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RESEARCH ARTICLE

Heavy metals in popularly sold branded cigarettes in Bangladesh and associated health hazards from inhalation exposure

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Abstract

Tobacco products are widely recognized as a major contributor to death. Cigarette smoke contains several toxic chemicals including heavy metals particulate causing high health risks. However, limited information has been available on the health risks associated with the heavy metals in cigarettes commonly sold in the Bangladeshi market. This study evaluated the concentrations and potential health risks posed by ten concerned heavy metals in ten widely consumed cigarette brands in Bangladesh using an atomic absorption spectrometer. The concentration (mg/kg) ranges of heavy metals Pb, Cd, Cr, As, Co, Ni, Mn, Fe, Cu, and Zn vary between 0.46–1.05, 0.55–1.03, 0.80–1.2, 0.22–0.40, 0.46–0.78, 2.59–3.03, 436.8–762.7, 115.8–184.4, 146.6–217.7, and 34.0–42.7, respectively. We assume that the heavy metals content among cigarette brands is varied due to the differences in the source of tobacco they use for cigarette preparation. The carcinogenic risks posed by heavy metals follow the order of Cr > Co > Cd > As > Ni > Pb, while the non-carcinogenic risks for Cu, Zn, Fe, and Mn were greater than unity (HQ > 1), except for Fe. The existence of toxic heavy metals in cigarette tobacco may thus introduce noticeable non-carcinogenic and carcinogenic health impacts accompanying inhalation exposure. This study provides the first comprehensive report so far on heavy metal concentration and associated health risks in branded cigarettes commonly sold in Bangladesh. Hence, this data and the information provided can serve as a baseline as well as a reference for future research and have potential implications for policy and legislation in Bangladesh.

Keywords Tobacco · Cigarette brands · Heavy metal(loid)s · Particulate inhalation · Human health risk

Introduction

Tobacco is an herbaceous plant (*Nicotiana tabacum*) that is used to produce several types of tobacco products such as cigarettes, Biri, Zarda, and Gul in several countries including Bangladesh. Raw tobacco leaves and their products' smoke contain more than 7000 harmful phytochemicals, including toxic metals, with at least 70 of them being carcinogenic (USDHHS 2014a). Toxic metals can be accumulated in tobacco leaves through different routes: the most probabilistic way could be soil-roots-shoots-leaves, wet and dry atmospheric deposition on the exposed surface of the plants in a polluted environment. Agronomic practices during tobacco growing, curing, and processing are also probable polluting sources for cigarette tobacco. Because of the presence of nicotine alkaloids, tobacco is considered one of the most addictive ingredients for humans (Tuesta

Highlights

- Estimated heavy metals in branded cigarettes of Bangladeshi markets for the first time
- Toxic metal level in the cigarette brands exceeded the WHO threshold limits
- Metallic particulate-rich cigarette smoke induces health risks on inhalation exposure
- Cu, Zn, and Mn cause high non-carcinogenic health risks, except for Fe
- Cr causes high cancer risks following the order of Cr > Co > Cd > As > Ni > Pb

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et al. 2011; Armendáriz et al. 2015). The addictive effects of nicotine are globally forbidden in drug production; it is derived from opium (*Papaver somniferum*) and cocaine (*E. novogranatense* and *Erythroxylum coca*) (EOL 2016).

Recently, WHO reported that globally, ~27.5% and 4.8% of males and females, aged 15 and above, are cigarette smokers. In Bangladesh, ~41.1 million people consume tobacco products regularly, among whom 20.9 million people consume tobacco either through cigarettes or Biris or both (ITC Project 2020). WHO (2019) demonstrated that cigarette smoking among male and female Bangladeshi people aged 15 and over was 0.7 and 39.8%, respectively. More than one in every three adults (35.5%) in Bangladesh uses tobacco in some form or the other, i.e., they either smoke or chew tobacco, apply it to their teeth and gums, or inhale it. Among the current tobacco users in Bangladesh, 93.1% are daily users and the remaining 6.9% are occasional users (GATS Report Bangladesh 2017). The risk for death is increased by cigarette (tobacco) smoking, which is accompanied by approximately 90 and 80% of deaths from diseases related to the respiratory system (chronic bronchitis, chronic obstructive thoracic disease, and emphysema) and lung cancer, respectively (NHS 2014). Globally, cigarette smoking and its related deaths are increasing day by day, particularly in low- and middle-income countries (LMCs), and tobacco-related deaths are predictable at more than 6 million people per year (USNCI and WHO 2016). Depending on current trends, tobacco consumption is expected to cause >8 million deaths during 2030, with ~4.8 million of these deaths occurring in LMCs (WHO 2011, 2013; USNCI and WHO 2016). A WHO study on the effects of tobacco-associated diseases in Bangladesh demonstrated that eight tobacco-related diseases were found among 2.9 million cases, and ~1.2 million of those could be owing to tobacco usage. Additionally, the estimated death count triggered by tobacco is 57,000 on average annually (ITC Project 2020), and this number is following an increasing trend, although the average lifetime of Bangladeshi people is 72 years (BLE 2023). Wu et al. (2013) evaluated that cigarette smoking is accountable for ~25.0% and 7.6% of deaths in males and females, respectively, in Bangladesh.

Bangladesh is one of the world's top tobacco-consumption countries (Hossain and Rahman 2013). The per capita income of people in Bangladesh is ~2488 $ (BGDPPC 2023). In the country, tobacco cultivation is popular in many districts, and a large number of people are economically dependent on tobacco cultivation and processing (Barkat et al. 2012). Many tobacco manufacturing industries (e.g., Akij Tobacco, British American Tobacco Company, Abul Khair, Nasir Tobacco, and Dhaka Tobacco) are located in Dhaka, the capital of Bangladesh, and produce international standards of tobacco and different brands of cigarettes (Fig. 1). Furthermore, in Bangladesh, cigarettes and Biri are the most commonly smoked tobacco products, smoked by 14.0 and 5.0% of adults, respectively (Gupta et al. 2022). The people of Bangladesh take cigarettes and Biris on average, 9 and 15 pcs per day, respectively, which is very significant in amount (GATS Report Bangladesh 2017). There are more than fifteen brands of cigarettes available in the local markets across the country, such as Gold Leaf, Benson & Hedges, Pilot, Hollywood, Marise, Sheikh, Marlboro, Navy, Star, and Derby, manufactured by the above-mentioned local and international tobacco companies. The cover pictures of some cigarette brands commonly sold in the Bangladesh market are shown in Fig. 1 along with their approximate price category.

Cigarettes contain a wide range of contaminants, including toxic heavy metals (Nada et al. 1999; Michael et al. 2022). Heavy metals such as Cr, Pb, Cd, As, Ni, and Co that are present in cigarettes can be toxic to human health even at low concentrations (Rubio et al. 2006). Furthermore, the contamination of toxic elements and their transfer into the human body is a global concern nowadays (Baroi et al. 2023; Rahman et al. 2023; Hasan et al. 2020). It is important to note that human exposure to potentially toxic elements is possible through several pathways, including oral ingestion, inhalation, and dermal absorption (Rahman et al. 2022; Baroi et al. 2023). Inhaling these toxic substances from smoke can lead to a range of health problems, including damage to the respiratory and cardiovascular systems, nervous system, and reproductive and developmental systems (Rubio et al. 2006). The toxic metals can be absorbed into the bloodstream through the lungs and then distributed to various organs and tissues. This can result in the accumulation of these toxic substances in the body over time, which can lead to various health problems. The severity of the health effects will depend on the amount and duration of exposure, as well as the individual's age, gender, and overall health status.

Many earlier investigations in several parts of the world investigated metal levels in cigarette tobacco (Nada et al. 1999; Massadeh et al. 2005; Zulfiqar et al. 2006; Ajab et al. 2008; Kazi et al. 2009; Viana et al. 2011; Iwuoha et al. 2013; Sebiawu et al. 2014; Armendáriz et al. 2015; Dahlawi et al. 2021), and some studies evaluated the associated human health risks of heavy metals in tobacco products including cigarettes (Hossain et al. 2018; Benson et al. 2017; Afridi et al. 2013; Verma et al. 2010). These studies confirmed that these products are remarkable sources of toxic metals and possibly induce serious human health and environmental risks (Michael et al. 2022; Pérez-Bernal et al. 2011). However, the previous studies considered only a limited number of samples and metals to evaluate health risks. Particularly in Bangladesh, there are only limited studies conducted to detect the extent of a few toxic elements in different types of tobacco products (Hossain et al. 2018). To the best of our knowledge, no studies have been conducted in Bangladesh to assess the human health risks posed by the heavy metals in branded cigarettes. Considering the large number of cigarette smokers, a comprehensive study is thus urgently needed in Bangladesh to evaluate the concentration of carcinogenic and non-carcinogenic metals in tobacco products and their effects on human health in a broad sense.

Therefore, the overall aim of the present work is to improve our understanding of the health risks due to the heavy metal content in cigarettes. Specifically, the aims of this work are (1) to explore the abundances of six carcinogenic heavy metal(loid)s (Pb, Cd, Cr, As, Co, and Ni) stipulated by the Integrated Risk Information System (IRIS) and four non-carcinogenic metals (Mn, Fe, Cu, and Zn) in tobacco of cigarettes (ten common brands) commercially available in Bangladesh and (2) to determine the human health risks due to the carcinogenic and non-carcinogenic elements obtained in various brands of cigarette tobacco. The outcome of this work will create awareness for cigarette smokers concerning their health and will also help achieve Sustainable Development Goal 3: "Good Health and Well-being: Ensure healthy lives and promote well-being for all at all ages."

Experimental

This study was conducted on different manufactured branded cigarettes that are commonly sold in the Bangladeshi markets and are also extensively consumed by the local people. For this study, we considered ten major branded cigarettes (sample identification number: CB1-CB10) with different price ranges categorized into three major price groups as shown in Table 1.

Sample collection and processing

A total of ten different brands of cigarettes were purchased from the local markets of two major cities, Dhaka and Rajshahi in Bangladesh. The samples were in their original packaging and placed in prewashed and dried plastic bags separately. Fresh 10 cigarette samples were randomly selected from 5 different batches, and by eliminating filters from each batch, a homogenized mixture was prepared. During this process, extra care was taken to resist any contamination of heavy metals.

Chemicals and reagents

All chemicals and reagents used in this study were of analytical grade and had the highest purity. The acids like HCl, HNO_3, and $HClO_4$ and reducing agents like $NaBH_4$ and KI

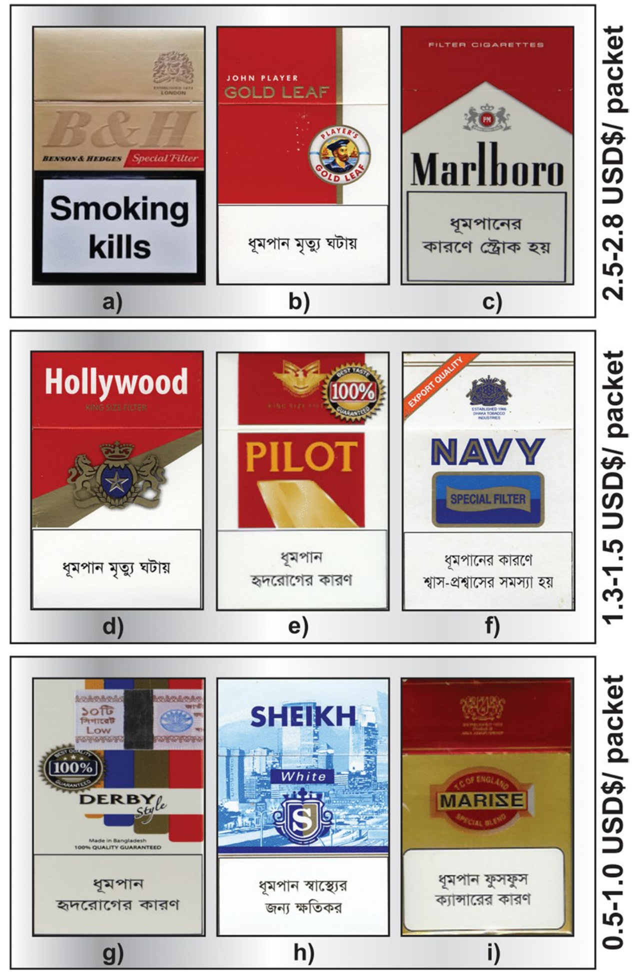

Fig. 1 The cover pictures of some cigarette brands commonly sold in Bangladesh market along with their approximate price category (image source: http://www.cigarety.by/country.php?n=10&l=1&p=0&w=Bangladesh)

were purchased from Merck, Germany. The metal standards used for calibration purposes were taken from Fluka Analytical, Sigma-Aldrich, Germany. Working standard solutions for target metals were freshly prepared by sequential dilution of standard stock solutions of 1000 ± 4 mg/L as metals traceable to the National Institute of Standards and Technology (NIST), USA. Deionized (DI) water was used for the sample and standard preparations.

Moisture and ash content

Empty-cleaned 100 mL beakers were collected, washed, and dried in an oven at 80 °C for 24 h before taking their weight in electrical balance. About 8–10 g of each sample were added to the separate beakers and reweighed. The samples were kept in the oven at 110 °C overnight. After oven drying, the samples were kept in the desiccator for 10 min and then again weighed with a beaker. The percentages of moisture content were calculated from the differences between the wet and dry weights of the samples taken.

Ash content represents the inorganic residue remaining after either ignition or total oxidation of organic components in food/biological samples. The primarily inorganic residue consists of the micronutrients present in the food samples. The ash content of samples (dry basis or wet basis) can be calculated using the following formula:

$$\text{Ash content }(\%) = (W1/W2) \times 100 \quad (1)$$

where W_1 is the weight of ash and W_2 is the weight of the dry sample.

Preparation of samples for elemental analysis

Dry ashing methods were used to extract metals from cigarette samples (Akinyele and Shokunbi 2015; Billah et al. 2017; Nasrin et al. 2022). Briefly, a sample of known weight (~10 g) was taken in a glass beaker and dried in the oven at 110 °C overnight. The beakers were then placed in the muffle furnace at 150 °C for 30 min. After that, the furnace temperature was raised to 200, 300, and 400 °C gradually holding for at least 30 min for each temperature. Finally, the temperature of the furnace was raised to 600 °C and held for 6 h to get ash which is free from all organic matter. Then, the furnace was stopped, cooled down at room temperature, and the ash samples were digested with HNO_3, $HClO_4$, and H_2O_2 (Ferdousi et al. 2023; Hasan et al. 2020). Beakers with samples were taken from the furnace, and about 5 mL of 1:1 concentrated HNO_3 and deionized water were added in it to sock the ash sample slowly. Then, 2 mL of concentrated $HClO_4$ was added, and the beaker was put on a hot plate at ~110 °C under a fume hood chamber until the fume was removed. To degrade the trace organic components, 2–3 mL H_2O_2 was added and heated slowly. The solutions were then cooled down and transferred in a calibrated 50 mL volumetric flask rinsing the solution several times and making it up to the mark with deionized water. To make homogeneous solutions, the flasks were shaken well and then filtered to previously cleaned and labeled 100 mL non-transparent plastic bottles using Whatman™ qualitative 1 filter paper (125 mm dia.) and preserved in the laboratory for elemental analysis.

For estimating the element As, with a relatively low boiling point, the sample was prepared following the acid digestion method (Hasan et al. 2020). In this method, about 8–10g of tobacco samples were digested with concentrated HNO_3 (20 mL) and $HClO_4$ (10 mL) in previously washed and dried beakers at 120–150 °C in a hot plate to almost dryness. The process was repeated with the addition of 2–3 mL of H_2O_2 to obtain a colorless solution by evaporating the volatile organic components after complete decomposition with the used inorganic oxidizing acids along with H_2O_2. After that, the solutions were cooled down and transferred in a calibrated 50 mL volumetric flask through filtration and rinsing the beakers several times with deionized water to make the flask up to the mark and shaken well for preparing homogeneous solutions. The solutions were transferred to 100 mL non-transparent plastic bottles and preserved until analysis.

Table 1 Ten major cigarette brands (CBs) with different price ranges per packet and three major price groups

Sl. no.	CBs	Price ranges per packet	Price groups
1	CB1	2.5–2.8 $	Expensive
2	CB2	2.5–2.8 $	Expensive
3	CB3	1.3–1.5 $	Medium cost
4	CB4	1.3–1.5 $	Medium cost
5	CB5	0.5–1.0 $	Low cost
6	CB6	0.5–1.0 $	Low cost
7	CB7	2.5–2.8 $	Expensive
8	CB8	1.3–1.5 $	Medium cost
9	CB9	1.3–1.5 $	Medium cost
10	CB10	0.5–1.0 $	Low cost

Instrumental analysis and quality control

An electric oven and a muffle furnace (Model: FHP-14, Brand: Witeg GmbH, Origin: Germany) were used for drying and ashing tobacco samples, respectively. The sample weights were taken carefully using a precisely calibrated electrical balance (Model: GR-200, A&D Company Limited, Japan). The concentrations of Cd, Cr, Pb, and Ni in each extract from tobacco samples were measured by Zeeman atomic absorption spectrometer (AAS; Model: GTA 120-AA240Z, Varian, Australia), and the As concentrations were quantified by electric hydride vapor generation technique in AAS (Model: SpectrAA 220, Varian, Australia), while other metals such as Cu, Co, Zn, Fe, and Mn were determined using flame AAS (Model: AA240FS, Varian, Australia). A metal-specific hollow cathode lamp was used for each elemental analysis under the conditions presented in Supplementary Table S1.

To ensure reliable data, sample collections, preparations, and analysis were performed carefully to avoid any kind of contamination. High-quality deionized water (conductivity: $<$ 0.5 μS/cm and resistivity: 18.2 MΩ cm), calibrated glassware, and analytical grade ultrapure HNO_3, $HClO_4$, H_2O_2, NaOH, KI, and $NaBH_4$ were used throughout the experiment. To reduce cross-contamination, all glassware was washed with 10% HNO_3 solution overnight followed by repeated washing with deionized water. The glassware (pipettes and volumetric flasks), oven, muffle furnace, and AAS instrument were calibrated from authorized sources as a part of the maintenance of our ISO/IEC 17025:2017 accredited laboratory (INARS, BCSIR, Dhaka). During analysis, the accuracy and precision of the analytical data were checked through the replicate analysis of the Certified Reference Materials (CRM) for each element. The sequential analysis of the quality control sample (CRM) and method blank was performed after 5 samples. Sample blank was also prepared and analyzed accordingly to avoid contamination from chemicals and reagents. The spike recovery in the analysis of all elements was in the range of 96–104% and was calculated following our previous works (Siddique et al. 2020; Hasan et al. 2020; Akbor et al. 2020). The instrumental limit of quantification (LOQ), the limit of detection (LOD), the calibration range, and measurement uncertainty for all the analyzed chemical elements are provided in Supplementary Table S1. All samples were measured in triplicate (relative standard deviation was less than 10%), and the mean results were taken to report.

Human health risk estimation

Analyzed elements in this study were classified into two categories according to the Integrated Risk Information System (IRIS) and International Agency for Research on Cancer (IARC): Pb, Cd, Cr, As, Co, and Ni are known as probable human carcinogens, whereas Fe, Mn, Cu, and Zn are known as non-carcinogenic elements (IARC 2011; Viana et al. 2011; Benson et al. 2017; Saha et al. 2016). These two categories of elements have been used in this study to estimate human health risks that could potentially induce long-term effects and may cause carcinogenic and non-carcinogenic effects on human health, respectively. The main purpose of human health effects is to check the possibility that toxic elements present in cigarettes upon emission during smoking can have serious health impacts on smokers. To perform a complete human health risk assessment associated with non-carcinogenic and carcinogenic heavy metals via inhalation exposure, a measurement of several steps such as exposure concentration (EC) followed by Hazard Quotients (HQ) for individual elements and Cancer Risk (CR) calculations were conducted using USEPA's methodology. We have considered that the potentially toxic elements present in cigarette fillers will be emitted and transferred to mainstream smoke during cigarette smoking and would be deposited into the human respiratory system through inhalation. As per EPA's guideline, for calculating EC then HQ, and finally CR, the following equations were used (USEPA 2009, 2011):

$$\text{Exposure Concentration, ECnc}\ \left(\mu g/m^3\right) = C_{metal} \times ET \times EF \times ED/AT \quad (2)$$

$$\text{Exposure Concentration, ECc}\ \left(\mu g/m^3\right) = C_{metal} \times ET \times EF \times ED/LT \quad (3)$$

$$\text{Hazard Quotients, HQ} = \text{ECnc}\ \left(\mu g/m^3\right)/\left(\text{RfC mg/m}^3 \times 1000\ \mu g/mg\right) \quad (4)$$

$$\text{Cancer Risk, CR} = \text{IUR}\ \left(\mu g/m^3\right)^{-1} \times \text{ECc}\ \left(\mu g/m^3\right) \quad (5)$$

Equations (2) and (3) were used for the exposure concentration via inhalation indicated as ECnc and ECc of non-carcinogenic and carcinogenic elements, respectively, where C_{metal} is the abundance of carcinogenic and non-carcinogenic elements from cigarettes (mg/m^3), ET denotes the exposure time, EF is the exposure frequency, ED is the duration of exposure, AT is the averaging time, and LT is the lifetime. The calculated exposure concentrations for non-carcinogenic and carcinogenic elements were used to determine the HQ and CR, respectively. Here, the values of these exposure factors were considered as summarized in Supplementary Table S2. According to the EPA, for carcinogens, the content is averaged over the lifetime of the exposed individual (70 years) (USEPA 2009, 2011).

On the other hand, HQ and CR due to exposure to heavy metals were estimated according to Eqs. (4) and (5), respectively, where CR is the cancer risk, IUR denotes the inhalation unit risk factor (per mg/m^3), and R_fC is the reference concentration (mg/m^3). According to USEPA, the IUR and R_fC values for all analyzed elements were used in calculations mentioned in Supplementary Table S2. The HQ was estimated from the ratio of exposure concentration (EC_{nc}) to the inhalation reference concentration (R_fC). HQ is the non-cancer health risk that might be accompanied by the potential inhalation exposure to the individual elements to smokers over a lifetime (USEPA 1994). Nevertheless, for characterizing the non-cancer risk, if HQ is greater than 1, then there might be adverse health impacts, but if HQ is less than 1, it suggests that no possibility of developing non-carcinogenic health effects in the human body. Moreover, the multiplication of the EC_c with the IUR is called Cancer Risk (CR). Generally, the threshold limit of the USEPA demonstrated that the tolerable risk is between 1.0×10^{-4} and 1.0×10^{-6} as a commonly referenced threshold for the protection of public health (Behera et al. 2014; Benson et al. 2017). As per USEPA's evaluation, the total CR accompanying the exposure to toxins over a lifetime greater than 1.0×10^{-6} is unacceptable (USEPA 1991).

Statistical analyses

A nonparametric Kruskal test was carried out to test the statistical differences of elements (Pb, Cd, As, Ni, Cr, Co, Fe, Mn, Cu, Zn) concentrations among price categories (low, medium, and expensive). Statistical analysis was performed using the {dplyr} package of the RStudio (R Core Team 2022; Wickham et al. 2023).

Results and discussion

Tobacco moisture, ash, and total organic content (TOC)

In the present investigation, overall tobacco samples represented analogous percentages of moisture among all the analyzed cigarette brands (Table 2). Though, CB3 cigarette filler possesses the highest moisture content of 11.3%, while the CB4 cigarette had the lowest moisture of 7.74%. Furthermore, the ash content in tobacco samples ranged between 15.0 and 21.4%. In this study, it was observed that the highest percentage of TOC was observed in CB7 (85.0 %); on the other hand, CB4 had the lowest value of 78.6% (Table 2).

Abundances of carcinogenic elements (Pb, Cd, Cr, As, Ni, Co)

Details of the elemental abundances are presented in Supplementary Table S3. The concentrations of carcinogenic elements (Pb, Cd, Cr, As, Co, Ni) in tobacco retained in investigated cigarette filler are presented in Fig. 2a. Among carcinogenic elements, the highest concentration of Pb was found in CB10 (1.05 mg/kg), exceeding the permeable limit defined by WHO (0.05 mg/kg), whereas the lowest was found in CB7 (0.46 mg/kg) (Fig. 2a). Pb content was similar among the price group ($\chi^2 = 5.98$; $p = 0.11$; Fig. 2b). The minimum and maximum Cd levels were found in CB7 (0.55 mg/kg) and CB9 (1.03 mg/kg), respectively, and were similar among price group ($\chi^2 = 3.11$; $p = 0.37$; Fig. 2b). The highest Cr-concentration was found in CB7 (1.2 mg/kg), whereas the lowest was in CB1 (0.80 mg/kg) with an average of 0.95 mg/kg. Cr content in the present investigation was found similar among price groups ($\chi^2 = 1.22$; $p = 0.74$; Fig. 2b). The highest concentration of As was measured in CB10 (0.40 mg/kg), while the lowest was found in CB7 (0.22 mg/kg) (Fig. 2a). Level of As in this study was not different among price group ($\chi^2 = 5.59$; $p = 0.13$; Fig. 2b). The Co content ranged between 0.78 and 0.46 mg/kg, and Co level was not different among price group ($\chi^2 = 4.89$; $p = 0.17$; Fig. 2b). Furthermore, Ni content ranged between 3.03 and 0.46 mg/kg and was similar among price group ($\chi^2 = 2.53$; $p = 0.46$). In the present investigation, Co content showed relatively high concentrations compared to other carcinogenic metals (Fig. 2b).

It was found in the present study that most of the lower limit values of the carcinogenic metals found in CB7 brands (Table S3) which is very expensive and manufactured by multinational company as they follow the exclusive manufacturing process. The presence of toxic metals is not expected in these products. The observed contamination and variations with toxic metals might be owing to the variable types of soils that are used in tobacco cultivation, differential degrees of rock-weathering, and variable agricultural activities such as the application of pesticides, chemical fertilizers, and manures. Moreover, Voutsa et al. (1996) demonstrated that trace elements in vegetable leaves mostly originated from the atmosphere. Saha et al. (2016) observed a special distribution of toxic metals in tobacco plants (root to leaf) as well as its cultivating soil in Bangladesh. Tobacco leaves are enriched by toxic metals from soils through the accumulation process from the soil through root to shoot to leaf (Hasan et al. 2020). Saha et al. (2016) found from contamination assessment that the Pb contamination was carried out from natural sources, i.e., the Earth's crust origin. Among carcinogenic metals, Ni was measured as the highest concentration in cigarette tobacco. The possible cause may be the physicochemical properties of soil and morphological/physiological properties of the plants as well as the accumulation abilities of heavy metals (Sanaei et al. 2021). Sanaei et al. (2021) reported that tobacco plants adulterated by Ni, most probably absorbed from the soil, fertilizing products, or pesticides. It has also been informed that the use of organic materials, such as composts, animal manures, and biosolids, acts as origins of heavy metals such as Cr and Ni in the agricultural field (Saha et al. 2016). The contamination of Ni in cigarette tobacco may also have occurred through the manufacturing process via the additives used to cure the tobacco leaves (Talio et al. 2011). Another reason could be ascribed to the fact that elemental pollution in tobacco leaves can mostly be explained in terms of local sources: traffic, industrial production, and fossil fuel combustion. Previous studies suggested that elements like Cu, Ni, As, and Zn are released from industrial metallurgical processes; Mn, Cr, Cu, As, and Zn from fossil fuels combustion; and Cd, Zn, and Cu from the abrasion of brakes and tires (Zhang et al. 2017). Maisto et al. (2004) stated that Pb and Cr are directly taken up from the atmosphere, while Cu is transported from the roots to the leaves.

There was approximately an equal distribution of Pb concentration in almost all cigarette brands. The average Pb concentration in this study (0.77mg/kg) was higher than the WHO recommendation (0.05 mg/kg). The gradual accumulation of Pb in the human body causes Pb poisoning that eventually can grow into various neurological disorders, hypertension, hearing loss, and kidney malfunction (Dahlawi et al. 2021). The mean contents of Pb obtained in the studied cigarette brands in Bangladesh were comparatively higher than the results of some other countries found in the

Table 2 Percentage of moisture content, ash content, and total organic content (TOC) in the studied cigarette tobacco in Bangladesh

Sample ID	Moisture (%)	Ash (%)	TOC (%)
CB1	11.0	17.5	82.5
CB2	10.7	16.1	83.9
CB3	11.3	18.9	81.1
CB4	7.74	21.4	78.6
CB5	10.7	17.7	82.4
CB6	10.4	17.9	82.1
CB7	10.6	15.0	85.0
CB8	10.9	17.1	82.9
CB9	10.6	18.4	81.6
CB10	10.9	18.5	81.5

reported literature (Table 3). As shown in Table 3, the mean Pb content is 2.9 times higher than the value obtained by Viana et al. (2011) in Brazil, almost 1.3 times higher than the concentration level in Poland (Galażyn-Sidorczuk et al. 2008), Spain (Armendáriz et al. 2015), and nearly to the value analyzed by Afridi et al. (2013) in Ireland, whereas 38, 23, and 18.5 times lower than reported by Benson et al. (2017) in Nigeria and Zulfiqar et al. (2006) and Ajab et al. (2008) in Pakistan.

For Cd, there was no considerable variation in the concentration level in the tobacco filler of the different studied brands. An assessment of the mean concentration of Cd (0.83 mg/kg) in tested cigarette fillers with other country's cigarette brands showed that it was 1.8 and 1.7 folds higher than the results reported for cigarettes from India (Verma et al. 2010) and Pakistan (Ajab et al. 2008), respectively, while 8 and 3 times lower than the observed value by Benson et al. (2017) in Nigeria and Kazi et al. (2009) in Pakistan, respectively (Table 3). This was an almost similar scenario to other researcher's studies by Galażyn-Sidorczuk et al. (2008) in Poland (0.61 mg/kg), Viana et al. (2011) in Brazil (0.65 mg/kg), and Wu et al. (1997) in the USA (0.96 mg/kg). However, the mean value of Cd (0.83 mg/kg) in the present analysis was more than 15 times higher than the standard value (0.05 mg/kg) suggested by WHO. For females, regular smoking causes deposition of Cd in the body, and a gradual increase in the Cd-contents through accumulation via a hematogenous tends to happen in endometrial cancer (Pinto et al. 2017).

Chromium is recognized as a human carcinogen when it gets oxidized from (3^+) to (6^+), which, if accumulated in the body, tends to create toxicity (Dahlawi et al. 2021). It is assumed that Cr^{3+} increases insulin activity and glucose metabolism. Consequently, Cr is often used as a weight-loss aid for bodybuilders and athletes. Conversely, several studies demonstrated that Cr (6^+) compounds could increase lung cancer risk, nerve tissue damage, respiratory problems, and alteration of genetics (Marrero et al. 2013; Elgammal et al. 2019). A study showed that random accumulations of potentially toxic elements such as Cd, As, Cr, and Ni are causative

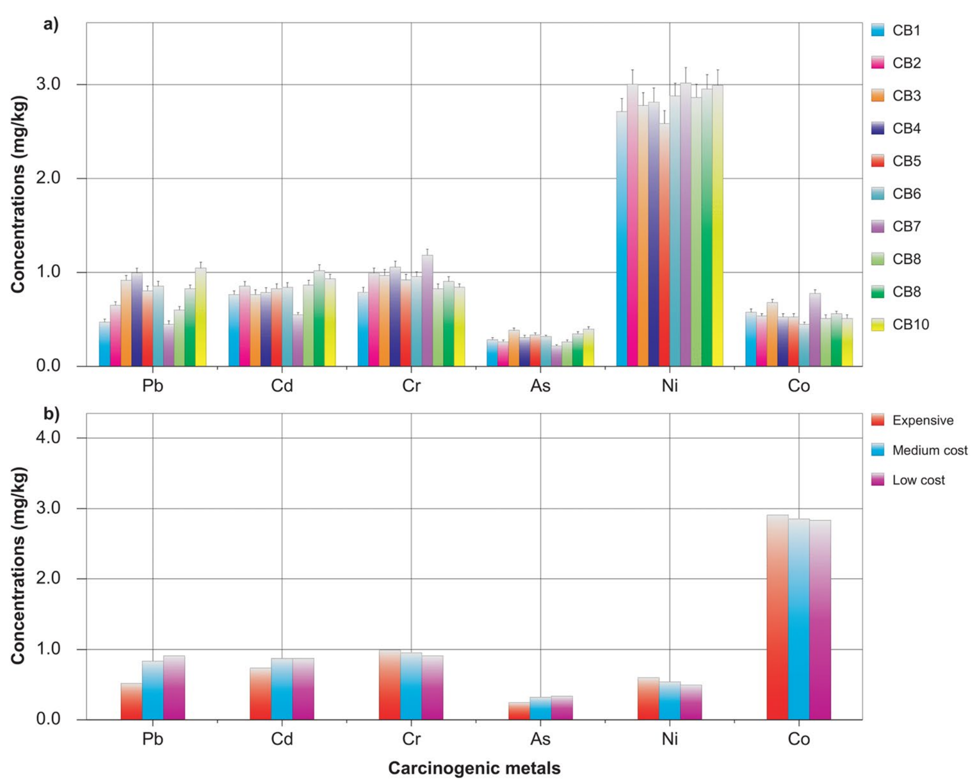

Fig. 2 Carcinogenic metal (Pb, Cd, Cr, As, Ni, and Co) concentrations in cigarette brands according to **a**) the brands and **b**) their cost in Bangladesh

factors for cancer of the head and neck. A considerable amount of these metals is found in samples from patients with tumors of the head and neck (Khlifi et al. 2013). The toxicity of Cr has been related to lung cancer, as well as genotoxicity and mutations in the DNA (Nathaniel et al. 2018). The mean contents of Cr in this work were 0.95 mg/kg which exceeds the maximum permissible level (0.5mg/kg) advised by WHO. The mean value of Cr in this study was readily 12 and 4.3-fold less than reported by Zulfiqar et al. (2006) in Pakistan and Verma et al. (2010) in India, respectively (Table 3). The variations in Cr mean concentration among different nations might be due to geological change or climate change.

Though Ni is an essential micronutrient and plays a vibrant role in most organisms, it can be toxic as well as carcinogenic at elevated contents (Gaucheron 2013). Moreover, higher concentrations of Ni may cause numerous adverse impacts on human physiology, e.g., inflammation, heart disorders, lower fertility, and neurasthenia (Qu et al. 2013; Das et al. 2008). Afterward, its deficiency results in anemia growth, and retardation, and also decreases certain enzymes' activity (Mohammadi et al. 2018; Qu et al. 2013). The mean concentration level (2.86 mg/kg) of Ni in this study is found the highest value among all carcinogenic metals and almost similar to the maximum literature's data but 3 times lower than Indian cigarette brands (Verma et al. 2010). It has been reported that Ni may make the volatile, gaseous compound, nickel tetracarbonyl in a burning cigarette and thereby be exposed to the respiratory tract (Torjussen et al. 2003). Arsenic, the 29th most abundant element on earth, is a protoplasmic poison that results in the malfunctioning of cell enzymes, cell respiration, and mitosis by distressing primarily the sulfhydryl group of cells (Jaishankar et al. 2014). Arsenic causes keratosis and skin pigmentation as well as chronic As-toxicity. This may affect intellectual function, neurobehavioral, memory, and neuropathic and leads to premature delivery, increasing fetal death, and respiratory and heart diseases. Arsenic can play the role of an endocrine disruptor and is assumed to increase the prevalence of type-2 diabetes (Munera-Picazo et al. 2015; Jaishankar et al. 2014). A few researchers quantified the level of As and Co in cigarettes. It has been reported that As and Co fixation on tobacco plants or leaves is likely to be caused by agronomic practices such as using organic fertilizers and pesticides that contain As (Saha et al. 2016). It was found that the obtained mean concentrations of As (0.32 mg/kg) and Co (0.57 mg/kg) in this work were much nearer to their observed values reported by Martínez et al. (2008) and Armendáriz et al. (2015) (Table 3). As a result of the presence of carcinogenic elements in the studied cigarette brands, locally produced and widely consumed by a substantial proportion of the population, there would be increased concerns about potential exposure to these toxic elements during cigarette smoking.

Abundances of non-carcinogenic metals (Fe, Mn, Cu, and Zn)

Among the non-carcinogenic metals (Fig. 3a), the highest concentration was found for Fe (mean: 631.9 mg/kg) with maximum and minimum concentrations of 762.7 mg/kg in CB5 and 436.8 mg/kg in CB7, respectively. Fe content in the present investigation was similar among price groups ($\chi^2 = 3$; $p = 0.39$). The reported value in this study is analogous to the Fe-contents (306–595 mg/kg) demonstrated in a study executed in Turkey involving various cigarette brands (Onojah et al. 2015) and closer to the value reported by Verma et al. (2010) in India. The mean Fe concentration reported by Benson et al. (2017) was almost 2 times greater than the value reported by Verma et al. (2010) in India (Table 3). Recommended daily allowances (RDA) of Fe for adult men and women are 9.0 and 16.0 mg/day, respectively (Vegarud et al. 2000; Gaucheron 2013). So, it has been seen that cigarette tobacco is a big source of Fe which would play a vital role in creating such types of diseases made of excess Fe. Ingestion or inhalation of excess Fe causes Alzheimer's disease, Parkinson's disease, and diabetes, as well as damages vital organs like the nervous system, heart, liver, thyroid, and pancreas (Elgammal et al. 2019; Ghuniem et al. 2019; Kohgo et al. 2008). Among the studied non-carcinogenic metals, Fe showed markedly high concentrations.

For Mn, the maximum concentration (184.4 mg/kg) was found in CB2 popular brand in the local market and the minimum (115.8 mg/kg) was in CB6 along with a mean value of 153.6 mg/kg; these values are markedly higher than the WHO/FAO standard value (6.61mg/kg) (Dahlawi et al. 2021). The Mn content in the present work was similar among price groups ($\chi^2 = 7.07$; $p = 0.06$; Fig 3b). The probable reason for Fe and Mn contaminations in tobacco leaves could be the water quality used in the cultivation process (Sharmin et al. 2020). Nervous system-associated problems and Parkinsonism syndromes are related to long-term exposure to Mn during the lifetime (Giri et al. 2020). It has been found that the average value of Mn was 3.4 times higher than the reported values of Mn concentration in Pakistan (Ajab et al. 2008) and almost similar to the obtained values of Martínez et al. (2008), Armendáriz et al. (2015), and Benson et al. (2017).

In the case of Cu, the highest concentration was 217.7 mg/kg (CB3) and the lowest was 146.6 mg/kg (CB2) with a mean value of 173.0 mg/kg. The level of Cu was similar among price groups ($\chi^2 = 1.86$; $p = 0.60$; Fig. 3b). The entrance of Cu into tobacco plants occurs due to agricultural practice, mainly when farmers apply phosphate fertilizer to the soil. Similar to other trace metals, Cu is essential for Fe metabolism, normal growth, formation of red blood cells (RBCs), as well as maintenance of vital tissues and

Table 3 Heavy metal concentrations (mg/kg) in various cigarette brands (tobacco) commercially consumed in different countries along with the present study (*Nd*, not detected; not available metal data are presented as dash (-) mark)

Pb	Cd	Cr	As	Mn	Fe	Co	Ni	Cu	Zn	Country	References
0.27	0.65	1.43	0.09	-	Nd	-	1.26	Nd	Nd	Brazil	Viana et al. (2011)
1.94	0.45	4.07	-	-	664	-	8.79	14.0	27.0	India	Verma et al. (2010)
0.78	1.87	Nd	-	-	Nd	-	1.03	Nd	Nd	Ireland	Afridi et al. (2013)
3.03	0.80	-	-	-	-	-	-	-	-	Malaysia	Janaydeh et al. (2019)
2.67	2.64	-	-	-	-	-	-	12.9	55.6	Jordan	Massadeh et al. (2005)
-	0.78	0.21	0.38	154.2	-	-	-	-	54.5	Mexico	Martínez et al. (2008)
0.92	2.30	-	-	-	-	-	1.10	-	-	Pakistan	Kazi et al. (2009)
17.8	1.90	11.4	-	Nd	Nd	-	2.00	11.4	15.2	Pakistan	Zulfiqar et al. (2006)
14.4	0.50	-	-	45.0	-	-	-	7.89	8.57	Pakistan	Ajab et al. (2008)
0.56	0.61	-	-	-	-	-	-	-	-	Poland	Galażyn-Sidorczuk et al. (2008)
0.60	0.81	1.44	-	112.0	-	0.56	2.24	-	-	Spain	Armendáriz et al. (2015)
1.02	1.70	1.63	-	-	-	-	0.22	2.45	-	Turkey	Barlas et al. (2001)
-	0.96	-	-	-	-	-	-	-	35.1	USA	Wu et al. (1997)
29.0	6.80	Nd	-	123.6	1138.2	-	Nd	26.8	96.7	Nigeria	Benson et al. (2017)
0.77	0.83	0.95	0.32	153.7	631.9	0.57	2.86	172.9	38.1	Bangladesh	This study (Mean)
0.45-1.05	0.55-1.03	0.80-1.17	0.22-0.40	116-184	437-762	0.46-0.78	2.6-3.03	147-218	34-43	Bangladesh	This study (Range)

organs (Gaucheron 2013). Cu, even though, is associated with many biochemical processes of the plants, long-term exposure can result in the causation of Wilson's disease, Menkes disease, and Indian childhood cirrhosis (Iwuoha et al. 2013). Alternatively, it becomes toxic at elevated concentrations and causes health risks. In human physiology, the necessities of Cu are not well characterized. However, the levels of Cu in all cigarette brands in this study are higher than the FAO/WHO prescribed daily and weekly recommended limits of 100 and 500 mg/kg, respectively (Sebiawu et al. 2014). In the case of Cu, it was observed that the average value found in the investigated sample was the highest among the values of all countries reported in the literature. The observed value was almost 71, 22, 15, 13, 12, and 6.5 times higher than the value obtained by Barlas et al. (2001), Ajab et al. (2008), Zulfiqar et al. (2006), Massadeh et al. (2005), Verma et al. (2010), and Benson et al. (2017), respectively.

The highest concentration of Zn (42.7 mg/kg) was found in CB6, and the lowest (34.0 mg/kg) was found in CB3 with an average value of 38.0 mg/kg, which is, however, lower than the threshold levels (50 mg/kg) prescribed by WHO (Hasan et al. 2020). The mean Zn concentration in the investigated cigarette samples is comparable to the study carried out by Ajab et al. (2008) in Pakistan which reported a Zn concentration value in the range of 1.1–41.4 mg/kg. Zn content showed significant differences among price groups (χ^2 = 1.00; p =0.80). The probable causes for such variations could be the differential characteristics of soil, the presence of heavy metals in soils, and areas under tobacco cultivation, along with the host of abiotic and biotic factors (Rai et al. 2019). Finally, Zn is another essential element in terms of its contribution to the growth and proper functioning of human physiology. Nevertheless, higher contents have been related to Cu deficiency in the serum, liver, and heart, interference with the functioning of copper metalloenzymes, along with the storage of Fe, and the consequential results of anemia (Kaličanin and Velimirović 2012). Moreover, increasing the contents of Zn levels in human physiology can interrupt the immune system by affecting the levels of high-density lipoproteins (Rai et al. 2019).

Human health risks assessment

In this study, it was found that the cancer risks posed by Pb, Cd, Cr, As, Co, and Ni ranged between 2.29×10^{-5} to 5.26×10^{-5}, 3.34×10^{-4} to 6.22×10^{-4}, 1.49×10^{-3} to 2.24×10^{-3}, 2.10×10^{-4} to 3.81×10^{-4}, 7.40×10^{-4} to 1.27×10^{-3}, and

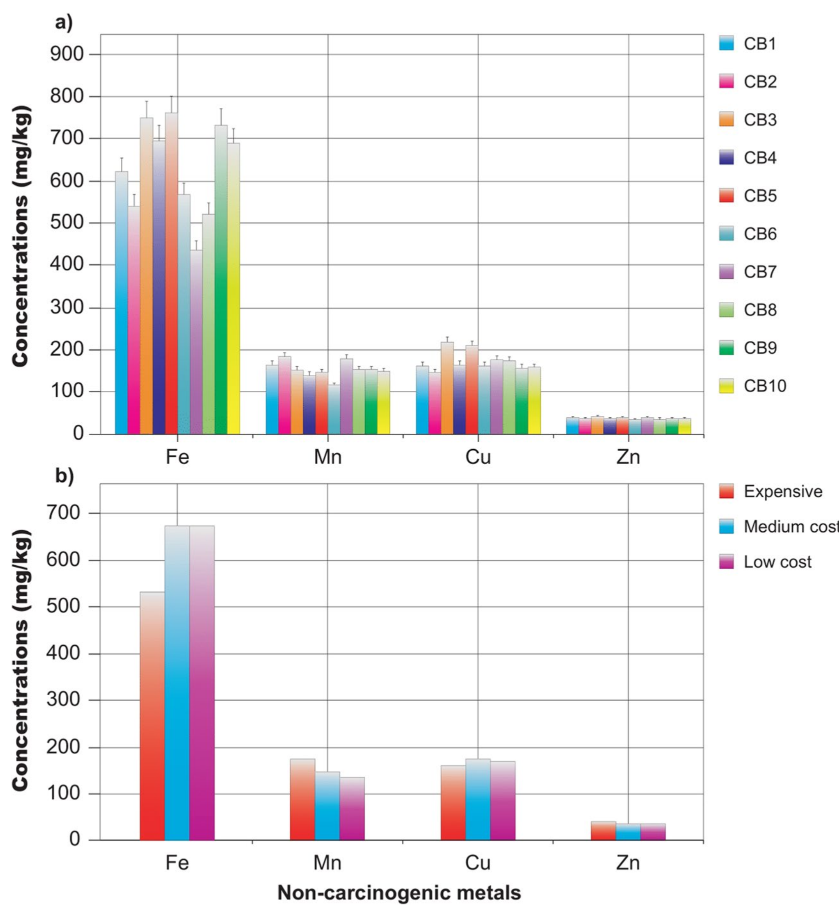

Fig. 3 Non-carcinogenic metal (Fe, Mn, Cu, Zn) concentrations in cigarette brands according to **a**) the brands and **b**) their cost in Bangladesh

2.50×10^{-4} to 2.93×10^{-4}, respectively (Table 4). Based on our analysis, the pattern of human health cancer risks due to carcinogenic metals was as follows: Cr (1.80×10^{-3}) > Co (9.41×10^{-4}) > Cd (5.04×10^{-4}) > As (2.97×10^{-4}) > Ni (2.80×10^{-4}) > Pb (3.81×10^{-5}), whereas non-carcinogenic risks of metals, Mn (1.4×10^{4}) > Cu (6.4×10^{3}) > Zn (4.8×10^{2}) > Ni (1.8×10^{2}) > Cd (6.5×10^{1}) > Co (4.0×10^{1}) > As (1.1×10^{1}) > Pb (7.5×10^{0}) > Cr (3.5×10^{0}) > Fe (5.5×10^{-2}). In general, the incremental lifetime cancer rate values for all carcinogenic metals except Pb for all cigarette brands investigated were greater than the acceptable limit of 1×10^{-4} specified by USEPA. The inhalation of these heavy metals from smoking can cause damage to the lung tissue and lead to respiratory problems such as chronic bronchitis and emphysema. Additionally, it can accumulate in the cardiovascular system and cause damage to the heart, leading to an increased risk of heart disease. In the present study, among these carcinogenic metals, Cr has the highest carcinogenic risk. The study shows that there is a very high chance of developing cancer during the lifetime of an active smoker through inhalation exposure of Cr-contaminated smoke, and this could be 18 cases in 10,000 cases, while the high probability of getting cancer through Cd, As, Co, and Ni-retained smoke could be 5, 3, 10, and 3 cases, respectively in 10,000 cases. But in the case of Pb, it could be 4 cases in 100,000 cases which is a medium risk of developing cancer. In other words, it can be said that carcinogenic risk due to inhalation exposure of the studied carcinogenic metals among active cigarette smokers is likely in the long term. These carcinogenic metals can increase the blood-brain barrier and cause neurotoxicity, leading to cognitive decline and an increased risk of neurological disorders. On the other hand, the non-carcinogenic health risk associated with human inhalation exposure to Pb, Cd, Cr, As, Mn, Fe, Co, Ni, Cu, and Zn was estimated using the concentration of toxic metals present in tobacco cigarettes. It was observed that the individual non-carcinogenic health risks and HQs for all individual metals in all brands except Fe were almost greater than 4.0 for all the investigated cigarette brands, whereas the USEPA target value was less than 1. It indicated that there could be a high possibility of getting adverse non-carcinogenic health risks. Therefore, the concentrations of those metals having HQ estimates greater than 1.0 could carriage non-cancer health effects to smokers through direct and long-term inhalation exposure.

Limitation and suggestions

This study did not consider the harmful effects of secondhand smoke. Secondhand smoke is also a significant concern for public health due to having no risk-free exposure level. Non-smokers who live with the smoker(s) are also at high health risks due to secondhand smoke. It causes cancer, stroke, heart attacks, asthma, headaches, dizziness, nausea, and irritation problems in humans (USDHHS 2014b; USDHHS 2006; IOM 2009). So, the human health risks of heavy metals particulate-contaminated secondhand smoke should be conducted to delineate the health impact of complete smoke exposure. In addition, in vivo and in vitro toxicity assessments of heavy metals contaminated tobacco smoke should also be conducted. Further studies should be carried out to analyze the heavy metals directly in tobacco smoke and evaluate their health risks. This could be performed by collecting the tobacco-burned smoke in an acidified solvent such as water, and then, the heavy metals content can be determined from the solution accordingly.

Whatever the types of smoke and techniques of heavy metals analysis and their risk assessments, it is evident that exposure to heavy metals and other organic chemicals contaminated by cigarette smoke has several health implications. Therefore, taking the proper steps for the concerned authority to quit smoking is crucial. Although self-motivation is very important for smoking cessation, the restrictions imposed by the family, educational institutes, officials, and motivational organizations can play an effective role in quitting smoking. To reduce the health risks, cessation of smoking has long been prescribed, and it has several benefits. After stopping smoking, (1) lung function will be developed with proper blood circulation within 2–12 weeks, (2) shortness of breathing and coughing will be reduced within 1–9 months, (3) stroke-risk will be similar to those of non-smokers within 5–15 years, and (4) lung-cancer death rate will be half relative to those of smokers within 10 years. Other benefits of quitting smoking include better sleep at night, healthy hair, sexual improvement, avoidance of germs, and so on. So, considering these beneficial issues, smokers should be encouraged to stop smoking.

Conclusions

This study investigated the levels and potential risks associated with exposure to carcinogenic and non-carcinogenic metals in locally and internationally manufactured cigarette brands commonly sold and smoked in Bangladesh. The mean concentrations of the analyzed elements for all considered cigarette brands exceed WHO recommended threshold limits. Most of the carcinogenic metals were similar or, in some cases, relatively higher than the metal loads in branded cigarettes reported in the literature from other developing and developed countries. The concentrations of carcinogen Ni were found high in all cigarette brands, but very high cancer risks were obtained due to the presence of Cr which is very familiar as a carcinogen. Furthermore, the concentrations of all metals in all cigarette brands were less than Fe,

Table 4 Estimated non-cancer and cancer risks of heavy metals due to inhalation exposure to cigarette smoke

Brands	Metals	ECnc	ECc	HQ	CR
CB1	Pb	6.94×10^{-1}	2.97×10^{-1}	4.63×10^{0}	2.38×10^{-5}
	Cd	6.03×10^{-1}	2.59×10^{-1}	6.03×10^{1}	4.65×10^{-4}
	Cr	2.90×10^{-1}	1.24×10^{-1}	2.90×10^{0}	1.49×10^{-3}
	As	1.49×10^{-1}	6.39×10^{-2}	9.94×10^{0}	2.75×10^{-4}
	Co	2.43×10^{-1}	1.04×10^{-1}	4.05×10^{1}	9.37×10^{-4}
	Ni	2.35×10^{0}	1.01×10^{0}	1.68×10^{2}	2.62×10^{-4}
	Fe	2.43×10^{3}	1.04×10^{3}	5.40×10^{-2}	
	Mn	6.30×10^{2}	2.70×10^{2}	1.26×10^{4}	
	Cu	7.18×10^{2}	3.08×10^{2}	5.98×10^{3}	
	Zn	1.84×10^{2}	7.88×10^{1}	5.10×10^{2}	
CB2	Pb	9.54×10^{-1}	4.09×10^{-1}	6.36×10^{0}	3.27×10^{-5}
	Cd	6.80×10^{-1}	2.91×10^{-1}	6.80×10^{1}	5.25×10^{-4}
	Cr	3.63×10^{-1}	1.56×10^{-1}	3.63×10^{0}	1.87×10^{-3}
	As	1.38×10^{-1}	5.90×10^{-2}	9.18×10^{0}	2.54×10^{-4}
	Co	2.26×10^{-1}	9.69×10^{-2}	3.77×10^{1}	8.73×10^{-4}
	Ni	2.61×10^{0}	1.12×10^{0}	1.86×10^{2}	2.90×10^{-4}
	Fe	2.11×10^{3}	9.04×10^{2}	4.69×10^{-2}	
	Mn	7.08×10^{2}	3.04×10^{2}	1.42×10^{4}	
	Cu	6.51×10^{2}	2.79×10^{2}	5.43×10^{3}	
	Zn	1.68×10^{2}	7.20×10^{1}	4.67×10^{2}	
CB3	Pb	1.34×10^{0}	5.74×10^{-1}	8.92×10^{0}	4.59×10^{-5}
	Cd	6.09×10^{-1}	2.61×10^{-1}	6.09×10^{1}	4.70×10^{-4}
	Cr	3.56×10^{-1}	1.53×10^{-1}	3.56×10^{0}	1.83×10^{-3}
	As	2.01×10^{-1}	8.63×10^{-2}	1.34×10^{1}	3.71×10^{-4}
	Co	2.85×10^{-1}	1.22×10^{-1}	4.74×10^{1}	1.10×10^{-3}
	Ni	2.41×10^{0}	1.03×10^{0}	1.72×10^{2}	2.69×10^{-4}
	Fe	2.93×10^{3}	1.25×10^{3}	6.50×10^{-2}	
	Mn	5.83×10^{2}	2.50×10^{2}	1.17×10^{4}	
	Cu	9.67×10^{2}	4.14×10^{2}	8.06×10^{3}	
	Zn	1.95×10^{2}	8.35×10^{1}	5.41×10^{2}	
CB4	Pb	1.45×10^{0}	6.22×10^{-1}	9.68×10^{0}	4.98×10^{-5}
	Cd	6.25×10^{-1}	2.68×10^{-1}	6.25×10^{1}	4.82×10^{-4}
	Cr	3.88×10^{-1}	1.66×10^{-1}	3.88×10^{0}	2.00×10^{-3}
	As	1.65×10^{-1}	7.05×10^{-2}	1.10×10^{1}	3.03×10^{-4}
	Co	2.25×10^{-1}	9.66×10^{-2}	3.76×10^{1}	8.69×10^{-4}
	Ni	2.45×10^{0}	1.05×10^{0}	1.75×10^{2}	2.73×10^{-4}
	Fe	2.71×10^{3}	1.16×10^{3}	6.03×10^{-2}	
	Mn	5.39×10^{2}	2.31×10^{2}	1.08×10^{4}	
	Cu	7.30×10^{2}	3.13×10^{2}	6.08×10^{3}	
	Zn	1.67×10^{2}	7.16×10^{1}	4.64×10^{2}	
CB5	Pb	1.18×10^{0}	5.04×10^{-1}	7.85×10^{0}	4.04×10^{-5}
	Cd	6.53×10^{-1}	2.80×10^{-1}	6.53×10^{1}	5.03×10^{-4}
	Cr	3.38×10^{-1}	1.45×10^{-1}	3.38×10^{0}	1.74×10^{-3}
	As	1.75×10^{-1}	7.52×10^{-2}	1.17×10^{1}	3.23×10^{-4}
	Co	2.24×10^{-1}	9.60×10^{-2}	3.74×10^{1}	8.64×10^{-4}
	Ni	2.25×10^{0}	9.62×10^{-1}	1.60×10^{2}	2.50×10^{-4}
	Fe	2.98×10^{3}	1.28×10^{3}	6.62×10^{-2}	
	Mn	5.61×10^{2}	2.40×10^{2}	1.12×10^{4}	
	Cu	9.35×10^{2}	4.01×10^{2}	7.79×10^{3}	
	Zn	1.83×10^{2}	7.86×10^{1}	5.09×10^{2}	
CB6	Pb	1.26×10^{0}	5.41×10^{-1}	8.41×10^{0}	4.32×10^{-5}
	Cd	6.67×10^{-1}	2.86×10^{-1}	6.67×10^{1}	5.14×10^{-4}
	Cr	3.50×10^{-1}	1.50×10^{-1}	3.50×10^{0}	1.80×10^{-3}
	As	1.67×10^{-1}	7.17×10^{-2}	1.11×10^{1}	3.08×10^{-4}
	Co	1.92×10^{-1}	8.22×10^{-2}	3.20×10^{1}	7.40×10^{-4}
	Ni	2.50×10^{0}	1.07×10^{0}	1.78×10^{2}	2.78×10^{-4}
	Fe	2.21×10^{3}	9.49×10^{2}	4.92×10^{-2}	
	Mn	4.45×10^{2}	1.91×10^{2}	8.90×10^{3}	
	Cu	7.22×10^{2}	3.09×10^{2}	6.01×10^{3}	
	Zn	1.55×10^{2}	6.66×10^{1}	4.32×10^{2}	

Table 4 (continued)

Brands	Metals	ECnc	ECc	HQ	CR
CB7	Pb	6.69×10^{-1}	2.87×10^{-1}	4.46×10^{0}	2.29×10^{-5}
	Cd	4.32×10^{-1}	1.85×10^{-1}	4.32×10^{1}	3.34×10^{-4}
	Cr	4.35×10^{-1}	1.86×10^{-1}	4.35×10^{0}	2.24×10^{-3}
	As	1.14×10^{-1}	4.88×10^{-2}	7.59×10^{0}	2.10×10^{-4}
	Co	3.28×10^{-1}	1.41×10^{-1}	5.47×10^{1}	1.27×10^{-3}
	Ni	2.63×10^{0}	1.13×10^{0}	1.88×10^{2}	2.93×10^{-4}
	Fe	1.70×10^{3}	7.31×10^{2}	3.79×10^{-2}	
	Mn	6.88×10^{2}	2.95×10^{2}	1.38×10^{4}	
	Cu	7.85×10^{2}	3.36×10^{2}	6.54×10^{3}	
	Zn	1.81×10^{2}	7.77×10^{1}	5.04×10^{2}	
CB8	Pb	8.89×10^{-1}	3.81×10^{-1}	5.93×10^{0}	3.05×10^{-5}
	Cd	6.88×10^{-1}	2.95×10^{-1}	6.88×10^{1}	5.31×10^{-4}
	Cr	3.06×10^{-1}	1.31×10^{-1}	3.06×10^{0}	1.57×10^{-3}
	As	1.37×10^{-1}	5.88×10^{-2}	9.14×10^{0}	2.53×10^{-4}
	Co	2.18×10^{-1}	9.34×10^{-2}	3.63×10^{1}	8.40×10^{-4}
	Ni	2.48×10^{0}	1.06×10^{0}	1.77×10^{2}	2.77×10^{-4}
	Fe	2.04×10^{3}	8.73×10^{2}	4.53×10^{-2}	
	Mn	5.89×10^{2}	2.53×10^{2}	1.18×10^{4}	
	Cu	7.77×10^{2}	3.33×10^{2}	6.48×10^{3}	
	Zn	1.65×10^{2}	7.07×10^{1}	4.58×10^{2}	
CB9	Pb	1.21×10^{0}	5.18×10^{-1}	8.05×10^{0}	4.14×10^{-5}
	Cd	8.06×10^{-1}	3.45×10^{-1}	8.06×10^{1}	6.22×10^{-4}
	Cr	3.32×10^{-1}	1.42×10^{-1}	3.32×10^{0}	1.71×10^{-3}
	As	1.81×10^{-1}	7.76×10^{-2}	1.21×10^{1}	3.34×10^{-4}
	Co	2.37×10^{-1}	1.01×10^{-1}	3.95×10^{1}	9.13×10^{-4}
	Ni	2.56×10^{0}	1.10×10^{0}	1.83×10^{2}	2.86×10^{-4}
	Fe	2.86×10^{3}	1.23×10^{3}	6.36×10^{-2}	
	Mn	5.89×10^{2}	2.53×10^{2}	1.18×10^{4}	
	Cu	6.97×10^{2}	2.99×10^{2}	5.81×10^{3}	
	Zn	1.68×10^{2}	7.20×10^{1}	4.67×10^{2}	
CB10	Pb	1.53×10^{0}	6.57×10^{-1}	1.02×10^{1}	5.26×10^{-5}
	Cd	7.31×10^{-1}	3.13×10^{-1}	7.31×10^{1}	5.64×10^{-4}
	Cr	3.07×10^{-1}	1.31×10^{-1}	3.07×10^{0}	1.58×10^{-3}
	As	2.07×10^{-1}	8.85×10^{-2}	1.38×10^{1}	3.81×10^{-4}
	Co	2.18×10^{-1}	9.34×10^{-2}	3.63×10^{1}	8.40×10^{-4}
	Ni	2.60×10^{0}	1.12×10^{0}	1.86×10^{2}	2.90×10^{-4}
	Fe	2.69×10^{3}	1.15×10^{3}	5.98×10^{-2}	
	Mn	5.69×10^{2}	2.44×10^{2}	1.14×10^{4}	
	Cu	7.03×10^{2}	3.01×10^{2}	5.86×10^{3}	
	Zn	1.71×10^{2}	7.34×10^{1}	4.76×10^{2}	

but high non-carcinogenic health risks were found for all analyzed carcinogenic and non-carcinogenic metals except Fe. To reduce cancer risks and non-carcinogenic health risks due to cigarette smoking, continuous monitoring and regulations of the cultivation of tobacco and manufacturing of imported and locally produced tobacco products should be maintained. A threshold limit for toxic chemicals could be established by regulators or the Government in Bangladesh. A complete assessment of the materials and all the ingredients in cigarettes consumed in Bangladesh and potential health risks associated with exposure to these ingredients should be informed to general people, especially cigarette smokers. This study provides vital information for international and local health authorities, law and policymakers, standard enforcement organizations, antidrug enforcement agencies, and the general population on the inherent dangers of smoking cigarettes.

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Declarations

Ethics approval All the authors have read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the "Instructions for Authors."

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