DOI: https://doi.org/10.3126/cognition.v7i1.74770

HEAVY METAL CONTAMINATION IN COMMERCIAL TURMERIC: A PUBLIC HEALTH PERSPECTIVE

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ABSTRACT

Turmeric is a spice obtained by drying and grinding the rhizomes of the plant Curcuma longa. Turmeric is a key component of traditional Ayurvedic medicine which is also one of the basic and most widely used spice in regular cooking. It has an active component curcumin. Due to its increasing popularity, turmeric is found to be adulterated with the salt of Lead and Chromium, usually with lead chromate. The presence of these two heavy metals in the turmeric elevates the level of these metals in our body causing various health implications. The presented study aimed to analyze the concentration of Lead and Chromium in the commercial turmeric powder. For this study, seven turmeric samples of different brands were collected from Itahari and Biratnagar. From the collected seven turmeric samples, seven sample solutions were prepared by aqua regia acid digestion. Then, for obtaining the concentration of Lead and Chromium the sample solution was analyzed by AAS. The AAS analysis revealed the concentration of lead and chromium in the sample taken. The concentration of the two metals obtained from the AAS analysis was compared to the limit recommended by WHO and DFTQC. In sample A, the concentration of both lead and chromium was found to be the highest, with the lead concentration higher than the permissible limit recommended by both DFTQC and WHO. The lead concentration in other samples (B, C, E & G) was also higher than the limit. While in two samples, (D & E) the concentration of lead was <0.01ppm. The chromium concentration in all seven samples was less than 6ppm which is less than the limit recommended by both WHO and DFTQC. Additionally, the moisture content and pH of the turmeric samples were also determined.

Keywords: Turmeric, Lead, Chromium, adulteration, concentration, AAS

INTRODUCTION

There are many *curcuma* species, among these *curcuma* longa commonly known as Turmeric is the most recognized and widely used, it is a cultivated plant and mostly grows in warm climates in various regions of the world. Turmeric plants are widely grown in tropical and subtropical regions of the world and can measure up to 1m high. The plant is mainly grown to obtain turmeric which is a vibrant yellow spice obtained from the rhizomes of the plant *curcuma* (Omosa et al., 2017).

Originating from the Indian sub-continent, turmeric is not only permitted to the culinary world but also has been reserved for its medicinal properties for centuries. Turmeric, also being a key component of traditional Ayurvedic medicine, has an active ingredient named *curcumin* which is anti-inflammatory and has antioxidant characteristics (Srivastava et al., 1995). Turmeric is a staple and basic ingredient of cooking in almost every household in Nepali, South Asian, and Middle Eastern cuisines which adds color and warm earthy flavor to dishes. It is believed to alleviate various ailments from arthritis to digestive issues (Khanal et al., 2021).

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Received on Oct. 19, 2024 *Accepted on Dec. 24, 2024* *Published on Jan. 31, 2025*

Turmeric has rich cultural significance; the distinct golden color of turmeric also finds its way to natural dye. In recent years, turmeric has gained attention with research going in, exploring its potential in treating various conditions including neurological disorders and cancer. Due to the capability of turmeric as supplement in the form of capsules containing powder, fluids extract and tinctures have been increased (Tabrizi et al., 2019).

As the global interest, turmeric stands at the cross roads of tradition and modernity. Captivating both chefs and health enthusiasts alike. The journey of turmeric from ancient rituals to contemporary kitchens exemplifies the enduring allure of this vibrant golden spice. However, due to the growing use of turmeric, with recent studies and research in various countries, concerns of possible adulteration of turmeric have been known. Adulteration can be defined as the substitution of the original substances with other spoiled, useless, or harmful substances or synthetic chemicals that do not conform with the original standards (Adugna et al., 2024; Girme et al., 2020; Lanjewar et al., 2024; Macêdo et al., 2021).

The turmeric is found to be adulterated with various compounds among which the adulteration with lead chromate is emerging as a major issue. Lead chromate is a compound which has almost the exact color of turmeric, it contains two heavy metals Lead and Chromium, being highly toxic compounds, its presence in turmeric can be crucial for public health. Lead and chromium are heavy metals that possesses serious health risks when present in turmeric, especially for children (Adugna et al., 2024; Forsyth et al., 2019, 2023; Girme et al., 2020).

It was demonstrated that lead chromate induces concentration-dependent DNA double-strand breaks (DSBs), evidenced by significant increases in tail-integrated intensity ratios. Sodium chromate, another Cr(VI) compound, also caused similar genotoxic effects. The activation of key DNA damage response proteins, such as ataxia telangiectasia mutated (ATM) and phosphorylation of H2A.X on serine 139 (r-H2A.X), further confirms the induction of DSBs. The formation of r-H2A.X foci was also concentration-dependent, increasing with higher lead chromate exposure levels. These findings suggest that particulate Cr(VI) not only causes various forms of DNA damage but is also a potent inducer of DSBs, implicating its significant carcinogenic potential through mechanisms of genomic instability and disrupted DNA repair processes (Xie et al., 2005).

Even in trace amounts, Lead (Pb) is known to be a potent neurotoxin that can accumulate in our body over time. Lead can induce cognitive impairment development issues in children and even damage the nervous system with its prolonged exposure (Prüss-üstün et al., 2003). On the other hand, chromium is known to exist in different forms with, trivalent chromium being an essential nutrient for our body. However, hexavalent chromium is a more toxic form and can be harmful in high concentrations. Respiratory issues, skin irritation, and an increased risk of certain cancers can be induced by prolonged exposure to elevated levels of hexavalent chromium. Hexavalent chromium is also found to be carcinogenic, nephrotoxic, and tumorigenic (Achmad et al., 2017).

By the use of turmeric adulterated with lead chromate, the levels of lead and chromium in the human body are found to be elevated. Lead poisoning is emerging as one of the major health issues, particularly for young children and pregnant women in developing countries. In a recent study in Bangladesh, pregnant women had elevated levels of Lead and the reason behind it was Lead chromate that was added to Turmeric (Mitra et al., 2009) . Repeated lead exposure is known to induce kidney and reproductive issues as well as high blood pressure in Adults. With time, the body can mistake lead for Calcium due to identical chemical properties, and hence lead can integrate into bones (Sanders et al., 2009).

Analysis of turmeric samples from India, Pakistan, Sri Lanka, and Nepal revealed that 14% of the 356 samples contained lead above 2 µg/g, with concentrations exceeding 1000 µg/g in some regions, such as Patna (India) and Karachi (Pakistan). This level of contamination suggests intentional adulteration with lead chromate, evidenced by a 1:1 molar ratio of lead to chromium in highly contaminated samples. The implications are severe, as projected child blood lead levels in these regions could be up to 10 times the CDC's threshold of concern, posing risks of cognitive impairment, developmental delays, and other health issues. The findings underscore the urgent need for interventions to eliminate lead chromate from the turmeric supply chain and protect public health (Forsyth et al., 2024).

The concentration of heavy metals must be as per World Health Organization (WHO) i.e., 0.1 ppm for Pb and < 6.00 ppm for chromium and as per Department of Food Technology and Quality Control (DFTQC) the concentration of Lead must be nil and the concentration of chromium must be < 6.00 ppm. The concentration exceeding this level can be a threat to human health (WHO, 2018). To ensure the safety of the public and the quality of our regular ingredients, this analysis is essential. As the cases of adulteration are a major issue nowadays, we should be aware of the quality of the spice that we buy and that goes into our diet.

The study outcomes provide valuable information about the concentration of lead and chromium in the turmeric of commercial brands that we use. This study was conducted in the turmeric samples found in the local markets and supermarkets of Itahari and Biratnagar as they lie closer to the Indian border and most of the products enter the country by these cities.

MATERIALS AND METHODS

Materials

Collection of samples: Different turmeric samples such as raw dried turmeric (which was not powdered) (A), and unpacked turmeric powders (B) were bought from the local market of Itahari. Three National branded packed turmeric powders with brand name Bansuri (C) RKM turmeric powder (D), Durga turmeric powder (E) were bought from the Gorkha departmental store, Itahari. Two internationally branded turmeric powders with the brand name Goldiee (F) and Tata Samapann (G) were brought from Bhat Bhateni supermarket, Biratnagar, Nepal. All the samples in this study were collected randomly. Raw and unpacked turmeric's were chosen as major of the population uses it for the regular cooking. Nepali brands of turmeric were chosen as these brands were also the choice of locals. And internationally branded were chosen to compare the quality with the national ones. All chemicals and reagents required during the research are listed in Table 1.

Table 1. List of chemicals used

Chemicals & reagents	Manufacturer
Distilled water	Digital conductivity meter (Indian Company,Systronics)
Hydrochloric acid	Thermofischer scientific Pvt. Ltd. India
Hydrogen peroxide	Qualiken Fine Chemicals Pvt Ltd. India
Nitric acid	Qualiken Fine Chemicals Pvt. Ltd. India
Lead nitrate $(PbNO_3)_2$	Flinn Scientific Chemical Co. Ltd. U.S.A
Chromium (III) oxide	United Nuclear Scientific equipment & supplier, Sigma Aldrich, USA
Ethanol	Changu Hongsheng Fine Chemical Co. Ltd. China.

Methods

Sample preparation:

The raw dried turmeric collected from the local market was dried in an air oven and ground to powder form by using the grinder. The powdered turmeric samples were then packed and kept for analysis. All the turmeric samples were then labeled as A, B, C, D, E, F, and G. For further process, digestion of the sample was needed, so each sample was dried at 65ºC for 48 hours (2 days) before digestion process. The digestion method used for getting the sample solution was the Aqua Regia acid digestion method. About 1 gram of sample (Turmeric) was weighed in a butter paper and then it was placed in a clean and dry beaker of 250ml and 50ml distilled water was added. After that, Aqua regia (3ml conc. Hydrochloric acid and 1ml conc. HNO_3) was added to the same beaker as the sample. The sample was then digested in a hot plate until the volume was reduced from 10-20ml (for 2-3 hours). The sample was then cooled and filtered and 50ml volume was made up in 50ml volumetric flask using distilled water. The different stages of sample treatment are shown in figure 1. The method was performed in triplicate for each sample & hence (7*3 = 21) sample solutions were obtained from seven initial samples.

For the calibration curve, three different concentrations (1 ppm, 3 ppm, and 5 ppm) of each standard metal solution were prepared from the 1000 ppm of stock solution (Certified Reference Material, Merk Germany). Hollow cathode lamps for Pb (wavelength 217 nm) and Cr (357.5 nm) were used to record the absorbance. A calibration curve was prepared by plotting absorbance verses of their concentration with correlation coefficient (r) of 0.998 and 0.997 respectively. The limit of detection of both the metal ions were 0.01 ppm.

Heavy metal analysis

The concentration of lead and chromium in the different turmeric samples was determined by using Atomic Absorption Spectroscopy (Thermo Science 3000 Series, U.S.A). The nebulizer or aspirator was rinsed by aspirating water which contained 1.5ml conc. HNO_3. Again, the blank was aspirated, and samples were aspirated and their absorbance was determined.

Determination of moisture content

The Moisture content of Turmeric was determined by using Hot air oven Drying method. 10g of each seven samples were weighed in Petri dish and heated in hot air oven at 120ºC for 30 minutes. After 30 minutes of heating the sample were cooled in a desiccator and the moisture content of the sample was determined by weighing the sample using the following formula:

Moisture content = Initial wt. – final wt./ sample weight * 100%

Determination of pH:

As solids have no pH. However, the pH of turmeric can be determined by forming its solution with water. The pH value of the Turmeric samples was determined by the Digital pH Meter (SYSTRONICS, India) as described by (Sakina Saadawi, 2020). The conductance of distilled water was measured by the Indian Company, Systronics as mentioned in the literature (Yadav et al., 2024).

Figure 1. Different stages of sample treatment (a. Sample collected from the market, b. Drying of sample in Hot air oven, c. Acid digestion of sample, d. Sample prepared after digestion for AAS)

RESULTS AND DISCUSSION

The analysis focused on the levels of Pb and Cr detected in various Turmeric samples along with measurement of moisture content and pH to evaluate overall product quality. The results provide critical insights into the potential health risks associated with heavy metal contamination in commonly consumed turmeric powders.

Concentration of Lead (Pb) and Total-Chromium (Cr):

The presence of Pb and Cr in Turmeric powder samples were measured using AAS technique. Table 2 in the study presents specific concentrations of these metals across seven Turmeric samples, labeled A through G. The findings are compared to permissible limits set by WHO (Mengistu, 2021) and DFTQC, with acceptable lead concentration at or below 0.1 ppm (WHO) and Cr at or below 6 ppm (WHO, DFTQC).

Figure 2 compares the concentration of Pb and Cr in several samples of Turmeric. Sample A (Raw Dried Turmeric) showed the highest concentration at 0.50 ppm, exceeding WHO's recommendation limit by five times. This suggest a significant contamination level, possibly due to lead chromate, a compound used to enhance Turmeric's yellow color (Forsyth et al., 2019). Samples B, C, E and G also recorded Pb levels above WHO's acceptable limit of 0.1 ppm, with values 0.24 ppm, 0.45 ppm, 0.37 ppm, and 0.41 ppm respectively. These values indicate possible adulteration with lead-containing compounds, raising serious health problems. In contrast, Samples D and F had Pb concentrations below 0.01 ppm, indicating minimal contamination and safer levels of Pb content relative to WHO and DFTQC (DFTQC, n.d.).

All the samples contained Cr levels well within the WHO and DFTQC limit of 6 ppm. Sample A again had the highest Cr concentration at 3.31 ppm, while other samples ranged between 1.48 to 2.62 ppm. Despite the presence of Cr, these levels are within acceptable health and safety standards, which suggest these samples are less concerning than those with high lead levels.

Health implications:

Bioaccumulation and chronic exposure risks: Chronic exposure to lead from turmeric adulterated with lead chromate poses significant health risks, especially for populations with high consumption. Lead is a potent neurotoxin, and repeated ingestion can lead to cognitive impairment, developmental delays in children, and organ damage in adults. A study in Bangladesh linked elevated blood lead levels in pregnant women to turmeric consumption, showing how such contamination contributes to long-term health crises in vulnerable populations (Mitra et al., 2009). Similar trends could be observed in other turmeric-consuming regions such as India and Nepal.

While trivalent chromium is an essential nutrient, hexavalent chromium, often introduced via adulteration, is carcinogenic. Its ingestion over time can cause gastrointestinal distress, kidney damage, and increased risks of lung and stomach cancers (Achmad et al., 2017). In populations with high turmeric consumption, cumulative exposure to Cr(VI) exacerbates these risks.

Elevated blood lead levels in children: Children are particularly vulnerable due to their small body size and higher rates of absorption. A study in South Asia projected child blood lead levels in regions like Patna (India) and Karachi (Pakistan) to be up to 10 times the CDC's threshold of concern, directly attributed to lead adulterated turmeric (Forsyth et al., 2019; 2024). Such exposure is linked to irreversible neurodevelopmental deficits, including reduced IQ, attention disorder, and behavioral issues.

Health comparisons across regions: In the United States, lead exposure from turmeric has been identified in immigrant communities with dietary habits relying heavily on imported turmeric. For instance, lead chromate-adulterated turmeric has been implicated in cases of elevated blood lead levels in Bangladeshi American children (Forsyth et al., 2024). Comparing this with South Asian populations, where turmeric use is more pervasive in daily diets, highlights a potentially greater public health burden in countries like India, Nepal, and Bangladesh.

Gendered and Socioeconomic Vulnerabilities: Studies have shown that women and children in lower-income households are more likely to consume cheaper, adulterated turmeric, increasing their exposure risk. Pregnant women exposed to lead through turmeric may experience complications like miscarriage or low birth weight, as seen in studies in Bangladesh (Mitra et al., 2009).

Long-term health outcomes: Chronic ingestion of heavy metals through turmeric can lead to cumulative toxic effects. Adults may experience hypertension, kidney damage, and increased cancer risks, while children face lifelong cognitive and developmental challenges. A study by Sanders et al. (2009) noted that lead accumulates in bones and is released during periods of physiological stress, compounding health risks over time.

The sources of lead chromate contamination in Nepal's turmeric supply chain are likely multifaceted, with significant contributions from processing and intentional adulteration, as well as potential contamination during farming and storage. Addressing these issues will require interventions across the supply chain, including stricter regulations, quality control measures, and public awareness campaigns targeting both producers and consumers.

Table 2. Concentration of Lead & Chromium in different samples of Turmeric

Samples	Moisture (% by wt.)	pH	Pb (ppm)	Cr (ppm)
A	18.22±1.32	5.8	0.50±0.06	3.31±0.06
B	13.83±1.06	6.0	0.24±0.01	2.21±0.02
C	9.34±1.02	6.1	0.45±0.08	1.48±0.05
D	10.44±1.02	6.0	<0.01	2.05±0.01
E	9.94±0.04	5.6	0.37±0.02	2.44±0.02
F	10.56±0.95	5.8	<0.01	2.62±0.01
G	10.68±2.80	6.1	0.41±0.03	2.62±0.04

*The values given in the above table are the Mean of the triplicate values with standard deviations.

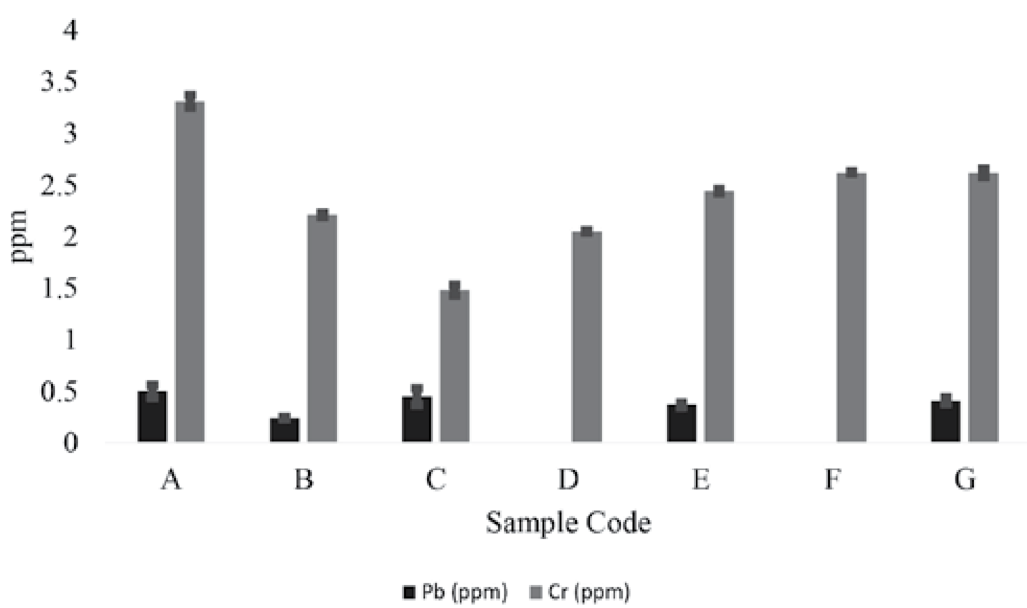

Figure 2. Comparison of concentrations of Lead and Chromium in various samples of Turmeric (with error bars)

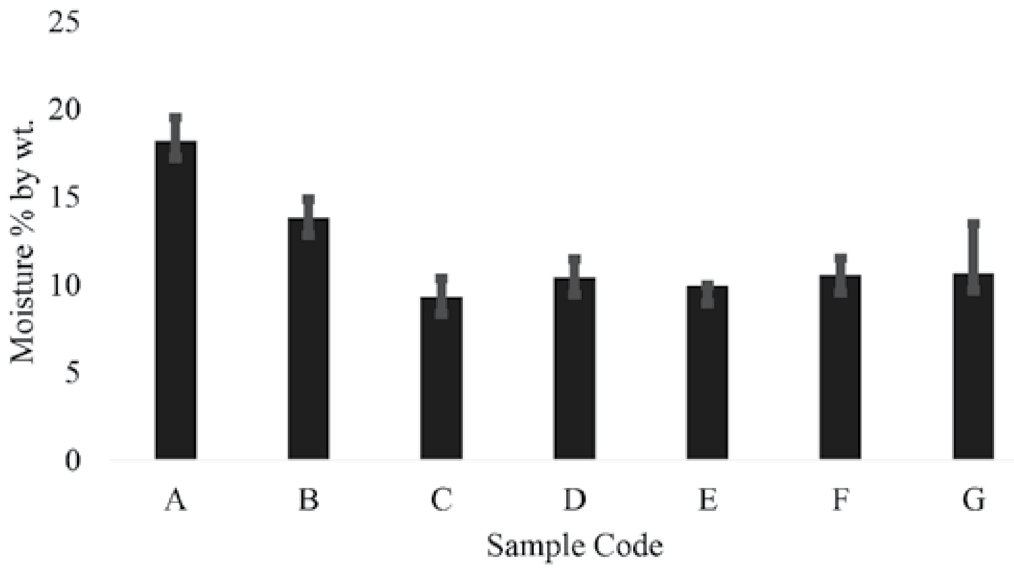

Figure 3. Comparison of moisture content in several samples of Turmeric (with error bars)

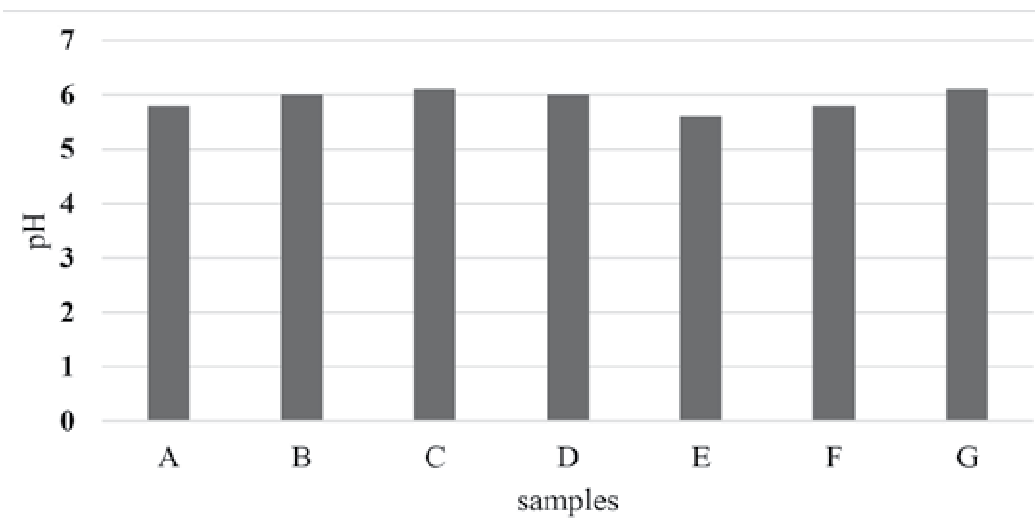

Figure 4. Comparison of pH of various samples of Turmeric

Moisture Content of Turmeric:

The Moisture content of the given turmeric samples is presented in Table 2 and compared in figure 3. Moisture content is another quality indicator, with DFTQC's recommended threshold set below 12%. Excess moisture in Turmeric can promoted microbial growth, reduce shelf life, and impact the spice's overall quality. Sample A has a moisture content of 18.22%, the highest among the samples, indicating that it might not have been adequately dried before grinding. Sample B also exceeds the 12% limit with a content of 13.83%. The other samples had moisture content acceptable levels, ranging from 9.34 to 10.68%. This suggests that most commercially packaged Turmeric powders are adequately dried, helping maintain their quality and preventing potential spoilage.

pH levels:

The pH of Turmeric is essential for ensuring the spice's stability, flavor, and safety, with a ideal pH range between 4.5 to 7.5 as per WHO and DFTQC guidelines. Turmeric's pH impacts not only its taste but also its suitability for culinary uses.

The pH values of all Turmeric samples were within the acceptable range, falling between 5.6 and 6.1. This consistency across samples reflects uniform acidity levels, which supports flavor stability and aligns with culinary expectations for Turmeric.

The balanced pH in all samples reinforces their usability in food, as this range indicated good quality Turmeric that is less likely to cause adverse reactions and affect the taste profile of culinary dishes.

Relating parameters to product quality and safety

Moisture Content and Risk of Contamination or Spoilage

Moisture content is a critical parameter for assessing the quality and safety of turmeric, as elevated moisture levels can create an environment conducive to microbial growth and spoilage. The results of this study revealed that:

Sample A had the highest moisture content at 18.22%, which exceeds the Department of Food Technology and Quality Control (DFTQC) recommended threshold of 12%. Such high moisture levels suggest inadequate drying during processing, which not only compromises the shelf life but also increases the risk of microbial contamination, including molds and bacteria. These microorganisms can degrade turmeric quality and potentially produce mycotoxins, further threatening consumer health.

Sample B, with a moisture content of 13.83%, also exceeded the permissible limit, indicating poor drying or improper storage conditions.

The other samples, with moisture levels ranging from 9.34% to 10.68%, were within acceptable limits, suggesting adequate processing and better product stability. Proper drying of turmeric is essential to maintain its chemical integrity and minimize spoilage during storage.

Lead and Chromium Contamination about Safety Standards

The presence of lead and chromium in turmeric samples is directly related to product safety:

Lead Levels: Five out of seven samples (A, B, C, E, G) had lead concentrations exceeding the World Health Organization (WHO) permissible limit of 0.1 ppm. This poses a significant safety risk, as lead is a potent neurotoxin, particularly harmful to children and pregnant women. High lead levels are often associated with intentional adulteration using lead chromate to enhance turmeric's color, compromising product integrity and consumer trust.

Chromium Levels: While all samples had chromium concentrations below the WHO and DFTQC limit of 6 ppm, the presence of chromium, even in permissible quantities, raises concerns about potential environmental contamination during farming or processing stages.

pH and Product Quality:

The pH values of the turmeric samples, ranging from 5.6 to 6.1, were within the ideal range of 4.5 to 7.5 for culinary use. This indicates that the samples were stable in terms of acidity, with no indications of spoilage or chemical degradation affecting pH. A balanced pH is crucial for maintaining turmeric's flavor, stability, and suitability for culinary applications.

Adopting alternatives to lead chromate is feasible and economically viable. For processors prioritizing health and safety, curcumin extracts or natural alternatives like annatto are excellent choices. In cost-sensitive contexts, food-grade synthetic dyes provide a practical solution (Vinha et al., 2018; Wijesekara & Xu, 2024). Educating stakeholders and implementing stricter regulations can accelerate the transition to safer alternatives, safeguarding public health and ensuring sustainable turmeric production.

CONCLUSIONS

This study highlights significant public health concerns related to lead contamination, moisture content, and pH levels in commercially available turmeric. Analysis of seven turmeric samples using Atomic Absorption Spectroscopy revealed that five samples (A, B, C, E, G) contained lead concentrations exceeding the WHO permissible limit of 0.1 ppm, with Sample A showing the highest concentration at 0.50 ppm. These elevated levels strongly indicate potential intentional adulteration with lead chromate to enhance the yellow color of turmeric. While chromium was detected in all samples, its concentrations were below the WHO and DFTQC limit of 6 ppm, posing a lesser safety concern. Moisture content, a critical parameter for product quality and safety, was notably high in Sample A (18.22%) and Sample B (13.83%), exceeding the DFTQC threshold of 12%. Elevated moisture increases the risk of microbial contamination, spoilage, and reduced shelf life. The pH levels of all samples ranged between 5.6 and 6.1, remaining within the ideal range of 4.5 to 7.5, which supports the stability and flavor profile of the turmeric. These findings underscore the urgent need for stricter regulatory enforcement, improved quality control in the turmeric supply chain, and greater public awareness to address the risks associated with heavy metal contamination and suboptimal product quality.

RECOMMENDATIONS

Actionable steps for consumers: Consumers can take several actionable steps to minimize the risk of purchasing lead chromate-adulterated turmeric and protect their health. Rapid testing kits designed for detecting heavy metals provide an easy way to identify adulteration at home, with some tests offering instant results by analyzing color changes when turmeric is mixed with water or reagents. Certified organic turmeric, labeled with standards like USDA Organic or India Organic, is a safer choice, as such certifications ensure the product is cultivated and processed without synthetic chemicals or heavy metals. Additionally, purchasing from reputable brands with clear quality control practices reduces the likelihood of contamination, while consumers should also avoid unpackaged turmeric from unverified sources, especially those with unnaturally bright yellow hues that may indicate synthetic coloring. Supporting trusted local farmers and buying raw turmeric rhizomes directly from verified markets further minimizes exposure to adulterated products. Finally, advocating for routine heavy metal testing by regulatory bodies and the availability of affordable, portable testing kits can empower consumers and promote a safer supply chain. By adopting these measures, consumers can safeguard themselves from the health risks associated with contaminated turmeric.

Consumer Awareness: Public health authorities should work to increase awareness among consumers about the risks of heavy metal contamination in turmeric. Consumers should be encouraged to opt for organic or certified brands to reduce the risk of exposure.

Regulatory Action: Regular monitoring and stricter enforcement by food safety authorities, such as DFTQC, are essential. Penalties for companies found adulterating turmeric with lead should be strengthened to deter such practices.

Adoption of Alternative Methods: Encourage producers to use non-toxic alternatives to achieve the desired yellow coloration in turmeric, reducing the economic incentive for adulteration.

Further Research: Continued studies are needed to monitor heavy metal levels in widely consumed spices and explore more effective detection techniques, especially for small-scale markets where adulteration is more common.

Consumer Guidance on Usage: Limiting turmeric consumption and opting for verified, quality-assured sources could help mitigate the risks associated with lead contamination.

Implementing these recommendations will support public health efforts to prevent exposure to heavy metals from food sources and contribute to higher standards in food quality.

LIMITATIONS OF THE STUDY

Limited Sample Size and Geographic Scope:

While the study analyzed turmeric samples from Itahari and Biratnagar, the sample size was relatively small, and the geographic scope was confined to a specific region. This may not fully represent the diversity of turmeric contamination across Nepal or other turmeric-importing regions.

Focus on Total Chromium, Not Speciation:

The study measured total chromium concentrations without distinguishing between hexavalent chromium (Cr(VI)) and trivalent chromium (Cr(III)). Since Cr(VI) is significantly more toxic and carcinogenic, speciation analysis would provide a clearer understanding of the health risks associated with chromium contamination.

Lack of Longitudinal Data:

The study provides a snapshot of lead and chromium contamination but does not assess temporal variations. Seasonal changes in turmeric production and market dynamics could influence contamination levels, and longitudinal data could help establish trends over time.

Absence of Detailed Source Tracing:

While the study identifies contamination, it does not trace the sources of lead and chromium adulteration in the turmeric supply chain. Understanding whether contamination originates from agricultural practices, processing, or intentional adulteration would enable targeted interventions.

Health Impact Assessment:

The study highlights potential health risks but does not directly measure the impact of contaminated turmeric on consumer health. Incorporating biomonitoring data, such as blood lead or urinary chromium levels in frequent turmeric consumers, would strengthen the connection between contamination and health outcomes.

Focus on Packaged Turmeric:

Although the study includes both raw and packaged turmeric samples, its emphasis on commercial brands may overlook contamination in locally sourced or small-scale processed turmeric, which are commonly used by lower-income households.

Instrument Sensitivity and Detection Limits:

The limit of detection for lead and chromium was set at 0.01 ppm, which is sufficient for regulatory standards but may not capture ultra-trace levels of contamination. Advanced analytical techniques could provide even more precise data.

Consumer Behavior and Cooking Practices:

The study does not account for how cooking methods might affect the bioavailability of lead and chromium. For instance, boiling or frying turmeric might alter the metal content and its absorption in the body.

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