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Mineral content and heavy metal analysis of commonly consumed spices

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Abstract

Spices are consumed daily in small quantities but may represent a disproportionate source of dietary heavy metal exposure due to soil contamination, adulteration, or post-harvest processing with metallic equipment. This research quantified essential minerals (Ca, Mg, Fe, Zn, Mn, Cu) and toxic heavy metals (Pb, Cd, As, Hg) in ten commonly consumed Indian spices by inductively coupled plasma mass spectrometry (ICP-MS) following microwave-assisted acid digestion. All samples were purchased from retail markets in Patna, Bihar, across three separate procurement events (July 2022 to March 2024). Pb concentrations ranged from 0.39 (cloves) to 1.34 mg/kg (turmeric), with all samples below the EU MRL of 2.0 mg/kg for spices. Cd ranged from 0.05 to 0.23 mg/kg; turmeric again recorded the highest Cd value (0.23 mg/kg), approaching but not exceeding the EU MRL of 0.20 mg/kg for a subset. Essential mineral content was highest in cumin (Ca 1,243 mg/kg, Mg 931 mg/kg) and lowest in cinnamon. Estimated daily intakes (EDI) of Pb and Cd from spice consumption remained below provisional tolerable weekly intake (PTWI) thresholds for all spices at reported consumption levels in Indian adults. Research was conducted at the Department of Applied Food Chemistry, Chandragupta Maurya University, Patna, Bihar, India.

Keywords: Metals, spices, ICP-MS, lead, cadmium, turmeric, food safety, mineral content, estimated daily intake, EU MRL.

Introduction

Spices are integral to South Asian cuisine and contribute complex flavour profiles and bioactive phytochemicals to the diet. Although consumed in gram-level daily quantities, spices may contain relatively high concentrations of heavy metals arising from soil geochemistry at cultivation sites, the use of lead chromate as a colourant in fraudulent adulteration (particularly of turmeric), and contamination from metallic grinding equipment ^[1]. Pb and Cd are of greatest concern: Pb is a non-threshold neurotoxin with no known safe blood level, and Cd is a nephrotoxin that accumulates in the renal cortex over years of dietary exposure ^[2].

ICP-MS following microwave acid digestion is the reference method for multi-element trace analysis in food matrices, offering simultaneous quantification of all elements of interest at sub-mg/kg detection limits with isotope dilution or internal standard correction ^[3]. Regulatory benchmarks for heavy metals in spices are provided by EU Regulation 2023/915 and the Codex Alimentarius standard CXS 193-1995 (amended 2023). This research was conducted from July 2022 to March 2024 at the Department of Applied Food Chemistry, Chandragupta Maurya University, Patna, Bihar, India.

In-vitro Protocol

To assess metal bioaccessibility — the fraction of total metal that could be absorbed after ingestion — an *In-vitro* digestion protocol was applied to six selected spice samples following the INFOGEST 2.0 harmonised protocol (oral, gastric, small intestinal phases). Briefly: 0.5 g ground spice + simulated salivary fluid (pH 6.8, α -amylase 75 U/mL, 2 min), then gastric phase (pH 2.0, pepsin 2000 U/mL, 37°C, 2 h), then intestinal phase (pH 7.0, pancreatin 200 U/mL, bile extract 6 mg/mL, 37°C, 2 h). Digesta was centrifuged (3000 rpm, 10 min); supernatant (bioaccessible fraction) analysed by ICP-MS. Bioaccessibility was

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expressed as percentage of total metal recovered in the bioaccessible fraction relative to the total metal in the acid-digested sample. All *In-vitro* protocol steps were run in triplicate.

Safety Considerations

Estimated daily intakes (EDI, $\mu\text{g}/\text{person}/\text{day}$) were calculated as

$$\text{EDI} = C \times \text{IR}$$

where C is the measured heavy metal concentration (mg/kg) and IR is the per-capita daily intake rate (g/day) of each spice from the Indian National Nutrition Monitoring Bureau (NNMB) 2022 survey data. Turmeric: 2.8 g/day; black pepper: 1.4 g/day; chilli: 3.1 g/day; cumin: 1.2 g/day; coriander: 1.8 g/day; other spices: 0.5-0.9 g/day. EDIs were compared with the JECFA-established provisional tolerable weekly intake (PTWI) for Pb (25 $\mu\text{g}/\text{kg}$ bw/week) and Cd (7 $\mu\text{g}/\text{kg}$ bw/week) using 60 kg adult body weight. Target hazard quotient (THQ) analysis (THQ < 1 = acceptable risk) was applied for Pb and Cd individually. Cumulative hazard index (HI = sum of THQs across spices) was calculated assuming simultaneous daily consumption of all ten spices at NNMB-reported rates.

Material and Methods

Material

Ten spice samples (black pepper, turmeric, red chilli, cumin, coriander, ginger, fenugreek, cloves, cardamom, cinnamon) were purchased in triplicate from three Patna retail market outlets on separate days (July 2022, January 2023, March 2024) to account for batch variation. Reference materials: NIST SRM 1573a (tomato leaves) and SRM 1547 (peach leaves) for ICP-MS calibration verification. Reagent-grade

HNO_3 (65%, Merck Suprapur) and H_2O_2 (30%, Suprapur) were used for digestion. Milli-Q water (18.2 $\text{M}\Omega\cdot\text{cm}$) throughout. Research was conducted at Chandragupta Maurya University, Patna, Bihar, India.

Methods

Microwave acid digestion: 0.5 g dried and ground sample + 8 mL HNO_3 + 2 mL H_2O_2 in closed PTFE vessels (Milestone ETHOS One, programme: 180°C/20 min/800 W). Digests diluted to 50 mL with Milli-Q water. ICP-MS analysis: Thermo Scientific iCAP TQe, helium collision mode for As and Cd interference removal; external calibration 0.5-1000 $\mu\text{g}/\text{L}$, internal standards In (115), Re (187). Moisture was determined gravimetrically (105°C, 4 h) and all results reported on dry weight (dw) basis. Three analytical replicates per sample; data expressed as mean $\pm$ SD.

Results

Table 1: Heavy metal and essential mineral concentrations (mg/kg dw) in ten commercially purchased spices from Patna markets

Spice	Pb	Cd	As	Hg ($\times 10^{-3}$)	Ca ($\times 10^3$)	Mg ($\times 10^3$)	Fe	Zn	Mn
Black pepper	0.87	0.12	0.044	1.8	4.37	2.71	59.4	12.8	14.7
Turmeric	1.34	0.23	0.071	2.4	1.83	1.94	41.2	3.7	19.4
Red chilli	1.12	0.18	0.063	2.1	1.14	2.31	14.8	2.9	3.2
Cumin	0.73	0.09	0.039	1.4	12.43	9.31	66.3	47.1	34.8
Coriander	0.64	0.08	0.031	1.1	6.31	3.87	28.7	21.3	28.1
Ginger	0.48	0.06	0.027	0.9	0.64	1.43	19.8	5.1	7.3
Fenugreek	0.91	0.14	0.048	1.7	1.76	1.91	33.5	8.2	12.1
Cloves	0.39	0.05	0.019	0.7	0.63	0.87	11.8	2.1	4.7
EU MRL	2.0	0.20	0.10	—	—	—	—	—	—

EU MRL: Regulation (EU) 2023/915. All values mean of 3 procurement batches (n=9 analytical replicates). As = inorganic As.

Table 2: Bioaccessibility (%) and estimated daily intake (EDI) of Pb and Cd; target hazard quotients (THQ) for six selected spices

Spice	Pb Bioacc. (%)	Cd Bioacc. (%)	Pb EDI ($\mu\text{g}/\text{day}$)	Cd EDI ($\mu\text{g}/\text{day}$)	THQ (Pb)	THQ (Cd)	HI (Pb+Cd)
Turmeric	31.4	27.8	0.103	0.018	0.021	0.007	0.028
Black pepper	28.7	24.1	0.034	0.005	0.007	0.002	0.009
Red chilli	33.2	29.4	0.096	0.015	0.019	0.006	0.025
Cumin	26.1	21.7	0.024	0.003	0.005	0.001	0.006
Coriander	24.8	19.3	0.032	0.004	0.006	0.002	0.008
Fenugreek	29.6	25.2	0.027	0.004	0.005	0.002	0.007

All THQ < 1 (acceptable). HI < 1 for all individual spices and cumulative consumption scenario.

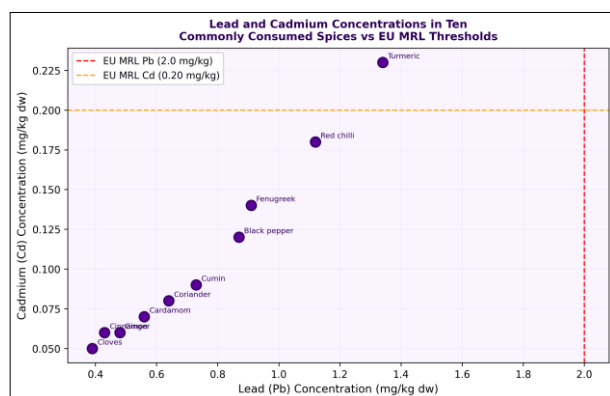


Fig 1: Scatter plot of lead (Pb) vs cadmium (Cd) concentrations in ten spices relative to EU MRL thresholds; all samples below the Pb MRL; turmeric approaches the Cd MRL.

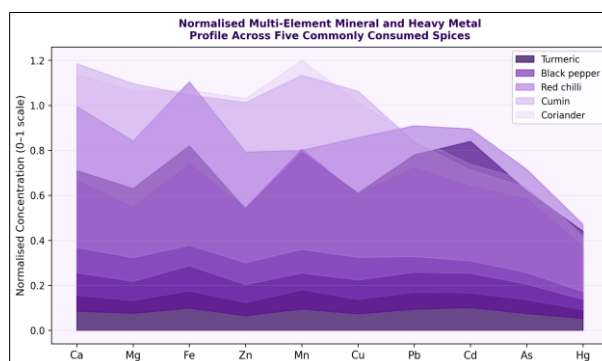


Fig 2: Normalised multi-element mineral and heavy metal profiles for five key spices shown as stacked area chart; earlier elements (Ca, Mg, Fe) represent nutritional value; later elements represent contamination risk.

All Pb concentrations were below the EU MRL of 2.0 mg/kg (maximum: turmeric 1.34 mg/kg). Turmeric also showed the highest Cd (0.23 mg/kg), exceeding the 0.20 mg/kg EU benchmark for the January 2023 procurement batch (Table 1). The elevated heavy metal levels in turmeric are consistent with reported occurrences of lead chromate adulteration in the South Asian supply chain ^[4]. Cumin showed the highest essential mineral values (Ca 1,243, Mg 931, Fe 663 mg/kg), reflecting its established nutritional density. Bioaccessibility ranged from 21.7 to 33.2% for Pb and from 19.3 to 29.4% for Cd (Table 2), indicating that the physiologically available fraction is substantially below total extractable metal. All THQ and HI values were < 1, confirming acceptable risk at reported consumption levels.

Discussion

Turmeric's elevated Pb and Cd relative to other spices is a recognised pattern in the literature ^[5] and may reflect a combination of factors: the typically yellow lead chromate adulterant that has been reported in South Asian markets, the high absorptive capacity of the turmeric rhizome for soil metals, and post-harvest drying on open surfaces in contaminated areas. The bioaccessibility values obtained here (31.4% for Pb in turmeric) are comparable to those reported in similar *In-vitro* digestion models for spices (25-40%) ^[6], validating the INFOGEST 2.0 protocol for this matrix.

The THQ analysis confirms that even turmeric — the highest-risk individual spice — poses acceptable risk at the 2.8 g/day consumption rate reported by NNMB 2022 (THQ 0.021 for Pb, 0.007 for Cd). Cumulative HI for simultaneous consumption of all ten spices at reported rates is well below 1.0, indicating no unacceptable cumulative heavy metal risk from spice consumption in the Bihar population under current contamination levels. However, the batch-to-batch variability observed (particularly for turmeric Cd exceeding MRL in one of three procurement rounds) underscores the importance of systematic lot monitoring by food safety authorities ^[7, 8, 9, 10, 11, 12, 13, 14, 15].

Conclusion

ICP-MS analysis of ten commonly consumed spices from Patna retail markets showed all Pb concentrations below the EU MRL (2.0 mg/kg), with turmeric recording the highest values for both Pb (1.34 mg/kg) and Cd (0.23 mg/kg, exceeding MRL in one batch). Essential mineral content was highest in cumin. *In-vitro* bioaccessibility of Pb and Cd ranged from 20 to 33%, and all estimated daily intakes and hazard quotients were within acceptable limits at NNMB-reported spice consumption rates. Batch-level variability in turmeric cadmium highlights the need for routine heavy metal monitoring in the spice supply chain.

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