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Element Composition of Tea Leaves and Tea Infusions and Its Impact on Health

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Abstract Tea infusion is the most frequently consumed beverage worldwide next to water, with about 20 billion cups consumed daily. In Taiwan, daily consumption averages 2.5 cups of tea infusion per person. Many studies have concluded that tea has numerous beneficial effects on health. However, some undesirable trace elements, such as arsenic, chromium, cadmium, lead, etc., are a concern. This study has three aims: (1) to measure the concentrations of arsenic and heavy metal elements, such as chromium, cadmium, and lead, as well as the essential trace elements contained in dried tea leaves of the common brands in Taiwan; (2) to determine the percentage released and concentration of each of these elements after infusion of these tea leaves with boiling water; (3) to assess the carcinogenic risk from daily tea consumption, to provide reference values for the general public. This study showed the total content of arsenic and heavy metals in green tea, oolong tea, and black tea produced in Taiwan was 0.11, 5.61, and 10.11 ug/g, respectively, indicating that the level of arsenic and heavy metal contamination of tea leaves was lower in Taiwan than other regions of the world. The hazard index (HI) of daily tea drinking of green tea, oolong tea, and black tea was low and within the bounds of safety (<1). Tea is an indispensable part of everyday life for many people in Taiwan, studies should continue to ensure that public health is maintained.

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Tea infusion is the most frequently consumed beverage worldwide next to water, with about 20 billion cups consumed daily. In Taiwan, daily consumption averages 2.5 cups of tea infusion per person (Department of Health, Taiwan 2004). Tea is made from the processed leaves of the plants. The three most popular types of tea (green, oolong, and black) are distinguished on the basis of degree of fermentation. The leaves of green tea are dried and roasted but not fermented, whereas black tea leaves are additionally fermented. If leaves are only partially fermented, then oolong tea is the result. After fermentation, tea is rated with respect to aroma, color, and taste (Fujihara et al. 2007).

Many studies have concluded that tea has numerous beneficial effects on health, including the prevention of many diseases such as skin cancer, Parkinson's disease, myocardial infarction, and coronary artery disease (Qin and Chen 2007). However, some undesirable trace elements, such as arsenic, chromium, cadmium, lead, etc., are a concern. Plants obtain these trace elements from growth media such as nutrient solutions and soils (Herrador and González 2001; Kabata-Pendias and Pendias 1984). The extent to which they take up metals depends on the extent to which trace elements are bound to soil constituents. Other sources include pesticides and fertilizers. Arsenic is strongly associated with lung and skin cancer in humans, and may cause other internal cancers as well. Skin lesions, peripheral neuropathy, and anemia are hallmarks of chronic arsenic ingestion. Arsenic is a major risk factor for blackfoot disease, which is caused by intake contaminated groundwater and was once endemic on the southern coast of Taiwan (Chen 2006). Chromium exposure produces acute overt symptoms and delayed manifestations including increases in the incidence of various human cancers (Cohen et al. 1993). An acute intake of cadmium causes testicular damage. Within a few hours of exposure, there is necrosis and degeneration of the testes with complete loss of spermatozoa. Cadmium is also known to be carcinogenic, and has been linked to lung and prostate cancer. Lead is a physiologic and neurological toxin that can affect several organs and organ systems in the human body. Cadmium and lead can reduce cognitive development and intellectual performance in children and damage kidneys and the reproductive system (ATSDR 2005). Therefore, the arsenic and heavy metal content of tea has become a public health issue. This study has three aims: (1) to measure the concentrations of arsenic and heavy metal elements, such as chromium, cadmium, and lead, as well as the essential trace elements contained in dried tea leaves of the common brands in Taiwan; (2) to determine the percentage released and concentration of each of these elements after infusion of these tea leaves with boiling water; (3) to assess the carcinogenic risk from daily tea consumption, to provide reference values for the general public.

Materials and Methods

Three types of tea with different degrees of fermentation were selected for this study: black (fully fermented), oolong (partially fermented), and green tea (unfermented). A total of 48 commercial tea samples were collected from six markets in Hsinchu. They included both imported and locally produced teas. The samples (2 g of dried tea leaves) in polytetrafluoroethylene (PTFE) vessels containing concentrated HNO_3 (20 mL) were digested in a microwave digestion bomb (MD2000, CEM Corporation, Matthews, NC, USA). The digestion program consisted of 11.72 bar with temperature ramped to 190°C over 30 min and then maintenance at 190°C for 40 min. The digested solutions were filtered and diluted to 50 mL with deionized water. The usual method for preparing tea infusion was used: 2.0 g of each tea sample was transferred into a glass beaker, 100 mL of boiling water (100°C) was added, and the sample was left at room temperature for 10 min. The supernatant was recovered by filtering through filter paper (Whatman no. 42). Digestion of 5.0 mL of this solution transferred to a PTFE vessel was carried out as described above. Contents of all elements were analyzed three separate times using an inductively coupled mass spectrometry method (Chen 2007; Herrador and González 2001) performed on a Perkin-Elmer Elan 5000 Inductively Coupled Plasma Mass Spectrometer (ICP-MS). The operating conditions were as follows: (1) carrier gas (argon, 99.999%): 0.8 L/min; (2) plasma gas (argon, 99.999%): 13 L/min; (3) auxiliary gas (argon, 99.999%): 0.8 L/min; (4) pump rate: 1.5 mL/min; and (5) power: 1,055 KW. The quantitative determinations of elements in samples were done using calibration curves obtained from diluted stock solutions of standard elements (1,000 mg/L). Rhodium and germanium were used as internal standards. The recovery yields, detection limits, and % R.S.D. for triplicate measurements of the elements were 90%–95%, below 50 ppt, and less than 5%, respectively. Data are expressed on a dry weight basis, and element contents in the infusion are listed. The analyses of variance (F) and Kruskal-Wallis test were performed to compare the concentration differences between the three types of tea. Statistical analysis was performed using SPSS/PC$^+$ (SPSS, Inc., Chicago, IL, USA).

Results and Discussion

Table 1 shows the composition of arsenic, heavy metals and essential trace elements in marketed tea leaves measured in this study. The heavy metals included chromium (Cr), cadmium (Cd), and lead (Pb). Arsenic (As) was called a semimetal. The six essential trace elements included Co Cu, Fe, Mg, Zn and Se. All these elements are essential to humans for growth, metabolism, and hormone balancing. On a dry weight basis, the lowest amount of arsenic and heavy metals was found in green tea (mean, 0.11 μg/g), followed by oolong tea (5.61 μg/g) and black tea (10.01 μg/g). A statistically significant difference ($p < 0.05$) in arsenic and heavy metal content was found between green tea and oolong tea between green tea and black tea but not between oolong tea and black tea. Green tea contained no As and Cd and very low amounts of Cr (0.1 μg/g) and Pb (0.011 μg/g). In both oolong tea and black tea, Cr was the most abundant heavy metal (5.2 μg/g vs. 7.92 μg/g) followed by Pb (0.4 μg/g vs. 2.01 μg/g), and very low amounts of As and Cd (both below 0.1 μg/g). In the order of concentration (from high to low), Mg, Zn, Fe, and Cu were the most abundant trace elements in tea leaves. The concentrations of Mg, Fe, and Cu were higher in oolong tea than in green tea and black tea, while the concentration of Zn was higher in green tea than in oolong tea and black tea. Moreover, the concentrations of Se and Co were higher in green tea than in oolong tea and black tea. The concentrations of Zn, Se, and Co were highest (6.3, 0.3, 0.7 μg/g, respectively) in green tea (which is the least fermented of the three types of tea). Mineral loss due to fermentation during the manufacture of oolong and black tea may explain why green tea retains the highest concentrations of these minerals. Herrador and González (2001) in China and Nookabkaew et al. (2006) in Thailand reported the same finding.

Table 1 Concentrations of arsenic, heavy metals and essential trace elements in marketed tea products (μg/g of dry weight basis)

Elements	Green tea (n = 15)		Oolong tea (n = 18)		Black tea (n = 15)	
	Range	Mean	Range	Mean	Range	Mean
Arsenic and heavy metals						
As	ND[a]	ND	ND–0.01	0.005	ND–0.05	0.01
Cr	ND-0.5	0.1	3.9–6.2	5.2	5.5–9.3	7.92
Cd	ND	ND	ND–0.02	0.005	ND–0.1	0.07
Pb	ND-0.2	0.01	ND–1.2	0.4	ND–6.5	2.01
Total amounts		0.11		5.61		10.01
Essential trace elements						
Co	0.4–1.2	0.7	0.09–0.6	0.3	0.06–0.4	0.2
Cu	0.2–0.9	0.4	0.7–1.5	0.9	0.05–0.7	0.3
Fe	0.4–1.2	0.6	0.7–1.3	0.9	0.7–1.2	0.9
Mg	145–212	175.9	220–320	270.1	105–165	135.3
Zn	4.8–9.7	6.3	2.5–4.6	3.4	0.9–1.5	1.2
Se	0.1–0.6	0.3	0.005–0.1	0.09	0.001–0.1	0.06

[a] ND is non detectable. The detection limits of elements are below 50 ppt

Table 2 shows the mean released percentage and content of arsenic, heavy metals and essential trace elements in tea infusions (μg/100 mL) to assess their potential consumption from drinking tea. Oolong tea infusion had the highest mean percentage release of Mg, Cr, Fe, Pb, and Zn, while green tea infusion had the highest mean content of Mg, Zn, Co, and Se. Black and oolong tea infusions were similar in this respect. The highest percentage release of As, Cr, Cd, Pb, and Mg (44.9%–52.7% released) was found in oolong tea infusions, while that of Zn, Co, and Se (52.5%–60.7% released) was found in green tea infusions. The percentage released by black tea was similar to that released by oolong, except for the percentages of Zn, Se, and Co (which were particularly low (9%–15%)). Interestingly, the percentage of Cr and Pb released in green tea infusions was lower (12.4% and 7.1%, respectively). The three types of tea listed in ascending order of percentage of heavy metals released into infusions are green tea $<$ oolong tea $<$ black tea. However, the release of essential trace elements was much higher (60.7% 52.5% and 59.3% for Zn, Se, and Co, respectively) in green tea than in oolong or black tea, indicating the opposite order for release of these elements.

Although the concentrations of heavy metals in the three types of teas may seem rather low, these metals in tea infusions can pose a health risk to daily consumers of tea. We estimated this risk using the Hazard Quotient (HQ) and

Table 2 Released percentage and contents of arsenic, heavy metals and essential trace elements in infusion (μg/100 mL)

Elements	Green tea (n = 15)		Oolong tea (n = 18)		Black tea (n = 15)	
	% release	Mean content	% release	Mean content	% release	Mean content
Arsenic and heavy metals						
As	ND[a]	ND	44.9	0.005	36.8	0.007
Cr	12.4	0.02	47.5	4.9	67.5	10.7
Cd	ND	ND	52.7	0.005	40.3	0.06
Pb	7.1	0.01	50.1	0.4	58.6	2.4
Essential trace elements						
Co	59.3	0.7	30.5	0.1	25.3	0.1
Cu	22.9	0.18	23.9	0.4	21.8	0.1
Fe	10.9	0.13	42.3	0.7	30.9	0.5
Mg	34.6	121.7	51.4	277.6	50.6	136.9
Zn	60.7	7.6	27.5	1.8	9.6	0.2
Se	52.5	0.3	27.6	0.05	9.2	0.01

[a] ND is non detectable. The detection limits of elements are below 50 ppt

Table 3 Assessment of health risk to intake arsenic and heavy metals from tea infusion consumption (mg/kg-day) using Hazardous Index method

Elements	RfD (mg/kg-day)	Hazard quotient (HQ)		
		Green tea	Oolong tea	Black tea
As	3×10^{-4}	None	2.1×10^{-3}	3.0×10^{-3}
Cr	3×10^{-3}	8.5×10^{-4}	2.1×10^{-1}	4.5×10^{-1}
Cd	1×10^{-3}	None	6.3×10^{-4}	7.7×10^{-3}
Pb	1.43×10^{-3}	4.2×10^{-4}	3.5×10^{-2}	2.1×10^{-1}
Hazard Index (HI = ΣHQ)		1.3×10^{-3}	2.4×10^{-1}	6.7×10^{-1}

Table 4 Comparison on arsenic and heavy metals in tea products from other regions (μg/g)

Tea type	Country	As	Cr	Cd	Pb	Reference
Green tea	Taiwan	ND	0.1	ND	0.01	This study
	China	0.14	0.40	0.24	–	Han et al. 2005
	Japan	–	0.49	0.04	–	Tsushida and Takeo 1977
	Thailand	0.09	1.48	0.04	3.93	Nookabkaew et al. 2006
Oolong tea	Taiwan	0.005	5.2	0.0050	0.4	This study
	China	0.20	0.28	0.03	–	Han et al. 2005
Black tea	Taiwan	0.01	7.92	0.07	2.01	This study
	China	0.69	0.35	0.01	–	Han et al. 2005
	India	–	–	0.66	3.7	Natesan and Ranganathan 1990
	Turkey	–	–	2.3	17.9	Narin et al. 2004
	Nigeria	–	1.1	0.13	0.50	Onianwa et al. 1999

[a] ND is non detectable

Hazard Index (HI) from the US EPA's IRIS database (US EPA 2004). The sum of all the HQs for each element is referred to as the Hazard Index (HI). The formulas are as follows:

$$\text{Hazard Quotient} = \frac{\text{Exposure Dose}}{RfD} \quad (1)$$

$$\text{Exposure Dose} = \frac{Ci \times \mathrm{D}v \times \mathrm{E}d}{Bw \times At} \quad (2)$$

$$\text{Hazard Index} = \sum_{n=1}^{n=k} \text{Hazard Quotient} \quad (3)$$

R*f*D is the recommended reference dose; C*i* is the average concentration of the element in the infusion (μg/100 mL); D*v* is the daily volume of tea consumed (e.g., 1,250 mL); E*d* is the average exposure duration (e.g., 50 years); *Bw* is the average weight (e.g., 70 kg); *At* is the average lifetime (e.g., 70 years). According to US EPA guidelines for assessing conservative risk, HI can be interpreted as follows: HI < 1: no adverse human health effects are expected to occur; HI ≥ 1 there is moderate or high risk of adverse human effects occurring. Table 3 shows our assessment of health risk. The analysis found that the HI for daily intakes of 1.25 L of green tea, oolong tea, and black tea was 1.3×10^{-3}, 2.4×10^{-1}, 6.7×10^{-1}, respectively, showing the health risk is significantly (ca. 100-fold) lower for green tea consumption than for oolong tea or black tea consumption. For all three types of tea, HI was lower than 1, within the bounds of safety. However, for frequent consumption of black tea, HI was close to 1.0, suggesting that black tea consumption is likely to have adverse effects. To safeguard the health of the general public, black tea should continue to be monitored. Although there may be health risks from tea consumption, this study indicated that teas still contain many trace elements, such as Zn, Se, and Co, that are essential for maintaining and improving human health. The zinc and selenium contained in superoxide dismutase (SOD) act as antioxidants, reducing oxidative damage to cellular DNAs, while enhancing the function of the immune system (Rükaguer et al. 2001). According to Azin et al. (1998), Zn and Se are effective in preventing breast cancer and esophageal cancer. Cobalt is a constituent of vitamin B_{12}. Its deficiency causes impairment of the central nervous system, impairment of neurotransmission, and decline the immune function (Vellema et al. 1996).

Table 4 compares findings of this study to those of other studies on arsenic and heavy metal content of teas. The concentrations of As, Cr, Cd, and Pb were much lower in infusions of green tea produced in Taiwan than in China, Japan, or Thailand (Han et al. 2005; Nookabkaew et al. 2006; Tsushida and Takeo 1977). Oolong tea produced in Taiwan and China were compared, since China is the largest producer of oolong tea. This study found that the Cr concentration in infusions of China-produced oolong tea was much higher than that previously reported by studies from China, and the concentrations of As and Cd were lower in oolong tea produced in Taiwan than in China. Since black teas are produced worldwide, this study used black tea products from India, Turkey, and Nigeria for comparison (Narin et al. 2004; Natesan and Ranganathan 1990; Onianwa et al. 1999). The Cd content of black tea leaf from Taiwan was similar to that of Nigerian-made tea, but lower than that of black teas produced in India and Turkey, while the Pb content of black tea from Taiwan was similar to that of Indian black tea, yet between that of black teas from Turkey and Nigeria. Thus, tea leaves from Taiwan do not seem to be heavily contaminated with arsenic and metals.

This study showed the total content of arsenic and metals in green tea, oolong tea, and black tea produced in Taiwan was 0.11, 5.61, and 10.11 μg/g, respectively, indicating that the level of arsenic and heavy metals contamination of tea leaves was lower in Taiwan than other regions of the world. This study also found that the percentage of arsenic and heavy metals released into hot water infusions is higher for black tea than green tea, and that the hazard index of daily tea drinking of green tea, oolong tea, and black tea was low and within the bounds of safety (<1). However, as tea is an indispensable part of everyday life for many people in Taiwan, studies should continue to ensure that public health is maintained. Although the risk of tea drinking is slight, its benefits are great. Many scientific studies have concluded that tea has helps prevent many diseases, including skin cancer, Parkinson's disease, myocardial infarction, and coronary artery disease. Significant antimutagenic and anticlastogenic effects of both green and black tea and its polyphenols have been demonstrated in multiple mutational assays (Gupta et al. 2002). Therefore, tea drinking in moderation should be encouraged to maintain health.

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