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Dietary Content and Potential Health Risks of Metals in Commercial Black Tea in Kampala (Uganda)

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Abstract

Tea (*Camellia sinensis* (L.) Kuntze) is among the most widely consumed non-alcoholic beverages. It is a rich source of essential dietary elements mainly potassium and manganese. Tea may also contain toxic metals such as cadmium and lead which pose a threat to human health because of their toxicity. Twenty samples of commercial black tea in Kampala city were randomly obtained and analysed for potassium, sodium, aluminium, arsenic, cadmium, chromium, copper, iron, mercury, manganese, nickel, lead and zinc using Atomic Absorption Spectrophotometry. Human health risks due to exposure to toxic elements from daily consumption of tea were determined using incremental lifetime cancer risk and non-cancer hazard quotient. Metal contents of black tea sold in Kampala were below international regulatory limits. The estimated daily intake of the elements in two grams of black tea was below the recommended values. Hazard quotient and hazard index were within acceptable range. Total cancer risk levels for all the teas were also within United States Environmental Protection Agency (USEPA) acceptable range. Daily consumption of one cup containing two grams of black tea over a lifetime will promote consumer overall health and wellbeing.

Keywords: black tea, heavy metals, exposure, cancer risk, Uganda

1. Introduction

Tea (*Camellia sinensis* (Linnaeus) O. Kuntze) is the most widely consumed beverage because of its medicinal, refreshing and mild stimulant effects, attractive aroma and good taste (Karak & Bhagat, 2010; Ambadekar, Parab, & Bachankar, 2012; Zhong, Ren, & Zhao, 2016). Different types of tea including black, green and white teas are produced (Adak & Gabar, 2011; Marbaniang et al., 2011; Santos, Duboc, Goncalves, & Jacob, 2015). Of these, black tea is the most popular non-alcoholic beverage consumed by over two-thirds of the world's population (Sharangi, 2009; Chaturvedula & Prakash, 2011; Rajavelu, Tulyasheva, Jaiswal, Jeltsch, & Kuhnert, 2011; Fernando & Soysa, 2015; Santos et al., 2015). Tea is produced from the tender shoots of *Camellia sinensis* by withering, maceration, aeration and drying. In 2012, the world production of tea was estimated at 4.81 million tons (Karak et al., 2017). An estimated 18 to 20 billion teacups are consumed worldwide each day (Karak & Bhagat, 2010; Karak, et al., 2017). There is no precise data on tea consumption in Kampala. However, the recommended number of teacups is ≥ 3 for coronary heart disease (CHD) risk reduction (Gardner, Ruxton, & Leeds, 2007). In Uganda, black tea is usually served with sugar, milk, or herbs such as ginger (*Zingiber officinale*), lemongrass (*Cymbopogon citratus*) and leaves of *Ocimum suave*. Only loose leaf black tea is used in the traditional Ugandan family setting and tea is often introduced during infancy. According to WHO (2015), life expectancy in Uganda is 60.3 years for male and 64.3 for female, with 62.3 years as the total life expectancy. Lately, tea has attracted much attention due to its antioxidant, antimicrobial, anticarcinogenic and anti-inflammatory properties (Li et al., 2013). Tea’s phytochemical composition of polyphenols, alkaloids (caffeine and theobromine), amino acids (mainly L-theanine or 5-N-ethylglutamine), chlorophyll, minerals and trace elements accounts for its antioxidant activity, immune system boosting, protective effect against cancers, and blood cholesterol lowering effects (Adak & Gabar, 2011; Fernando & Soysa, 2015).

Toxicity of food materials is of concern because food and beverage consumption is a major route of human exposure to toxic chemicals (Coelho et al., 2016). Tea takes up toxic metals from the soil which bioaccumulate in the leaves (Zazouli, Bandpei, Maleki, Saberian, & Izanloo, 2010). The presence of toxic elements in trace amounts is adverse both in qualitative and quantitative production of tea. Heavy metals are major environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons (Nagajyoti, Lee, & Sreekanth, 2010). Environmental pollution may cause the occurrence of excessive amounts of heavy metals in plants and food products. These elements have been found in drinking water (Bamuwamye et al., 2017), tea leaves and brewed black tea infusions (Lasheen, Awwad, El-khalafawy, & Abdel-Rassoul, 2008; Schwalfenberg, Genuis, & Rodushkin, 2013). Tea hence accumulates heavy metals (HM) in concentrations capable of causing toxic effects to human health (Shekoohiyan et al., 2012).

Despite the fact that many studies reported high concentration of toxic and essential elements in commercial teas (Karak & Bhagat, 2010; Mohagheghian et al., 2015; Soliman, 2016; Karak et al., 2017), there is limited data on the metal composition of teas sold to the public in Uganda. This study determined the concentration of potassium (K), sodium (Na), aluminium (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn) contained in commercial black teas in Uganda. The human health risks posed by these metals from daily consumption of black tea were computed.

2. Materials and Methods

2.1 Materials

Stock standard solutions of Nitric acid (Sigma-Aldrich, analytical grade) for calibration were purchased from Chem-lab NV (Belgium). Distilled water was used to prepare solutions. All glassware was washed, cleaned and dried in the oven at 105 ℃. Locally produced, imported branded and non-branded tea bags, and loose leaf type tea leaves were used in this study.

2.2 Sample Collection

Twenty samples comprising of 15 locally processed and 5 imported black teas from Rwanda, Kenya and United Arab Emirates were obtained from different selling points in Kampala city. Locally processed tea comprised eleven branded teas and four open type (non-branded) teas. Three of the imported samples, were tea bag type while the rest of the samples were loose leaf tea type. Samples were coded in order to conceal their identity and source of origin. They were ground into fine powder using a pestle and motor and the powder stored at room temperature in dry, air-tight bags. Sample preparation and analysis was done at the Natural Chemotherapeutics Research Institute chemistry laboratory (Uganda).

2.3 Determination of Metals

Measurements were performed using an AA6300 - Shimadzu double beam atomic absorption spectrophotometer, AAS (Shimadzu Corporation, Japan) with graphite furnace atomization, equipped with deuterium lamp for background correction and hallow-cathode lamps for each of the studied elements, as well as with an ASC-6100F autosampler, data acquisition and processing software. Standard solution of each metal was prepared at five different concentrations of 0.2, 0.5, 1.0, 2.0, 4.0 ppm. Analysis was done at wave length (λ) 589.6, 259.9, 309.3, 193.7, 228.8, 357.9, 324.8, 248.3, 253.7, 279.5, 232.0, 283.3, and 213.9 nm for K, Na, Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn, respectively. Weights for mineral analysis were standardized at 5.0 g. All metal concentrations in teas were reported in mg/kg wet weight. Samples were dried at 105 ℃ for 6 hours and then burned in a muffle furnace at 550 ℃ for 4 hours. They were then acid digested and diluted with distilled water to 100 mL. Each of the samples was aspirated into the AAS and the absorbance measured was used to determine the concentration of the metal from the standard curves. The obtained metal concentrations were compared with regulatory limits for metals in herbal medicines set by World Health Organization (WHO), United States Food and Drug Administration (USFDA), and the European Pharmacopoeia (Ph. Eur.) shown in Table 1.

Table 1. Regulatory limits (mg/kg) established by WHO, US FDA, and Ph. Eur. for metals in herbal drugs (mg/kg)

Metal	K	Na	Cr	Cu	Fe	Mn	Zn	Al	As	Cd	Hg	Ni	Pb
WHO/FDA	-	-	-	-	-	-	-	-	10	0.3	1	-	10
Ph. Eur.	-	-	-	-	-	-	-	-	-	0.5	0.1	-	5

Source: Sarma, Deka, Deka, & Saikia, 2011; Ph. Eur.: European Pharmacopoeia

2.4 Estimated Daily Intake of Mineral and Heavy Metals through Black Tea Consumption

The daily intake of metals depends on the metal concentration in food and the daily food consumption as well as the average body weight (Batista, Nacano, Freitas, Oliveira-Souza, & Barbosa, 2012; Muhib, et al., 2016). Estimated daily intake (EDI) was calculated as follows:

$$EDI = (C \times IR)/BWa \quad (1)$$

where: EDI is the estimated daily intake of the chemical element (mg/kg BW day^{-1}), C is the chemical element concentration (mg/kg) in black tea, IR is the mass (kg) of tea consumed daily and BWa, the average body weight (70 kg).

2.5 Estimation of Health Risk Associated With Exposure to Heavy Metals in Black Tea

The health risks associated with HM in tea were assessed using the non-carcinogenic hazard quotient (HQ) and the incremental lifetime cancer risk (ILCR) for the non-cancer and cancer risks, respectively. The expressions for human health risk assessment were obtained from the USEPA Risk Assessment Guidance for Superfund (RAGS) methodology (USEPA, 1989). The relation for the calculation is given by Equations 2 and 3 (Lin & Liao, 2008).

$$HQ = (C \times IR \times EF \times ED)/ (RfD \times BWa \times ATn) \quad (2)$$

$$ILCR = (C \times IR \times EF \times ED \times CSF)/ (BWa \times ATc) \quad (3)$$

where: HQ = hazard quotient; C = average concentration of HM in black tea (mg/kg); IR = ingestion rate, the amount of black tea consumed per unit time (kg/day); EF = exposure frequency (365 days/year); ED = exposure duration of 30 years; RfD = chronic oral reference dose (mg/kg-day); BWa = average adult body weight (70 kg); ATn = averaging time, non-carcinogens (ED × 365 days/year = 10950 days); ILCR = incremental lifetime cancer risk; CSF = cancer slope factor $(mg/kg/day)^{-1}$; ATc is the averaging time, carcinogens (62.3 years × 365 days/year = 22,739.5 days) (USEPA, 1989).

Risks from multiple chemicals and exposure routes were assumed to be additive (Qu, Li, Wu, Wang, & Giesy, 2015). Potential non-cancer risk to human health through more than one HM, was measured by the chronic hazard index (HI), which is the sum of all HQ calculated for individual HM (Li, et al., 2013; Bamuwamye, Ogwok, & Tumuhairwe, 2015; Bamuwamye, et al., 2017). Similarly, the total cancer risk was assumed to be the sum of the individual metal incremental risks. Oral reference dose values of 0.14, 0.0003, 0.0005, 1.5, 0.04, 0.7, 0.0003, 0.14, 0.02, 0.0004, and 0.3 mg/kg/day were used for Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and zinc, respectively (USEPA, 2016). Cancer risks are determined for those substances for which cancer slope factors are available. Only oral ingestion and inhalation routes of exposure were considered in cancer risk analysis. The cancer slope factors used were 1.5, 6.3, 42, 0.84 and 0.0085 $(mgkg^{-1}day^{-1})^{-1}$ for As, Cd, Cr, Ni, and Pb, respectively (USEPA, 2016).

3. Results and Discussion

3.1 Metal Concentrations in Black Tea

3.1.1 Macroelements

Potassium was the most abundant element in tea with concentrations ranging from 8539.32 to 28006.39, 8704.19 to 11321.36 and 8816.77 to 10822.77 mg/kg, for locally manufactured branded tea, non-branded tea and imported branded tea, respectively (Table 2). The corresponding mean concentrations were: 14740.41 mg/kg, 10003.69 mg/kg, and 9969.74 mg/kg. Levels of potassium were higher in locally manufactured branded tea, than in non-branded and imported branded tea. The observed concentrations of potassium are a result of specific incorporation of potassium within a binding ligand of the tea leaves (Brzezicha-Cirocka, Grembecka, & Szefer, 2016). The studied black teas showed high potassium contents in agreement with previous researches (Table 3). Potassium is the most important element in fertilizers (Han, Mihara, & Fujino, 2014). It is needed for enzyme activation, photosynthesis, starch formation and protein synthesis, and in the maintenance of the circadian rhythm in plants and cardiac rhythm in humans. Sodium content varied between 77.54 and 266.14 mg/kg in the tea, with mean values of 186.54 mg/kg for locally manufactured branded tea, 163.54 mg/kg for non-branded tea and 195.08 mg/kg for imported branded tea (Table 2). Results do not show marked differences in sodium levels among the different teas. Sodium is characterized by low concentrations, and shows large variability within different brands of tea. A high ratio of potassium-to-sodium implies that tea could be beneficial in the management of hypertension (Han et al., 2014).

3.1.2 Microelements

3.1.2.1 Essential Elements

Tea leaves contained high concentration of manganese (Table 2). Locally manufactured branded tea had a significantly higher Mn content than other brands. There was no difference between non-branded tea and imported branded tea in terms of Mn content. The permissible limit of manganese in medicinal plants is estimated to be 200 mg/kg (Shah et al., 2013). In this study, the concentration of manganese was recorded above the limit in 70% of the samples. Nevertheless, the observed Mn levels were within the range previously reported for African teas (Table 3). Tea leaves bioaccumulate Mn and can be a good source of dietary Mn. Manganese plays a key role in the water-splitting system in photosystem II, ATP synthesis, RuBP carboxylase reactions and the biosynthesis of fatty acids, acyl lipids and proteins (Upadhyaya, Dutta, Sahoo, & Panda, 2012). It also plays a role in controlling many diseases as it has an important role in lignin and suberin biosynthesis, phenol biosynthesis, photosynthesis and several other functions (Dordas, 2008). Manganese is a major mineral related to carbohydrate and lipid metabolism, and is essential for normal functioning of nerve, heartbeat and the central nervous system in humans (Petrović, Savić, Dimitrijević, & Petronijević, 2015). It is also a good anti-oxidant, and is required for bone formation, red blood cell regeneration and aids enzymatic actions.

Levels of Fe ranged from 1.10 to 39.87 mg/kg in tea leaves. The mean concentrations were in the order; locally manufactured branded tea > non-branded tea > imported branded. Iron is an essential micronutrient for almost all living organisms because it plays a critical role in metabolic processes such as DNA synthesis and respiration (Dordas, 2008). In plants, it is involved in the synthesis of chlorophyll, and is essential for the maintenance of chloroplast structure and function (Rout & Sahoo, 2015). Many other metabolic pathways are activated by iron, and it is a prosthetic group of many enzymes and cytochromes of the electron transport chain.

The minimum (1.89 mg/kg) and maximum (13.82 mg/kg) concentrations of Cu were observed in locally manufactured branded tea and imported teas, respectively. Copper concentration regulatory limits in herbal medicines are yet to be established by WHO/FAO. However, the Cu levels observed in this study were higher than levels reported by Ahmad et al. (2012) and Hussain, Khan, Iqbal, & Khalil (2006) in Kenyan black teas. Copper is involved in several metabolic processes. It is essential in several enzyme systems in plants. It is also required in the process of photosynthesis, plant respiration, and assists in plant metabolism of carbohydrates and proteins. High concentrations of copper in dry materials of teas are mainly attributable to machinery processing in factories that use copper (Han, Liang, Yang, Ma, & Ruan, 2006). Copper is also a component of fungicides applied regularly on tea plantations for protection against pathogens inducing leaf infestation (Sembratowicz & Rusinek-Prystupa, 2014).

Chromium content ranged from n.d. to 7.73 mg/kg. The highest Cr content (7.73 mg/kg) was registered in locally manufactured branded tea and the minimum in imported branded tea. Experimental data of chromium in tea leaves are very scanty (Karak & Bhagat, 2010). However, Cr concentrations were higher than reported for African teas (Marcos et al., 1998; Moreda-Piñeiro, Fisher, & Hill, 2003). Chromium is regarded as one of the most toxic elements and is released by sewage sludge and alloys in motor vehicles (Kulhari, et al., 2013).

Zinc concentration ranged from n.d. to 7.94 mg/kg (Table 2). The level of zinc was higher in locally manufactured branded tea. Zinc content in Ugandan commercial teas was higher than reported by Nkansah, Opoku, & Ackumey (2016), and Ahmad et al. (2012) and Hussain et al. (2006) for Ghanaian and Kenyan teas.

3.1.2.2 Toxic Metals

Aluminium, arsenic, cadmium, mercury and lead have no known biological functions in humans and are toxic at low doses. Aluminium concentrations in the teas analysed (425.57 to 966.24 mg/kg) were relatively high (Table 2). There are no prescribed limits for Al in food. However, *Camellia sinensis* is known to be an Al hyperaccumulator (Tadayon, Lahiji, & Tamiji, 2010; Brunner & Sperisen, 2013). It accumulates Al in leaves at concentrations as high as 30000 and 600 mg/kg dry weight in old and young leaves, respectively (Hajiboland & Poschenrieder, 2015). Aluminium is a growth stimulant in the tea plant and acts by decreasing Fe uptake and translocation (Hajiboland, Barceló, Poschenrieder, & Tolrà, 2013). It also inhibits Mn toxicity by preventing translocation of Mn from roots to shoots in tea plants. In the presence of Al, cells of tea plants produce large amounts of polyphenols to mask Mn which is absorbed in order to maintain normal growth. In addition, Al stimulates photosynthetic rates, reduces lignification, and enhances the activity of the antioxidant defense system (Hajiboland, Rad, Barceló, & Poschenrieder, 2013).

The concentration of Pb was found in variable amounts in all the tea samples processed and was detectable in the range of 0.35 to 8.09 mg/kg (Table 2). The mean concentrations of Pb in the studied teas were in line with international regulatory limits (Table 1). The result of this study show higher Pb levels than previously reported for other African countries (Table 4). However, levels in the range of 8.381 to 15.840 mg/kg, 6.0 to 7.6 mg/kg, and 0 to 240.1 mg/kg have been reported (Karak & Bhagat, 2010). Ninety percent of Pb in plants is due to foliar uptake (Sarfo, et al., 2012). Therefore, Pb content variability among teas could be attributed to different environmental conditions such as air, water and soil quality.

Cadmium was detected in only three samples, two of which were imported and had a maximum concentration of 0.24 mg/kg. Therefore, all samples had Cd concentration within the internationally acceptable range of 0.3 to 0.5 mg/kg recommended for raw herbal material (Sarma et al., 2011). Cadmium content was also lower than that reported for black tea in Nigeria but higher than in other studies (Table 4). The main sources leading to the accumulation of Cd in soil and plants are phosphate fertilizers, non-ferrous smelters, and zinc mines, combustion of fossil fuels and sewage sludge application (Roberts, 2014).

Mercury concentration was in the range of n.d. to 0.35 mg/kg, while As was not detected in any of the samples analysed (Table 2). Toxic metal concentrations in teas were below WHO and USFDA limits (Table 1). Levels of metals in tea plants depend on age of the tea leaves, soil conditions, rainfall, altitude, and genetics (Jamshidpour, faramarzi, Mahmoudi, & Varmira, 2016; Brzezicha-Cirocka et al., 2016). The amount of HM in tea leaves may be interpreted as an indicator for contamination of the environment by heavy metals (Gebretsadik & Chandravanshi, 2010).

According to Marcos et al. (1998), Ni concentration in African tea ranged from n.d. to 9.864 mg/kg. Nickel levels ranging from n.d. to 12.4 mg/kg have been reported by other studies (Karak and Bhagat, 2010). Lower levels ranging from n.d. to 6.35 mg/kg were found in the teas analyzed in this study (Table 2). Non-branded tea had the highest amount (6.35 mg/kg) of Ni. The USEPA has recommended that the daily intake of Ni should be less than 1 mg beyond which it is toxic. Nickel was recognized as an allergen by the American Contact Dermatitis; however, no limit has been set for this metal in food stuffs and medicinal plants (Mohagheghian et al., 2015). It exerts a potent toxic effect on peripheral tissues, the reproductive system, and causes dose related decreases in bone marrow cellularity (Annan, Kojo, Cindy, Samuel, & Tunkumgnen, 2010). However, in humans, about 1% is absorbed when nickel is given with food moreover absorbed nickel is efficiently excreted into urine (Liu, Goyer, & Waalkes, 2008).

Table 2. Total contents of macro- and micro- elements in locally processed and imported black teas on market in Uganda (mg/kg)

Metal	Local Branded Tea				Non-branded Tea				Imported Branded Tea			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
K	8539.32	28006.4	14740.41[a]	6864.73	8704.2	11321.36	10003.69[a]	1314.03	8816.77	10822.75	9969.74[a]	771.19
Na	52.06	133.07	93.13[a]	55.08	38.77	102.33	81.77[a]	60.16	80.5	124.55	97.54[a]	35.48
Cr	0.4	7.73	3.91[a]	2.36	1.48	2.43	1.82[ab]	0.45	n.d.	1.75	1.02[b]	0.8
Cu	1.89	11.93	8.29[a]	3.29	2.98	10.84	7.28[a]	3.88	2.22	13.82	8.70[a]	4.56
Fe	1.1	39.87	17.89[a]	10.96	4.2	26.62	16.44[a]	9.3	1.83	34.46	14.21[a]	12.43
Mn	131.1	1427.7	1095.69[a]	600.89	649.5	1115.4	893.48[ab]	253.95	252.9	1063.5	639.54[b]	235.64
Zn	n.d.	7.94	4.05[a]	3.03	1.18	4.74	2.60[a]	1.52	n.d.	5.81	2.37[a]	2.25
Al	143.65	2084.98	966.2 4[a]	55	118.9	991.57	530.60[ab]	380.63	74.75	667.25	425.57[b]	7242.1
As	n.d.	-	-		n.d.	-	-		n.d.	-	-	-
Cd	n.d.	0.01	0.01[a]	-	n.d.	-	-	-	0.12	0.24	0.18[a]	0.08
Hg	-	0.35	0.18[a]	0.14	0.24	0.34	0.30[a]	0.05	0.22	0.33	0.30[a]	0.04
Ni	-	2.73	1.11[a]	0.98	n.d.	6.35	1.96[a]	2.99	n.d.	1.98	0.40[a]	0.89
Pb	0.35	8.39	4.27[a]	2.31	2.73	6.6	5.18[a]	1.76	0.64	8.09	3.56[a]	2.88

n.d. = not detected. Means within a row with different superscripts are significantly different ($p<0.05$)

Table 3. Comparison of potassium (g/kg), sodium (g/kg), and trace elements content (mg/kg) of black teas with data reported in the literature from other African countries (mg/kg)

Country	K	Na	Cr	Cu	Fe	Mn	Zn	Ref.
Uganda	8.54-28.01	0.08-0.27	n.d.-7.73	1.89-13.82	1.10-39.89	18.5-1820	n.d.-7.94	1
Kenya	25.36-28.38	0.13-0.31	0.4-1.8	16.7-20.7	5.1-5.4	332-682	25.0-29.9	2
Ghana	-	-	-	-	1.05-7.45	-	0.10-0.30	3
Egypt	-	-	-	9.61-30.09	97.9-488.49	-	-	4
Nigeria	-	-	-	7.36-10.93	180.38-320.04	104.78-117.85	21.17-40.0	5
Kenya	-	-	-	9.0-17.8	81-369	-	17.1-44.9	6
Ghana	-	-	< 0.01-0.9	-	27.30-302.95	5.34-219-25	2.80-5.50	7
Kenya	-	-	-	0.57	6.69	2.37	2.89	8
Africa	17.25	0.32	-	11.7	364.6	837.8	26.5	9
Ethiopia	11.50-13.78	-	-	9.1-11.5	319-467	1242-1421	20.2-21.6	10
Kenya	20.0	0.89	14.8	19.86	117.4	1181	48.4	11
Kenya	18.4-20.8	0.56-0.58	2.25-4.5	0.5	n.d.-2.00	155.25-197.25	n.d.-0.25	12
Kenya	-	-	-	38.1	227	2072	51.1	13
Africa	-	-	2.39	19.14	178.97	562.61	25.06	14
Kenya	14.61-17.20	0.31-0.43	-	11.1-11.8	247.2-282.4	797.6-874.6	24.4-26.9	15
Nigeria	-	-	0.01-3.60	6.78-13.4	12.5-201	-	16.6-24.2	16
Africa	-	-	0.65-5.83	11.5-17.7	133-225	405-1604	19.5-30.4	17

n.d. = not detected; (Source: 1. this study; 2. Brzezicha-Cirocka, Grembecka, Ciesielski, Flaten, & Szefer (2017); 3. Nkansah et al. (2016); 4. Soliman (2016); 5. Modupe, Obimakinde, & Olutona (2013); 6. Moseti et al. (2013); 7. Sarfo et al. (2012); 8. Ahmad et al. (2012); 9. Olivier, Symington, Jonker, Rampedi, & Eeden (2012); 10. Gebretsadik & Chandravanshi (2010); 11. Soomro, Zahir, Mohiuddin, Khan, & Naqvi (2008); 12. Hussain et al. (2006); 13. Street, Száková, Drábek, & Mládková (2006); 14. Moreda-Piñeiro et al. (2003); 15. Fernández-Cáceres, Martín, Pablos, & González (2001); 16. Onianwa, Adetola, Iwegbue, Ojo, & Tella (1999); 17. Marcos et al. (1998).

Table 4. Comparison of the levels (mg/kg) of potentially toxic elements in black teas with data reported in literature from other African countries

Country	Al	As	Cd	Hg	Ni	Pb	Ref.
Uganda	74.75-2084.98	n.d.	n.d.-0.24	n.d.-0.35	n.d.-6.35	0.35-8.39	1
Kenya	-	-	n.d.	-	2.90-4.40	0.1-0.2	2
Ghana	-	1.40-2.00	0.10-1.50	-	-	0.10-0.40	3
Egypt	-	-	-	-	-	0.29-3.2	4
Nigeria	-	-	-	-	-	-	5
Kenya	-	-	0.0091-0.04	-	-	0.12-0.41	6
Ghana	-	-	-	-	-	< 0.001-2.05	7
Kenya	-	-	0.05	-	0.64	0.26	8
Africa	1268	-	-	-	-	-	9
Ethiopia	-	-	n.d.	-	-	n.d.	10
Kenya	-	-	0.011	-	1.77	0.25	11
Kenya	-	-	n.d.	-	n.d.	1.75-3.25	12
Kenya	-	-	-	-	-	-	13
Africa	789.81	-	-	-	4.76	1.12	14
Kenya	593.0-704.1	-	-	-	-	-	15
Nigeria	-	-	0.056-0.28	-	0.040-3.55	0.16-1.32	16
Africa	495-1342	-	0.026-0.161	0.248-0.456	n.d.-9.864	0.182-0.561	17

n.d. = not detected; (Source: 1. this study; 2. Brzezicha-Cirocka et al. (2017); 3. Nkansah et al. (2016); 4. Soliman (2016); 5. Modupe et al. (2013); 6. Moseti et al. (2013); 7. Sarfo et al. (2012); 8. Ahmad et al. (2012); 9. Olivier et al. (2012); 10. Gebretsadik & Chandravanshi (2010); 11. Soomro et al. (2008); 12. Hussain et al. (2006); 13. Street et al. (2006); 14. Moreda-Piñeiro et al. (2003); 15. Fernández-Cáceres et al. (2001); 16. Onianwa et al. (1999); 17. Marcos et al. (1998)).

3.2 Estimated Daily Intake (EDI) of Heavy Metals in Black Tea

Estimated daily intake (EDI) for essential elements followed the order K > Mn > Na > Fe > Cu > Zn > Cr (Table 5), while for the toxic elements, was in the order Al > Pb > Ni > Hg > Cd > As (Table 6). The EDI was compared with Dietary Reference Intakes (DRI) suggested by the Institute of Medicine (IOM, 2001) for the essential elements, and the Provisional Tolerable Daily Intake (PTDI) suggested by JECFA (1999; 2010a) for the toxic elements. EDI values for black tea were far below the recommended values implying that a daily consumption of one 240 ml cup containing two grams of black tea by an adult makes a negligible contribution towards HM intakes. Similar findings have previously been reported by Gonzalez-Weller, et al. (2015) and Soliman (2016). EDI of Aluminium was the highest among the toxic elements, and ranged between 8.5 and 19.3% of the PTDI. Human exposure to excessive aluminium has been associated with adverse neurologic, hematopoietic, skeletal, respiratory, immunologic, and other health effects (Yeh, Liu, Liou, Li, & Chen, 2016).

Table 5. Estimated daily dietary intakes (EDI) of essential elements by an adult person weighing 70 kg via consumption of one 240 ml cup containing 2.0 g of black tea compared with DRI (mg/day)

Element	RDA/AI (19-50 years)				EDI		
	Men	Women	Pregnancy	Lactation	LT	NT	IT
K	4700	4700	4700	5100	29.48	20.01	19.94
Na	1500	1500	1500	1500	0.37	0.33	0.39
Cr	0.035	0.025	0.03	0.045	0.01	< 0.01	< 0.01
Cu	0.9	0.9	1	1.3	0.02	0.01	0.02
Fe	8	18	27	9	0.04	0.03	0.03
Mn	2.3	1.8	2	2.6	1.1	0.4	0.4
Zn	11	8	11	12	0.01	0.01	< 0.01

Source: Institute of Medicine: Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium and zinc, Washington, DC, 2001, National Academy Press. EDI Estimated daily intake; LT locally manufactured branded tea; NT non-branded tea; IT imported branded tea.

Table 6. Estimated daily dietary intakes (EDI) of toxic metals via consumption of one 240 ml cup containing 2.0 grams of black tea compared with Provisional Tolerable Daily Intakes (μg/kg bw/day).

Heavy metal		Al	As	Cd	Hg	Ni	Pb
EDI (μg/kg bw/day)	LT	27.6	-	< 0.0001	0.00051	0.032	0.122
	NT	15.2	-	-	0.00086	0.056	0.148
	IT	12.2	-	0.00052	0.00084	0.011	0.102
PTDI (μg/kg bw/day)[1]		143	2.1	0.83	0.57	7	3.57
% PTDI		8.5-19.3	-	0.012-0.063	0.09-0.15	0.16-0.80	2.86-4.15

The provisional tolerable daily intake (PTDI) for Al, Hg, Pb, and Cd were based on the provisional tolerable weekly intake (PTWI) for Al, Hg, Pb and the provisional tolerable monthly intake for Cd establish by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). LT = locally manufactured branded tea; NT = non-branded tea; IT = imported branded tea

3.3 Non-cancer Risks

The mean hazard quotient (HQ) of HM was low in all tea types ranging from < 0.001 to 0.370 (Table 7). The highest HQ was observed for Pb in locally manufactured branded tea, and the lowest value observed for Cr in all three tea types. In general, HQ values followed the order: Pb > Al > Ni > Cd > As. For the essential elements, however, the following pattern is revealed: Mn > Cu > Fe > Zn > Cr. According to Sofuoglu and Kavcar (2008), the non-cancer risk levels through consumption of black tea are not significant for Cr. The mean hazard index HI was in the order: locally manufactured branded tea > non-branded tea > imported branded tea. Heavy metal HI was lower for imported tea because of relatively low amounts of Pb and Al. The health protection standard for non-cancer risks is 1. A value of HQ or HI < 1 implies no significant non-cancer risks; a value ≥ 1 implies significant non-cancer risks (Wei, et al., 2015). The results of this study mean that excessive metal intake through daily consumption of 2.0 g of black tea may not result in significant health risks. However, there is potential for risk of Al and Pb toxicity in regular consumers of more than 2 cups per day.

Table 7. Non-carcinogenic hazard quotient (HQ) and hazard index (HI) values of heavy metals for consumers due to black tea consumption

Tea type	Cr	Cu	Fe	Mn	Zn	Al	As	Cd	Hg	Ni	Pb	HI
LT	< 0.001	0.006	0.001	0.11	< 0.001	0.197	-	0.001	0.017	0.002	0.305	0.643
NT	< 0.001	0.005	0.001	0.04	< 0.001	0.108	-	-	0.029	0.003	0.370	0.569
IT	< 0.001	0.006	0.001	0.04	< 0.001	0.087	-	0.010	0.028	0.001	0.254	0.503

LT = locally manufactured branded tea; NT = non-branded tea; IT = imported branded tea.

3.4 Cancer Risks

Non-branded tea had a higher incremental lifetime cancer risks (ILCR) compared with locally manufactured branded tea and imported branded tea, because of high concentration of Ni. The total ILCR of locally manufactured branded tea was lower than that of imported tea implying that consumers of locally manufactured branded tea would experience less effect. There was no pronounced difference between non-branded tea (NT) and imported tea (IT) in terms of cancer risks. Nickel contributed > 95% of the ILCR in locally manufactured branded tea and non-branded tea, but its contribution was 22% in imported tea. Cadmium was the predominant risk contributor in imported tea at 75%. Lead contribution towards the ILCR was < 3% in all tea types. The USEPA considers a one out of one million (10^{-6}) chance of additional cancers as the management goal for risks posed by environmental contaminants (Qu et al., 2015). Risks ranging from 10^{-6} to 10^{-4} are considered as acceptable, depending on the circumstances (Qu et al., 2015). Cancer risk for Ni in non-branded and imported tea types, was of concern since ILCR values are > 10^{-6}; but not unacceptable, < 10^{-4} (Sofuoglu & Kavcar, 2008). The toxicity of Cr is dependent on its oxidation state: Cr (III) is essential for human health but Cr(VI) is carcinogenic. This study focused on the total Cr rather than Cr speciation. Special attention should be given to the speciation of Cr because of its abundance in tea (Han et al., 2014).

Table 8. Incremental lifetime cancer risks (ILCR) for a 70 kg adult weight through consumption of black tea in Kampala

Tea type	Cr	As	Cd	Ni	Pb	∑ ILCR
LT	-	-	1.1×10^{-6}	1.3×10^{-5}	5.0×10^{-7}	1.4×10^{-5}
NT	-	-	-	2.3×10^{-5}	5.4×10^{-7}	2.3×10^{-5}
IT	-	-	1.6×10^{-5}	4.6×10^{-6}	4.2×10^{-7}	2.1×10^{-5}

LT = locally manufactured branded tea; NT = non-branded tea; IT = imported branded tea.

4. Conclusions

The intake of two grams of black tea per adult per day contributes little to the dietary intake of macro-elements, micro-elements and heavy metals. According to population non-cancer risk distributions, the risk levels were not significant for any of the metals evaluated. The cumulative cancer risk was also within acceptable range. Daily consumption of one cup of locally branded black tea over a lifetime will bring about health benefits thereby helping to promote overall health and wellbeing.

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