Brewing Toxins

Exposing the Heavy Metal Hazard in Teabags and Dried Loose Tea

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About ESDO

Environment and Social Development Organization- ESDO is an action research-oriented non-profit and non-government organization based in Bangladesh. It is an environmental action research group dedicated to a toxic-free, zero-waste planet. This entails fighting pollution and building regenerative solutions in cities through local campaigns, shifting policy and finance, research and communication initiatives, and movement building. ESDO is working relentlessly to ensure biological diversity since its formation in 1990. It is the pioneer organization that initiated the anti-polythene campaign in 1990, which later resulted in a complete ban on polythene shopping bags throughout Bangladesh in 2002.

About BAN

Toxics BAN Toxics is a Philippine-based environmental NGO founded in 2006, dedicated to promoting environmental justice, health, and sustainable development through sound chemicals and waste management. The organization focuses on protecting vulnerable groups, especially women and children, by conducting scientific research, advocating for policy reforms, and raising public awareness about toxic substances in everyday products.

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Disclaimer

This report, "*Brewing Toxins: Exposing the Heavy Metal Hazard in Teabags and Dried Loose Tea"*, has been prepared by the Environment and Social Development Organization - ESDO, with testing support provided by Ban Toxics. The content, findings, and recommendations are based on field data, laboratory screenings, and policy analyses conducted during the project period.

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The findings are based on scientific methods, including XRF analysis, but are not intended to replace official regulatory testing or serve as legal certification. This report is intended for informational, educational, and advocacy purposes only. It aims to raise awareness, inform policy discussions, and contribute to the broader dialogue on consumer safety and public health regarding heavy metal contamination in teabags and loose-leaf tea. Readers are advised to consult relevant national and international regulatory authorities for official standards and compliance requirements. Neither ESDO, Ban Toxics, nor any of their representatives shall be held liable for any loss or damage arising, directly or indirectly, from the use of or reliance on this publication.

Contents

Executive Summary

Introduction

Tea is the most consumed beverage in Bangladesh and an integral part of everyday life for millions. Beyond its cultural and economic importance, tea is also valued for its nutritional benefits. However, new evidence reveals alarming levels of toxic heavy metals in tea bags sold across the country. This study—conducted by the Environment and Social Development Organization (ESDO), with X-ray Fluorescence (XRF) testing support from Toxics BAN Toxics, is the first nationwide assessment of its kind, combining laboratory analysis with consumer surveys. The results expose a pressing public health concern and highlight critical gaps in the enforcement of Bangladesh's food safety regulations.

The study was carried out in two distinct phases. In the **first phase**, 13 popular teabag brands were analyzed to assess both the tea content and the packaging materials. The **second phase** aimed to broaden the scope of the investigation by increasing the sample size and brand diversity, thereby ensuring a more comprehensive and representative evaluation of toxic heavy metal contamination. Importantly, this phase focused exclusively on **teabag packaging materials**.

A total of **19 additional commercially available brands** were included in the second phase. From each brand, **three samples** were randomly selected, resulting in **57 packaging material samples**. These samples were tested using **handheld X-ray fluorescence (XRF)** technology to detect the presence of heavy metals such as **arsenic, lead, cadmium, mercury, antimony, and chromium**. The findings highlight an **urgent need for stronger regulatory oversight** of packaging safety standards within the tea industry to protect public health.

X-ray Fluorescence (XRF) serves as a preliminary screening technique for identifying and quantifying heavy metals in various materials. While XRF provides accurate detection of heavy metals present at measurable levels, it may not identify elements that occur in **very low concentrations**. Therefore, we recommend **further confirmatory analysis** using more sensitive techniques—such as **Inductively Coupled Plasma Mass Spectrometry (ICP-MS)** or **Atomic Absorption Spectroscopy (AAS)**—to ensure comprehensive and precise quantification of trace metal contaminants.

Consumer Survey Findings

A nationwide survey of 3,571 consumers confirmed the pervasive role of tea in daily life: more than 96% of respondents drink tea regularly, with over half consuming 2–3 cups daily and more than a quarter consuming four or more. This level of intake significantly increases potential exposure to contaminants. Yet awareness of related health risks is alarmingly low—only 1% of consumers had heard about heavy metals in teabags, and more than 90% reported never checking packaging labels or certifications.

When asked about potential solutions, nearly half of the respondents supported stronger government regulation, while others recommended public awareness campaigns, bans on unsafe products, and the promotion of safer alternatives. These findings highlight a dangerous disconnect: high consumption rates combined with extremely low awareness.

Laboratory Analysis

The first phase X-ray fluorescence (XRF) analysis of 13 tea brand samples in the first phase revealed widespread contamination, with teabags posing the greatest risk. Toxic metals detected in teabag packaging material included lead (up to 51 ppm), cadmium (83 ppm), mercury (108 ppm), arsenic (14 ppm), and chromium (1,690 ppm)—all far exceeding both Bangladesh's draft standards and international safety limits. Antimony, linked to PET-based packaging, further raised concerns about leaching and microplastic release during brewing.

Analysis of loose tea leaves and tea contents from tea bags revealed the presence of essential nutrients such as iron, manganese, copper, and zinc, but also carried toxic elements, including antimony (up to 154 ppm) and traces of radioactive substances like uranium and thorium. This "nutrient–toxin paradox" underscores the gravity of the issue: a beverage long celebrated for its cultural and nutritional value is also a significant source of hazardous exposure.

Building on these findings, the **second phase** focused exclusively on **teabag packaging materials**, analyzing a **larger and more diverse set of 57 samples** from **19 additional popular brands**. The results revealed **widespread contamination with toxic heavy metals** across brands and countries of origin.

Policy Implications and Recommendations

Millions of Bangladeshis consume tea daily without realizing these hidden risks. Weak regulatory standards, combined with poor enforcement, leave consumers unprotected. Urgent action is required—through stricter safety standards, routine monitoring, safer packaging solutions, and widespread consumer education—to ensure that the dangers of toxic contamination do not overshadow the benefits of tea.

Key Findings

Highlights of the Nationwide Study

This study is based on one of the largest nationwide surveys on tea consumption in Bangladesh, with **3,571 respondents** drawn from all major regions. The large sample size ensures the findings reflect the habits and perceptions of a broad cross-section of the population.

- Tea is nearly universal: 96% of respondents consume tea regularly.
- High daily intake: 55% drink 2–3 cups daily; 27% drink 4 or more cups.
- Lack of awareness: Only 1% had heard of heavy metal contamination in teabags.
- Poor safety practices: 92% never check packaging labels or safety certifications.
- Public demand for action: 46% want stricter government regulation; 22% call for awareness campaigns; 18% favour banning unsafe brands; 13% recommend safer alternatives.

Laboratory Findings: Public Health Risks from Teabags Materials and Loose Tea Leaves

The first-phase analysis reveals **high levels of toxic heavy metals** in widely consumed teabag materials, far exceeding national and international safety standards:

- Lead: up to 51 ppm (limit: 5 ppm)
- Cadmium: up to 83 ppm (limit: 1 ppm)
- Mercury: up to 108 ppm (limit: 0.3 ppm)
- Arsenic: up to 14 ppm (limit: 2 ppm)
- Chromium: up to 1690 ppm (limit: 5 ppm)

- PET-based teabags contained antimony (38–106 ppm), raising risks of leaching and microplastic release during brewing.

- **Dried loose tea leaf – Benefits and Risks**
  - Contained essential micronutrients such as iron, manganese, copper, and zinc.
  - At the same time, several samples carried toxicants, including antimony (up to 154 ppm), and traces of uranium and thorium.
  - This presents a **nutrient–toxin paradox**: tea offers valuable nutrients but also significant contamination risks.

Second Phase Analysis Reveals Persistent Heavy Metal Contamination in Teabag Packaging Materials

The recent second-phase analysis reveals elevated levels of toxic heavy metals in widely consumed **teabag packaging materials**, further substantiating the contamination identified in the initial phase.

- **Arsenic (As):** Detected in 13 samples, with a range from 4 to 15 ppm.
- **Lead (Pb):** Present in several samples, ranging from 20 to 58 ppm.
- **Cadmium (Cd):** Detected in most samples, with levels ranging from 19 to 87 ppm.
- **Mercury (Hg):** Found in multiple samples, with concentrations between 23 and 98 ppm.
- **Antimony (Sb):** Appeared in more than half of the samples, with concentrations ranging from 38 to 117 ppm
- **Chromium (Cr):** Commonly present, with levels ranging from 316 to 1,710 ppm.

Introduction

1. Introduction

1.1 Background

Tea is one of the most popular non-alcohol beverages for its pleasant aroma, flavor, and refreshing characteristics. Tea trees are mainly cultivated in Asia, Europe, and East Africa, such as China, India, and Turkey. Global tea cultivation area reaches 4.1×106 hm^2, producing 5.95×10^6 tons of tea annually[1].

Bangladesh is ranked in the 9th position, contributing 1.5 % in world tea production. Historically, Bangladesh has had remarkable importance in world tea exports since the start of the tea trade. At present, Bangladesh shares only 0.04 % of the world's tea exports. Bangladesh is the 8th most densely populated country in the world, and tea is the highest consumed beverage in Bangladesh. The increasing demand for tea consumption by a large number of people has significantly affected the export of Bangladesh tea. In 2001, the tea export was 12.93 million kilograms, which declined to 0.68 million kilograms in 2021. Internal demand for tea consumption increases faster than production due to the growing population, and the increase in tea-drinking habits has led to a decline in exports[2].

[1] Ju, Y., Luo, Z., Bi, J., Liu, C. and Liu, X. (2023). Transfer of heavy metals from soil to tea and the potential human health risk in a regional high geochemical background area in southwest China. *The Science of The Total Environment*, 908, pp.168122–168122. https://doi.org/10.1016/j.scitotenv.2023.168122.

[2] Boonerjee, S., Islam, M.A., Islam, S.M.M., Paul, S.K., Uddin, M.T. and Alamgir, M.S. (2024). Consumption and export potential of tea in Bangladesh: A field study. *Journal of Agriculture and Food Research*, [online] 19, p.101607. https://doi.org/10.1016/j.jafr.2024.101607.

The safety and health of tea cannot be separated from the soil environment quality in tea plantations. Soil heavy metals pollution in agricultural soils is also a very important issue, as petrochemical, mining, and industrial discharges increasingly contaminate environments. Excessive heavy metals can change the soil's physicochemical properties, reduce soil productivity, and decrease the quantity and quality of tea, causing a long-term toxic impact on human health via entering and transferring along food chains due to their toxicity, persistence, and non-biodegradability. Arsenic (As), chromium (Cr) and lead (Pb) exposure have been related to many diseases, including cardiovascular and nerve system conditions, and as an essential trace element, excessive copper (Cu) concentrations also affect human health[3].

Several studies have reported that the concentrations and possible health risks of heavy metals in tea leaves, made tea, and tea infusions, such as lead (Pb), arsenic (As), chromium (Cr), cadmium (Cd), nickel (Ni), mercury (Hg), antimony (Sb), and thallium (Tl). These studies have shown that tea contains toxic heavy metals, and long-term exposure may cause their accumulation in the human body. Several researches have shown that the content of manganese (Mn) in tea leaves was extremely high, indicating that the tea plant, as the hyperaccumulator of Mn, could be used in phytoremediation for Mn-contaminated soil. Numerous studies have been performed to investigate the concentration levels of heavy metals in tea from many countries or regions worldwide, such as Sri Lanka, Italy, Ghana, Brazil, India, and China. Several studies have shown that there were phenomena of distinctly exceeding the standard limits for heavy metals in tea leaves from some areas seriously affected by human activities[4].

[3]Chang, Y., Jiang, F., Josep Peñuelas, Jordi Sardans and Wu, Z. (2024). Assessment of Heavy Metals in Tea Plantation Soil and Their Uptake by Tieguanyin Tea Leaves and Potential Health Risk Assessment in Anxi County in Southeast China. *Agriculture*, 14(11), pp.1907–1907. doi:https://doi.org/10.3390/agriculture14111907.

[4] Zhang, J., Yang, R., Li, Y.C., Peng, Y., Wen, X. and Ni, X. (2020). Distribution, accumulation, and potential risks of heavy metals in soil and tea leaves from geologically different plantations. *Ecotoxicology and Environmental Safety*, 195, p.110475. doi:https://doi.org/10.1016/j.ecoenv.2020.110475.

1.2 Rationale of the Study

Tea is the most widely consumed beverage in Bangladesh, playing a central role in daily life across all regions and communities. As the population grows and tea-drinking habits become more ingrained, domestic consumption of tea has increased significantly, surpassing national production and contributing to a sharp decline in tea exports over the past two decades. Despite its popularity and reputation as a healthy beverage, there is growing concern about potential contamination from heavy metals, which may pose serious health risks with long-term exposure.

Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), and chromium (Cr) are toxic even at low concentrations. These substances can accumulate in the human body over time and are linked to a range of chronic health conditions. Contamination may occur during cultivation due to the use of chemical fertilizers, pesticides, or irrigation with polluted water, and can also be introduced during post-harvest processing and packaging. In a country like Bangladesh, where tea is consumed multiple times a day by people of all ages, even low levels of heavy metals in tea products could lead to significant cumulative exposure.

While several international studies have explored the presence of heavy metals in tea, Bangladesh lacks sufficient, up-to-date research on this issue. To date, only one known study—***"Screening for Heavy Metals in Tea Leaves from Bangladesh Using X-Ray Fluorescence"*** by **Amber Wolf**—has investigated this topic. However, that study focused solely on tea leaves and did not assess teabag materials or provide a comparative analysis across different brands. No comprehensive study has yet been conducted to evaluate both tea leaves and packaging materials available in the local market using standardized laboratory techniques.

This lack of local data creates a significant gap in understanding the potential public health risks associated with tea consumption in Bangladesh. In the absence of regular testing, public reporting, or consumer awareness, exposure to heavy metals may go undetected. Although the Bangladesh Food Safety Authority (BFSA) introduced a draft regulation in 2023 to define permissible limits of certain heavy metals in tea, the enforcement of these limits remains limited, and routine monitoring is virtually absent.

This study was therefore designed to address this critical knowledge gap by screening both tea leaves and teabag materials from a range of popular brands in the Bangladeshi market. The results aim to support evidence-based policy decisions, enhance consumer protection, and encourage better regulatory oversight in the tea industry.

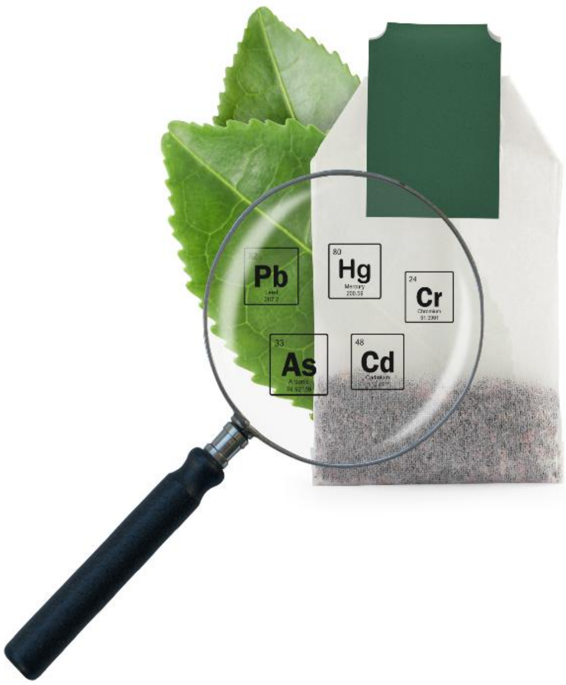
1.3 Objectives of the study

The key objectives of this study are to:

1. Assess the presence and concentration of heavy metals such as lead, cadmium, arsenic, and chromium in the materials of commercial teabags through laboratory analysis. This includes evaluating both the paper or synthetic bag material and the tea it contains.

2. Examine loose, dried tea leaves from various brands to detect and quantify heavy metal contamination prior to brewing. This helps establish a baseline for understanding potential exposure through dry tea products.

3. Evaluate the potential health risks linked to regular consumption of tea containing heavy metals by comparing estimated daily intake with national and international safety thresholds.



4. Conduct a consumer survey to assess public awareness, perceptions, and purchasing behavior related to heavy metal contamination in tea products.

1.4 Overview of XRF Technology

Introduction to handheld XRF Analyzer

A handheld XRF (X-ray fluorescence) analyzer is a portable device used to determine the elemental composition of materials quickly and non-destructively. It works by emitting X-rays onto a sample, causing elements within the material to emit secondary (fluorescent) X-rays, which are then detected and analyzed. Commonly used in fields like environmental testing, mining, metallurgy, and product safety, handheld XRF analyzers provide rapid, on-site analysis of metals, alloys, soils, plastics, and more, helping professionals make informed decisions without the need for laboratory testing.

Effectiveness screening tool for RoHS substances?

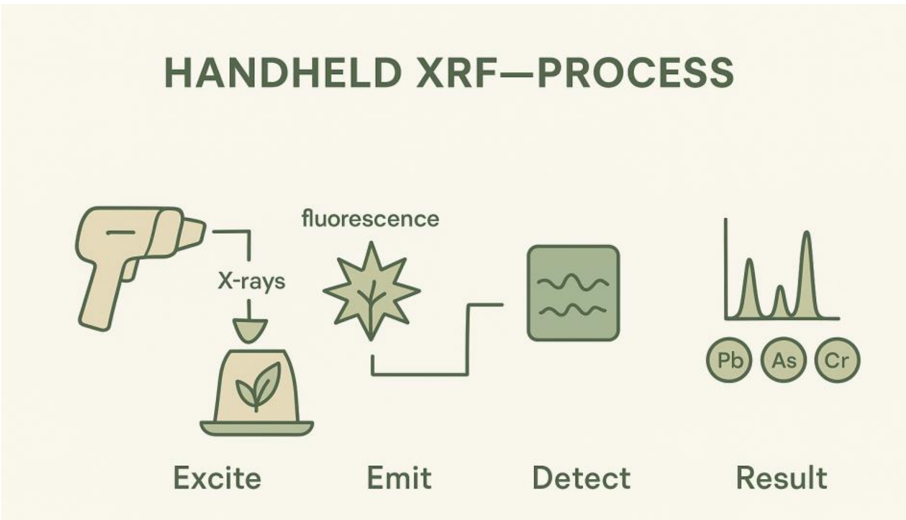
Handheld XRF offers the best combination of speed, reliability, and versatility of any RoHS screening technique. XRF testing can be done in seconds, enabling producers to make actionable decisions immediately, rather than waiting several hours or days for laboratory results. XRF can screen for multiple RoHS elements simultaneously in a variety of materials, all using one device with minimal sample preparation. Finally, it is completely nondestructive, meaning it can be performed at any point in the manufacturing process — even on finished goods[5].

Popularity and Practical Advantages of Handheld XRF

Handheld XRF provides an excellent combination of speed, reliability, and low cost compared to other testing techniques. It can generate results in seconds, enabling organizations to quickly test large amounts of material and pick out potential risks for further testing. It can measure, either directly or indirectly, most RoHS materials at levels well below actionable limits. Finally, testing can be done with little sample preparation, reducing both cost and potential testing errors.

Laboratory testing will always be required to meet some testing obligations, but XRF can reduce the amount of lab testing needed and the costs associated with it. All these aspects are combined in a flexible instrument that can be used at any point in the supply chain and requires minimal training to operate [3].

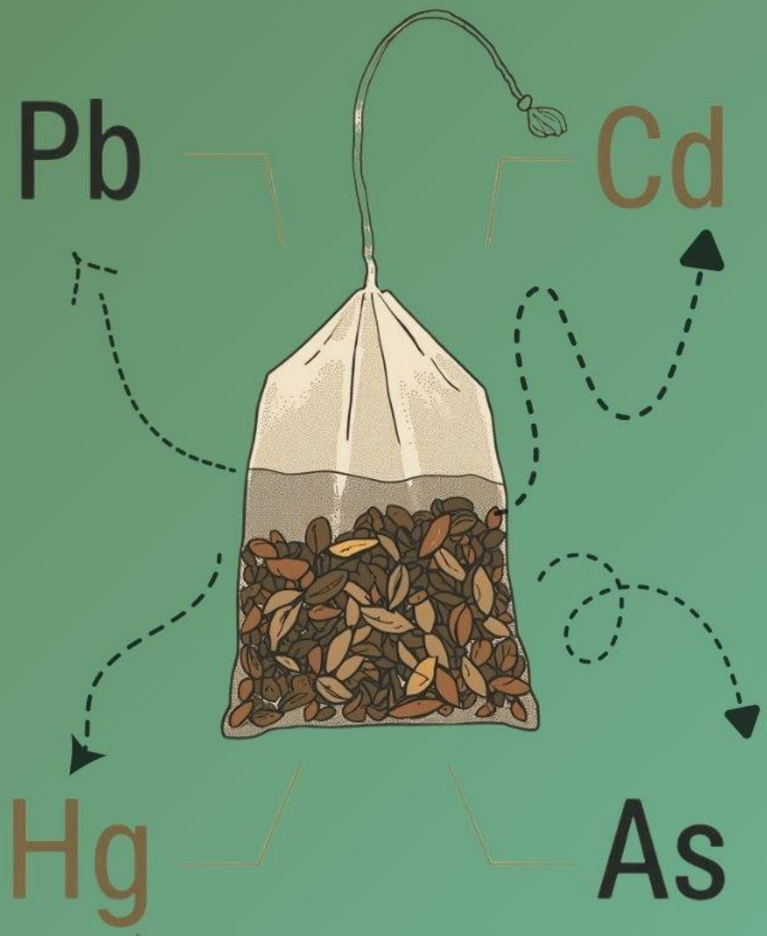
Understanding handheld XRF results is critical for meeting compliance criteria. What has Olympus done to make screening easier and faster?



[5]Milne, S. (2017). *AZoM*. [online] AZoM.
Available at: https://www.azom.com/article.aspx?ArticleID=13691 [Accessed 10 July. 2025].

RoHS guidelines can be tricky to navigate, so our analyzers make the process simpler by providing a clear indication of “Pass/Fail” based on the IEC guidelines. This way, even if your operator isn’t knowledgeable about current guidelines, the analyzer will inform them how best to interpret the results according to IEC 62321. Additionally, the analyzer can identify the family of material being tested, be it a polymer or an alloy, and automatically adjust so that it reports such determinations based on specific material types. Finally, our analyzers possess tools that enable automated report generation as well as fast data uploads to computer or network systems for better tracking [3].

Heavy Metal Contamination in Tea and Overall Toxicity of Heavy Metals



2. Heavy Metal Contamination in Tea and Overall Toxicity of Heavy Metals

2.1 Mechanisms of Heavy Metals Accumulating in Tea Leaves

Previous studies have reported that a dose–response relationship was found between tea intake and blood heavy metal concentration. Therefore, the transferability of heavy metals to tea leaves from soils and the health risks induced by tea intake need attention. Numerous studies have demonstrated that heavy metal pollution depends primarily on industrial activities and agricultural activities, such as the application of pesticides and chemical fertilizers containing heavy metals. Soil's physicochemical properties can affect the heavy metal concentration of soil and tea leaves. Soil with heavy metal concentrations was correlated with soil texture and soil particle diameter, soil H+ activity, soil SOM, and pH. The soils of tea plantations become acidified with the increase of tea plants, which contributes to elevated concentrations of bioavailable water-soluble and exchangeable metals. Soil pH is thought of as a key influencing factor in the transfer and accumulation of heavy metals from soil to plants.

The Cu concentration in tea leaves was found to be closely correlated with the soil's H+ activity. Previous studies have shown that Cr and Pb concentrations in tea leaves were negatively correlated with soil Cr and Pb concentrations, respectively, which showed that Pb and Cr in soil will inhibit absorption by tea leaves [3].

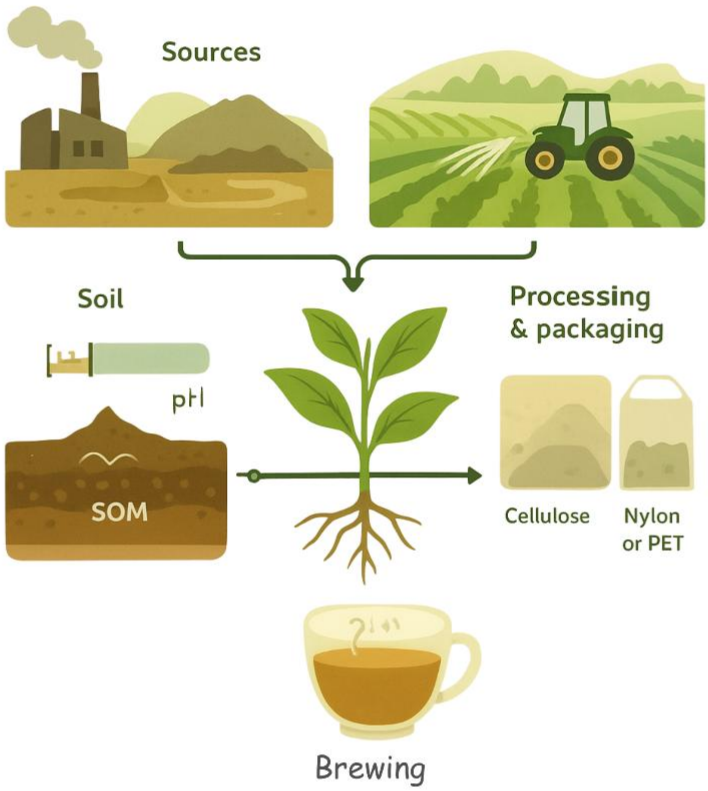
In recent years, concerns have emerged about the materials used in tea bags. Their design, shape, and texture have noticeably changed, with many now made from synthetic or semi-synthetic materials like nylon or PET instead of traditional cellulose. When steeped in hot water, these materials may release microplastics and harmful substances. Studies have also found traces of heavy metals—such as lead (Pb), chromium (Cr), cadmium (Cd), and arsenic (As)—in some tea bag materials, likely from dyes, adhesives, or manufacturing residues. Researchers have analyzed various tea bags from different brands to assess whether both the packaging and the tea contribute to potential heavy metal exposure.

In this study, we will assess the presence of heavy metals not only in the tea itself but also in the materials used in tea bags. The aim is to understand the potential health impacts of consuming tea that may be contaminated through both environmental exposure and packaging materials, and to provide data that can inform safer consumption practices and regulatory standards.

2.2 Bioaccumulation of Heavy Metals in Living Organisms from Tea

Bioaccumulation is essentially the buildup of contaminants such as heavy metals or pesticides in living organisms. Humans can also experience bioaccumulation through exposure to contaminants in our food, air, or water. Since heavy metals do not biodegrade, they can last for a long time in our bodies [6]

Trace metal contamination of food and water is a worldwide public health concern. In Southeast Asia, metal contamination has been found in several foods such as vegetables, fish, milk, and tea leaves. Tea, in particular, is a potential source of exposure to heavy metals such as lead and other metals, such as manganese, cadmium, and chromium [7].
Heavy metals in tea are important indicators of tea quality, as they can be transferred into tea infusions through the process of brewing tea, then enter the human body by means of tea consumption, and thus pose potential risks to human health[8].



[6] Heavy Metals And Bioaccumulation: Why Heavy Metals Accumulate in Your Food and Your Body? (n.d.) Heavy Metals and Bioaccumulation. Available at: https://dspmuranchi.ac.in/pdf/Blog/Heavy%20Metals%20And%20Bioaccumulation.pdf (Accessed: 9 September 2025).
[7] Wolf, A. (2021). Screening for Heavy Metals in Tea Leaves from Bangladesh Using X-Ray Fluorescence. *Crossing Borders: A Multidisciplinary Journal of Undergraduate Scholarship*, 5(1). doi:https://doi.org/10.4148/2373-0978.1095.
[8] Zhang, J., Yang, R., Chen, R., Peng, Y., Wen, X. and Gao, L. (2018). Accumulation of Heavy Metals in Tea Leaves and Potential Health Risk Assessment: A Case Study from Puan County, Guizhou Province, China. *International Journal of Environmental Research and Public Health*, [online] 15(1). doi:https://doi.org/10.3390/ijerph15010133.

2.3 Toxicity of Heavy Metals

Heavy metal toxicity has proven to be a significant hazard, with various health risks associated with it. The toxic effects of these metals, even though they do not have any biological role, remain present in some or the other form, harmful to the human body and its proper functioning. The following is a system-wise summary of key heavy metals, their mechanisms of toxicity, and associated health effects.

Neurotoxicity

As an essential element, manganese is involved in several physiological functions of the body. It's acute exposure exerts potential neuroprotective action by reducing apoptotic cellular death but exposure to a large quantity may induce harmful conditions like neurological complications, such as Alzheimer and Parkinson disease, which leads to apoptotic cell death and alteration of homeostasis[9]. Homeostasis of the cellular Mn relies on sufficient intake, storage, as well as excretion via different cell receptors and ion channels. The receptors associated with metal uptaking are down-regulated by homeostatic pathways in terms of excessive Mn exposure, whereas those engaging in its discharge from this cell become up-regulated. However, ongoing Mn accumulation leads to the increased formation of ROS, which contributes to mitochondrial dysfunction. Mitochondrial dysfunctions result in the discharge of cytochrome *c*, stimulating the apoptosis precursor caspase-9, by which caspase-3 cleaves. The cleaved caspase-3 fragment binds to a pro-apoptotic protein, PKCδ (protein kinase C delta). The proteolytic cleavage of PKCδ induced by caspase-3 contributes to DNA fragmentation, as well as apoptosis.

The central nervous system suffers from cognitive impairment when arsenic is consumed. It's also linked to a number of neurological illnesses, including neurodevelopmental changes, and leads to an excess of neurodegenerative diseases. Arsenic poisoning also causes changes in synaptic transmission and neurotransmitter balance[10]. Additionally, the neurotoxic effects of arsenic are attributed to inducing multiple apoptotic mechanisms. Firstly, arsenic and its methylated metabolites facilitate caspase- induced apoptosis in neural cells via the MAPK signaling pathways that include the ERK2, JNK, or p38; following the intrinsic mitochondrial-apoptotic mechanisms. Besides, arsenic initiates an intracellular calcium upturn that arbitrates apoptosis. On the contrary, cellular apoptosis can be mediated by activation of autophagy via the stimulation of the AMPK as well as inhibition of the mammalian target of rapamycin (mTOR). Autophagy is a homeostatic mechanism where double-membraned autophagosomes erupt cellular constituents to be eventually degraded when fused with lysosomes (Garza-Lombó et al., 2019).

Neurodegenerative defects, including amyotrophic lateral sclerosis, Parkinson's disease, Alzheimer's disease, and multiple sclerosis, result from neurotoxicity induced by cadmium. Numerous preclinical evidences have revealed that cadmium severely affects the

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[9] Goldhaber, S.B. (2003). Trace element risk assessment: essentiality vs. toxicity. *Regulatory Toxicology and Pharmacology*, [online] 38(2), pp.232–242. doi:https://doi.org/10.1016/s0273-2300(02)00020-x.

[10] Harischandra, D.S., Ghaisas, S., Zenitsky, G., Jin, H., Kanthasamy, A., Anantharam, V. and Kanthasamy, A.G. (2019). Manganese-Induced Neurotoxicity: New Insights Into the Triad of Protein Misfolding, Mitochondrial Impairment, and Neuroinflammation. *Frontiers in Neuroscience*, 13. doi:https://doi.org/10.3389/fnins.2019.00654.

functionalities of PNS and CNS, with many clinical manifestations, such as peripheral neuropathy, olfactory dysfunctions, neurological disturbances, learning disabilities, and mental retardation, along with the impairment of motor function and behavioral changes in both adults and children. Additionally, many types of cellular activity, such as cell differentiation, proliferation, and cell death, are affected.

The neurotoxicity of cadmium arises from neural cell death via apoptosis, providing plenty of apoptosis-induction factors, including impairment of neurogenesis, inhibition of neuron gene expression, offering epigenetic effects, endocrine disruption, etc [11].

In addition to manganese, arsenic, and cadmium, a lot of heavy metals have been established for their neurotoxic consequences. As well, copper and zinc, like iron, act as impediments to neurodevelopment when an excessive amount enters the brain. Excess copper retention causes Wilson's disease, a hereditary condition that causes neurobehavioral abnormalities similar to schizophrenia. Zinc deficiency has an adverse influence on neurodevelopment, but the consequence of vast quantities is not clear. An experimental study by Ken-ichiro Tanaka and Masahiro Kawahara showed that copper augments zinc-induced neurotoxicity[12].

Nephrotoxicity

Nephrotoxicity induced by cadmium leads to intense clinical symptoms such as glucosuria, Fanconi-like syndrome, phosphaturia, and aminoaciduria. The proximal tubular epithelium is affected by direct exposure to the kidneys, resulting in a significant level of cadmium in urine, aminoaciduria, 32-microglobulinuria, and glucosuria, as well as impaired renal tubular phosphate reabsorption. Renal tubular acidosis, renal failure, and hypercalciuria can all result from excessive exposure[13].

Lead has deleterious effects on all organs, but it has the greatest influence on the kidneys. Acute lead nephropathy causes proximal tubular dysfunction, resulting in Fanconi-like syndrome. Chronic lead nephropathy can be characterized by hyperplasia, interstitial fibrosis, atrophy of the tubules, renal failure, and glomerulonephritis.

Acute exposure of the kidneys to mercury causes acute tubular necrosis, and has many clinical symptoms, such as acute dyspnea, altered mental status, abdominal pain, profuse salivation, tremors, vomiting, chills, and hypotension. In contrast, chronic exposure to mercury causes injury to the epithelium and necrosis in the pars recta of the proximal tubule. Tubular failure, higher urine excretion of albumin and retinol-binding protein, and a nephritic state with a characteristic of membranous nephropathy are all symptoms of mercury-induced chronic kidney injury.

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[11] Wang, B. and Du, Y. (2013). Cadmium and Its Neurotoxic Effects. *Oxidative Medicine and Cellular Longevity*, 2013, pp.1–12. doi:https://doi.org/10.1155/2013/898034.
[12] Tanaka, K. and Kawahara, M. (2017). Copper Enhances Zinc-Induced Neurotoxicity and the Endoplasmic Reticulum Stress Response in a Neuronal Model of Vascular Dementia. *Frontiers in Neuroscience*, 11. doi:https://doi.org/10.3389/fnins.2017.00058.
[13] Friberg, L.T., Elinder, G.-G., Kjellstrom, T., & Nordberg, G.F. (Eds.). (1985). Cadmium and Health: A Toxicological and Epidemiological Appraisal: Volume 2: Effects and Response (1st ed.). CRC Press. https://doi.org/10.1201/9780429260599

Thallium sulfate excretion via the kidneys is delayed and can take up to two months after consumption. Toxic injury to the kidneys is indicated by albuminuria and hematuria. However, thallium poisoning does not cause gross diminishment of renal function[14].

Carcinogenicity

Almost all heavy metals are serious toxicants as carcinogens [15]. The following heavy metals cause cancer through different mechanisms:
Arsenic causes epigenetic alterations, damage to DNA, changes in the p53 protein's expression, histone modifications, DNA methylation, and reduced p21 expression. Arsenic poisoning raises the risk of cancer by attaching to DNA-binding proteins and slowing down the DNA-repair process

Lead is a carcinogenic substance that causes damage to the DNA repair mechanism, cellular tumour-regulating genes, and chromosomal structure and sequence by releasing ROS. It disrupts transcription by shifting zinc from certain regulatory proteins.

Mercury's peroxidative activity generates a significant quantity of reactive oxygen species (ROS), which can aid protumorigenic signaling and cancerous cell growth. ROS can contribute to carcinogenesis by damaging cellular proteins, lipids, and DNA, resulting in cell damage[16].

Nickel works as a carcinogen via controlling a variety of carcinogenic mechanisms, including gene regulation, transcription factor management, and free radical generation. It controls the expression of particular long non-coding RNAs, mRNAs, and microRNAs. It participates in the methylation of the promoter and the downregulation of gene 3 (MEG3) to increase the modulation of hypoxia-inducible factor-1, both of which contribute to carcinogenesis[17].

[14] Yumoto, T. (2017). A Successfully Treated Case of Criminal Thallium Poisoning. *Journal of Clinical and Diagnostic Research*, 11(4). doi:https://doi.org/10.7860/jcdr/2017/24286.9494.
[15] Kim, H.S., Kim, Y.J. and Seo, Y.R. (2015). An Overview of Carcinogenic Heavy Metal: Molecular Toxicity Mechanism and Prevention. *Journal of Cancer Prevention*, 20(4), pp.232–240. doi:https://doi.org/10.15430/jcp.2015.20.4.232.
[16] Zefferino, R., Piccoli, C., Ricciardi, N., Scrima, R. and Capitanio, N. (2017) 'Possible mechanisms of mercury toxicity and cancer promotion: Involvement of gap junction intercellular communications and inflammatory cytokines', *Oxidative Medicine and Cellular Longevity*, 2017, Article ID 7028583. doi: 10.1155/2017/7028583.
[17] Zhou, C., Huang, C., Wang, J., Huang, H., Li, J., Xie, Q., Liu, Y., Zhu, J., Li, Y., Zhang, D., Zhu, Q. and Huang, C. (2017). LncRNA MEG3 downregulation mediated by DNMT3b contributes to nickel malignant transformation of human bronchial epithelial cells via modulating PHLPP1 transcription and HIF-1α translation. *Oncogene*, [online] 36(27), pp.3878–3889. doi:https://doi.org/10.1038/onc.2017.14.

Hepatotoxicity

Heavy metals pose a serious threat if they go beyond permissible limits in our bodies. Many heavy metal's including lead, chromium, arsenic, mercury, nickel, and cadmium, pose a serious threat when they go beyond permissible limits and cause hepatotoxicity[18].

The toxicity of lead on liver cells is well established. Exposure to it increases oxidative stress, resulting in liver damage. Organic solvents, combined with lead, also cause injury to the liver because of have the same characteristics as lead. Chronic lead exposure is potentially toxic to liver cells, resulting in glycogen depletion and cellular infiltration, which can result in chronic cirrhosis[19].

Cadmium has two human target tissues: the renal cortex and the liver. During acute exposure, it accumulates in the liver and is linked to a variety of hepatic dysfunctions. Cadmium changes the cellular redox balance, resulting in oxidative stress and hepatocellular damage. Hepatotoxicity induced by cadmium, both acute and chronic, causes liver failure and therefore, can increase the risk of cancer[20].

Copper is well known to accumulate in the liver due to Wilson's disease. Increased levels of copper may cause oxidative stress; therefore, hepatic copper deposition is not only pathognomonic, but also pathogenic. Elevated hepatic copper levels are also observed in cholestatic liver diseases. However, they result from diminished biliary excretion of copper and are not a cause of hepatic infection[21].

Numerous studies have shown that Cr(VI) can harm the liver, and histopathological changes such as steatosis of hepatocytes, parenchymatous degeneration and necrosis were already identified. Elevated ROS levels, lipid peroxidation, suppression of DNA, RNA, and protein synthesis, DNA damage, decrease of antioxidant enzyme activity, mitochondrial dysfunction, such as impaired mitochondrial bioenergetics, cell growth arrest, and apoptosis, are all associated with Cr (VI) hepatotoxicity[22].

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[18] Renu, K., Chakraborty, R., Myakala, H., Koti, R., Famurewa, A.C., Madhyastha, H., Vellingiri, B., George, A. and Valsala Gopalakrishnan, A. (2021). Molecular mechanism of heavy metals (Lead, Chromium, Arsenic, Mercury, Nickel and Cadmium) - induced hepatotoxicity – A review. *Chemosphere*, 271, p.129735. doi:https://doi.org/10.1016/j.chemosphere.2021.129735.
[19] Hegazy, A.M.S. and Fouad, U.A. (2014). Evaluation of Lead Hepatotoxicity; Histological, Histochemical and Ultrastructural Study. *Forensic Medicine and Anatomy Research*, [online] 2(3), pp.70–79. doi:https://doi.org/10.4236/fmar.2014.23013.
[20] Hyder, O., Chung, M., Cosgrove, D., Herman, J.M., Li, Z., Firoozmand, A., Gurakar, A., Koteish, A. and Pawlik, T.M. (2013). Cadmium Exposure and Liver Disease among US Adults. *Journal of Gastrointestinal Surgery*, 17(7), pp.1265–1273. doi:https://doi.org/10.1007/s11605-013-2210-9.
[21] Yu, L., Liou, I.W., Biggins, S.W., Yeh, M., Jalikis, F., Chan, L. and Burkhead, J. (2019). Copper Deficiency in Liver Diseases: A Case Series and Pathophysiological Considerations. *Hepatology Communications*, 3(8), pp.1159–1165. doi:https://doi.org/10.1002/hep4.1393.
[22] Hasanein, P. and Emamjomeh, A. (2019) 'Beneficial effects of natural compounds on heavy metal–induced hepatotoxicity', in Watson, R.R. and Preedy, V.R. (eds.) *Dietary interventions in liver disease*. Academic Press, pp. 345–355. doi: 10.1016/B978-0-12-814466-4.00028-8.

Immunological Toxicity

Acute and chronic lead exposure lead to several toxic effects on the immune system and cause many immune responses, such as increased allergies, infectious diseases, and autoimmunity, as well as cancer. A high risk of lung, stomach, and bladder cancer in several demographic groups has been linked to lead exposure. Exposure to lead triggers the production of B and T-cells as well as MHC activity. It can influence cellular and humoral responses by modifying the role of T-cell and increasing susceptibility to the development of autoimmunity and hypersensitivity.

Occupational and environmental exposure to cadmium may induce immunosuppressive effects based on varying exposure conditions. Humoral immune responses are amplified at low exposure, whereas the effects at higher exposures are not yet established. However, phagocytosis, natural killer cell activity, and host resistance in experimental infections are notably reduced in most cases.

Chromium is known to have many adverse effects on the human immune system. The influence of chromium on the immune system has been explored in numerous experimental studies. According to *Faleiro et al*., who used CoCrMo disc samples, lymphocyte proliferation is obstructed. High doses of hexavalent chromium reduce the phagocytic action of alveolar macrophages and the humoral immune response. In addition, chromium induces two types of hypersensitivity reactions: type I (anaphylactic type); and type IV (delayed type). Development of allergic contact dermatitis due to chromium exposure has also been found in many studies [23].

Cardiovascular Toxicity

Lead exposure, either acute or chronic, produces a variety of abnormalities in the human body. Chronic exposure to lead may cause arteriosclerosis and hypertension, thrombosis, atherosclerosis, and cardiac disease by increasing OS, reducing NO availability, increasing vasoconstrictor prostaglandins, altering the renin–angiotensin system, lowering vasodilator prostaglandins, disrupting vascular smooth muscle Ca^{2+} signaling, increasing inflammation and endothelium-dependent vasorelaxation, and adjusting the vascular response to vasoactive agonists. Exposure for a long time also increases arterial pressure[24].

Cadmium is a toxicant and carcinogenic metal. In addition to its carcinogenic properties, cadmium induces kidney disease, bone disease, and cardiovascular disease. Low to moderate cadmium exposure results in hypertension, diabetes, carotid atherosclerosis, peripheral arterial disease, chronic kidney disease, myocardial infarction, stroke, and heart

[23] C. Leroyer, Dewitte, J.D., A. Bassanets, M. Boutoux, Daniel, C. and Clavier, J. (1998). Occupational Asthma due to Chromium. *Respiration*, 65(5), pp.403–405. doi:https://doi.org/10.1159/000029303.
[24]Vaziri, N.D. (2008) 'Mechanisms of lead-induced hypertension and cardiovascular disease', *American Journal of Physiology - Heart and Circulatory Physiology*, 295(2), pp. H454–H465. doi: 10.1152/ajpheart.00158.2008.

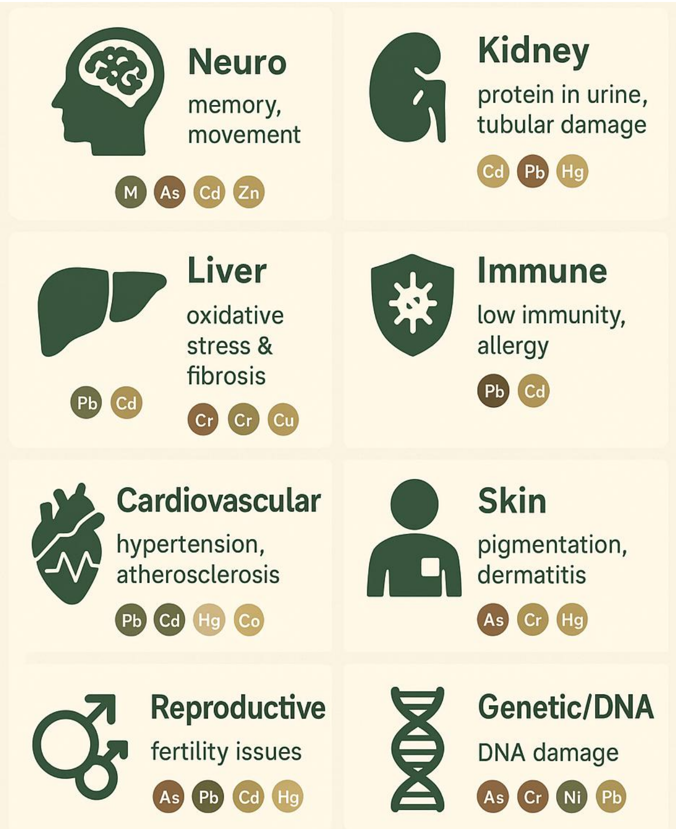
failure. In prospective studies, cadmium was linked to an increased risk of cardiovascular death in the general population of the United States[25].

Mercury has been shown to cause neurotoxicity, nephrotoxicity, and hepatotoxicity in humans. Cardiovascular toxicity has also been discovered in recent research. Levels of mercury in hair have been linked to oxidized LDL levels in atherosclerotic lesions, acute coronary failure, and atherosclerosis. Paraoxonase, an extracellular antioxidative enzyme linked to HDL dysfunction, is likewise inactivated by mercury; this is directly linked to the progression of atherosclerosis and the increased risk of a coronary heart disease, cardiovascular disease, acute myocardial infarction, coronary heart disease, and carotid artery stenosis [26].

Cobalt exposure causes reversible systolic cardiac depression, which may be distinguished from other cardiomyopathy disorders. Cardiomyopathy caused by cobalt can be slow and fatal. However, the cardiac function of survivors usually recovers. Additionally, cobalt exposure has been associated with increased T cell proliferation.

Skin Toxicity

Chronic arsenic exposure promotes a lot of possible skin diseases, including hyperkeratosis, hyperpigmentation, and several types of skin cancer. Hyperpigmentation is the most prevalent skin change caused by prolonged arsenic exposure. Arsenic exposure can potentially cause Bowen's disease, a type of early skin cancer. Arsenic hyperkeratosis commonly affects the palms and soles but may also involve the legs, toes, fingers, arms, and hand dorsum. Some hyperkeratotic and Bowen's disease lesions have the potential to develop into invasive malignancies[27].The skin, the body's outermost organ, acts as a barrier against contaminants. Chromium exposure can cause acute and chronic severe dermatological consequences, including contact dermatitis, systemic contact dermatitis, and skin cancer.



[25] Tellez-Plaza, M., Guallar, E., Howard, B.V., Umans, J.G., Francesconi, K.A., Goessler, W., Silbergeld, E.K., Devereux, R.B. and Navas-Acien, A. (2013). Cadmium Exposure and Incident Cardiovascular Disease. *Epidemiology*, [online] 24(3), pp.421–429. doi:https://doi.org/10.1097/ede.0b013e31828b0631

[26] Kulka, M. (2016). A review of paraoxonase 1 properties and diagnostic applications. *Polish Journal of Veterinary Sciences*, 19(1), pp.225–232. doi:https://doi.org/10.1515/pjvs-2016-0028.

[27] Huang, H.-W., Lee, C.-H. and Yu, H.-S. (2019). Arsenic-Induced Carcinogenesis and Immune Dysregulation. *International Journal of Environmental Research and Public Health*, 16(15), p.2746. doi:https://doi.org/10.3390/ijerph16152746.

Contact dermatitis is a common skin disorder characterized by delayed hypersensitivity as a result of recurrent dermal contact with allergens (haptens). Systemic contact dermatitis induced by systemic exposure to an allergen, which causes the skin to become sensitive through direct dermal contact at first.

Many skin infections are caused by mercury and its compounds, such as acrodynia (pink disease), a common dermatological condition in which the skin turns pink due to heavy metal exposure, especially mercury. People tattooed with the red pigments cadmium sulfide and mercury sulfide may have inflammation restricted to specific areas, typically within six months after getting tattooed. Moderate swelling, scaling, vesiculation, and irritation are symptoms of acute contact dermatitis caused by mercury-containing substances. According to several studies, mercury poisoning is the most prevalent cause of dermatological problems[28].

Reproductive and Developmental Toxicity

Arsenic is a known reproductive toxin in humans, and it causes abnormalities in experimental animals, particularly neural tube anomalies. Inorganic arsenic impairs male reproduction by reducing the weights of the testes, the accessory sex organs, and the number of sperm in the epididymis. Aside from affecting sperm production, inorganic arsenic exposure also causes variations in testosterone and gonadotropin levels, as well as disturbances in the steroidogenesis process. In females, arsenic consumption is associated with an increased incidence of endometrial cancer. Endometrial angiogenesis, which is critical for embryo development, is then impaired by arsenic exposure during pregnancy. Symptoms of endometriosis, subfertility, prematurity, sterility, and spontaneous abortions are all caused by these conditions[29].

Several studies conducted by the World Health Organization (WHO) have found that more than 10% of women are at risk of infertility because of their exposure to heavy metals such as lead, cadmium, mercury, and other pollutants, which are the most common environmental contaminants that can cause reproductive disorders. According to a study conducted by the WHO, the condition of infertility is more prevalent in women than in men. Ovulation disturbances are a frequent cause of subfertility in women. Ovulation disturbances are characterized by irregular or absent menstrual cycles, and they may be corrected with the use of reproductive hormones. The risk of infertility in women elevated as a result of increasing levels of toxin exposure, which resulted in hormonal disruption, delayed ovulation, and chromosomal abnormalities in oocytes. Female infertility is caused mostly by hormonal imbalance, which is exacerbated by endocrine disruption caused by heavy metal poisoning, which is the most common cause of female infertility currently[30].

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[28] Boyd, A.S., Seger, D., Vannucci, S., Langley, M., Abraham, J.L. and King, L.E. Jr. (2000) 'Mercury exposure and cutaneous disease', *Journal of the American Academy of Dermatology*, 43(1 Pt 1), pp. 81–90. doi: 10.1067/mjd.2000.106360.

[29] Milton, A.H., Hussain, S., Akter, S., Rahman, M., Mouly, T.A. and Mitchell, K. (2017) 'A review of the effects of chronic arsenic exposure on adverse pregnancy outcomes', *International Journal of Environmental Research and Public Health*, 14(6), p. 556. doi: 10.3390/ijerph14060556.

[30] Rattan, S., Zhou, C., Chiang, C., Mahalingam, S., Brehm, E. and Flaws, J.A. (2017). Exposure to endocrine disruptors during adulthood: consequences for female fertility. *Journal of Endocrinology*, 233(3), pp.R109–R129. doi:https://doi.org/10.1530/JOE-17-0023.

Genotoxicity

Several investigations have shown significant interindividual variability in receptiveness to arsenic poisoning, with genetic factors as the fundamental source of this variability being identified. The genotoxicity of arsenic results in deoxyribonucleic acid alteration, which includes chromosomal abnormalities, mutation, micronuclei production, deletion, and sister chromatid exchange. Numerous investigations have been conducted to determine the mechanism of arsenic's genotoxic impact, which includes the induction of oxidative stress and the disruption of DNA repair. Arsenic has been shown to have no direct effect on DNA and is regarded as a weak mutagen because, despite its low mutagenicity, it impacts the mutagenicity of other carcinogens. In human cells, for example, an increased mutagenicity of arsenic has been found when exposed to UV light[31].

The genotoxic effects of human exposure to chemical compounds cause changes in the genetic material primarily via two processes: teratogenesis and carcinogenesis. Teratogenesis is a process in which a chemical compound causes changes in the genetic material. The first of these may manifest itself in the offspring in the form of congenital abnormalities, whilst the second manifests itself in the development of malignancies in those who have been exposed directly. The development of the central nervous system is especially affected by certain mercury compounds, known as teratogenic agents, which are toxic to the developing neurological system. However, the relationship between mercury exposure and carcinogenesis (one of the most serious outcomes of DNA-induced damage) is still debated, since some experiments appear to show that mercury has genotoxic activity, while others have not proven such DNA-damaging effects[32].

Those who work in the mining and consuming sectors that use chromium have also been shown to be at risk for cancer. Researchers found that Cr(VI) causes a wide range of genetic material structural changes, including DNA chromosomal protein cross-links, inter-DNA strand cross-links, and nucleotide strand breakage in living and cultured cells[33].

[31] Yin, Y., Meng, F., Sui, C., Jiang, Y. and Zhang, L. (2018). Arsenic enhances cell death and DNA damage induced by ultraviolet B exposure in mouse epidermal cells through the production of reactive oxygen species. *Clinical and Experimental Dermatology*, 44(5), pp.512–519. doi:https://doi.org/10.1111/ced.13834.

[32] Crespo-López, M.E., Macêdo, G.L., Pereira, S.I.D., Arrifano, G.P.F., Picanço-Diniz, D.L.W., Nascimento, J.L.M. do and Herculano, A.M. (2009). Mercury and human genotoxicity: Critical considerations and possible molecular mechanisms. *Pharmacological Research*, 60(4), pp.212–220. doi:https://doi.org/10.1016/j.phrs.2009.02.011.

[33] Mitra, S., Chakraborty, A.J., Tareq, A.M., Emran, T.B., Nainu, F., Khusro, A., Idris, A.M., Khandaker, M.U., Osman, H., Alhumaydhi, F.A. and Simal-Gandara, J. (2022). Impact of Heavy Metals on the Environment and Human health: Novel Therapeutic Insights to Counter the Toxicity. *Journal of King Saud University - Science*, 34(3), p.101865. doi:https://doi.org/10.1016/j.jksus.2022.101865.

2.4 Steeped Tea: Heavy Metal Contamination – Literature Review

Tea is one of the most widely consumed beverages globally. Recent studies have highlighted concerns regarding the presence of heavy metals in both tea leaves and brewed tea (tea infusions). Heavy metals such as aluminum (Al), lead (Pb), arsenic (As), cadmium (Cd), and chromium (Cr) are of particular concern due to their potential adverse health effects when consumed over time.

Chromium

A study found that the chromium content per cup of tea (200 mL prepared with 2 g of tea leaves or a standard tea bag) varies among different types of tea. They reported that black tea contains the highest levels of Cr(VI), reaching up to 17.5 µg per cup, whereas green tea contains much lower amounts, approximately 0.06–0.28 µg per cup[34].

Aluminum (Al)

A study found that all teas analyzed contained significant concentrations of aluminum. Tea leaves were reported to contain 568–3287 ng/g, while brewed teas steeped for 3–15 minutes contained 1131–8324 µg/L and 1413–11,449 µg/L, respectively. Notably, two teas exceeded acceptable limits after 3 minutes of brewing, and six teas surpassed the upper daily limit of 7000 µg/L after 15 minutes of brewing. This indicates that prolonged steeping time considerably increases aluminum leaching into tea infusions, making extended brewing (>3 minutes) inadvisable.

Lead (Pb)

Detectable levels of lead were present in both tea leaves and brewed teas, with concentrations ranging between 0.1 and 4.39 µg/L. Among the different varieties, Chinese oolong teas exhibited the highest levels, followed by green and black teas. Organic white tea displayed the lowest lead concentrations. The presence of lead in all samples highlights a potential risk to consumers, given its well-documented neurotoxic effects.

Arsenic (As)

All brewed teas contained detectable levels of arsenic. Concentrations ranged from 0.06–1.12 µg/L for teas steeped 3 minutes and 0.08–1.27 µg/L for teas steeped 15 minutes. Chinese oolong teas, both organic and conventional, showed the highest arsenic levels. Considering arsenic's carcinogenic properties, even low-level chronic exposure through regular tea consumption may pose a public health risk.

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[34] Schwalfenberg, G., Genuis, S.J. and Rodushkin, I. (2013). The Benefits and Risks of Consuming Brewed Tea: Beware of Toxic Element Contamination. *Journal of Toxicology*, [online] 2013, pp.1–8. doi:https://doi.org/10.1155/2013/370460.

Cadmium (Cd)

Tea leaves consistently contained detectable cadmium. After brewing, 18 teas had detectable levels at 3 minutes, increasing to 21 teas at 15 minutes. This pattern indicates that cadmium leaches further into the infusion over longer steeping durations. The maximum cadmium concentration detected was 0.067 µg/L, found in standard oolong tea. While the levels appear low, chronic exposure remains a concern due to cadmium's cumulative toxicity.

Other metals

In addition to these toxic elements, brewed teas were also found to contain cesium, tin, barium, antimony, and thallium. For example, one organic tea had 3103 ng/g of cesium in dry leaves, translating to 12.4 µg/L after 3 minutes of brewing and 16.5 µg/L after 15 minutes. Although barium, antimony, and thallium were consistently detected across tea types, their concentrations were considered within non-concerning levels.

Summary of findings

Overall, the evidence demonstrates that tea is a source of multiple heavy metals, with concentrations influenced by both tea type and steeping duration. Aluminum, lead, arsenic, and cadmium were of particular concern, with prolonged steeping significantly increasing metal concentrations in infusions. These findings underscore the importance of monitoring heavy metal contamination in teas to minimize potential long-term health risks for consumers[35].

[35] Schwalfenberg, G., Genuis, S.J. and Rodushkin, I. (2013). The Benefits and Risks of Consuming Brewed Tea: Beware of Toxic Element Contamination. *Journal of Toxicology*, [online] 2013, pp.1–8. doi:https://doi.org/10.1155/2013/370460.

Overview of the Tea Market and Industry

3. Overview of the Tea Market and Industry

3.1 Global Market Overview

Tea remains one of the most consumed non-alcoholic beverages worldwide, with a global annual consumption of approximately **6.5 million metric tons** and a market value projected to reach **USD 73.7 billion by 2027**[36]. China leads global production, accounting for over **40%** of total output, followed by India, Kenya, Sri Lanka, and other producing nations[37].

Shifts in consumer preferences—such as the rise in specialty teas, organic blends, and health-oriented products—are influencing production and marketing strategies globally[38]. At the same time, sustainability and ethical sourcing have become critical drivers of purchasing decisions, pushing the industry practices[39].

[36] Jain, S., & Jain, P. (2021). Global tea market: Trends and forecasts. Beverage Research, 12(3), 78-91.
[37] FAO. (2020). FAOSTAT: Food and Agriculture Data. Retrieved from http:// www.fao.org/faostat/en/
[38] Euromonitor International. (2022). Tea: A Global Market Overview. London, UK: Euromonitor International.
[39] Cesareo, L., & McMullen, J. S. (2023). The sustainability imperative: Trends in the global tea industry. Journal of Sustainable Development, 15(2), 45-58.

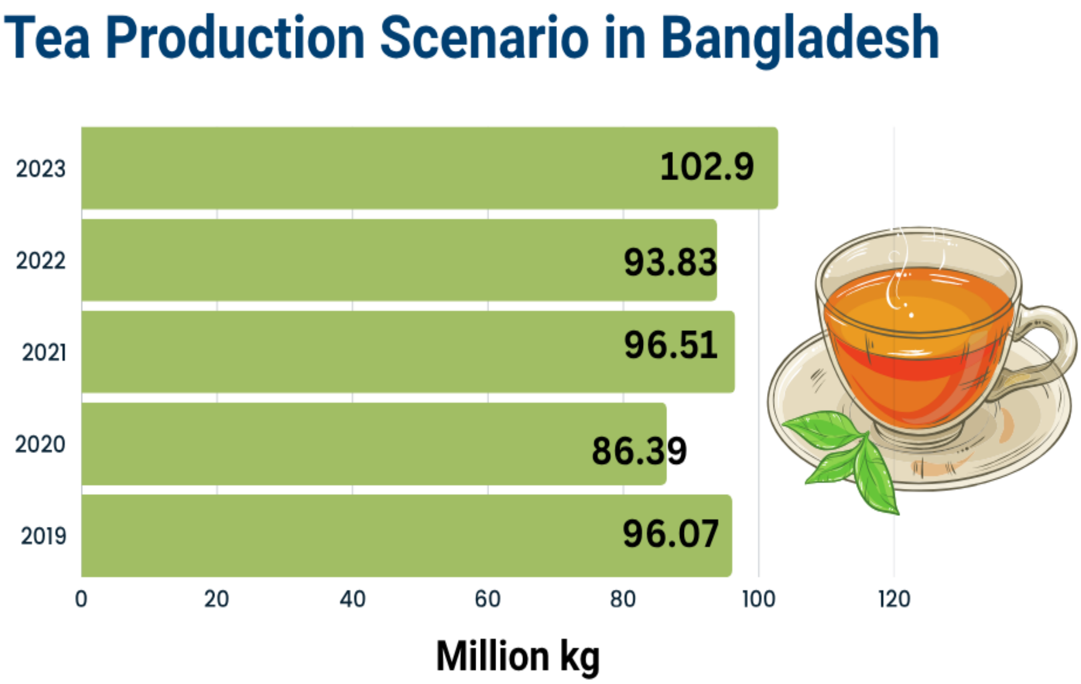
3.2 Bangladesh Market Overview

Bangladesh has emerged as a significant player in the global tea market. The country's tea industry dates back to the mid-19th century. According to the Bangladesh Tea Board (2020), globally, Bangladesh ranks among the top tea producers and contributes approximately 3% of total global tea production (Firsdtea, 2023). Although this share is relatively modest compared to global leaders like China and India, the country's tea sector plays a critical role in both domestic consumption and economic contribution. Over the past decade, production has shown a steady upward trend with some variability, reflecting both resilience and the influence of external factors such as climatic changes and market conditions.

The sector contributes significantly to the country's economy, providing employment to thousands and contributing to export revenues[40]. The sector is a vital component of the national economy, contributing 0.11% to GDP through employment and export earnings[41].

3.3 Tea Production Scenario in Bangladesh

In 2023, Bangladesh recorded its highest-ever annual tea production of 102.92 million kg, crossing the 100 million kg mark for the first time.



[40] Ibrahim, A.A., Rahman, M.S., Noman, R. and Nur, A.H. (2025). Tea and Tea Industry Scenario : A Review of World and Bangladesh Perspective. *International Journal of Tea Science*, 18(2), pp.6–17. DOI: 10.20425/ijts18202

[41] Ahammed, K. M. 2012. Investment for Sustainable Development of Bangladesh Tea Industry - An Empirical Study. Bangladesh Journal of Political Economy, vol. 28(1), pp. 135-160. Available at: https://bea-bd.org/site/article-details/458 (Accessed: 14 August 2025).

The fiscal year 2023–24 also saw a strong output of 100.66 million kg, the highest in any fiscal year[42]. Over the past decade, tea production in Bangladesh has more than doubled—from 63.88 million kg in 2014 to 102.92 million kg in 2023. This growth reflects the expanding capacity and increasing importance of the tea industry in Bangladesh[43]. Tea production has increased by 7% over the last 5 years. Tea production in the northern area has increased by 86% over the last 5 years[44].

This growth reflects the expanding capacity and increasing importance of the tea industry in Bangladesh[45]. Tea production has increased by 7% over the last 5 years. Tea production in the northern area has increased by 86% over the last 5 years[46].

3.4 Tea Industry Landscape in Bangladesh

Bangladesh is an important tea-producing country, ranking as the 9th largest tea producer in the world, contributing about 3% of global tea production. Commercial tea gardens in the country employ approximately 100,619 workers, with half of them being women[47].

As of the latest reports, Bangladesh is home to 168 commercial tea gardens, primarily located in the northeastern Sylhet Division and parts of the Chittagong Division[48].

Currently, there are five types of tea produced in Bangladesh:

- Green Tea
- Black Tea
- Oolong Tea
- Instant Tea
- White Tea

[42] https://teaboard.gov.bd/site/publications/947b1901-c43d-4352-a94d-313b9eeca4c4/Annual-Review-of-bd-Tea-2023-24

[43] Press Xpress (2024). *Tea Waves: Bangladesh Surpasses 2023 Records!* [online] Press Xpress. Available at: https://pressxpress.org/2024/01/22/tea-waves-bangladesh-surpasses-2023-records/(Accessed 4 August 2025).

[44] Tea Board Bangladesh (2024) *Annual Review of Bangladesh Tea 2023-24* [PDF]. Dhaka: Tea Board Bangladesh. Available at: https://teaboard.gov.bd/sites/default/files/files/teaboard.portal.gov.bd/publications/9c72aa4b_ef89_4f32_a27e_689289826a2b/2024-06-25-10-41-ef4c78691dd0b2df9251989696a2eeb2.pdf (Accessed 4 August 2025)

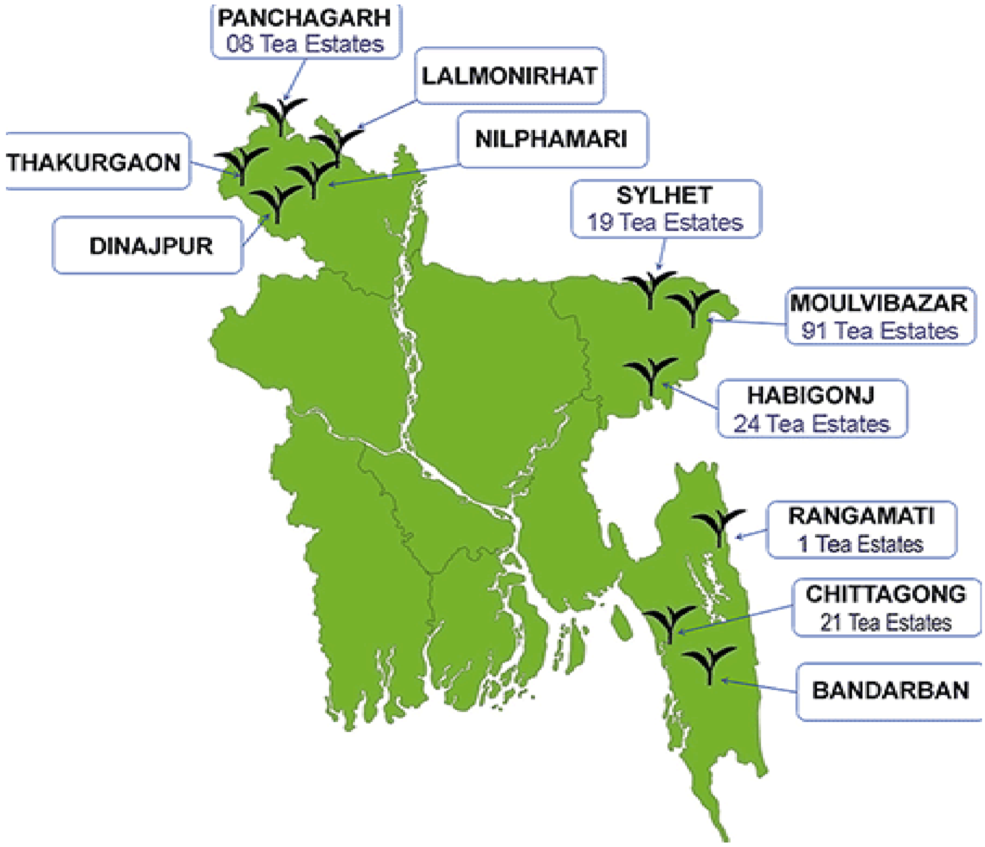
[45] Press Xpress (2024). *Tea Waves: Bangladesh Surpasses 2023 Records!* [online] Press Xpress. Available at: https://pressxpress.org/2024/01/22/tea-waves-bangladesh-surpasses-2023-records/ [Accessed 4 August 2025].

[46] https://teaboard.gov.bd/sites/default/files/files/teaboard.portal.gov.bd/publications/9c72aa4b_ef89_4f32_a27e_689289826a2b/2024-06-25-10-41-ef4c78691dd0b2df9251989696a2eeb2.pdf

[47] International Labour Organization. (2024). *Tea workers, tea garden owners and government discuss on economic diversification and decent work in tea industry in Bangladesh*. [online] Available at: https://www.ilo.org/resource/news/tea-workers-tea-garden-owners-and-government-discuss-economic [Accessed 13 September. 2025].

[48] https://thefinancialexpress.com.bd/national/country/all-168-tea-gardens-start-tea-plucking-as-season-begins

Infographic: Tea-Growing Regions of Bangladesh



(Source: https://www.btabd.com/overview?utm)

Top Tea Companies in Bangladesh

According to a 2022 report by Business Inspection BD, the leading tea companies in Bangladesh are[49]:

- Ispahani Tea Ltd.
- Finlay Tea (The Consolidated Tea and Lands Company (Bangladesh) Ltd.)
- Kazi & Kazi Tea Estate Ltd.
- HRC Tea (H.R.C.Syndicate Ltd)
- Tetley ACI Bangladesh Ltd.
- National Tea Company Ltd. (NTC)
- Duncan Brothers (Bangladesh) Ltd.
- Seylon Tea (Abul Khair Consumer Products Ltd.)
- Jafflong Tea Company Ltd from (Orion Group)
- Fresh Tea (Meghna Group of Industries) (MGI)

[49] https://businessinspection.com.bd/tea-industry-of-bangladesh/

Top Tea Exporters of Bangladesh – 2023

Bangladesh's tea industry not only serves domestic demand but also contributes significantly to exports. The leading tea exporters in 2023 include:

- Abul Khair Consumer Products Ltd.
- The Consolidated Tea and Lands Company (Bangladesh) Ltd. (Finlay)
- Ispahani Tea Ltd.
- Kazi & Kazi Tea Estate Ltd.
- City Tea Estate Ltd.
- Imperial Ventures Ltd.
- Orion Tea Company Ltd.
- Arif Tea Company Ltd.

These companies represent the largest players in the export segment, collectively contributing to Bangladesh's position in the global tea market[50].

3.5 Tea Export Performance in Bangladesh

Bangladesh Tea Board's Annual Review of Bangladesh Tea 2023–24:

According to the *Bangladesh Tea Board's Annual Review of Bangladesh Tea 2023–24*, the country's tea export sector has shown remarkable growth over the past year.

Fiscal Year 2023–24

- Export volume: 1,804 tonnes
- Earnings: Tk 362 million
- The major export destinations included the United Arab Emirates (UAE), Pakistan, the USA, and India, reflecting a diversified international market presence.

Fiscal Year 2022–23

- Export volume: 849 tonnes
- Earnings: Tk 205 million
- Export destinations included Brunei, Canada, Cyprus, Ireland, Japan, Kuwait, Poland, Pakistan, Saudi Arabia, Sri Lanka, U.A.E., U.K., and U.S.A.

The export volume from Bangladesh more than doubled in fiscal year 2023–24 compared to 2022–23, indicating strong growth in the country's tea export sector[42].

[50]https://teaboard.gov.bd/sites/default/files/files/teaboard.portal.gov.bd/publications/9c72aa4b_ef89_4f32_a27e_689289826a2b/2024-06-25-10-41-ef4c78691dd0b2df9251989696a2eeb2.pdf

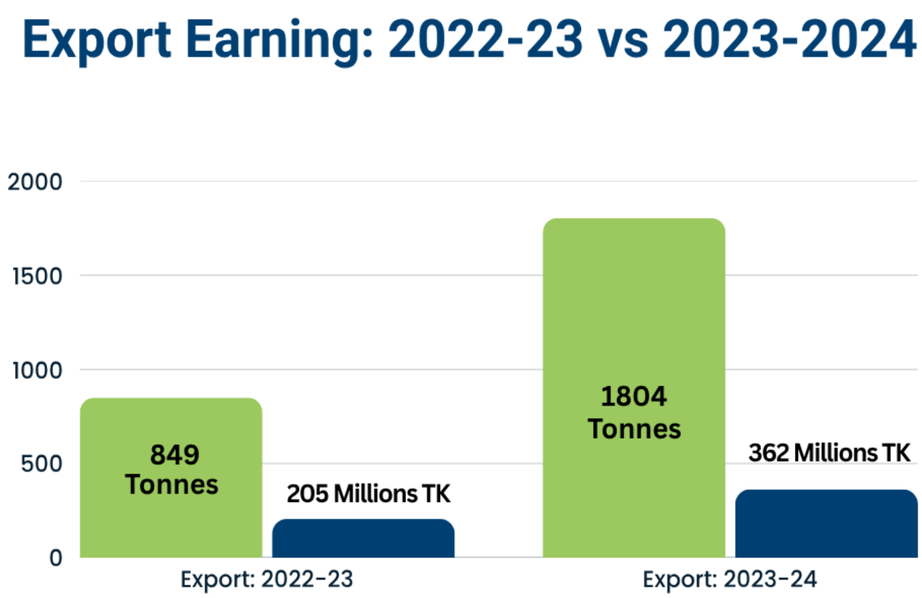


Figure 1. Annual Tea Export Volume and Earnings in Bangladesh (2022–23 and 2023–24)

3.6 Tea Consumption, Production, and Declining Exports in Bangladesh

Tea is one of the most widely consumed beverages globally and holds significant cultural and economic importance in Bangladesh. It is deeply embedded in the daily lives of the population as an affordable, social beverage, and the tea industry is a vital sector, providing substantial employment opportunities and contributing notably to the national economy. In recent years, socioeconomic advancements have further increased the prevalence of tea consumption, resulting in a steady rise in domestic demand.

According to *Consumption and Export Potential of Tea in Bangladesh: A Field Study* by Boonerjee *et al.* (2024)., current production levels are adequate to meet domestic demand; however, exports remain minimal due to a lack of exportable surplus. Based on field visits, interviews, and online surveys conducted across multiple regions of Bangladesh, the study estimated that approximately 92.15 million kilograms of tea are consumed annually, equivalent to around 142.8 million cups per day. In 2021 and 2022, domestic consumption accounted for 95.48% and 98.21% of total production (96.51 million kg and 93.83 million kg, respectively), leaving only 1.95 million kg available for export in 2022.

The study further highlights that, Bangladesh Tea Board has undertaken several effective plans and initiatives, resulting in the fastest growth in tea production to date. According to the Board, the average production growth rate over the last five years has been 3.97%. At the same time, domestic tea consumption in Bangladesh has also been rising. The *International Tea Committee* reports that consumption has been increasing at a rate of 2.93%. This steady rise in domestic demand has become a significant factor in shaping Bangladesh's tea market. This growing demand reflects the global popularity of tea but simultaneously poses a critical challenge by reducing the exportable surplus and threatening Bangladesh's competitiveness in international trade.

The persistent rise in domestic consumption, outpacing production growth, has significantly reduced the volume of tea available for the international market. Historical data indicate a sharp decline in export volumes, from 12.93 million kg in 2001 to only 0.68 million kg in 2021, illustrating Bangladesh's transition from a notable tea-exporting nation to one primarily serving its domestic market[51].

[51] Boonerjee, S., Islam, M.A., Islam, S.M.M., Paul, S.K., Uddin, M.T. and Alamgir, M.S. (2024). Consumption and export potential of tea in Bangladesh: A field study. *Journal of Agriculture and Food Research*, [online] 19, p.101607. https://doi.org/10.1016/j.jafr.2024.101607

Regulatory Framework

4. Regulatory Framework

4.1 Existing Laws & Regulations and their Gaps

Assessing the safety of food products, particularly widely consumed beverages like tea, requires reference to established regulatory benchmarks. These benchmarks define the maximum allowable concentrations of hazardous substances, such as heavy metals, that can be present in consumable items without posing significant health risks. Heavy metals—including lead (Pb), arsenic (As), cadmium (Cd), and chromium (Cr)—are known to accumulate in the human body and may cause long-term adverse health effects when ingested regularly, even in low amounts.

As tea is consumed frequently and in large quantities in Bangladesh, understanding the regulatory framework for permissible heavy metal limits is essential to interpreting the findings of this study. Referencing both national and international safety standards enables a comprehensive evaluation of the potential health risks posed by heavy metal contamination in tea products available in the local market.

4.2 National Standards Overview (Bangladesh)

In 2023, the Bangladesh Food Safety Authority (BFSA), under the Ministry of Food, developed a **draft regulation** outlining permissible limits for certain heavy metals in tea. This regulatory move marks an important step toward recognizing and addressing contamination risks in the country's most consumed beverage. However, the regulation is still in draft form and has not yet been officially enacted. As a result, there is currently no mandatory testing or enforcement in place.

Additionally, the scope of the BFSA's proposed limits remains narrow, focusing on only a few elements, which may not be sufficient to ensure comprehensive consumer protection given the broader range of heavy metals known to be present in tea. Table 1 below summarizes the draft permissible limits of selected heavy metals in tea, as proposed by BFSA.

Table 1. Draft Regulation on Permissible Limits of Heavy Metals in Tea by Bangladesh Food Safety Authority, Ministry of Food, 2023

SI	Heavy Metal	Limit (ppm)
1	Arsenic (As)	1.1
2	Lead (Pb)	5 on dry matter basis
3	Copper (Cu)	150

Source[52]

[52]https://bfsa.portal.gov.bd/sites/default/files/files/bfsa.portal.gov.bd/page/c6eaf0ee_f70a_42b9_ab35_48f1ccc4878e/2023-07-16-05-06-26ba0f07236f03ffe39832ff1a4e95d0.pdf

4.3 International Standards Overview

In contrast to the limited scope of the national guidelines, international standards—particularly those based on recent studies—tend to be more comprehensive. For instance, a 2024 study by Fan et al. conducted in the Hangzhou region of China assessed the occurrence and health risks of multiple heavy metals in green tea samples. The study provides a set of standard reference values for heavy metals based on broader toxicological and dietary exposure assessments.

These international benchmarks serve as valuable references in the absence of fully developed national regulations. They include a wider array of elements, such as cadmium and mercury, which are often omitted in local regulatory drafts. By comparing the results of this study with such international standards, it becomes possible to assess potential health risks more rigorously and highlight gaps in current national policies. Table 3 presents the standard limit values derived from the study by *Fan et al.* (2024).

Table 2. Standard limit values of heavy metals in tea (Fan et al. 2024)

Sl	Heavy Metal	Limit (ppm)	Reference standard
1	Arsenic (As)	2.0	NY659-2003
2	Cadmium (Cd)	1.0	NY659-2003
3	Chromium (Cr)	5.0	NY659-2003
4	Mercury (Hg)	0.3	NY659-2003
5	Lead (Pb)	5.0	GB2762-2022

Values represent the maximum permissible limits of heavy metals in tea as reported by Fan et al. (2024). Units are expressed in ppm (equivalent to mg/kg)[53]

To evaluate the safety of tea products in Bangladesh, this study considers both the national draft regulation and international benchmarks. While the BFSA's initiative demonstrates an acknowledgment of the issue, its regulatory scope remains narrow and lacks enforcement. As a result, consumers may be exposed to harmful substances without adequate oversight or awareness.

On the other hand, internationally recognized standards, such as those proposed by Fan et al., offer a more robust basis for health risk assessment. These standards cover a wider spectrum of toxic elements and reflect the cumulative health concerns associated with long-term tea consumption. They also align with best practices adopted in other tea-producing and exporting countries.

By referencing both national and international regulatory frameworks, this study provides a balanced and evidence-based approach to evaluating heavy metal contamination in Bangladeshi tea products. This dual comparison helps identify critical regulatory gaps and supports the need for improved monitoring, enforcement, and consumer awareness in the context of tea safety.

[53] Fan, J., Wang, S., Gong, L. *et al.* Occurrence, exposure and health risk assessment of heavy metals in green tea samples cultivated in Hangzhou area. *Sci Rep* **15**, 19405 (2025). https://doi.org/10.1038/s41598-024-84287-2

Materials and Methods

5. Materials and Methods

5.1 Study Design

This study was conducted from November 2024 to August 2025 in two complementary parts:
Consumer Survey – to assess awareness and practices regarding heavy metals in tea bags.
Laboratory Analysis (XRF Testing) – to measure the presence of heavy metals in tea bag packaging materials, and tea content and loose-leaf samples, conducted in two phases:
Phase 1: Preliminary analysis of heavy metal contamination in tea bag packaging materials, tea content, and loose-leaf samples from different brands.
Phase 2: Expanded Phase 1 with more samples and brands, focusing on tea bag packaging materials to strengthen results.

5.2 Part I: Consumer Survey

5.2.1 Study Design

A nationwide cross-sectional survey was conducted to assess consumer awareness regarding heavy metals in tea bags. To ensure geographic representation, the survey was designed to cover both tea-producing regions and other parts of Bangladesh to capture a representative picture of awareness and purchasing practices.

5.2.2 Study Population and Sample Size

The survey collected responses from a total of 3,571 participants across Bangladesh. Participants were selected from diverse backgrounds, ensuring variation in age, gender, education, and occupation.

5.2.3 Study Areas and Zonal Distribution

To ensure wide geographic representation, the country was divided into six zones, with a specific focus on major tea-producing areas such as Sylhet, Chattogram, and Dhaka. The distribution of respondents by zone is shown below:

- Sylhet Division (tea-producing hub) – 830 respondents
- Chattogram Division – 550 respondents
- Dhaka (capital and urban zone) and Mymensingh Division– 840 respondents
- Rajshahi Division – 430 respondents
- Khulna & Barishal Division – 411 respondents
- Rangpur Divisions – 510 respondents

5.2.4 Data Collection

A structured questionnaire was used to collect information on:

- Awareness of heavy metals in tea bags
- Daily tea consumption patterns
- Precautionary practices while purchasing tea
- Data were collected through face-to-face interviews in tea-producing and rural areas, as well as through online surveys in urban areas, to reach a broader population.

5.2 5 Ethical Considerations

Ethical standards were strictly followed throughout the study to protect participants and ensure the integrity of research:

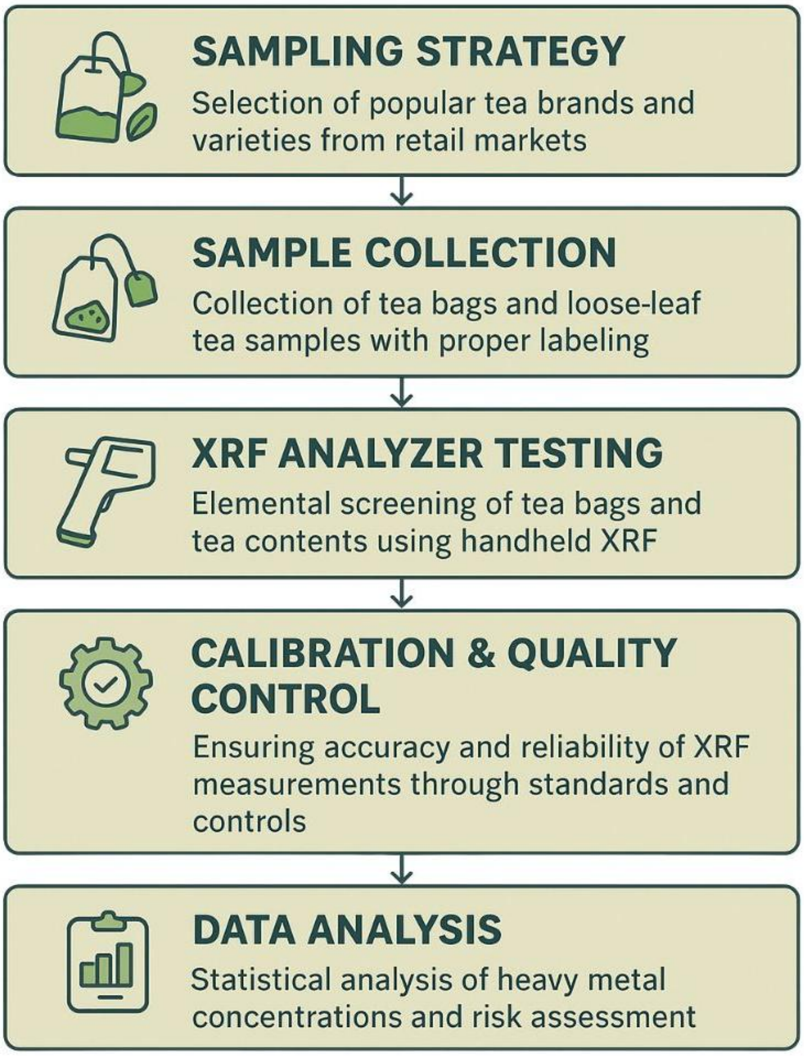
- **Informed Consent:** All survey participants voluntarily agreed to participate after receiving clear information about the study's purpose and procedures.
- **Confidentiality and Anonymity:** No personally identifiable information was collected, and responses were anonymized to protect participants' privacy.
- **Voluntary Participation:** Participants had the right to withdraw from the study at any time without any consequences.

5.2.6 Data Analysis

All collected survey data were reviewed for completeness and consistency before entry. The dataset from 3,571 respondents was coded and analyzed using descriptive statistical methods. Frequencies and percentages were calculated to describe participants' socio-demographic characteristics, awareness levels, daily tea consumption patterns, and precautionary purchasing practices.

5.3 Part II: First Phase of Laboratory Analysis (XRF Testing)

This section outlines the laboratory-based component of the study, which involved X-Ray Fluorescence (XRF) testing to detect and quantify heavy metals in tea samples. The process included sampling, sample collection, preparation, and analysis of tea, designed to accurately address the research objectives. It focused on determining the presence and concentration of heavy metals — including lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), and others — in commercial tea bags, as well as analyzing loose, dried tea leaves from various brands.
The XRF analysis of the study was conducted by Toxics BAN Toxics, a Philippine-based environmental organization.



5.3.1 Sample Size

A total of thirteen samples were collected for this study. These included twelve tea bag samples—eleven from Bangladeshi brands and one from a foreign brand—and one loose-leaf sample from a different foreign brand. All samples were purchased from grocery stores and supermarkets across Dhaka. These retail outlets were strategically selected to represent a broad distribution network, reflecting the availability of these tea products to consumers throughout the country.

5.3.2 Sample Collection

Thirteen popular tea brands, comprising twelve tea bag varieties and one loose-leaf option, were purchased from both grocery stores and supermarkets across Dhaka, Bangladesh, in May 2025. These retail outlets were strategically selected because they represent a broad distribution network that spans across the country, including remote and rural areas where access to branded products may be limited. By targeting such widely available stores, the sampling aimed to reflect the types of tea most commonly consumed by households throughout Bangladesh.

5.3.3 Sampling Technique

To ensure the relevance and representativeness of the samples, a **market basket sampling technique** was used. This approach replicates typical consumer behavior, mirroring how families select and purchase food items in their day-to-day lives. The tea samples were selected randomly, with particular emphasis placed on tea bags due to their rising popularity and widespread usage.

This sampling methodology is inspired by the Total Diet Study conducted by the United States Food and Drug Administration (FDA). In the Total Diet Study, food samples are routinely purchased from retail stores across the United States to estimate the population's annual dietary intake of various nutrients and potential contaminants. Similarly, this study adopts a comparable strategy to assess the types of tea products regularly consumed in Bangladesh, thereby ensuring the results are both reflective of real-world consumer patterns and useful for evaluating potential health or environmental risks associated with tea consumption[54].

[54] Wolf, Amber (2021) "Screening for Heavy Metals in Tea Leaves from Bangladesh Using X-Ray Fluorescence," Crossing Borders: A Multidisciplinary Journal of Undergraduate Scholarship: Vol. 5: Iss. 1. https://doi.org/10.4148/2373-0978.1095

5.3.4 Sample Preparation

To ensure consistency and reliability in analysis, all tea samples underwent a standardized preparation procedure.

Preparation of Teabag Material Samples

For each tea bag sample, the tea leaves were carefully removed from their original packaging to isolate the bag material. Five tea bags from the same brand were selected and grouped together to form a composite sample. The strings attached to the bags were secured using masking tape, which helped maintain the structural integrity of the sample during handling and testing. Each composite sample was clearly labelled with the corresponding brand name and assigned a unique identification number. This labelling system facilitated accurate sample tracking and ensured traceability throughout the analysis process.

Preparation of Loose Tea Leaf Samples

For the loose-leaf tea sample, a comparable approach was employed to maintain methodological consistency. An amount of loose tea equivalent to the contents of five standard tea bags was measured and transferred into a clean, resealable zip-lock bag to prevent contamination and preserve sample quality. This sample was also labelled with the brand name and a unique identification number, following the same format used for the tea bag samples. By applying this consistent labelling and grouping protocol across all sample types, the preparation process ensured that all materials were ready for uniform testing and analysis using the selected instrumentation.

5.3.5 Sample Analysis

For the elemental analysis, the tea content was first removed from the bags in order to isolate the packaging material. Five empty tea bag layers from each brand were carefully stacked and placed into the sample compartment of a handheld X-ray fluorescence (XRF) analyzer. This stacking was performed deliberately to increase the density of sample atoms within the detection area, thereby enhancing signal intensity and improving the accuracy and sensitivity of elemental readings. To ensure stable positioning and prevent any movement during the measurement, the stacked tea bags were securely fixed in place using masking tape.

Once properly positioned, the folded tea bag samples were analyzed using the handheld XRF device. Each sample underwent a one-minute scanning period, which was sufficient to detect and identify the elemental composition of the packaging material. This short analysis time allowed for rapid and efficient screening without compromising data quality[55]. A similar procedure was employed for the loose-leaf tea sample. An amount of tea equivalent to the contents of five standard tea bags was placed into a clean ziplock bag and held steadily in position for direct contact measurement using the same handheld XRF device. The blank ziplock bag was tested to ensure that there was no contamination with any metals. This ensured consistency in sample handling and analytical technique across both types of tea products.

[55]Oppermann, Uwe & Classon, Robert & Knoop, Jan & Egelkraut-Holtus, Marion & Ortlieb, Markus & Oyen, Albert. (2015). Determination of Antimony in Breakfast Tea Using Spectroscopic Methods. 10.13140/RG.2.2.32001.04961.

5.3.6 Analytical Mode and Target Elements

The elemental analysis was conducted using the **RoHS (Restriction of Hazardous Substances)** screening mode of the XRF analyzer. This technique is specifically designed to detect hazardous elements that are commonly regulated in consumer products, including lead (Pb), cadmium (Cd), mercury (Hg), hexavalent chromium (Cr^{6+}), and brominated flame retardants such as polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs). The use of the RoHS mode enabled a non-destructive, rapid, and reliable identification of these substances in both the packaging materials and the loose tea content, aligning the analysis with international safety and regulatory standards [3].

5.4 Phase 2: Laboratory Analysis (Handheld XRF Testing) of Toxic Heavy Metals in Tea Bag Packaging Materials

5.4.1 Rationale

The second phase of this study was undertaken to expand and strengthen the findings of the first phase. While the first phase provided important preliminary evidence of heavy metal contamination in tea bag packaging materials, it involved a certain number of samples and brands. Phase 2 aimed to further enhance the study by increasing the sample size and diversity of tea brands to ensure more comprehensive and representative findings.

X-ray fluorescence (XRF) analysis was employed in the second phase of the study due to its capability to provide rapid, non-destructive, and reliable detection of heavy metals with minimal sample preparation. The use of a handheld XRF analyzer facilitated efficient screening of a larger number of samples, ensuring comprehensive coverage. Implementation of the RoHS (Restriction of Hazardous Substances) screening mode enabled detection of regulated hazardous metals in compliance with international safety and regulatory standards, thereby strengthening the validity and comparability of results across both phases of the study.

5.4.2 Methods

Sampling Strategy

- Nineteen different tea bag brands were selected based on market availability and popularity.
- From each brand, three tea bag samples were collected randomly from different batches to ensure representative sampling.
- This resulted in a total of fifty-seven tea bag samples for analysis.

Sample Preparation

- Tea leaves were carefully removed from each tea bag to isolate the packaging material.
- Three empty tea bags from the same brand and batch were used for each sample.
- The tea bag materials were placed directly on the XRF instrument platform for analysis.
- All samples were labelled with brand name, batch number, and a unique ID code for traceability.

X-ray fluorescence (XRF) Analysis

- Samples were analyzed using a handheld X-ray fluorescence (XRF) analyzer in RoHS (Restriction of Hazardous Substances) screening mode.
- The analyzer was calibrated before each set of measurements according to manufacturer protocols.
- Each sample underwent a one-minute scanning period to detect and quantify heavy metals.
- Target metals included Arsenic (As), Lead (Pb), Cadmium (Cd), Mercury (Hg), Chromium (Cr), and Antimony (Sb).
- This non-destructive method provided rapid, reliable detection aligned with international safety and regulatory standards.

Quality Assurance

- Instrument calibration was performed before each set of measurements according to manufacturer protocols.
- Repeated measurements were performed to confirm reliability.

Data Analysis

- Raw XRF output was processed to calculate the concentration of each target metal in parts per million (ppm).
- For each brand, the mean concentration of each metal was computed from the three replicate samples.
- Data were checked for consistency and completeness prior to statistical analysis.
- Descriptive statistic was calculated to summarize contamination levels across brands.
- Results were compared with Phase 1 findings and relevant international safety limits to assess potential health risks.
- Data visualization (tables) was used to present findings clearly and facilitate interpretation.

Results

6. Results

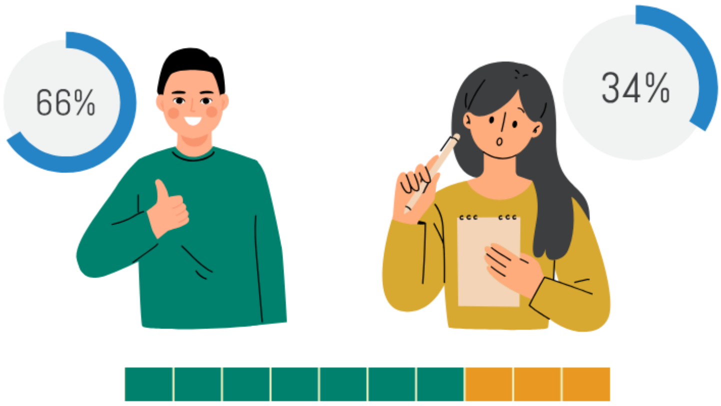
6.1 Part I: Survey Findings

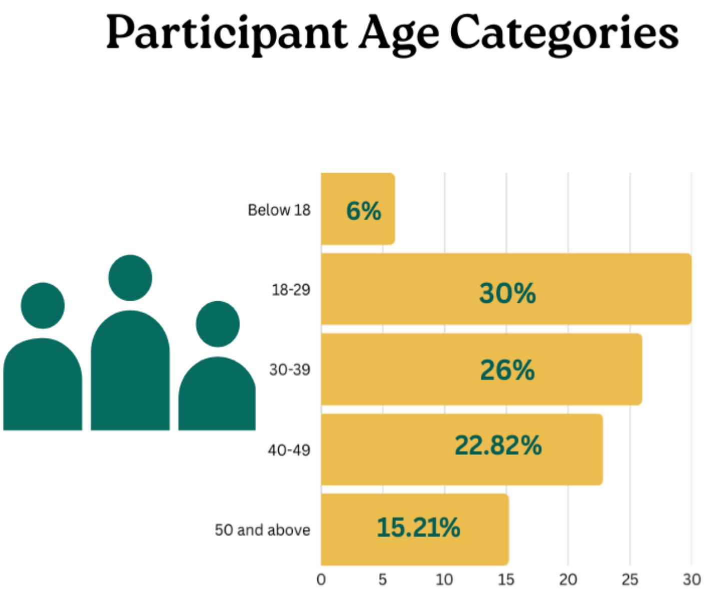
The survey collected responses from a total of **3,571 participants**. The socio-demographic characteristics and selected behavioral aspects of respondents are presented below.

6.1.1 Demographic Characteristics of Respondents

Gender Distribution of Respondents

Out of 3571 respondents, 1,214 (34%) were female and 2357 (66%) were male. This indicates that male respondents were more represented in the survey compared to female participants. This representation may reflect differences in accessibility or willingness to participate between genders in surveys.



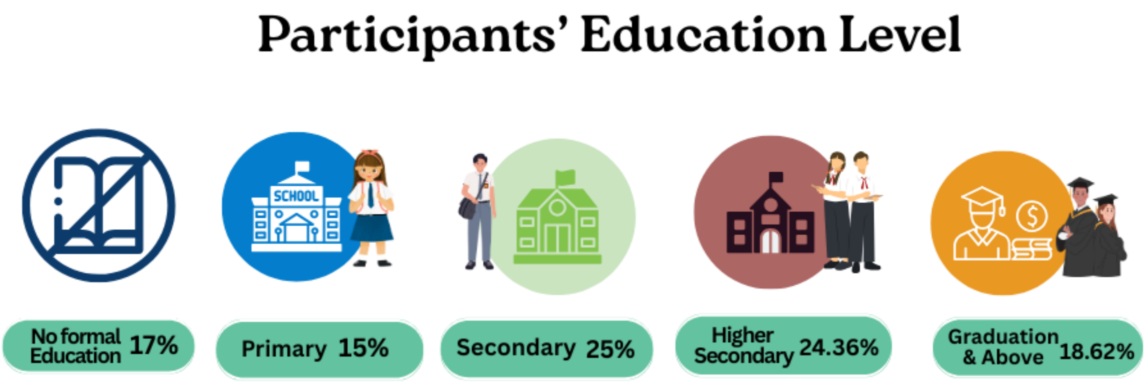


Age Profile of Respondents

The largest group was 18–29 years old (30.0%), followed by 30–39 years old (26.0%), 40–49 years old (22.8%), and 50 years and above (15.2%). Only 6.0% were below 18 years. The dominance of younger and middle-aged groups suggests that these age brackets were more actively engaged in the survey and likely form the core consumer group for tea products.

Educational Background of Respondents

Respondents had diverse educational attainments. A total of 893 respondents (25.0%) completed secondary education, 870 (24.4%) completed higher secondary, and 665 (18.6%) had graduate and above qualifications. Meanwhile, 607 (17.0%) reported having no formal education, and 536 (15.0%) had completed only primary education. The data reflect a balanced mix of participants with different educational levels.



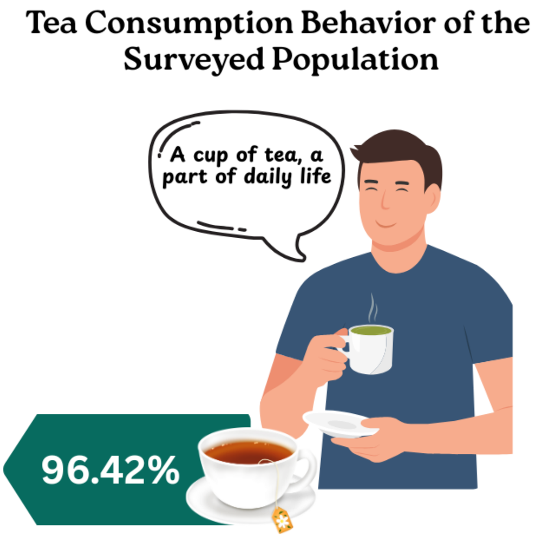
Occupational Status

In terms of occupation, 1178 participants (33.0%) were employed, 893 (25.0%) were students, 785 (21.98%) were housewives, and 536 (15%) were unemployed. An additional 179 (5%) fell into other occupational categories. This profile indicates that both working and non-working groups were represented, with students and employed individuals forming the majority, highlighting the engagement of economically active groups in the survey.

Table 3. Occupational Status of Survey Respondents

Occupational Status	Frequency (n)	Percentage (%)
Employed	1178	33
Students	893	25
Housewives	785	22
Unemployed	536	15
Others	179	5

6.1.2 Awareness and Practices Related to Tea Safety

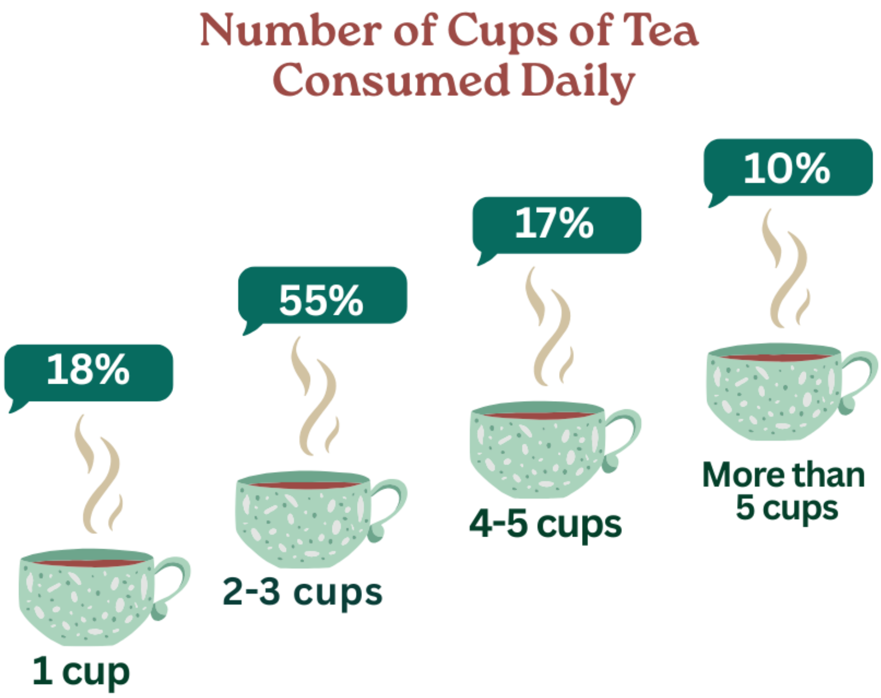


Tea Consumption Behaviour

Tea drinking was reported by an overwhelming majority, with 3443 respondents (96.42%) consuming tea and only 133 (3.72%) not doing so. This confirms that tea is deeply embedded in the daily lifestyle of the population.

Daily Tea Consumption Volume

When asked about cups of tea consumed per day, 1964 respondents (55%) reported drinking 2–3 cups, 643 (18%) reported drinking one cup, 607 (17%) consumed 4–5 cups, and 357 (10%) drank more than 5 cups daily. The majority of respondents consume tea in moderate quantities (2–3 cups). However, a considerable proportion (964 respondents, 27%) reported drinking 4 to 5 or more cups daily. While moderate consumption was most common, a significant proportion consumed high amounts, suggesting potential exposure concerns if contaminants such as heavy metals are present in tea bags.

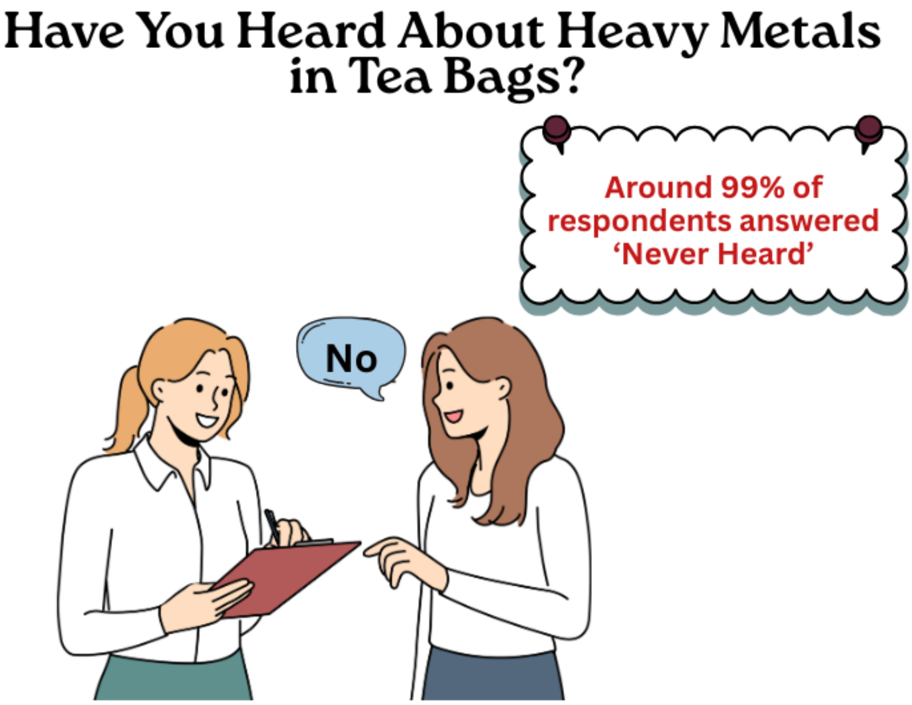


Checking Packaging Labels

In exploring **safety practices**, the vast majority (3,274 respondents; 91.7%) reported never checking tea packaging for safety labels or quality certifications. Only 37 (1.0%) always checked, 113 (3.16%) sometimes checked, and 147 (4.12%) rarely checked. Despite high tea consumption, very few respondents reported checking for safety labels or certifications. This indicates a lack of consumer practice in verifying product safety.

Knowledge of Heavy Metal Contamination in Tea Bags

When asked about awareness of heavy metals in tea bags, only 37 respondents (1.03%) reported having heard about the issue, while the vast majority (3,534; 98.96%) stated they had **not** heard about it. This indicates that despite the potential risks, almost all respondents are unaware of the presence of heavy metals in tea bags.



Recommendations to Address Heavy Metals in Tea Bags

Finally, participants were asked to provide their recommendations for addressing the issue of heavy metals in tea bags. The most common suggestion was to strengthen government regulations and enforce food safety laws, supported by 1637 respondents (45.84%). Other notable recommendations included increasing public awareness (781; 21.87%), banning unsafe tea bag brands (643; 18%), and promoting safer alternatives (457; 12.8%). A smaller group (53; 1.48%) proposed other measures. These findings suggest that people place strong trust in institutional interventions and expect regulatory authorities to take responsibility for ensuring tea safety.

Table 4. Public Recommendations for Ensuring Tea Safety

Recommendation	Frequency (n)	Percentage (%)
Strengthen government regulations and enforce food safety laws	1637	45.84%
Increasing public awareness	781	21.87
Banning unsafe tea bag brands	643	18
Promoting safer alternatives	457	12.8
Others	53	1.48

6. 2 Part II: Laboratory Findings (XRF Analysis)

This part of the study presents the results of X-Ray Fluorescence (XRF) analysis conducted on commercially available teabags and loose dried tea leaves. The findings are organized into two categories: heavy metal concentrations in teabags' packaging materials, and heavy metal and trace element levels in tea contents from tea bags and loose tea leaves. These results provide important insights into the safety of tea products and highlight the need for stricter quality control in tea production and processing. The detailed findings are presented in the following tables.

6.2.1 Heavy Metal Content in Teabags Packaging Material

The analysis of teabags' packaging material revealed significant variations in the concentrations of toxic heavy metals, including arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), antimony (Sb), and chromium (Cr). These elements were detected in varying amounts across different tea brands and origins, with some samples exhibiting concerningly high levels that may pose health risks upon prolonged consumption. XRF analysis of 12 commercial teabag brand samples revealed widespread contamination with toxic heavy metals (Table 5).

Toxic Heavy Metal Content: Comparison with National and International Standards

- **Arsenic (As):** Detected in seven samples, ranging from 2 ppm (TS005: Bengal Classic) to 14 ppm (TS012: Kazi Lemon Grass). All positive detections exceeded the Bangladesh standard (1.1 ppm) and the international standard (2 ppm).
- **Lead (Pb):** Found in four samples, with the highest level at 51 ppm (TS002: Finlay Gold Black) compared to the 5 ppm permissible limit in both Bangladesh and international guidelines.
- **Cadmium (Cd):** Detected in most of the tea bag samples, with the highest level at 83 ppm (TS005: Bengal Classic Tea), far above the international standard (1 ppm).
- **Mercury (Hg):** Present in eight teabag brands, with concentrations up to 108 ppm (TS005: Bengal Classic), far exceeding the international limit of 0.3 ppm.
- **Antimony (Sb):** Detected in six tea bag samples (38–106 ppm), though not regulated under Bangladesh standards.
- **Chromium (Cr):** Extremely elevated levels were found, ranging from 330 ppm (TS002: Finlay Gold Black) to 1690 ppm (TS006: Brooke Bond Taaza), surpassing the international permissible limit of 5 ppm.

Table 5: Content of heavy metals in teabags packaging material (ppm)

Teabag Packaging Materials									
Label No	**Product Name**	**Producer**	**Country of Origin**	**As**	**Pb**	**Cd**	**Hg**	**Sb**	**Cr**
TS001	Dilmah	Dilmah Ceylon Tea Company PLC, Sri Lanka.	Sri Lanka	13			79	106	
TS002	Finlay Gold Black	The consolidated tea & land company, Shrimangal, Moulvibazar	BD		51		17	66	330
TS003	Seylon	Abul Khair Consumer Products Limited, CTG, BD	BD		18	22		46	
TS004	Tetley	Tetley ACI BD LTD. Gazipur	BD	4		42			
TS005	Bengal Classic Tea	City Tea Estate LTD. Dhaka, BD	BD	2		83	108		
TS006	Brooke Bond Taaza	Trofima, Refreshments, Chittagong	BD		43	30	56	97	1690
TS007	Paragon	Paragon Agro Ltd. Factory-Moulvibazar	BD		42	42	29		890
TS008	Ishpahani Mirzapur	Ishpahani complex, Chittagong	BD	9		51		74	680
TS009	Lipton Green Tea	Trofima Refreshments, Chittagong	BD	5		37	30		630
TS010	Kazi Black tea	Kazi & Kazi Tea Estate Ltd., Dhaka	BD			27		38	450
TS011	Kazi green tea	Kazi & Kazi Tea Estate Ltd., Dhaka	BD	2			68		
TS012	Kazi lemon grass tea	Kazi & Kazi Tea Estate Ltd., Dhaka	BD	14		27	39		

Arsenic (As) Contamination

Arsenic, a well-known carcinogen associated with skin lesions, cardiovascular diseases, and neurological disorders, was detected in several teabag samples. The highest concentration of arsenic was found in Kazi lemon grass tea (TS012) at 14 ppm, followed closely by Dilmah (TS001) at 13 ppm. Lower but still notable levels were observed in Tetley (TS004, 4 ppm) and Bengal Classic Tea (TS005, 2 ppm). The presence of arsenic in tea is particularly alarming due to its cumulative nature in the human body. Chronic exposure, even at low concentrations, can lead to severe health complications, including cancer. Potential sources of arsenic contamination include contaminated soil, pesticide use, and industrial pollution in tea-growing regions. These findings underscore the need for stringent monitoring of arsenic levels in tea products to mitigate long-term health risks.

Lead (Pb) Contamination

Lead, a neurotoxic metal that can impair cognitive development, particularly in children, and cause cardiovascular and kidney damage in adults, was detected in multiple teabag samples. The highest lead concentration was recorded in Finlay Gold Black (TS002) at 51 ppm, followed by Brooke Bond Taaza (TS006) at 43 ppm and Paragon (TS007) at 42 ppm. The World Health Organization (WHO) has established strict limits for lead in food products due to its severe health effects. The elevated lead levels in these tea samples suggest potential contamination from environmental sources, such as lead-based pesticides or polluted irrigation water. Given the serious implications of lead exposure, these findings highlight the necessity for improved agricultural practices and regulatory oversight to minimize lead contamination in tea production.

Cadmium (Cd) Contamination

Cadmium, a cumulative toxin primarily affecting the kidneys and bones, was found in concentrations in several teabag samples. The highest cadmium level was detected in Bengal Classic Tea (TS005) at 83 ppm, followed by Ishpahani Mirzapur (TS008) at 51 ppm and Tetley (TS004) at 42 ppm. Long-term exposure to cadmium can lead to renal dysfunction and osteoporosis, making its presence in tea products a significant public health concern. The contamination likely stems from the use of phosphate fertilizers or industrial emissions in tea-growing areas. These results emphasize the importance of regular testing for cadmium in tea products and the implementation of measures to reduce its accumulation in tea leaves.

Mercury (Hg) Contamination

Mercury, a potent neurotoxin capable of damaging the nervous system, kidneys, and developing fetuses, was detected in multiple teabag samples. The highest mercury concentration was found in Bengal Classic Tea (TS005) at 108 ppm, followed by Dilmah (TS001) at 79 ppm and Kazi lemon grass tea (TS012) at 39 ppm. Mercury exposure, even at low levels, can have severe health consequences, particularly for pregnant women and young children. The presence of mercury in tea may result from environmental pollution, such as coal combustion or mining activities near tea plantations. These findings call for urgent action to monitor and regulate mercury levels in tea products to protect consumer health.

Antimony (Sb) and Chromium (Cr) Contamination

Antimony and chromium were also detected in several teabag samples, with varying concentrations. Antimony levels ranged from 38 ppm in Kazi Black tea (TS010) to 106 ppm in Dilmah (TS001). Chromium was particularly high in Brooke Bond Taaza (TS006) at 1690 ppm, far exceeding levels found in other samples. While chromium is an essential micronutrient in trace amounts, excessive intake can lead to toxicity, including respiratory and dermatological issues. Antimony, on the other hand, is a toxic metalloid associated with gastrointestinal and cardiovascular problems. The sources of these contaminants may include industrial pollution or packaging materials. These results highlight the need for further research into the sources of antimony and chromium in tea products and the development of strategies to minimize their presence.

6.3 Heavy Metal and Trace Element Content in Content in Tea Contents from Tea Bags and Loose Tea Leaves

The analysis of tea contents from tea bags and dried loose tea leaves revealed the presence of both toxic heavy metals and essential trace elements, including antimony (Sb), uranium (U), strontium (Sr), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), thorium (Th), and cobalt (Co). The concentrations of these elements varied significantly across different tea brands and origins, providing valuable insights into the safety and nutritional quality of loose tea leaves. **Notably, priority toxic heavy metals—lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), and chromium (Cr)—were not detected** in any of the analyzed samples of tea leaves. Thirteen loose tea leaf samples were analyzed for a wider range of elements (Table 6).

Table 6. Analysis of Nutrients and Heavy Metal Contaminants in Tea Contents from Tea Bags and Loose Tea Leaves (ppm)

Tea Contents from Tea Bags and Dried Loose Tea Leaves												
Label No	**Product Name**	**Producer**	**Country of Origin**	**Sb**	**U**	**Sr**	**Th**	**Co***	**Fe**	**Mn**	**Cu**	**Zn**
TS001	Dilmah	Dilmah Ceylon Tea Company PLC, Sri Lanka.	Sri Lanka	70	4	9	46		193	355	28	57
TS002	Finlay Gold Black	The consolidated tea & land company, Shrimangal, Moulvibazar	BD	107		13	46	11	365	1104	21	39
TS003	Seylon	Abul Khair Consumer Products Limited, CTG	BD	27		11	37	706	272	706	26	43
TS004	Tetley	Tetley ACI BD LTD. Gazipur	BD	28		13	30		285	920	20	43
TS005	Bengal Classic Tea	City Tea Estate LTD. Dhaka, BD	BD	40	4	12	41		327	988	26	37
TS006	Brooke Bond Taaza	Trofima Refreshments CTG	BD	154	3	12	50		276	978	26	46
TS007	Paragon	Paragon Agro Ltd. Factory-Moulvibazar	BD	126	4	15	46		463	516	29	55
TS008	Ishphahani Mirzapur	Ishphahani complex, CTG	BD	94		11	47		526	1042	30	47
TS009	Lipton Green Tea	Trofima Refreshments CTG	BD	106	4	17	42		261	1119	23	43
TS010	Kazi Black tea	Kazi & kazi tea estate ltd. Dhaka	BD	96		15	45		150	478	47	57
TS011	Kazi green tea	Kazi & kazi tea estate ltd. Dhaka	BD	51		19	38	11	169	442	50	
TS012	Kazi lemon grass tea	Kazi & kazi tea estate ltd. Dhaka	BD			23	39		247	459	53	58
TS013	DAMRO Labookelli	Damro Exports (Pvt) Ltd	Sri Lanka			11	38		204	845	26	47

Green: Essential trace elements: Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), and Cobalt (Co*).
Cobalt (Co) is essential as part of vitamin B12, but is toxic when present in excess.

Antimony (Sb) Contamination

Antimony was detected in all loose tea leaf samples, with the highest concentration found in Brooke Bond Taaza (TS006) at 154 ppm, followed by Paragon (TS007) at 126 ppm and Lipton Green Tea (TS009) at 106 ppm. Antimony is a toxic metalloid linked to gastrointestinal and cardiovascular issues, and its presence in tea leaves raises concerns about potential health risks. The contamination may originate from environmental pollution or the use of antimony-containing pesticides. These findings suggest the need for stricter regulations on antimony levels in tea products and further investigation into its sources.

Iron (Fe) and Manganese (Mn)

Iron and manganese, essential micronutrients vital for human health, were abundant in all loose tea leaf samples. The highest iron concentration was recorded in Ishpahani Mirzapur (TS008) at 526 ppm, while the highest manganese level was found in Lipton Green Tea (TS009) at 1119 ppm. While these elements are beneficial in moderate amounts, excessive intake can lead to toxicity. For instance, excessive iron can cause oxidative stress, while high manganese levels may result in neurological disorders. These results highlight the dual role of trace elements in tea, emphasizing the importance of balanced consumption.

Copper (Cu) and Zinc (Zn) Levels

Copper and zinc, essential for various physiological functions, were detected in all loose tea leaf samples. Copper concentrations ranged from 20 ppm in Tetley (TS004) to 53 ppm in Kazi lemon grass tea (TS012), while zinc levels peaked at 58 ppm in the same sample. Although these elements are crucial for health, excessive intake can lead to toxicity, including gastrointestinal distress and immune dysfunction. The presence of these elements in tea underscores the need for awareness about their dietary contributions and potential risks.

Uranium (U) and Thorium (Th) Contamination

Trace amounts of uranium and thorium, radioactive elements, were detected in some loose tea leaf samples, such as Dilmah (TS001) and Brooke Bond Taaza (TS006). While their concentrations were low, their presence raises questions about environmental contamination in tea-growing regions. Chronic exposure to these elements, even at low levels, may pose long-term health risks, including cancer. These findings warrant further investigation into the sources of radioactive contamination in tea and the implementation of measures to minimize their presence.

Strontium (Sr) Contamination

Strontium was detected in all loose tea leaf samples, with concentrations ranging from 9 ppm (Dilmah, TS001) to 23 ppm (Kazi lemon grass tea, TS012). While non-radioactive strontium is less hazardous than its radioactive counterpart (Sr-90), excessive accumulation may interfere with calcium metabolism and bone mineralization processes. The element's presence primarily stems from natural soil composition, as tea plants readily absorb it during growth. The consistent detection across samples from different regions suggests this is a common phenomenon in tea cultivation areas. Although current concentrations fall below concerning thresholds, the potential for bioaccumulation warrants monitoring, particularly for individuals with existing bone health concerns or those consuming large quantities of tea regularly.

Cobalt (Co) Content

Cobalt was identified in four samples, with consistent concentrations of 11 ppm (Finlay Gold Black, TS002 and Kazi green tea, TS011). While cobalt is an essential component of vitamin B12, the inorganic form found in tea differs from the biologically active form in the vitamin. Industrial activities and certain agricultural practices may contribute to localized cobalt presence in some growing regions. The element's detection pattern suggests variable environmental distribution rather than systematic contamination. Although the measured levels don't pose immediate health risks, the potential for additive exposure from multiple dietary sources should be considered, especially given cobalt's association with thyroid dysfunction and cardiomyopathy at higher doses. Periodic monitoring would help ensure concentrations remain within safe limits.

Comparative Analysis and Implications

The results indicate that both teabags and loose tea leaves contain varying levels of heavy metals, with some products exhibiting concentrations that may pose health risks upon prolonged consumption. Notably, tea products from Bangladesh (BD) generally showed higher heavy metal concentrations compared to those from Sri Lanka, suggesting regional differences in soil composition, industrial pollution, or agricultural practices.

The presence of toxic heavy metals such as lead, cadmium, and mercury in tea products is particularly concerning due to their severe health effects. These findings underscore the importance of regular monitoring and regulation of heavy metal content in tea to ensure consumer safety. Additionally, the dual presence of essential and toxic elements in tea highlights the need for balanced consumption and awareness of potential risks.

Chemical Composition of Tea Bags and Consumer Exposure Risks

The composition of tea bags presents significant concerns regarding heavy metal contamination, particularly antimony (Sb). While cellulose-based tea bags typically do not contain Sb, plastic varieties - especially those made from polyethylene terephthalate (PET) - often incorporate this heavy metal as a catalyst during production. A critical issue lies in the inability of consumers to visually distinguish between these materials, as both cellulose and PET tea bags can appear remarkably similar in texture and transparency despite their fundamentally different chemical compositions and associated health risks [4].

X-ray fluorescence (XRF) analysis revealed "polymer failed" readings for certain tea bag samples, strongly indicating the presence of plastic rather than pure cellulose components. This finding raises substantial concerns beyond just Sb contamination, as plastic tea bags may also release microplastics and endocrine-disrupting phthalates during the brewing process, particularly when exposed to hot water at typical steeping temperatures exceeding 80°C. The potential for these materials to leach multiple contaminants into the brewed beverage underscores the urgent need for comprehensive research to quantify Sb migration levels, assess concurrent release of microplastics and phthalates, and evaluate the long-term health implications of regular exposure through tea consumption. Furthermore, these findings highlight the necessity for improved regulatory standards in tea bag manufacturing and more transparent labeling practices to better inform consumers about the materials used in their tea products[56].

[56] Kashfi, F.S., Mohammadi, A., Rostami, F., Savari, A., De-la-Torre, G.E., Spitz, J., Saeedi, R., Kalantarhormozi, M., Farhadi, A. and Dobaradaran, S. (2023). Microplastics and phthalate esters release from teabags into tea drink: occurrence, human exposure, and health risks. *Environmental Science and Pollution Research International*. [online] doi:https://doi.org/10.1007/s11356-023-29726-9.

6.4 Phase 2: Laboratory Analysis (Handheld XRF Testing) of Toxic Heavy Metals in Tea Bag Packaging Materials

The second phase of this study was undertaken to expand and strengthen the findings of the first phase. Phase 2 involved a larger and more diverse set of 19 commercial tea bag brands and a total of 57 packaging samples, with three samples taken from each brand. These tea bag packaging samples were analyzed using handheld X-ray fluorescence (XRF) technology. This analysis targeted toxic heavy metals, including arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), antimony (Sb), and chromium (Cr). The results revealed widespread contamination with these metals across different brands and origins, with samples showing elevated concentrations that could pose health risks upon prolonged exposure. These findings emphasize the need for ongoing monitoring and quality control in tea bag packaging materials to ensure consumer safety.

Range of Heavy Metal Levels Detected in Teabag Packaging Material

- **Arsenic (As)** was detected in thirteen samples, with concentrations ranging from 4 to 15 ppm, highest in Dr. H&H Triphala Tea.
- **Lead (Pb)** appeared in several samples, ranging from 20 to 58 ppm, with the highest level found in Magnolia Tea.
- **Cadmium (Cd)** was widely present, with levels between 19 and 87 ppm, peaking in Shawan Premium Tea.
- **Mercury (Hg)** was present in multiple samples, ranging from 23 to 98 ppm, with the highest concentration in Magnolia Tea Gold.
- **Antimony (Sb)** appeared in more than half of the samples, with concentrations ranging from 38 to 117 ppm, highest in Fresh Premium Green Tea.
- **Chromium (Cr)** was commonly detected, with levels ranging from 316 to 1710 ppm, the highest being in Danish Classic Black Tea Bag.

Table 7. Average Concentration of Heavy Metals (ppm) in Tea Bag Packaging Materials from Different Brands in Bangladesh

Teabag Packaging Materials									
Label No	**Product Name**	**Producer**	**Country of Origin**	**As**	**Pb**	**Cd**	**Hg**	**Sb**	**Cr**
TS001	Dr. H&H Mint Pudina Black Tea	Dr. H&H Food & Tea Solution Ltd.	BD	11	37	32	–	–	–
TS002	Dr. H&H Triphala Tea	Dr. H&H Food & Tea Solution Ltd.	BD	15	49	20	–	–	316
TS003	Dr. H&H Zeera Black Tea	Dr. H&H Food & Tea Solution Ltd.	BD	11	27	29	–	38	341
TS004	Revival Ginger & Honey Tea	Imperial Ventures Ltd.	BD	6		24	38	–	360
TS005	Shokal Shondha Cha (Black Tea)	Halda Valley Food & Beverage Ltd.	BD	9	–	19	–	–	865
TS006	Meghalay Tea	Arif Tea Co. Ltd.	BD	4	–	25	56	–	–
TS007	Bashundhara Premium Tea	Bashundhara Group	BD	7		34		54	–
TS008	Finlay Pure Green Tea	The Consolidated Tea & Land Co.	BD	–	47	–	23	78	389
TS009	Finlay Masala Cha Tea	The Consolidated Tea & Land Co.	BD	–	49		26	64	340
TS010	Shawan Premium Tea	Shawon Tea Co. Ltd.	BD	7		87	34	96	880
TS011	Magnolia Tea	M. Ahmed Tea & Land Co. Ltd.	BD	4	58	62	88	–	–
TS012	Magnolia Tea Gold	M. Ahmed Tea & Land Co. Ltd.	BD	5	52	66	98	–	–
TS012	Seylon Gold Blend Tea	Abul Khair Consumer Products Ltd.	BD	–	20	29		44	–
TS014	Shaw Wallace Special Tea Bag	Shaw Wallace Bangladesh Ltd.,	BD	–		28	42	–	790
TS015	Danish Classic Black Tea Bag	Danish Food. Ltd	BD	4	28	–	42	–	1710
TS016	Danish Simla Premium Blend Tea	Danish Food. Ltd	BD	6	25	–	40	–	1522
TS017	Fresh Premium Green Tea	Meghna Group Industries	BD	–	–	42	36	117	–
TS018	Vitacare Green Tea	Vitalac Dairy & Food Industries Ltd.	BD	–	–	22	27	104	640
TS019	Ispahani Blender's Choice (Lemon)	Ispahani Complex	BD	8	–	46	–	76	686

Values represent the mean of three independent measurements and are rounded to the nearest whole number.
"–" indicates that the metal was not detected.

Discussion

7. Discussion

7.1 Heavy Metal Contamination in Tea Bags Materials

The analysis of the teabag revealed concerning levels of toxic heavy metals, some of which were not detected in loose tea leaves. The most significant contaminants identified include **arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), antimony (Sb), and chromium (Cr)**. These elements. Nonessential metals are toxic even in very low concentrations for human health and the environment[57].

Arsenic (As) was present in several samples (2–14 ppm), with the highest in Kazi lemon grass tea, TS012 (14 ppm). Arsenic has both chronic (e.g., cancers and skin lesions) and acute (e.g., nausea, vomiting, burning in the stomach and esophagus, abdominal pain, and diarrhoea) toxic effects on human health[58].

Lead (Pb) contamination was observed in multiple samples (up to 51 ppm in Finlay Gold Black, TS002). Exposure to lead can affect multiple body systems and is particularly harmful to young children and women of childbearing age[59]. Compared to the 5 ppm permissible limit in both Bangladesh and international guidelines, the detected levels are high, raising serious safety concerns.

Cadmium (Cd) was detected in most of the tea bag samples, with the highest level at 83 ppm in Bengal Classic Tea, TS005, suggesting that these concentrations far exceed permissible limits (1 ppm). Phosphate fertilizers, often used in agriculture, can contain cadmium as a contaminant. Tea plants from the soil can absorb this cadmium.

Mercury (Hg) was present in several samples (17–108 ppm), far exceeding the international limit of 0.3 ppm. Mercury is highly toxic; mercury exposure – even small amounts – may cause serious health problems, damaging the nervous, digestive, and immune systems[60]. Its detection in teabags, but not in loose leaves, may indicate contamination from packaging, adhesives, or ink used in teabag materials.

Antimony (Sb), already elevated in loose-leaf teas, was also detected in teabags (38–108 ppm). Antimony can leach from packaging materials.

[57] Desideri, D., Meli, M.A., Roselli, C. and Feduzi, L. (2011). Polarized X ray fluorescence spectrometer (EDPXRF) for the determination of essential and non essential elements in tea. *Microchemical Journal*, 98(2), pp.186–189. doi:https://doi.org/10.1016/j.microc.2011.01.008.
[58] Rahaman, Md.S., Mise, N. and Ichihara, S. (2022). Arsenic contamination in food chain in Bangladesh: A review on health hazards, socioeconomic impacts and implications. *Hygiene and Environmental Health Advances*, 2, p.100004. doi:https://doi.org/10.1016/j.heha.2022.100004.
[59] World Health Organization (2024). *Lead Poisoning and Health*. [online] Who.int. Available at: https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health Accessed: 10 August 2025).
[60] World Health Organization (2024). *Mercury and Health*. [online] Who. Available at: https://www.who.int/news-room/fact-sheets/detail/mercury-and-health (Accessed: 10 August 2025).

Chromium (Cr), in this study, extremely elevated levels of chromium were detected in teabags, ranging from 330 ppm in Finlay Gold Black (TS002) to 1690 ppm in Brooke Bond Taaza (TS006). These values far exceed the international permissible limit of 5 ppm. While Chromium (III) is essential for glucose metabolism, cholesterol control, protein synthesis, pain resistance, and appetite regulation, hexavalent chromium, Cr(VI), is toxic and carcinogenic to humans[61].

7. 2 Micronutrients / Essential Trace Elements and Heavy Metal Content in Loose Tea Leaves

The analysis of heavy metals in dried loose tea leaves revealed considerable variation across brands, both locally produced and imported. Among the tested samples, micro and trace elements such as **manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and cobalt (Co), were** consistently detected, whereas certain toxic elements like **strontium (Sr)**, **antimony (Sb), thorium (Th), and uranium (U)** appeared in lower but variable concentrations.

Among these, manganese (Mn) was found in the highest concentrations across all samples, ranging from 355 ppm to 1119 ppm. Iron (Fe) levels varied considerably (150–526 ppm), while copper (Cu) and zinc (Zn) were present in moderate amounts, with maximum values of 53 ppm and 58 ppm, respectively. Cobalt (Co) was detected at levels (Co: up to 706 ppm). The variability in concentrations reflects differences in cultivation practices, geographical origin, and processing techniques of the tested brands.

From a nutritional standpoint, these elements contribute significantly to human health. Fe, Cu, Mn, and Zn are essential cofactors in enzyme metabolism and immunomodulation, thereby influencing susceptibility to viral infections and disease outcomes. Iron supports oxygen transport, while Mn is associated with glucose metabolism and diabetes regulation. Zn functions as an antioxidant, enhancing DNA stability and immune defense, and Vitamin B12 is crucial for proper nervous system function and immune response, with deficiency leading to neurological impairment and immune decline[62].

Of concern, however, are the non-essential/toxic elements. Strontium (Sr) was detected at a level (Sr: 9–23 ppm). Although there are no reported physiological effects of Sr at low concentrations, its accumulation in the body system could be detrimental to health.

Antimony (Sb) was detected in nearly all Bangladeshi teas, with particularly high concentrations in Brooke Bond Taaza (TS006) at 154 ppm and Paragon (TS007) at 126 ppm, potentially posing long-term health risks. Uranium (U) was found at low levels in Dilmah

[61] Mandiwana, Khakhathi L., et al. "Determination of Chromium(VI) in Black, Green and Herbal Teas." *Food Chemistry*, vol. 129, no. 4, Dec. 2011, pp. 1839–1843, https://doi.org/10.1016/j.foodchem.2011.05.124. Accessed 25 Oct. 2020.
[62] Desideri, D., Meli, M.A., Roselli, C. and Feduzi, L. (2011). Polarized X ray fluorescence spectrometer (EDPXRF) for the determination of essential and non essential elements in tea. *Microchemical Journal*, 98(2), pp.186–189. doi:https://doi.org/10.1016/j.microc.2011.01.008.

(TS001) at 4 ppm and Paragon (TS007) at 4 ppm, while thorium (Th) ranged from 30 to 50 ppm in several Bangladeshi teas, including Brooke Bond Taaza (TS006) at 50 ppm and Ishpahani Mirzapur (TS008) at 47 ppm. These elements are reported to be toxic and should be considered significant risk factors for public health.

In summary, Teabags showed high levels of arsenic, lead, cadmium, mercury, antimony, and chromium, which have no known physiological function yet reported, and can pose serious health risks even at low exposure. On the other hand, loose tea samples analyzed provide a range of essential elements such as iron, manganese, copper, zinc, cobalt, potassium, and magnesium. At the same time, certain toxic or non-essential elements, including strontium, antimony, uranium, and thorium, were detected in some samples, which could pose potential health risks if consumed regularly over long periods. These findings highlight the importance of monitoring and quality control to ensure that tea consumption delivers nutritional benefits while minimizing exposure to harmful elements.

Recommendations

8. Recommendations

Given the presence of heavy metals in tea products and their potential health implications, proactive measures are needed to ensure consumer safety while maintaining tea's nutritional benefits. The following recommendations provide a balanced approach to risk management, combining regulatory standards, agricultural practices, and consumer awareness:

1. **Adoption of the WHO Drinking Water Guidelines for Tea Liquids**
   Since tea is consumed in liquid form, the WHO guidelines for heavy metals in drinking water should serve as a benchmark for acceptable limits in brewed tea. This approach would provide a scientifically validated framework for assessing safety.

2. **Implementation of Regular Monitoring Programs**
   Tea producers and regulatory bodies should establish routine testing protocols for both raw tea leaves and final products to monitor heavy metal content, ensuring compliance with international safety standards.

3. **Soil Quality Management in Tea Plantations**
   Agricultural practices should focus on soil testing and remediation in tea-growing regions to minimize heavy metal uptake by tea plants. This includes reducing the use of contaminated fertilizers and implementing phytoremediation techniques where necessary.

4. **Consumer Awareness and Labeling**
   Tea products should include clear labeling about heavy metal content, similar to nutritional information. Public health campaigns should educate consumers about potential risks and safe consumption practices, especially for vulnerable populations.

5. **Development of Tea-Specific Safety Standards**
   While WHO water guidelines provide a useful reference, dedicated standards for tea products should be developed, accounting for typical consumption patterns and the unique bioavailability of metals in tea infusions.

6. **International Collaboration for Harmonized Regulations**
   Global tea trade organizations should work towards harmonizing heavy metal limits across producing and importing countries to ensure consistent product safety worldwide.

7. **Alternative Packaging Solutions**

   For tea bags, research should explore safer packaging materials that minimize the potential for additional metal contamination during production and storage.

8. Advanced Analytical Studies

While X-ray fluorescence (XRF) has provided initial insights into heavy metal content, further advanced analyses—such as ICP-MS (Inductively Coupled Plasma Mass Spectrometry) or AAS (Atomic Absorption Spectroscopy)—are recommended to obtain more precise quantification and speciation of metals in tea products. This will strengthen risk assessment and support more informed regulatory decisions.

9. Research on Brewing Methods and Metal Leaching

Further studies should investigate how different brewing parameters (temperature, time, water quality) affect heavy metal leaching from tea leaves to the liquid, enabling the development of safer preparation guidelines.

These recommendations aim to balance realistic implementation with meaningful improvements in tea safety, focusing on prevention, monitoring, and consumer protection.

Conclusion

9. Conclusion

Tea, widely consumed around the world, provides several essential nutrients and offers notable health benefits. However, regular monitoring of its elemental composition is critical, as contamination by toxic elements can pose serious health risks. Heavy metals are persistent, non-biodegradable, and can accumulate in the environment and the food chain, making their presence in tea a matter of public health concern.

This study reveals significant heavy metal contamination in both teabags' packaging materials and loose tea leaves commercially available in Bangladesh, highlighting potential risks to consumers. Analysis detected alarming concentrations of arsenic, lead, cadmium, mercury, and antimony across multiple product packaging samples in both phases of testing, with Bangladeshi teas exhibiting higher contamination levels compared to Sri Lankan samples. Notably, plastic teabags contained antimony—a byproduct of PET manufacturing—alongside potential microplastic and phthalate leaching during brewing, further increasing consumer exposure.

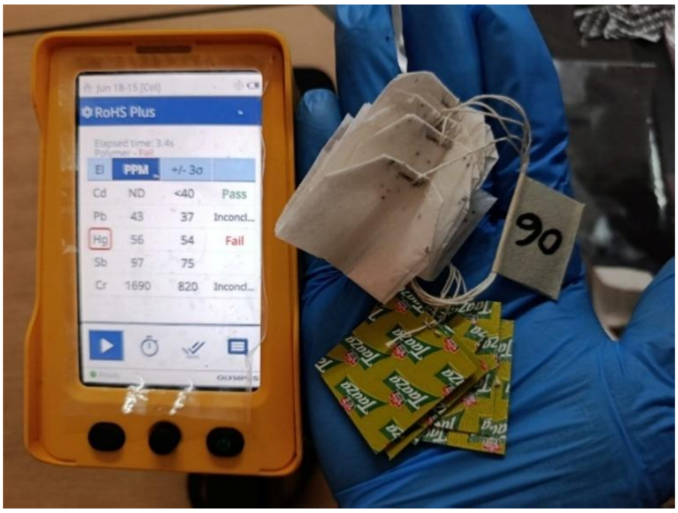
The findings underscore critical gaps in Bangladesh’s regulatory framework, where draft safety standards for heavy metals in tea remain unenforced and limited in scope. International benchmarks, such as WHO drinking water guidelines, emphasize the urgency of adopting stricter, tea-specific regulations to prevent long-term exposure.

To safeguard public health, immediate actions are needed: implementing routine heavy metal monitoring, improving soil and plantation management, mandating transparent product labeling, and promoting safer packaging alternatives. Collaborative efforts among policymakers, producers, and researchers are essential to establish harmonized safety standards and raise consumer awareness.

While tea remains a culturally cherished beverage, this study calls for a balanced approach—preserving its nutritional and cultural benefits while addressing contamination risks through science-based interventions. Future research should investigate contamination sources, bioavailability, and the cumulative health impacts of chronic exposure, ensuring safer tea consumption for Bangladesh’s population and beyond.

Annex

Pictorials


RoHS Plus
El PPM +/- 3σ
Cd ND <40 Pass
Pb 43 37 Incond...
Hg 56 54 Fail
Sb 97 75
Cr 1690 820 Incond...
90


Jun 18-18 [Col]
RoHS Plus
Elapsed time: 2.8s
Polymer - Inconclusive
El PPM +/- 3σ
Pb ND <9 Incond...
Cd ND <30 Pass
Cr ND <260 Pass
As 2 2
Hg 68 66 Incond...
OLYMPUS


Jun 18-13 [Col]
RoHS Plus
Elapsed time: 15.0s
Polymer - Inconclusive
El PPM +/- 3σ
Pb ND <2 Incond...
Hg ND <11 Incond...
Cd 27 16 Pass
Sb 38 34
Cr 450 260 Incond...
OLYMPUS


Jun 17-32
Elapsed time: 16.9s
El PPM +/- 3σ
Sr 11 2
Cu 26 6
Sb 27 24
Th 37 7
Zn 43 5
Rb 54 2
Fe 272 28
Mn 706 47
OLYMPUS
3


Geochem(3-Beam)
El PPM +/- 3σ
U 4 3
Sr 17 2
Cu 23 6
Th 42 7
Zn 43 5
Rb 73 3


Jun 17-37
Geochem(3-Beam)
Elapsed time: 16.9s
El PPM +/- 3σ
Sr 11 2
Cu 30 6
Zn 47 5
Th 47 7
Rb 75 3
Sb 94 25

Survey Questionnaire

No. ....

Consumer Survey

Study Title: **Brewing Toxins: Exposing the Heavy Metal Hazard in Teabags and Dried Loose Tea**
Survey conducted by: Environment & Social Development Organization-ESDO
(জরিপ পরিচালনা: এনভায়রনমেন্ট অ্যান্ড সোশ্যাল ডেভেলপমেন্ট অর্গানাইজেশন- এসডো, ২০২৫)

Section 1: Socio-demographic characteristics of the respondents
(সেকশন ১: উত্তরদাতার সামাজিক ও জনসংখ্যাগত তথ্য)

1. Age (বয়স):

☐ Below 18 (১৮ বছরের নিচে) ☐ 18–29 (১৮–২৯)
☐ 30–39 (৩০–৩৯) ☐ 40–49 (৪০–৪৯)
☐ 50 and above (৫০ এবং তার বেশি)

2. Gender (লিঙ্গ):

☐ Male (পুরুষ) ☐ Female (নারী)

Education Level (শিক্ষাগত যোগ্যতা):

☐ No formal education (প্রাতিষ্ঠানিক শিক্ষা ☐ Primary (প্রাথমিক)
☐ Secondary (মাধ্যমিক) ☐ Higher Secondary (উচ্চ মাধ্যমিক)
☐ Graduate and above (স্নাতক বা স্নাতকোত্তর)

3. Occupation (পেশা):

☐ Student (ছাত্র/ছাত্রী) ☐ Employed (চাকরিজীবী)
☐ Unemployed (বেকার) ☐ Housewife (গৃহিণী)
☐ Other (please specify): অন্যান্য (উল্লেখ করুন) __________

Section 2: Awareness and Practices (সচেতনতা ও অভ্যাস)

4. Do you drink tea? (আপনি কি চা পান করেন?)

☐ Yes (হ্যাঁ) ☐ No (না)

5. How many cups of tea do you usually consume per day? (আপনি সাধারণত দিনে কত কাপ চা পান করেন?)

☐ 1 cup (১ কাপ) ☐ 2–3 cups (২–৩ কাপ)

☐ 4–5 cups (৪–৫ কাপ) ☐ More than 5 cups (৫ কাপের বেশি)

6. Do you check the brand or packaging for safety labels or quality certifications before buying tea bags? (চা-ব্যাগ কেনার সময় আপনি কি ব্র্যান্ড/প্যাকেটের সেফটি লেবেল বা মান নিয়ন্ত্রণের সনদ পরীক্ষা করেন?)

☐ Always (সবসময়) ☐ Sometimes (কখনও কখনও)
☐ Rarely (খুব কম) ☐ Never (কখনও না)

7. Have you ever heard about heavy metals (like lead, arsenic, mercury, cadmium, etc.) in tea bags? (আপনি কি কখনও শুনেছেন যে চা-ব্যাগে ভারী ধাতু (যেমন সীসা, আর্সেনিক, পারদ, ক্যাডমিয়াম ইত্যাদি) থাকতে পারে?)

☐ Yes (হ্যাঁ) ☐ No (না)

8. Please indicate your recommendations to address the presence of heavy metals in tea bags: (চা-ব্যাগে ভারী ধাতুর উপস্থিতি মোকাবেলায় আপনার সুপারিশ কী হবে?)

☐ Strengthen government regulations and enforce food safety laws (সরকারি নিয়ম-কানুন শক্তিশালী করা এবং খাদ্য নিরাপত্তা আইন কার্যকর করা)
☐ Ban tea bag brands found to contain heavy metals
(যেসব ব্র্যান্ডে ভারী ধাতু পাওয়া যায় সেগুলো নিষিদ্ধ করা
☐ Promote safer alternative tea brands (নিরাপদ বিকল্প চা ব্র্যান্ড প্রচার করা)
☐ Increase public awareness about heavy metals in tea (চায়ে ভারী ধাতুর বিষয়ে জনগণের সচেতনতা বৃদ্ধি করা)
☐ Other: __________ (অন্যান্য: __________)

Brewing Toxins
Exposing the Heavy Metal Hazard in Teabags and Dried Loose Tea

Tea is the most popular drink in Bangladesh and an important part of daily life for millions of people. However, a study by ESDO found toxic metals in many tea bags packaging material commonly used in the country. Dangerous substances such as Lead (Pb), Mercury(Hg), Arsenic (As), Cadmium(Cd), and Chromium(Cr) were found in these tea bags packaging material, at levels much higher than national and international safety standards.

Tea consumption behavior:

A nationwide survey of 3,571 consumers across Bangladesh reveals the widespread nature of tea consumption, with more than 96% of respondents drinking tea regularly. 55% people highly intake tea which is 2–3 cups daily. Despite this, awareness of health risks is strikingly low; Only 1% had heard of heavy metals in tea bags.

Objectives of the study

- Measure metals (Pb, Cd, As, Cr, Hg) in commercial teabags, both the bag packaging material and tea content.
- Baseline check: Analyze loose and dry tea from multiple brands pre-brewing to map contamination levels.
- Health risk: Convert results to estimated intake per day and compare with national/international limit

Sl	Heavy Metal	Safe Limit	Highest Found Limit (1st phase)	Highest Found Limit (2nd phase)
1	Arsenic (As)	2 ppm	14 ppm	15 ppm
2	Cadmium (Cd)	1 ppm	83 ppm	87 ppm
3	Chromium (Cr)	5 ppm	1690 ppm	1710 ppm
4	Mercury (Hg)	0.3 ppm	108 ppm	98 ppm
5	Lead (Pb)	5 ppm	51 ppm	58 ppm

Methodology

In the first phase, 13 tea brands (11 local, 1 foreign tea bag, and 1 foreign loose leaf) were collected and analyzed with a handheld XRF in RoHS mode for toxic elements (Pb, Cd, Hg, Cr, As, Sb). In the second phase, 19 brands were sampled, with three samples per brand, totaling 57 tea bag packaging samples.

Elements in Loose Tea

Loose tea leaves from the bag contained beneficial nutrients, such as iron, manganese, copper, and zinc, but also carried risks, as they contained toxicants, including antimony (up to 154 ppm) and traces of radioactive elements, such as uranium and thorium.

Recommendations

- Apply WHO drinking-water limits to brewed tea
- Establish routine monitoring from farm to cup
- Manage soil quality in tea estates
- Develop tea-specific standards
- Harmonize standards internationally
- Shift to safer teabag packaging

Health Hazards

Neurological
Heavy metals such as lead and mercury can cause brain damage, memory loss, behavioral problems, and tremors

Cardiovascular
Exposure to lead, cadmium, arsenic, and mercury can contribute to high blood pressure, damaged blood vessels, and increased risks of heart disease

Organ Damage
Heavy metals can cause severe damage to vital organs, including the kidneys and liver, leading to reduced filtration capacity, organ failure, and potentially conditions like liver cirrhosis

Cancer
Long-term contact with some heavy metals can damage DNA and nucleic acids, disrupting cellular processes and increasing the risk of developing cancer

Reproductive and Developmental
Heavy metals can disrupt reproductive health, causing infertility, hormonal imbalances, and increased risks of miscarriages and birth defects

Skin effects
Arsenic causes thickened and darkened skin, sometimes skin cancer; chromium triggers dermatitis; mercury can cause various skin reactions

Other Symptoms
Abdominal pain, weakness, nausea, vomiting, and numbness or tingling in the hands and feet can also occur

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Brew safely.

Demand safe tea, safer bags, and transparent standards

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