn (manganese), Zn (zinc), and toxic Al (aluminium) were quantified in green tea infusions with pH = 6 and pH = 2, and after infusion times of 5, 10, and 20 min. The mean value of the elements in 250 mL of beverage was the following: (mg) K— 114.68 ± 33.27 , Ca— 18.48 ± 334.24 , Na— 4.00 ± 0.92 , Mg— 2.71 ± 0.65 , and (μg) Al 1266.53 ± 0.56 , Mn— 488.19 ± 320.46 , Zn— 46.65 ± 5.18 , Fe— 34.30 ± 10.96 , Cu— 5.00 ± 0.01 . From 1 g of raw material, the following amounts of elements were leaching, $\mu\text{g/g}$: Al—ND-1479.89, Ca—190.42–7650.09, Fe—9.52–42.30, K—42108.07–108337.90, Mg—661.14–1760.73, Mn—58.82–931.19, Na—ND-1959.09, Zn—2.50–16.83. Cu content was at the LOD of the method. Based on the statistical analyses, significant differences between the sample series were found. Al and Mn significantly positively correlated with most of the elements studied. Both pH and brewing times affected the amount of extracted elements, especially in the case of Al, Ca, and Mn. The amount of K did not change much during the preparation of the brews. The acidic environment allows a large amount of leaching of Al and Mn into the infusion.

Keywords Bagged and leafy green tea infusions · Time · pH · Elements · Atomic absorption spectrometry

Abbreviations

AAS	Atomic absorption spectrometry
FAAS	Flame atomic absorption spectrometry
LOD	Limit of detection
\bar{x}	Arithmetic mean
sd	Standard deviation
r_s	Correlation coefficient
ND	Not detected

Introduction

Green and black teas differ in the technological methods used in processing the leaves of plants belonging to the genus *Camellia*, species *sinensis* (Family: *Theaceae*). Leaves of green tea are subjected to high temperature and then dried, while black ones are fermented first and subsequently dried. As a result of simple phenols (mainly catechins) enzymatic oxidation, condensed polyphenols are formed in the black tea leaves. Thus, infusions of green and black teas contain different amounts of bioactive compounds including flavonoids, organic acids, proteins, carbohydrates, vitamins, and minerals and are a valuable source of them [1].

Due to their presence, tea beverages have many health-promoting properties including antioxidant and anticancer activities, may reduce the risk of cardiovascular diseases as well help in the treatment of lung, skin, liver, and many other diseases. It has also been shown that they can prevent the development of type 1 diabetes and improve the immune system [2].

Environmental conditions and treatments used in the cultivation of tea bushes have a decisive impact on the elements

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content in fresh tea leaves. Climate, mineral resources of soil, water, and air, their pH value and possible degree of their contamination, fertilizers and crop protection products used, as well plant age affect the bioavailability of elements and their accumulation in tea leaves. They contain the most (milligrams per 1 g dry weight) K, Na, Ca, Mg, Al and Mn, and smaller amounts (micrograms to milligrams/1 g) of elements such as Fe, Zn, Cr, Ni, and Cu. The remaining elements occur in trace amounts. This also applies to toxic elements such as Pb, Cd, and Hg. Their presence may be influenced by, among others, a polluted environment, plant protection products, and fertilizers used [3].

The degree of macro- and trace element extraction from tea leaves into an infusion may be determined by factors such as the type of tea, brewing time, mineral composition and the temperature of water used for brewing, the pH of infusion, the tea/water ratio, and age of plant [3].

Tea infusions can provide many valuable elements, but also those that are harmful to health. The reactions occurring during the extraction of elements into tea infusion are very complex and complicated. To determine how much of them we consume with the infusion, beverages we prepared in a traditional way. Taking into account the fact that tea is one of the most widely consumed beverages in the world, we attempted to assess the influence of factors such as extraction time, the pH values in infusions made from green tea leaves and sachets to determine the optimal conditions for the leaching of elements (Ca, Cu, Fe, K, Mg, Mn, Na, Zn). We also checked what conditions are conducive to the extraction of Al, which is dangerous to our health. To assess the extent to which pH and time influence the transfer of elements to the tea infusion as well relationships between them, statistical analysis methods were used.

Materials and methods

Sampling

Green leaf tea, both loose and in sachets (Lipton) was purchased at a local supermarket. The purchased teas came from cultivation in Asian countries, mainly from Java and Sumatra. The infusions were prepared in the traditional way regarding the amount of tea and water, according to the manufacturer's suggestions, so that the amount of leached elements is adequate to their quantity consumed with a glass of tea.

Tea bags and loose leaf tea (approximately 2 g as recommended by the manufacturer) were weighed by analytical balance (ScalTec, Germany) and placed in beakers. The average weight of the tea bags from which the infusions were made was 1.2945 ± 0.0311 g, and infusions made from tea leaves contained 2.0337 ± 0.0292 g of the product.

The teas were poured with tap water at a temperature of about 90°C in the amount of 230 mL. The brewing time was 5, 10, and 20 min. The infusions were transferred into volumetric flasks (250 mL) and filled up to the mark with tap water. In parallel, the next nine infusions were prepared in the same way but with the addition of an appropriate amount of HNO_3 (Chemian Ciech, Poland, $\text{pH} \approx 2$). The value corresponds to the acidity of the infusion prepared with the addition of lemon. The collected infusion samples (50 mL) were transferred to plastic containers and the pH values were measured by the pH-meter CP 501 (Elmetron, Poland). The values were the following: 6.32 ± 0.19 and 1.89 ± 0.01 (bags) and 6.46 ± 0.12 and 2.04 ± 0.03 (leaf). Next, HNO_3 was added to make $\text{pH} = 1$ in all samples.

All infusions were made in three replicates ($n = 36$). Four tap water samples were treated as blanks.

Instrumental analyses

The content of elements was measured by the atomic absorption spectrometer AVANTA Σ (GBC Scientific Equipment Pty. Ltd, Australia). Measurements were made using the flame technique (FAAS), in standard conditions. Analytical procedures were developed based on the manufacturer's recommendations. Conditions of instrumental analysis and validation parameter values have been described previously [4]. In the analysis of Ca and Mg concentrations, LaCl_3 was used as a release buffer, while in the analysis of Na and K, CsCl was used as a deionization buffer. The last two elements were quantified at wavelengths—404.4 nm (K) and 330.2 (Na). In the case of Al, the element was measured in the N_2O -acetylene flame at $\lambda = 396.2$ nm, with the addition of CsCl. The determined limit of detection for the element— $0.47 \mu\text{g/mL}$, sensitivity— $0.50 \mu\text{g/mL}$, and accuracy 117.9% (reference material INCT-TL-1, Institute of Nuclear Chemistry and Technology, INCT/ICHTJ, Poland).

The accuracy of the remaining analytical procedures determined on the basis of the analysis of this material was as follows: Ca— $103.8 \pm 3.8\%$, Cu— $93.7 \pm 2.2\%$, Fe— $98.1 \pm 2.8\%$, K— $103.2 \pm 0.9\%$, Mg— $95.2 \pm 5.8\%$, Mn— $97.5 \pm 1.9\%$, Zn— 92.3 ± 1.0 , and for Na— $94.2 \pm 0.8\%$ (SRM 1577b).

Statistical analyses

All statistical analyses were performed using Statistica software ver. 9 (StatSoft Polska Ltd., Poland). Analysis of variables distribution (Shapiro–Wilk test) showed that they are non-parametric. Thus, the statistical tests performed are intended for such distributions. The Kolmogorov–Smirnov test was used to assess the significance of differences and the Spearman test for correlation between the variables. The Fisher test was used in analysis of variance (ANOVA)

to assess the homogeneity of variance between multiple groups, followed by the post hoc LSD (least significant differences) test to for verify the significance of differences between the groups was applied. The statistical significance level was considered at $p < 0.05$.

Results

Element content in infusions

The amount of elements given in Tables 1 and 2 as well as Figs. 1 and 2 is expressed in the form of the arithmetic mean and standard deviation and after deducting the element content in tap water (blanks).

Table 1 Macroelement content released from 1 g of green tea into infusions, ($\bar{x} \pm sd$)

	pH	Ca (mg)	K (mg)	Mg (mg)	Na (mg)
B ^a 5	6	0.19 ± 0.05	54.11 ± 12.43	0.86 ± 0.15	1.54 ± 0.03
B 10	6	0.85 ± 0.11	57.98 ± 13.75	0.89 ± 0.01	1.45 ± 0.23
B 20	6	0.84 ± 0.09	63.64 ± 7.51	0.91 ± 0.04	1.55 ± 0.36
B 5	2	2.09 ± 0.52	75.19 ± 6.96	1.05 ± 0.07	1.57 ± 0.01
B 10	2	5.35 ± 1.30	78.19 ± 12.45	1.40 ± 0.14	1.63 ± 0.23
B 20	2	5.40 ± 1.20	83.30 ± 22.79	1.47 ± 0.09	1.89 ± 0.06
L ^b 5	6	1.05 ± 0.09	55.98 ± 8.71	0.73 ± 0.02	ND
L 10	6	1.00 ± 0.30	56.20 ± 16.50	0.72 ± 0.09	ND
L 20	6	1.05 ± 0.40	59.04 ± 7.51	0.84 ± 0.04	0.21 ± 0.01
L 5	2	3.72 ± 0.71	59.06 ± 14.40	1.10 ± 0.12	0.49 ± 0.01
L 10	2	4.30 ± 0.19	71.23 ± 9.77	1.18 ± 0.09	0.33 ± 0.09
L 20	2	6.74 ± 1.32	79.60 ± 12.25	1.63 ± 0.23	0.09

^aBagged tea

^bLeafy tea

Table 2 Microelement content released from 1 g of green tea into infusions, ($\bar{x} \pm sd$)

	pH	Al (mg)	Fe (µg)	Mn (µg)	Zn (µg)
B ^a 5	6	254.70 ± 89.69	24.37 ± 2.06	407.51 ± 23.33	9.54 ± 0.03
B 10	6	532.30 ± 147.51	24.59 ± 0.39	457.60 ± 21.33	7.51 ± 2.04
B 20	6	627.73 ± 96.59	27.57 ± 1.05	471.52 ± 19.80	7.04 ± 0.87
B 5	2	987.95 ± 47.90	33.89 ± 0.93	544.69 ± 39.63	12.71 ± 1.28
B 10	2	1234.00 ± 127.03	36.00 ± 8.31	746.77 ± 175.08	13.08 ± 1.50
B 20	2	1415.36 ± 123.13	37.20 ± 2.80	862.51 ± 60.20	14.29 ± 3.59
L ^b 5	6	ND	9.81 ± 0.05	63.24 ± 7.41	3.73 ± 1.23
L 10	6	ND	9.91 ± 0.03	67.99 ± 7.32	4.81 ± 0.60
L 20	6	273.25 ± 75.90	9.76 ± 0.25	71.09 ± 1.86	7.39 ± 0.05
L 5	2	361.94 ± 45.40	18.34 ± 3.61	132.41 ± 1.38	7.76 ± 0.64
L 10	2	385.69 ± 21.13	19.27 ± 4.30	145.03 ± 2.94	7.80 ± 1.56
L 20	2	501.97 ± 22.58	22.77 ± 1.90	160.31 ± 16.73	8.55 ± 0.12

^aBagged tea

^bLeafy tea

In some cases, the content of elements (Al and Na) in the infusion was at the same level as the tap water used for their preparation as well as the limit of detection (Cu—0.02 µg/mL). Thus, the element amount released from tea leaves to beverage was treated as zero (Tables 1 and 2).

The mean value of the elements in 250 mL of beverage (including tap water) was the following: (mg) K—114.68 ± 33.27, Ca—18.48 ± 334.24, Na—4.00 ± 0.92, Mg—2.71 ± 0.65, and (µg) Al 1266.53 ± 0.56, Mn—488.19 ± 320.46, Zn—46.65 ± 5.18, Fe—34.30 ± 10.96, Cu—5.00 ± 0.01. Figure 1 (Ca, K, Mg, and Na) and 2 (Al, Fe, Mn, and Zn) demonstrate the element content in 1L of tea infusion but without their amounts in tap water.

Element amount leaching from 1 g of tea

Tables 1 and 2 show what amounts of the tested elements were extracted per 1 g of tea. Among the analyzed elements, the largest amount of K was transferred to the infusion, followed by Ca, Mg, and Na. Comparable quantities of Al and Mn were extracted as well as Zn and Fe, although to a lesser extent.

Taking into account the amount of leached elements from 1 g of all bagged and loose tea, comparable amounts of Ca, K, Mg, and Zn were extracted. Larger amounts of Al (about threefold), Fe (two-times), Mn (over fivefold), and Na (about sevenfold) transferred to the tea infusion from tea bags, compared to loose tea.

Element content in infusions according to their pH value

Table 3 illustrates the statistical significance related to the migration of elements in the infusions, taking into account

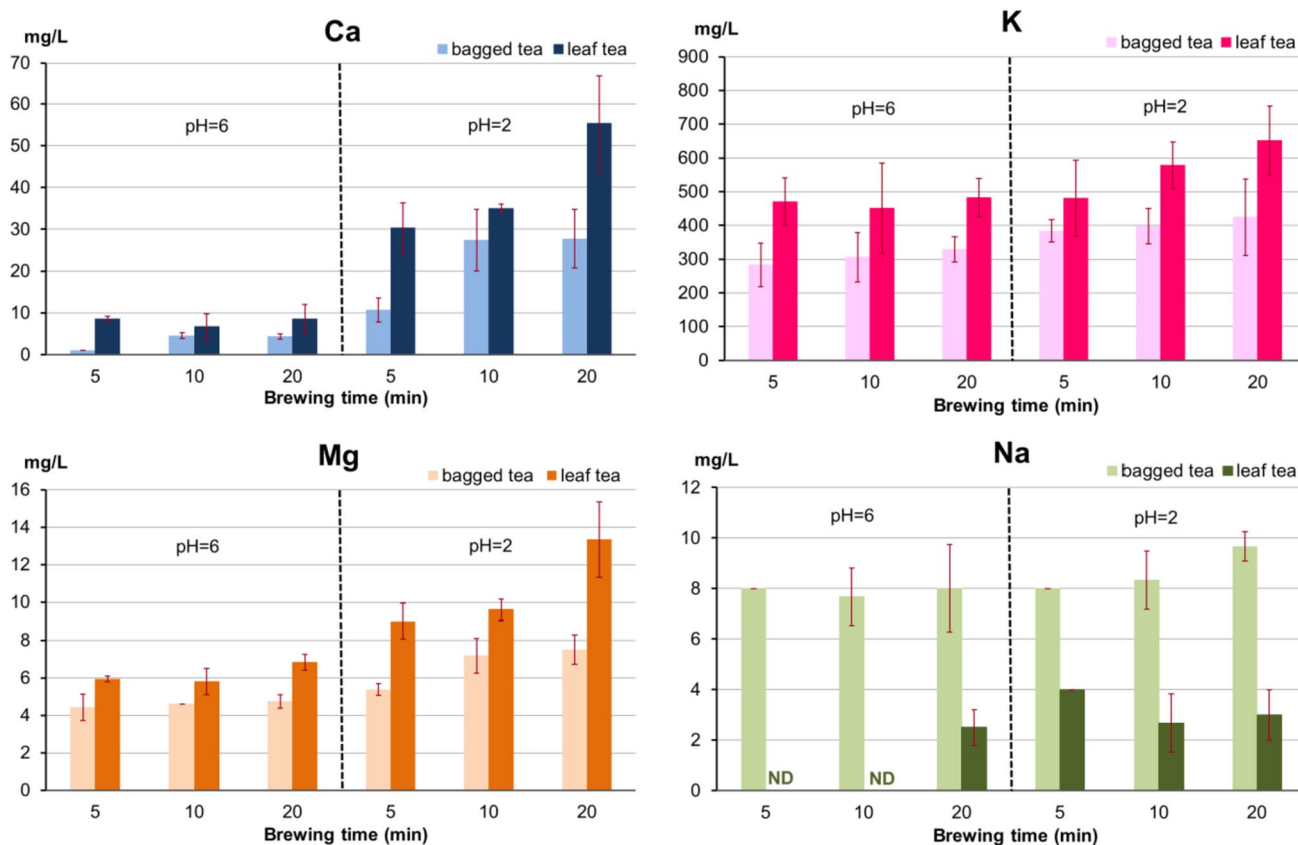


Fig. 1 Concentration (mg/L) of macroelements in teas infusions—without their content in tap water—(\bar{x} and sd)

their pH value. In infusions prepared from bagged tea, except for in the case of Na, the pH significantly affect its amount in the beverage, while in the case of loose tea infusions K was an exception. In infusions with a pH value of 6, both made from tea bags and loose tea, no significant differences were found in the amount of extracted elements such as Ca, K, and Zn. However, in infusions with pH = 2, such a difference was also not found in the case of Mg (Kolmogorov–Smirnov test, $p < 0.05$).

The content of elements in infusions depending on the brewing time

Table 4 shows the results of the statistical analysis (LSD test, $p < 0.05$) carried out to check how the brewing time affects the amount of the extracted elements. The factor significantly affected the amount of leached elements, especially in the case of Al, Ca, Mg, and Mn. Moreover, the time significantly affected the amount of Fe in bag infusions (pH = 6) as well as Zn in loose tea beverages (pH = 6). Under the conditions of the study, the brewing time did not significantly affect the amount of Na and K that passed into the solution.

Correlations between elements quantity in beverages

To determine the tendency to interact between the content of elements in the infusions, we used the Spearman correlation test ($p < 0.05$). The analysis included the amount of the element leached from 1 g of tea. The results (Spearman rank correlation coefficients, r_s) are present in Table 5. Part “a” of the table demonstrates the correlations in bagged tea infusions, where in the upper right corner there are r_s values for infusions with pH = 6, while in the lower corner—are infusions with pH = 2. Analogically, the table below (b) shows r_s values for loose tea infusions.

The elements show mutual correlations, usually positive, especially in infusions with an acidic environment. It can be observed that some pairs of elements are strongly correlated with each other, although these correlations are not statistically significant. The largest number of correlating pairs was created by Al, while the least was observed in the case of Na and Zn. In the beverages it was found that, Al mostly positively interacts with Ca, Fe, Mg, and Mn, Ca with Mg and Mn, Fe with Zn and K, Mg with Mn, Mn with Al, K, Na, and Fe.

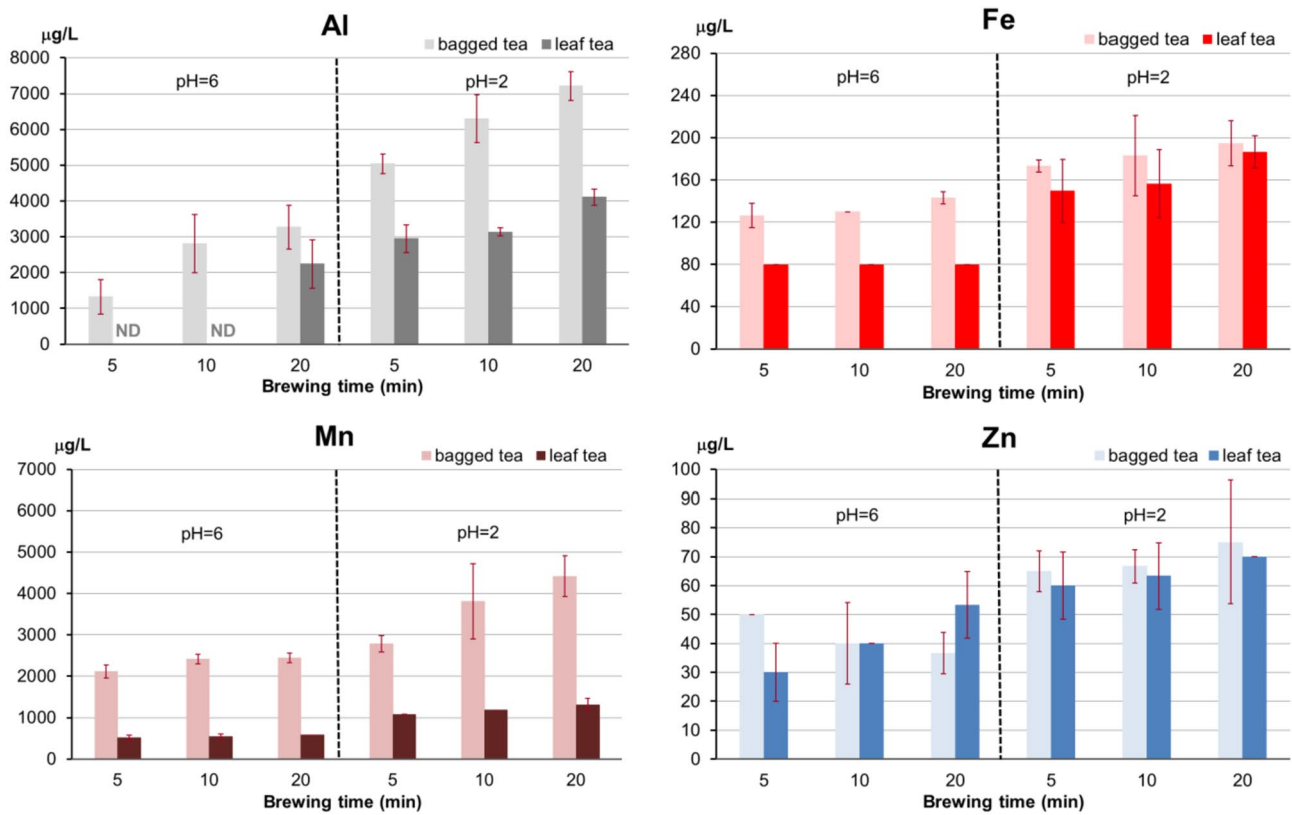


Fig. 2 Concentration (µg/L) of trace elements in teas infusions—without their content in tap water—(\bar{x} and sd)

Table 3 Analysis of the significance of differences between the groups depending on pH results, (Kolmogorov–Smirnov test)

	Al	Ca	Fe	K	Mg	Mn	Na	Zn
B, pH 2/6	0.001	0.001	0.005	0.025	0.005	0.001	$p > 0.1$	0.005
L, pH 2/6	0.005	0.001	0.001	$p > 0.1$	0.001	0.001	0.01	0.025
B vs L, pH=6	0.05	$p > 0.1$	0.001	$p > 0.1$	0.025	0.001	0.001	$p > 0.1$
B vs L, pH=2	0.001	$p > 0.1$	0.001	$p > 0.1$	$p > 0.1$	0.001	0.001	$p > 0.1$

Table 4 Analysis of the significance of differences between the groups depending on time brewing results, (LSD test)

	Al	Ca	Fe	K	Mg	Mn	Na	Zn
B, pH=6	1 ^a –2 ^b ,3 ^c	1–2,3	1–3, 2–3	–	–	1–2,3	–	–
B, pH=2	1–2, 3	1–2, 3	–	–	1–2, 3	1–3	1–3	–
L, pH=6	1–3, 2–3	–	–	–	1–3, 2–3	–	–	1–3, 2–3
L, pH=2	1–3, 2–3	1–3, 2–3	–	–	1–2, 2–3	1–3	–	–

^a5 min
^b10 min
^c20 min

Discussion

The content of elements in raw material of tea leaves, along with its infusions and bioavailability, is the subject of interest and research, especially given the popularity

of the beverages in the world. The published research results vary. The differences result, among others, from the heterogeneity of raw materials and the different conditions in preparing the infusions. However, there are some trends in relation to the content of elements in tea and infusions. Olivier [5] reported the following values for

Table 5 Results of correlation analysis between the amount of elements in infusions (Spearman rank correlation coefficients, r_s)

	Al	Ca	Fe	K	Mg	Mn	Na	Zn
(a) Bags								pH=6
Al	1	0.54	0.37	0.57	0.48	0.83*	- 0.08	- 0.39
Ca	0.42	1	0.46	- 0.08	0.08	0.28	- 0.28	- 0.20
Fe	0.45	0.36	1	0.69	0.19	0.63	0.42	- 0.32
K	0.35	- 0.42	0.17	1	0.57	0.83*	0.67	- 0.04
Mg	0.62	0.88*	0.24	- 0.30	1	0.26	0.24	- 0.49
Mn	0.62	0.63	0.33	- 0.20	0.85*	1	0.38	- 0.57
Na	0.75*	0.33	0.29	0.28	- 0.75	0.70*	1	- 0.14
Zn	- 0.11	0.28	0.86*	- 0.21	0.04	0.14	0.00	1
	pH=2							
(b) Leaves								pH=6
Al	1	-	-	-	-	-	-	-
Ca	0.95*	1	- 0.39	- 0.60	- 0.31	0.07	-	0.31
Fe	0.68*	0.63	1	- 0.09	- 0.70	0.70*	-	- 0.43
K	0.48	0.58	0.75*	1	0.40	- 0.09	-	0.07
Mg	0.85*	0.92*	0.63	0.73*	1	0.00	-	0.57
Mn	0.70*	0.73*	0.55	0.73*	0.85*	1	-	0.29
Na	- 0.12	- 0.25	0.25	0.03	- 0.05	- 0.12	1	- 0.14
Zn	0.47	0.45	0.72*	0.50	0.48	0.33	0.55	1
	pH=2							

*Statistically significant value, $p < 0.05$

the concentration of elements in dry green tea leaves (mg/kg): K— 13896 ± 811 , Ca— 5252 ± 937 , Mg— 1956 ± 214 , Al— 1362 ± 555 , Mn— 939.2 ± 196.3 , Fe— 312.6 ± 73.3 , Na— 132 ± 45 , Zn— 40.4 ± 8.9 , Cu— 23.0 ± 3.6 . The given element concentrations are in good agreement with other published data [3, 6, 7].

The health value of tea beverages is determined, among others, by the content of bioelements, but also toxic metals. Thus, their elemental composition and the factors affecting it are the subject of research. The authors [3, 8] divided the elements taking into account the possibility of their extraction rate into: highly extractable (> 55%, e.g., Na, K, Ni, Co), moderately extractable (20–55%, e.g., Mn, Mg, Zn, Al), and poorly extractable (< 20%, e.g., Ca, Cu, Mo, Fe, Sn, Cd, Pb). The efficacy of extraction depends on the chemical form of the element, i.e. also on the solubility of the compound. Generally, green tea leaves contain more flavonoids, such as catechins and flavonols (along with their glycosides) compared to black tea leaves and which also have much more condensed polyphenols [3, 9–11].

Most of the metals in tea leaves exist in complex compounds with flavonols, catechols, tannins, and polyphenols. Tannins and condensed polyphenols (theaflavins and thearubigins) form strong complexes with elements such as Al, Fe, and Mg, which limits their solubility in water. In general, metals such as Al, Co, Cr, Fe, K, Mn, Ni, Rb, Se, Sn, and Zn are extracted in larger amounts from green tea leaves than from black tea ones [3, 11]. Moisson et al. [12] reported that

the degree of water mineralization affects the efficiency of Al extraction as well as organic carbon and total polyphenols extraction, i.e. the higher the degree of mineralization, the lower the degree of extraction. Other authors stated [13] that higher temperatures (18, 40, 60, 80°C) increases metals (Cu, Fe, Ni, Cr) migration into infusion. On the other hand, higher concentration (1% and 8%) of the raw material (green tea leaves) resulted in less element leaching. As Ødegård and Lund [14] established, Mg, Mn, and Rb are present in tea infusions as cations (probably in association with inorganic compounds), whereas Ca, Fe, Co, Ni, Cu, Zn, Sr, and Zn may exist in both cationic and non-cationic fraction. In the case of Fe, Ni, Cu, and Zn organic complexes were found in the size of 4000–6000 Da. The authors stated that Al is mainly in non-cationic form, and occurs in compounds with the molecular weight of 4000–6000 Da and 6500–8500 Da. However, Matsura et al. [8] have determined other molecular weights for the elements, including Al (1200–1500 Da). They are also of the opinion that Al occurs mainly in chelate complexes with polyphenols in tea infusions.

In our research, taking into account the amount of elements leached from green tea leaves into infusion, we obtained comparable results with the data presented in the literature [5–7, 15, 16]. Differences in the content of some elements in the infusion samples of the same series may result from the heterogeneity of the raw material.

Alkaline elements (Na, K) are well soluble in aqueous solutions, while the alkaline earth metals (Ca, Mg) are less

Table 6 Percentage of elements contained in 250 ml of infusion in the realization of the RDA

	Ca	Fe	K	Mg	Mn	Na	Zn
pH=6	0.14	0.17 ^a 0.19 ^b	2.65	0.45 ^a 0.34 ^b	11.97	0.09	0.10 ^a 0.08 ^b
pH=2	0.81	0.26 ^a 0.36 ^b	3.47	0.72 ^a 0.62 ^b	20.27	0.10	0.16 ^a 0.13 ^b
Ref	[19]	[19]	[19]	[19]	[19]	[25]	[19]

^aWomen^bMen

soluble. Whereas, compounds of transition metals (Cu, Mn, Fe, Zn) and Al are slightly soluble or they are practically insoluble. Moreover, most of these metals form complicated complex compounds. The addition of an acid to an aqueous solution shifts the direction of the reaction towards greater solubility of the compound. We noted a significant effect of lower acidity on the migration of such elements as Al, Fe, and Mn into the infusion (Table 2). Furthermore, statistically significant differences between the amount of leached elements for infusions at pH=6 and pH=2 prepared from sachets and loose leaves, as well as between these infusions (B vs L, Table 3) were observed. Jeszka-Skowron et al. [17] found that the addition of citric acid increases the amount of Al, Cd, and Pb in the infusions and is associated with a greater amount of phenolic compounds in the beverage. Saletnik et al. [18] observed a significant effect of citric acid on the mobilization of Ca and Al for green tea infusions, while a smaller one for Mg and K.

Leaching of elements from tea leaves into the brew involves their migration from one phase to another (solid/liquid system) according to the law of diffusion. The process continues until the system reaches a state of equilibrium. We observed that longer tea brewing time affected the extraction of elements. However, in the neutral environment, these differences were not so pronounced (Tables 1, 2, and 4). The effect of time (5 and 15 min) on the degree of extraction of Ca, K, Mg, P, and Al from green tea for infusion was described by Saletnik et al. [18]. A greater mobility of elements, generally, was found after 15 min of brewing. Whereas, Özcan et al. [19] determined that a brewing time of 10 min is optimal for Al, B, Bi, Cu, Fe, K, Mg, Mn, Na, Ni, Sr, Tl, V, and Zn leaching.

Comparing infusions prepared from bagged and loose leaf green tea we should state that rather comparable amounts of Ca, K, Mg, and Zn were extracted from both kind of teas, but more Al, Fe, Mn and Na were leached from teas in bags. Furthermore, in bagged tea infusions, statistically significant differences occur between 1 (5 min) and 2 (10 min) as well 3 series (20 min), while in loose leaf teas between 1 and 3 as well 2 and 3.

Based on the experience of other authors [3, 5–7, 16] and assessing the content of elements in the analyzed green

tea infusions in the study, with respect to the EFSA recommendations, we can conclude that they are a valuable complementary source of elements such as K (about 15% vs 3500 mg) and Mn. 1 Liter of the bagged tea infusion (pH=2) may exceed adequate values for the Mn adequate intake (AI) – 3 mg/d [19].

Of the elements analyzed, Al requires more attention. Excessive exposure to this element leads to many vital dysfunctions of the human body, including to the nervous, skeletal, endocrinal and hematopoietic systems [20]. Human and animal tissues can accumulate Al in cell structures as well as physiological fluids, affecting, among others, disturbances in biochemical processes [20–22]. The *Camellia sinensis* bush is a plant that accumulates large amounts of the element and its significant amounts are transferred to infusions [3, 5, 20, 23]. As reported by Pohl et al. [11], 38.54% and 47.34% of the Al present in green tea infusions (leaves and bags, respectively) is in the cationic form. The bioavailability of Al and Fe was estimated by the authors at a lower level compared to Ca, Mg, Mn, Sr, and Zn. In this study, Al amounts determined in infusions are in good accordance with the other data [11, 12, 18, 24, 25]. Larger amounts of Al were leached into the solution from bagged (254.70–627.73 µg/g) than loose leaf tea (ND—273.25 µg/g). Also the time of brewing had an influence on the migration of the element. In the case of loose leaf tea, measurable amounts were extracted after 20 min. The acidic environment significantly increased Al mobility (987.95–1415.36 µg/g, 361.94–501.97 µg/g, respectively). One cup of tea may contribute about 0.5 mg Al, but with the addition of acid—approximately 1.2 mg of the element (excluding Al content in tap water). According to the EFSA recommendations, the tolerable weekly intake (TWI) for Al should not exceed 1 mg aluminium/kg bw/week [20]. With respect to the already proven Al toxicity, the possibility of higher exposure to this element in tea infusions with the addition of lemon should be taken into account in our daily diet. Similar observations were presented by other authors [11, 20, 23, 24] which justifies the need to monitor human exposure to this element.

Table 6 shows to what extent the average content of elements contained in one cup of green tea infusion (without their content in tap water) cover the Recommended Dietary

Allowance (RDA) [26]. Referring to the daily requirement for elements, 250 ml of infusion provides the least Ca, Na, and Zn, slightly more Fe, and the most K and Mn. Tea infusion contains significant amounts of Mn, therefore, taking into account an environmental or occupational exposure, its consumption should be controlled.

Conclusions

In this study, the effect of brewing time and pH on the amount of extracted elements from green tea in the form of sachets and loose leaves was evaluated. It was found that both factors affect the amount of elements migrating to the infusion. Generally, the longer the brewing time, the more metals migrated into the brew (specially Ca, Al, Mn). However, the time of 10 min is optimal for preparing infusions in most cases. The acidic environment favors the extraction, particularly, of Ca, Mg, Al, and Mn. Differences in the content of mainly Na, Al, Mn and Fe were visible between tea bags and loose leaves. Only with K content, little changed under different conditions in the preparation of infusions. Attention should be paid to the significant amounts of not just Al, but also Mn in infusions prepared in an acidic environment. In publications on the quantitative analysis of elements in tea infusions by various authors, including ours, it is possible to observe a convergence of the presented results, despite the diverse material, different analytical procedures and instrumental analysis methods used. This makes it easier to determine the trend accompanying the migration of elements from tea leaves into the infusion relatively in their quantity.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Conflict of interest The authors declare no conflict of interest.

Compliance with ethics requirements This study does not contain any studies with human participants or animal performed of any of the authors.

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