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Potential Health Risk Assessment of Heavy Metals via Consumption of Green, Black and Herbal Tea Marketed in Northwestern Nigeria

Rabiu, S.[1]* and Abubakar, M. G.[2]

[1]Department of Biochemistry and Molecular Biology, Usmanu Danfodiyo University Sokoto, Nigeria.
[2]Department of Biochemistry, Federal University Gusau, Zamfara State, Nigeria.
Corresponding Author email: sulaiman.rabiu@udusok.edu.ng, +2347032884007

ABSTRACT

Tea has become most popular non-alcoholic beverage consumed by people of different age group worldwide and regarded beneficial for public health. However, the acidophilic characteristic of tea plant and its potential tendency to bio-accumulate metals including heavy metals from the environment, is of serious concern to consumers and health authorities. Concentration of Cd, Fe, Cu, Ni, As and Pb in a total of 90 tea samples representing three most consumed tea varieties (green tea, black tea and herbal tea) from Northwestern Nigeria, were analyzed using microwave plasma atomic emission spectroscopy (MP-AES). The results indicated that the analyzed metals were detected in the three tea varieties except arsenic in green tea samples and the study observed significant percentage of metal transfer rate from tea leaves to infusion. The Heavy metal concentration varied among the different tea varieties in the study and with highest concentration of Cd and Pb in green tea while Fe, Cu, As and Ni in black tea infusions. The EDI values for all the metals in all the brands of green, black, herbal tea infusion in this study were below their corresponding RfD values. The THQ values of each metal through the consumption of green, black and herbal tea infusions were all below 1. However, some individual brands of green tea infusion (GT8 and GT10) have HI greater than 1 and this is an indication of some potential non-carcinogenic health risk to habitual green tea infusion in the study area. The estimated carcinogenic risk (ECR) values for Cd in green and black tea infusions as well as As in black tea infusion were at the upper margin of 10-4, suggesting possible carcinogenic risk to habitual tea consumers in the study area.

Keywords: *Metal Concentrations; Tea Infusions, exposure; non-carcinogenic; carcinogenic*

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INTRODUCTION

Tea is one of the most popular non-alcoholic and caffeinated beverages consumed by people of different age group due to its health benefits worldwide (Fan et al., 2025). The tea is prepared mainly from new leaves of the shrub (*Camellia sinensis*) and then brewed with boiling drinking water to get a tea infusion (Sun et al., 2019; Wu et al., 2023; Jurowski et al., 2024). The plant is mostly cultivated in Asia (particularly China Sri Lanka, and India) and Africa (Kenya) (Yang et al., 2022).The tea drink is considered the most consumed and preferred by the Asian people (particularly Arabs), with about 3-4 cups daily for adults. Green tea is usually obtained by drying and steaming processes while black tea by fermentation. Studies have shown that it contains polysaccharides, caffeine, polyphenols, amino acids, and antioxidants. In addition, it is rich in some essentials minerals, like potassium, manganese, selenium, boron, zinc, strontium, and copper (Seenivasan et al., 2008; Jurowski et al., 2024). Due to its various nutritional contents, several studies on the potential medicinal benefit of tea consumption were conducted. The substance found in tea are known to be beneficial to human health including cholesterol-lowering, hepatoprotective, immune system boosting, antioxidant activity, prevention of Alzheimer's disease, high blood pressure, obesity and protective effect against a wide range of cancers including that of lung, prostate, and breast (Mark, 2007; Fujita and Yamagami, 2008; Zhang *et al.,* 2018). Essential elements contribute positively to bodily functions; for instance, magnesium plays a crucial role in metabolic processes, helps prevent osteoporosis, and reduces chondrocyte apoptosis (Kuang et al., 2021). Selenium possesses antioxidant properties and supports red blood cell health, and it has been associated with cancer prevention (Cai et al., 2025).

In Northern Nigeria, consumption of tea is becoming alarming and more than 95% of the tea consumed in Nigeria are imported from China which is the highest exporter of tea globally (FAO 2015). People drink tea by the bowl because of many social advantages in addition to its known therapeutic effects (Achudume and Owoeye 2010). Multiple cups of tea infusion are served (usually late evening) daily, at strategic joints where people of like minds gathered. In fact, in some cities, tea drinkers associations are formed and registered. Green, black and herbal teas are the most consumed, believed to restore improve and maintain cell's antioxidant status, hence ensuring optimum health by many Nigerians (Orisakwe et al., 2015).

The ever increasing popularity of black, green and herbal tea products has raised significant concern regarding its safety, particularly the presence of heavy metals such as lead, arsenic, cadmium, chromium and mercury. These toxic elements tend to accumulate in plants via natural and anthropogenic activities such as weathering, construction, excessive use of synthetic fertilizers and pesticides and mining processes. Moreover, studies have indicated that different biological and industrial processing procedures of tea leaves, these metals become more concentrated and hence pose potential risk to consumers (Rezaee et al., 2014; Patrick-Iwuanyanwu., 2017). In developed countries, strict measures are put in place to reduce the concentration of these notorious metals in food and beverages outlined by joint WHO/JECFA, USEPA, and EFSA (Seenivasan et al., 2008). Contamination of tea by some known toxic metals such as arsenic, lead, and cadmium has recently attracted global attention (Patrick-Iwuanyanwu., 2017; Zhang et al., 2018) Exposure to even low level of lead has been implicated in central nervous system disorders, resulting in memory loss, reduced IQ and delay in response time (Abass et al., 2019), reproductive dysfunction (Rabiu et al., 2019) liver and kidney derangements (Rabiu et al., 2022). Dietary exposure to arsenic has been linked to cancer of the kidney and the lung, and skin lesions (Heshmati et al., 2017). Several studies have shown that cadmium accumulate in kidneys and consequently causing kidneys failure (Zhu et al., 2011; Hashemi, 2018). Effective and constant evaluation of these toxic metals in teas become necessary considering the health consequences associated upon consumption especially to habitual tea drinkers. Hence, chronic consumption of toxic metals like Pb, Cd, Cr, Hg and As which have been reported in green , black and herbal teas might lead to serious public health issues (Li et al., 2015; Orisakwe et al., 2015; Ozukwe et al., 2023).

Despite the known health risks associated with heavy metals exposure, there is limited data on the levels of these toxic metals in commonly used black, green and herbal tea products. This limited information has indeed pose a serious threat to consumer health. Therefore, the present study is aimed at determining the actual concentrations of Cd, Fe, Cu, Ni, As and Pb in various brands of green, black and herbal teas consumed, calculate the health risk parameters such as Estimated Daily Intake (EDI) of metals, Target hazard quotient (THQ), Hazard Index (HI) and the potential cancer risk associated with consumption of these tea samples available in the study area. This will surely impact on consumer safety and alert the producers and policy makers.

MATERIALS AND METHODS

All chemicals and reagents used in the study were of analytical grade and deionized water was used in preparation of all solutions. The chemicals were purchased from Sigma Aldrich Laborchemikalien (St Louis, MO, USA) through Applied Bioscience Solutions Sokoto State.

Sample collection

Thirty (30) samples of commonly consumed green tea (n = 10) black tea (n = 10) and herbal tea (n = 10) were randomly purchased from provisional stores and central markets of the capital cities of Sokoto, Kebbi and Zamfara State Northern Nigeria. Samples from at least three different batches were collected and mixed to make a representative sub-sample and each sample was coded to conceal the real source. Each tea sample is tagged by letter and number, green tea: GT1-10, black tea: BT1-10 and herbal tea: HT1-10. All samples were used according to the manufacturer's instruction, without any additional preparation procedure, flavoring or sweetening agents.

Sample preparation and digestion

Exactly 2.0g of each sample were accurately weighed, labelled and placed in porcelain crucibles. The crucibles were taken in a muffle furnace and gradually increased the temperature to about 500ºC. The light gray ash obtained was transferred to a 100 mL flask containing 12 mL mixture (3:1 v/v) concentrated HNO_3 and $HClO_4$ and digested in a microwave until the solution turned white. The digested sample was filtered and diluted to 100 mL with deionized water.

Sample infusion: The tea infusion process was carried out in accordance with the manufacturer's instructions (i.e., the amount of raw material and the time of infusion). In each sample, 2.0g were accurately weighed and boiled in 100 mL deionized water for about ten minutes in a porcelain cups. The solution was filtered, the residue was evaporated to near dryness and transferred to a 100 mL flask containing 12 mL mixture (3:1 v/v) concentrated HNO_3 and $HClO_4$ and digested in a microwave until the solution turned white. The solution was made up to 100 mL with deionized water. During the brewing process, the tea infusion was mixed with a plastic stirring rod to ensure adequate irrigation and then covered for 3 to 8 minutes. Addition of lemon juice, ginger or any substance known to enhance flavor or taste of the infusion was completely avoided. The digestion procedure was validated by using standard reference certified material.

Heavy metals analysis

Actual concentrations of Cd, Fe, Cu, Ni, As and Pb in the tea samples were determined using a Microwave Plasma Atomic Emission Spectrophotometer (MP-AES) at the Centre for Advanced Science Research and Analytical Services, Usmanu Danfodiyo University, Sokoto, Nigeria. Samples were analyzed in triplicates. Calibration curves were prepared for Cd, Fe, Cu, Ni, As and Pb from a stock standard solution (10 µg/mL) and appropriate dilutions (0.01, 0.2, 0.5, 1.0, and 2.0 µg/mL) the reagent blanks and standards were equally subjected to the same digestion procedure as the samples.

HUMAN HEALTH RISK

Non-carcinogenic risk assessment

The estimated daily intake (EDI) of heavy metals due to consumption of tea infusion amongst the habitual tea drinkers of the study area was deduced using the following equation:

$$\text{EDI (mg/kg)} = (C \times IR \times TR)/ (BW \times 1{,}000) \quad (1)$$

Where, C = metal concentration in tea infusion; IR = tea ingestion rate (11.4 $g \cdot person^{-1} \cdot day^{-1}$); TR = metal transfer rate from tea leaves to tea infusion (metal in tea infusion/metal in tea leaves). Non-carcinogenic health problems in habitual tea drinkers were evaluated, using the calculated Target Hazard Quotient (THQ) of each metal analyzed in the tea infusion. The THQ is a ratio between the measured concentration and the oral reference dose (RfD) as determined by FAO/WHO. Therefore, calculated THQ values of less than one (< 1), suggests the tea infusion is safe for drinkers while THQ ≥ 1, indicates that the tea infusion is likely to cause numerous known health problems related to the metals in question.

$$\text{THQ} = \text{Exposure dose/Oral reference dose (RfD) (mg/kg/day)} \quad (2)$$

The RfD values for Cd = 5×10^{-4}, Fe = 0.07, Cu = 0.04, Ni = 2×10^{-2}, As = 3×10^{-4}, and Pb = 4×10^{-3} mg/kg/day (USEPA 2015; Cai et al., 2019).

The study also investigated the overall risk potential for combination of the analyzed heavy metals in the tea infusion. It is expressed as the sum of THQ of all heavy metals analyzed.

$$\text{HI} = \sum_{i=1}^{n} THQi \quad (3)$$

Where THQi is the THQ value of metal i.

Carcinogenic risk assessment

The carcinogenic risk is a measure of the incremental probability of a person developing cancer in lifetime due to ingestion of food contaminated with potential carcinogen (USEPA, 2015). The carcinogenic risk for Cd, As, and Pb via consumption of tea infusion were evaluated using equation:

$$\text{ECRi} = \text{EDI} \times \text{CSFo} \quad (4)$$

Where,

ECRi = estimated cancer risk in a lifetime over exposure to a metal i
CSFo = oral carcinogenic slope factor (USEPA, 2015).
The CSFo for Cd = 0.38, As = 1.5, and Pb = 0.0085(mg/kg/day).

Statistical analysis

Data generated were analyzed using Graph Pad in Stat version 6.03 statistical package. All results were expressed as mean value ± standard deviation (SD). Statistical differences between different tea infusions were determined using one way ANOVA. Tukey-Karamer comparison test was used to compare mean and differences considered significant at $p < 0.05$. The Pearson correlation matrix was performed to identify the metals' probable common source in the tea infusion and associations or otherwise were also considered significant at $p < 0.05$.

RESULTS AND DISCUSSION

The mean concentrations of Cd, Fe, Cu, Ni, As and Pb in green, black and herbal tea leaves and their infusions as well as metal transfer rate from tea leaves to tea infusion

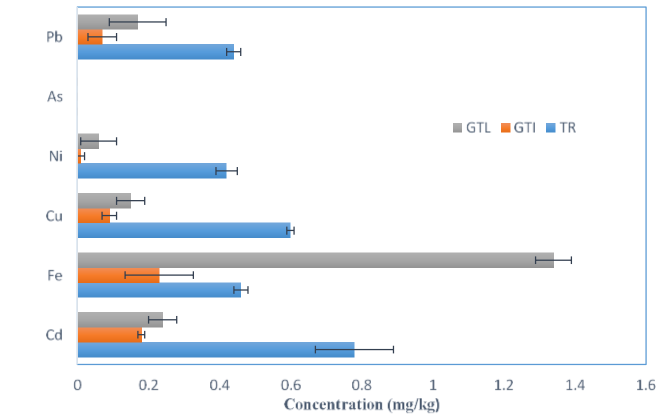

Figure 1: The concentration of heavy metals (ppm) and transfer rate (TR) in samples of green tea leaves and tea infusion for studied samples.

are shown in (Figures 1, 2 and 3) respectively. The concentration of heavy metals in green tea leaves were in the order of Fe > Cd > Cu > Pb > Ni. However, As was not detected in all the analyzed samples. In the tea infusion, Cd had the highest transfer rate of 78%, followed by Cu (60%) and the study recorded lowest concentration of Ni with the transfer rate of 42%. In the black tea leaves (Figure 2), the concentrations of the analyzed metals followed the order of Fe > Ni > Cu > Cd > As > Pb. The percentage metal transfer rate recorded in the infusion were 77%, 56%, 59%, 70%, 59%, and 48% respectively. Similarly, in herbal tea infusion, the study observed concentration of metals in the order of Fe > Cu > Cd > Ni/Pb >As and with metal transfer rate of 60%, 58%, 51%, 39%, 36% and 42% respectively. In all the tea samples, the study observed that metals leach from tea leaves to infusion with different degree of transfer.

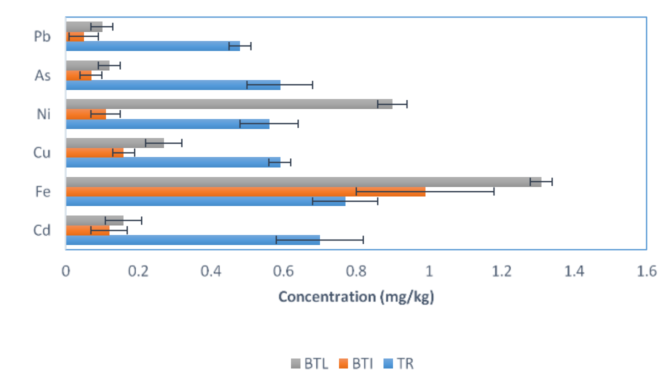

Figure 2: The concentration of heavy metals (ppm) and transfer rate (TR) in samples of black tea leaves and tea infusion for studied samples.

Among the metal detected, Fe had the highest concentration in the three types of the tea infusions and with the high value in black tea (0.94±0.19 mg/kg). The TR value is directly depends on infusion time in hot water, metals mobility, and total content of each metal in the tea

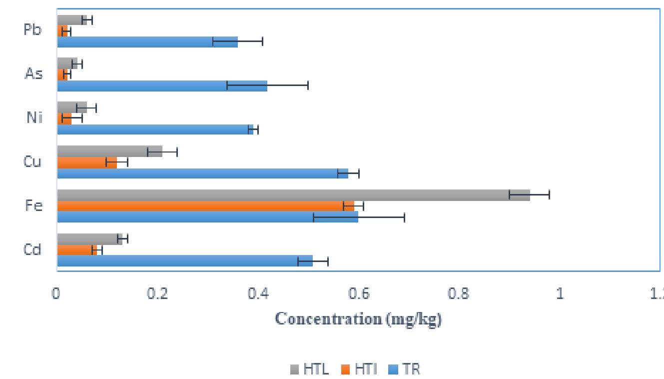

Figure 3: The concentration of heavy metals (ppm) and transfer rate (TR) in samples of herbal tea leaves and tea infusion for studied samples.

leaves (Zazouli et al. 2010; Herman et al., 2022). In fact, metals formed complexes with porphyrins in tea leaves therefore, are being release gradually into infusion (Wedepohl, 2000).

Moreover, the difference in the metals contents of the tea observed may be associated with the degree of pollution in agricultural lands or natural metals content of the earth's crust in the country of the tea production. Application of fertilizers and pesticides, which may contain different levels of some elements is another factor that could influence metal accumulation in tea leaves (Nkansah et al. 2016; Soliman 2016).

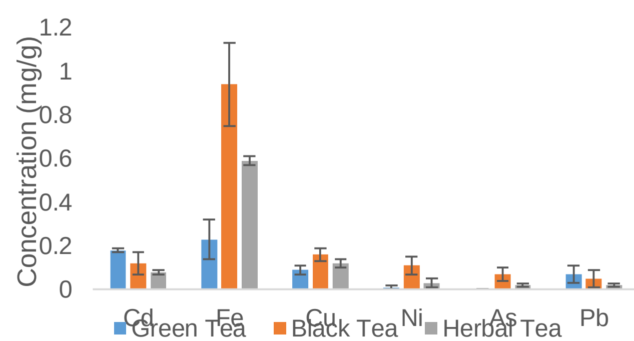

Figure 4 presents the mean concentration of heavy metals in green, black and herbal tea infusions. There was significantly ($p<0.05$) high concentration of Cd in green compared to herbal tea infusions, however, non-significant ($p> 0.05$) concentration of Cd was observed in green vs black and green vs herbal tea infusions. Significantly ($p< 0.05$) high concentration of Fe was recorded in black compared to green and herbal tea infusions. Similarly, significantly ($p< 0.05$) high concentration of Cu was recorded in black compared to green and herbal tea infusions. The concentrations of Ni and As were significantly ($p< 0.05$) high in black tea infusion compared to green and herbal tea infusions respectively. However, non-significant ($p>0.05$) concentrations of Ni and As were observed in green and herbal tea infusions respectively.

The study recorded significantly ($p<0.05$) high concentration of Pb in green tea infusion compared to black and herbal tea infusions.

The significantly high mean concentrations of Fe, Cu, Ni, and As (0.94±0.19, 0.16±0.03, 0.11±0.04, and 0.07±0.03 mg/kg respectively) observed in black tea infusion were far below the World Health Organization (WHO) and US Pharmacopeia (USP) guideline of 26.0, 2.0, 1.63 and 0.3 mg/kg respectively. Similarly, the high mean concentration of Cd (0.18±0.09 mg/kg) and Pb (0.07±0.04 mg/kg) detected in green tea infusion were within the permissible limits of 0.5 and 10.0 mg/kg respectively set by WHO. Achudume and Owoeye (2010) reported as high as 1716.6±186,2 mg/kg of Fe in some teas marketed in Nigeria. Mahmoud et al (2019) reported high concentration of Fe (2.36±0.71 µg/L) in black tea infusion consumed in Cairo, Egypt. Nkansah et al. (2016) and Sarfo et al. (2012) reported 7.24±0.00 mg/kg and 302.95–27.30 µ g/g of Fe in black tea marketed in Ghana. Our findings are in corroboration with those obtained by Garba et al (2015) from tea brands marketed in Zaria, Nigeria and Herman et al. (2022) from tea purchased from local stores in Olsztyn, Poland.

The mean concentration of Cu detected in this study is lower than those reported by Charlse et al. (2021), 0.06–0.20 µg/g of Cu from tea samples in Kakara District of Taraba, Nigeria and 13.54 to 29.87 ppm with an average value of 18.64 ± 0.48 ppm by Sultana et al (2023) in black tea infusion available in Bangladeshi local market. Heshmati et al. (2022) recorded mean concentration of Cu (11.10 ± 2.49 mg/kg) in black tea purchased from Hamadan city, Iran. Cu play a crucial role in the process of tea plant metabolism and as a cofactor to an enzyme superoxide dismutase responsible for the protection of cell's integrity. However, in excess, copper can induce chlorosis, Fe deficiency and cause lung issues, acute anemia, nausea, and vomiting (Jin et al., 2005; Michael et al., 2007; Zhong et al., 2016).). Cu toxicity is associated with Wilson illness, and can cause lung issues, acute anemia, nausea, and vomiting (Sultana et al., 2023). Cd may accumulate liver and kidneys, causing derangement and is associated with osteoporosis and bond softening, severe irritation, vomiting, diarrhoea, lung damage and death (Garba et al., 2015; Hu et al., 2023).

The mean concentration of Cd (0.18 ± 0.09 mg/kg) recorded in this study is in agreement with the values (0.18 ± 0.23 mg/kg) reported by Heshmati et al. (2020) and was higher than that reported by Hosseni et al. (2013) in Iran (0.027 mg/kg), Li et al. (2015) in China (0.05 mg/kg) and Mahmoud et al (2019) in Egypt (0.004±0.02 µg/L). Cd enters the blood stream, when Cd-contaminated food or water is consumed, and can cause various harmful health effects such as severe irritation, vomiting, diarrhoea, lung damage; it can be accumulated in the kidneys and lead to renal and nervous problems, high blood pressure, and death (Saini and Dhania, 2020).

The mean concentration of Pb (0.07±0.04mg/kg) in green tea infusion was high than that of black and herbal tea infusions (0.05±0.04) and (0.02±0.01) respectively. Similarly, De Oliveira et al. (2018) reported higher Pb level in green tea (0.76 ±0.12 mg kg−1), Mahmoud et al (2019) reported high concentration of Pb in green tea infusion (0.02± 0.02 µg/L). However, the level of Pb in green tea samples (0.47 ± 0.07 mg kg−1) analyzed by Barone et al. (2016) was lower than that of black tea (0.55 ± 0.35 mg kg−1). The values obtained in this study was lower than that reported by Alwan (2022) (1.19±0.00 mg/kg), Nkansah et al. (2016) (0.16±0.00 mg/kg).

The high mean concentration of As (0.07±0.03mg/kg) recorded in black infusion of this study was far below the permissible limit of 0.3 mg/kg by WHO and lower than that reported by De Oliveira et al. (2018) in the United State (0.22 ± 0.02 mg/kg), Jurowski et al. (2024) (0.325µg/L). However, it was high than the concentration reported by Milani et al. (2016) in Brazil (0.021 mg/kg), Zhelev et al. (2019) in India (0.05 mg kg−1), and Popović et al. (2017) in Belgrade (0.04 mg/kg). Unfortunately, cadmium, arsenic, and lead are well known carcinogenic and can accumulate in the human body to levels that cause irreversible damage.

Mean concentration of Ni (0.11±0.04 mg/kg) in the current study was far below the values obtained by Sultana et al. (2023) in Bangladesh (23.28 mg/kg), Alwan (2022) in Babylo Province, Iraq (2.137mg/kg). However, it is above the values reported by Aikpokpodion et al. (2020) (3.50-8.00µg/g) in commercial tea sold in South Western, Nigeria. Nickel has been recognized as human carcinogen, and known to affect the function of most prevalent antioxidant in the human body—α-tocopherol (Karak et al., 2016; Kan et al., 2021).

Metal-to-metal correlation coefficient matrix is presented in (Table 1). The Pearson's correlation was performed to determine the actually direction and strength of the association among heavy metals in tea infusion. Significant ($p<0.05$) positive correlation was only observed between Ni/As ($p = 0.0328$). However, non-significant ($p>0.05$) negative correlations were recorded between Cd/Fe, Cd/Cu, Fe/Ni, and Cu/Ni ($p = 0.1188$, 0.8713, 0.5761 and 0.6321 respectively). The pairwise associations among the analyzed metals determined using Pearson's correlation analysis have indicated that the direction and strength of the association among the metals. Strong positive correlation ($p = 0.031$)) was observed for the concentrations of Ni/As. The association between Ni/As, Ni/Pb, Pb/As, Cd/Ni, Cd/As, and Cd/Pb may predict a common source. The estimated daily intakes (EDIs) of the analyzed heavy metals via green tea infusion consumption are shown in (Table 2). To estimate daily metal intake through tea infusion, metal transfer rate (TR) from tea leaves to hot infusions must therefore be taken into consideration. In fact, not all of the heavy metals found in tea leaves are usually transferred into the tea infusion. Therefore, the calculated TR values were used to determine daily consumption of each metal. The mean EDI values in the different brand of green tea were in the order of Cu > Cd > Fe > Pb > Ni. The highest EDIs recorded were: Cd (1.81×10^{-3}), Fe (1.30×10^{-3}), Cu (4.21×10^{-2}) Ni (1.97×10^{-6}), and Pb (3.87×10^{-4}) via consumption of green tea infusion from GT10, GT8, GT8, GT3 and GT3 respectively.

Table 1: Metal-to-metal correlation coefficient matrix for tea samples (r = 95 %).

	Cd	**Fe**	**Cu**	**Ni**	**As**	**Pb**
Cd	1					
Fe	-0.568	1				
Cu	-0.088	0.228	1			
Ni	0.279	-0.069	-0.074	1		
As	0.068	0.149	0.230	0.673	1	
Pb	0.585	0.072	0.035	0.556	0.148	1

Table 2: Estimated daily intakes (EDIs; mg/kg bw/day) of heavy metals based on the consumption of green tea infusion.

Code	**Cd**	**Fe**	**Cu**	**Ni**	**Pb**
GT1	2.17×10^{-5}	1.09×10^{-5}	5.72×10^{-6}	7.32×10^{-7}	1.18×10^{-5}
GT2	2.35×10^{-5}	2.65×10^{-5}	1.29×10^{-5}	2.28×10^{-9}	1.56×10^{-5}
GT3	2.88×10^{-5}	1.46×10^{-5}	6.88×10^{-6}	1.97×10^{-6}	3.87×10^{-4}
GT4	2.63×10^{-5}	1.56×10^{-5}	7.89×10^{-6}	1.46×10^{-6}	6.88×10^{-6}
GT5	1.99×10^{-5}	4.56×10^{-5}	7.16×10^{-6}	-	7.81×10^{-6}
GT6	2.37×10^{-5}	4.69×10^{-5}	1.88×10^{-5}	1.56×10^{-7}	4.10×10^{-4}
GT7	2.19×10^{-5}	1.42×10^{-5}	5.78×10^{-6}	1.30×10^{-7}	7.82×10^{-6}
GT8	1.70×10^{-5}	1.30×10^{-3}	4.21×10^{-2}	5.13×10^{-9}	7.82×10^{-7}
GT9	2.22×10^{-5}	2.50×10^{-5}	6.89×10^{-5}	1.39×10^{-6}	4.04×10^{-6}
GT10	1.80×10^{-3}	2.19×10^{-5}	1.23×10^{-4}	2.69×10^{-7}	6.59×10^{-7}

Table 3: Target Hazard Quotient (THQ) and hazard index (HI) of metals for consumers due to green tea consumption.

Code	**Cd**	**Fe**	**Cu**	**Ni**	**Pb**	**HI**
GT1	1.45×10^{-2}	1.56×10^{-4}	1.43×10^{-4}	3.66×10^{-5}	2.95×10^{-3}	0.02
GT1	1.57×10^{-2}	3.79×10^{-4}	3.23×10^{-4}	1.14×10^{-7}	3.90×10^{-3}	0.02
GT3	1.92×10^{-2}	2.09×10^{-4}	1.72×10^{-4}	9.85×10^{-5}	9.68×10^{-2}	0.12
GT4	1.75×10^{-2}	2.23×10^{-4}	1.97×10^{-4}	7.30×10^{-5}	1.72×10^{-3}	0.02
GT5	1.33×10^{-2}	6.51×10^{-4}	1.79×10^{-4}	-	1.95×10^{-3}	0.02
GT6	1.58×10^{-2}	6.70×10^{-4}	4.70×10^{-4}	7.80×10^{-6}	1.03×10^{-1}	0.12
GT7	1.46×10^{-2}	2.03×10^{-4}	1.45×10^{-4}	6.50×10^{-6}	1.96×10^{-3}	0.02
GT8	1.13×10^{-2}	1.86×10^{-2}	1.05×10^{1}	2.57×10^{-7}	1.96×10^{-4}	1.08
GT9	1.48×10^{-2}	3.57×10^{-4}	1.73×10^{-3}	6.95×10^{-5}	1.01×10^{-3}	0.02
GT10	1.3×10^{1}	3.13×10^{-4}	3.08×10^{-3}	1.35×10^{-5}	1.65×10^{-4}	1.20

The THQs and IH value of heavy metals via consumption of green tea infusion are presented in Table 3. THQ value ranged from 1.92×10^{-2} to 1.30×10^{-1} for Cd, 6.70×10^{-4} to 1.86×10^{-2} for Fe, 4.76×10^{-4} to 1.05×10^{1} for Cu, 0 to 9.85×10^{-5} for Ni and 1.65×10^{-4} to 1.03×10^{-1}. Copper (GT8 sample) had the highest THQ value compared to all other metals. The mean THQ value of each of the metal in the tea infusion decreased in the order of Cd > Cu > Pb > Fe > Ni. The hazard index (HI) of the analyzed heavy metal consumption in the tea infusion for GT8 and GT10 were found to be above 1. The EDI values for all the metals in all the brands of green tea infusion in this study were below their corresponding RfD values. This indicates that green tea consumption might not pose health risk to normal habitual tea drinkers in the study area. However, the calculated mean EDIs for metals in the green tea infusion has implicated Cd and Cu for concentrations greater than their RfD values. Findings from our study is consistent with that of Idrees et al. (2020) who reported EDIs values lower than reference dosage except for Cu in different commercial tea brands in Pakistan. Several studies have reported EDIs values below RfD values of the metals studied (Nkansah et al., 2016; Peng et al. 2018; Zhang et al. 2018; Barman et al., 2020; Alwan 2022). Table 4 shows EDIs of the analyzed heavy metals via consumption of black tea infusion in the study area. The mean EDI values recorded in the different brand of green tea infusion were in the order of Fe > Cd > Cu > As > Ni > Pb. The highest EDIs value observed among the individual brand tea infusion were: Cd (1.52×10^{-4}), Fe (1.53×10^{-3}), Cu (1.04×10^{-5}), Ni (1.31×10^{-5}), As (1.31×10^{-5}) and Pb (1.01×10^{-5}) through consumption of black tea infusion from BT10, BT9, BT4, BT9, BT4/BT9 and BT10 respectively. The calculated THQs and IH value of heavy metals through consumption of black tea infusion in the study area are presented in (Table 5). THQ value recorded ranged from 1.91×10^{-3} to 1.01×10^{-1} for Cd, 6.63×10^{-5} to 2.19×10^{-2} for Fe, 2.22×10^{-4} to 5.48×10^{-2} for Cu, 2.12×10^{-5} to 9.86×10^{-4} for Ni, 1.30×10^{-3} to 2.18×10^{-2} for As and 4.48×10^{-5} to 3.38×10^{-3} for Pb. The highest THQ value was observed in Cd (BT10 sample). The mean THQ value of each of the metal in the tea infusion decreased in the order As > Cd > Fe > Pb > Ni > Cu. Therefore, the THQ values of each metal through the consumption of black infusions were all below 1, indicating that the daily intake of each metal in black and herbal tea infusions may not pose a significant potential health risk to normal habitual tea drinkers in the study area. This finding is consistent with earlier researches in Nigeria (Patrick-Iwuanyanwu et al., 2017), in Ghana (Nkansah et al., 2016), in China (Zhang et al.,

Table 4: Estimated daily intakes (EDIs; mg/kg bw/day) of heavy metals based on the consumption of black tea infusion.

Code	Cd	Fe	Cu	Ni	As	Pb
BT1	7.29×10^{-6}	1.27×10^{-4}	1.25×10^{-5}	4.23×10^{-7}	9.45×10^{-7}	4.07×10^{-7}
BT2	6.55×10^{-5}	4.64×10^{-6}	8.89×10^{-6}	4.95×10^{-6}	3.91×10^{-7}	4.49×10^{-6}
BT3	1.42×10^{-5}	1.42×10^{-4}	2.10×10^{-5}	8.21×10^{-6}	1.09×10^{-5}	4.07×10^{-7}
BT4	2.66×10^{-5}	1.76×10^{-4}	1.04×10^{-5}	1.96×10^{-5}	1.31×10^{-5}	8.73×10^{-6}
BT5	1.31×10^{-5}	1.33×10^{-4}	2.19×10^{-5}	1.09×10^{-5}	1.01×10^{-5}	9.38×10^{-6}
BT6	1.44×10^{-5}	1.53×10^{-4}	2.19×10^{-5}	1.47×10^{-5}	6.91×10^{-6}	7.17×10^{-7}
BT7	2.57×10^{-5}	1.12×10^{-4}	1.63×10^{-5}	6.59×10^{-6}	1.61×10^{-6}	9.51×10^{-6}
BT8	2.87×10^{-6}	1.37×10^{-4}	1.43×10^{-5}	9.85×10^{-6}	1.19×10^{-5}	1.79×10^{-7}
BT9	1.42×10^{-5}	1.53×10^{-3}	1.64×10^{-5}	1.31×10^{-5}	1.31×10^{-5}	8.73×10^{-6}
BT10	1.52×10^{-4}	1.75×10^{-4}	2.12×10^{-5}	1.61×10^{-5}	6.55×10^{-6}	1.01×10^{-5}

Table 5: Target Hazard Quotient (THQ) and hazard index (HI) of metals for consumers due to black tea consumption.

Code	Cd	Fe	Cu	Ni	As	Pb	HI
BT1	4.86×10^{-3}	1.81×10^{-3}	3.13×10^{-4}	2.12×10^{-5}	3.15×10^{-3}	1.01×10^{-4}	0.01
BT2	4.37×10^{-2}	6.63×10^{-5}	2.22×10^{-4}	2.48×10^{-4}	1.30×10^{-3}	1.12×10^{-3}	0.05
BT3	9.47×10^{-3}	2.03×10^{-3}	5.25×10^{-4}	4.11×10^{-4}	3.63×10^{-2}	1.02×10^{-4}	0.05
BT4	1.77×10^{-2}	2.51×10^{-3}	2.60×10^{-4}	9.80×10^{-4}	4.37×10^{-2}	2.18×10^{-3}	0.07
BT5	8.73×10^{-3}	1.90×10^{-3}	5.48×10^{-4}	5.45×10^{-4}	3.37×10^{-2}	2.35×10^{-3}	0.05
BT6	9.60×10^{-3}	2.19×10^{-3}	5.48×10^{-4}	7.35×10^{-4}	2.30×10^{-2}	1.79×10^{-4}	0.04
BT7	1.71×10^{-2}	1.60×10^{-3}	4.08×10^{-4}	3.30×10^{-4}	5.37×10^{-3}	2.38×10^{-3}	0.03
BT8	1.91×10^{-3}	1.96×10^{-3}	3.58×10^{-4}	4.93×10^{-4}	3.97×10^{-2}	4.48×10^{-5}	0.04
BT9	9.47×10^{-3}	2.19×10^{-2}	4.10×10^{-4}	6.55×10^{-4}	4.37×10^{-2}	2.18×10^{-3}	0.08
BT10	1.01×10^{-1}	2.50×10^{-3}	5.30×10^{-4}	8.05×10^{-4}	2.18×10^{-2}	2.53×10^{-3}	0.13

Table 6: Estimated daily intakes (EDIs; mg/kg bw/day) of heavy metals based on the consumption of herbal tea infusion.

Code	Cd	Fe	Cu	Ni	As	Pb
HT1	1.63×10^{-6}	3.22×10^{-5}	9.38×10^{-6}	1.63×10^{-6}	1.07×10^{-6}	2.16×10^{-6}
HT2	5.37×10^{-7}	1.04×10^{-4}	7.52×10^{-6}	8.14×10^{-7}	1.63×10^{-6}	5.37×10^{-7}
HT3	3.00×10^{-5}	3.22×10^{-5}	1.17×10^{-5}	1.07×10^{-6}	5.37×10^{-7}	1.07×10^{-6}
HT4	1.25×10^{-6}	1.14×10^{-5}	1.89×10^{-5}	1.30×10^{-6}	2.44×10^{-6}	2.10×10^{-6}
HT5	4.07×10^{-7}	4.32×10^{-5}	1.02×10^{-5}	5.37×10^{-7}	8.14×10^{-7}	1.86×10^{-6}
HT6	1.07×10^{-6}	2.44×10^{-6}	1.19×10^{-5}	9.38×10^{-6}	1.63×10^{-6}	1.07×10^{-6}
HT7	2.93×10^{-6}	1.26×10^{-4}	1.78×10^{-5}	2.35×10^{-6}	5.37×10^{-7}	4.67×10^{-7}
HT8	3.00×10^{-5}	1.50×10^{-4}	7.77×10^{-6}	7.17×10^{-7}	5.37×10^{-7}	1.07×10^{-6}
HT9	1.75×10^{-5}	1.94×10^{-5}	9.32×10^{-6}	1.07×10^{-6}	1.63×10^{-6}	1.86×10^{-6}
HT10	8.79×10^{-6}	1.27×10^{-4}	8.24×10^{-6}	5.37×10^{-7}	1.63×10^{-6}	1.30×10^{-6}

2018; Zhang et al., 2020), in Bangladesh (Sultana et al., 2023). The EDIs of the analyzed heavy metals via consumption of herbal tea infusion in the study area are presented in (Table 6). The calculated mean EDIs values in the brands of herbal tea infusion follows the order of Fe > Cu > Cd > Ni > As and Pb. Highest EDIs value recorded among the individual herbal tea infusion were: Cd (3.00×10^{-5}), Fe (1.50×10^{-4}), Cu (1.89×10^{-5}), Ni (9.38×10^{-6}), As (2.44×10^{-6}), and Pb (2.16×10^{-6}) through consumption of herbal tea infusion from HT8, HT8, HT4, HT6, HT4, and HT1 respectively. Moreover, THQ of the individual metal and accumulative IH value of heavy metals through consumption of herbal tea infusion in the study area are depicted in (Table 7). The THQ value ranged from 2.71×10^{-4} to 2.00×10^{-2} for Cd, 3.49×10^{-5} to 2.14×10^{-3} for Fe, 1.88×10^{-4} to 4.73×10^{-4} for Cu, 2.69×10^{-5} to 4.69×10^{-4} for Ni, 1.79×10^{-3} to 8.13×10^{-3} for As and 1.17×10^{-4} to 5.40×10^{-4} for Pb, and the highest THQ value was recorded in Cd (HT3 sample). The mean THQ value of each of the metal in the herbal tea infusion decreased in the order of Cd > As > Fe > Pb > Cu > Ni. The accumulative HI values calculated in all brands of the herbal tea infusion were lower than 1. Thus, this indicates that the daily intake of each metal in herbal tea infusions may not pose a significant potential health risk to normal habitual tea drinkers in the study area. This finding is consistent with earlier researches in Nigeria (Patrick-Iwuanyanwu et al., 2017), in Ghana (Nkansah et al., 2016), in China (Zhang et al., 2018; Zhang et al., 2020), in Bangladesh (Sultana et al., 2023). The carcinogenic risk evaluation for Cd, As, and Pb via consumption of green, black and herbal tea infusion are presented in (Figures 5, 6, and 7).The ECR value for each metal in green tea infusion decreased in the order of Cd (7.74×10^{-4}) > Pb (7.30×10^{-6}) > As (ND), in black tea infusion As (1.20×10^{-4}) > Cd (1.14×10^{-4}) > Pb (4.30×10^{-7}), and in herbal tea infusion Cd (3.22×10^{-5}) > As (1.50×10^{-5}) > Pb (8.50×10^{-8}). All calculated ECR values of the metals were lower than the standard limit (10^{-6}–10^{-4}). The estimated carcinogenic risk (ECR) values for Cd in green and black tea infusions as well as As in black tea infusion were at the upper margin of 10^{-4} and is in corroboration with the findings of Na Nagara et al. (2022) in black tea infusion marketed in tree countries and Taghizadeh et al. (2023) in herbal tea consumed in Iranian population.

Table 7: Target Hazard Quotient (THQ) and hazard index (HI) of metals for consumers due to herbal tea consumption.

Code	Cd	Fe	Cu	Ni	As	Pb	HI
HT1	1.09×10^{-3}	4.60×10^{-4}	2.35×10^{-4}	8.15×10^{-5}	3.57×10^{-3}	5.40×10^{-4}	0.01
HT2	3.58×10^{-4}	1.49×10^{-3}	1.88×10^{-4}	4.07×10^{-5}	5.43×10^{-3}	1.34×10^{-4}	0.01
HT3	2.00×10^{-2}	4.60×10^{-4}	2.93×10^{-4}	5.35×10^{-5}	1.79×10^{-3}	2.68×10^{-4}	0.02
HT4	8.33×10^{-4}	1.62×10^{-4}	4.73×10^{-4}	6.50×10^{-5}	8.13×10^{-3}	5.25×10^{-4}	0.01
HT5	2.71×10^{-4}	6.17×10^{-4}	2.55×10^{-4}	2.69×10^{-5}	2.71×10^{-3}	4.65×10^{-4}	0.01
HT6	7.13×10^{-4}	3.49×10^{-5}	2.98×10^{-4}	4.69×10^{-4}	5.43×10^{-3}	2.68×10^{-4}	0.01
HT7	1.95×10^{-3}	1.80×10^{-3}	4.45×10^{-4}	1.18×10^{-4}	1.79×10^{-3}	1.17×10^{-4}	0.01
HT8	2.00×10^{-2}	2.14×10^{-3}	1.94×10^{-4}	3.59×10^{-5}	1.79×10^{-3}	2.68×10^{-4}	0.02
HT9	1.17×10^{-2}	2.77×10^{-4}	2.33×10^{-4}	5.35×10^{-5}	5.43×10^{-3}	4.65×10^{-4}	0.02
HT10	5.86×10^{-3}	1.81×10^{-3}	2.06×10^{-4}	2.69×10^{-5}	5.43×10^{-3}	3.25×10^{-4}	0.01

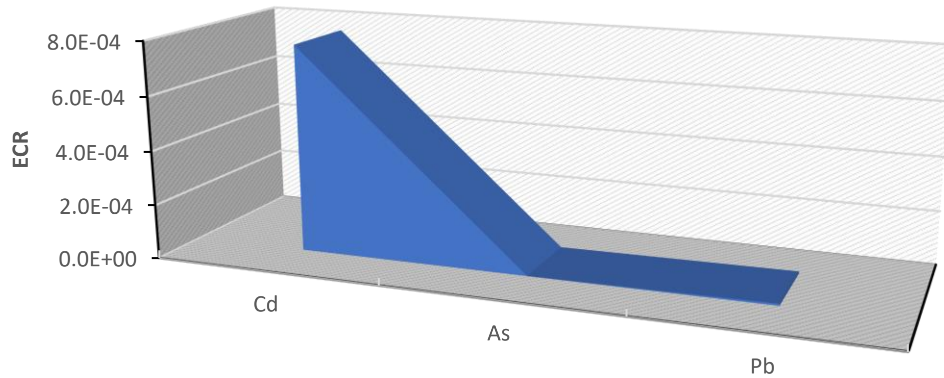

Figure 5: 3D Presentation of ECR of heavy metals based on the consumption of green tea infusion.

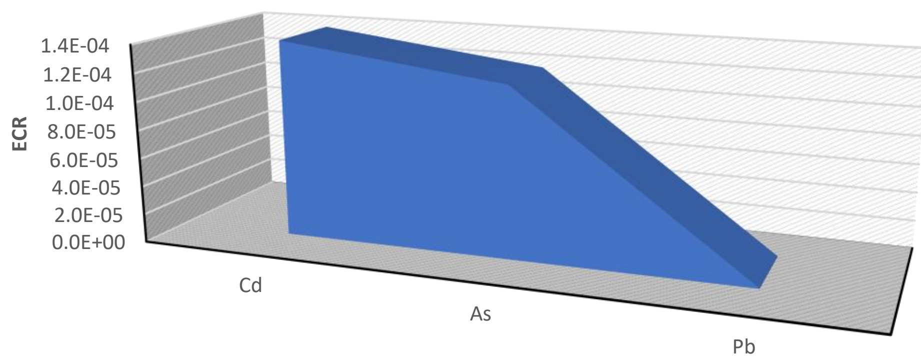

Figure 6: 3D Presentation of ECR of heavy metals based on the consumption of black tea infusion.

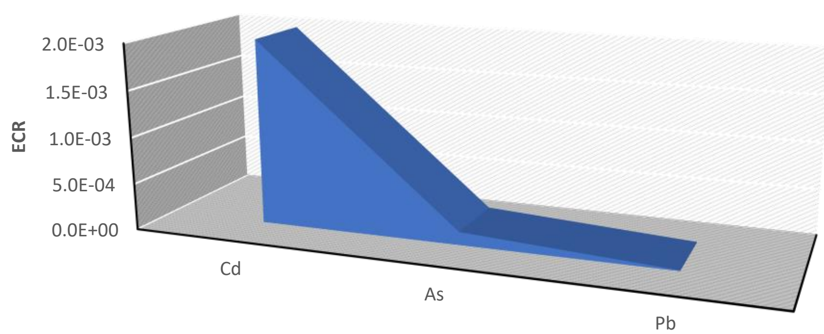

Figure 7: 3D Presentation of ECR of heavy metals based on the consumption of herbal tea infusion

In principles, ECR risks (calculated values) lying between 10^{-6} and 10^{-4} are generally considered safe range (USEPA-IRS, 2017) while values above10^{-4} are considered unacceptable. Therefore, consumers of green and black teas in the study area are highly exposed to cancer risk later in life.

Conclusion

This study evaluated the potential health risk of Cd, Fe, Cu, Ni, As, and Pb, in green, black, and herbal tea infusion from 30 different brands commonly consumed in Northwestern Nigeria. The heavy metal concentrations for all the tea infusions were below the permissible limits for human consumptions set by World Health Organization (WHO) and US Pharmacopeia (USP). Strong positive correlation was established between Ni/As and correlation pairs between Ni/As, Ni/Pb, Pb/As, Cd/Ni, Cd/As, and Cd/Pb which strongly predict a common source. All the EDI values for analyzed metals were below their corresponding RfD values except for Cu in green tea (sample GT10). Thus, this indicates possible significant health risk to consumers. The THQ and HI values in black and herbal tea infusion were all below 1, indicating that the consumption of black and herbal tea infusion in the study area may not cause significant non-carcinogenic health risks. However, the estimated carcinogenic risk (ECR) values for Cd in green and black tea infusions as well as As in black tea infusion were at the upper margin of 10^{-4}, suggesting possible carcinogenic risk to habitual tea consumers in the study area. Thus, continuous consumption of green and black tea infusions is likely going to increase the body burden of toxic metals in habitual tea drinkers. Therefore, identification and concentrations of heavy metal in all kind of teas consumed by population must be measured and monitored to ensure its quality and safeguard the public health of teeming Nigerians.

Declaration of competing interest

The authors declared no known competing interests or personal relationships what so ever that could have appeared to influence the research work reported in this paper and have sole responsibility for the writing and content of the paper.

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