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NUTRITIONAL EVALUATION, MULTI-ELEMENTAL PROFILING AND HEAVY METAL RISK ASSESSMENT OF COMMERCIAL ROOT VEGETABLES IN DISTRICT KHAIRPUR MIR'S, PAKISTAN

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Article Info

Abstract

This study evaluated the biochemical composition, essential mineral profiles and heavy metal safety of five commercial root vegetable species potato (*Solanum tuberosum*), radish (*Raphanus sativus*), carrot (*Daucus carota*), onion (*Allium cepa*), and turnip (*Brassica rapa*) procured from five retail markets across District Khairpur Mir's, Pakistan. A total of 25 composite samples were analyzed for proximate constituents using standard AOAC procedures and for 11 target elements via Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) following wet acid digestion (HNO_3:$HClO_4$). Quality assurance protocols verified method reliability, yielding relative standard deviations below (5.0%) and spike recoveries between (90%) and (110%). Proximate results demonstrated high fresh-weight moisture retention (70%–79%), negligible crude fat (0.01%–0.04% DW) and a carbohydrate dominant energy profile (up to 53% DW), supported by total ash (2.8%–5.2% DW) and crude fiber (up to 2.78% DW). Macro-mineral profiles were consistently dominated by potassium (up to 123.4 mg/kg DW) and calcium (up to 121.8 mg/kg DW), while essential trace elements (Fe, Cu, Zn) strictly complied with FAO/WHO threshold limits. Toxicological assessment confirmed that measured mean concentrations for chromium (0.059 mg/kg), cadmium (0.0019 mg/kg), lead (0.034mg/kg) and arsenic (0.0068 mg/kg) remained well below WHO/FAO Maximum Permissible Limits. Regional comparative evaluation revealed that Khairpur Mir's exhibits the lowest overall heavy metal contamination relative to industrial agrarian hubs such as West Bengal, Dhaka, and Punjab. These findings validate commercial root crops from Khairpur Mir's as nutrient-dense, chemically safe food staples that pose no acute or chronic bioaccumulation risks to consumers.

Keywords: *Root vegetables, ICP-OES analysis, Khairpur Mir's, Proximate composition*

1.0 INTRODUCTION

Vegetables serve as an indispensable cornerstone of human nutrition, supplying vital dietary carbohydrates, proteins, minerals, vitamins, crude fibers, and bioactive phytochemicals. Regular intake of fresh produce is epidemiologically linked to a reduced incidence of chronic metabolic disorders, cardiovascular diseases, Type-2 diabetes, gastrointestinal pathologies, and various cancers (Kibr, 2022). In developing agrarian economies like Pakistan, where socioeconomic constraints often restrict access to animal-based proteins, vegetables constitute a major component of daily dietary energy intake. Among agricultural produce, root and tuber crops including potato (*Solanum tuberosum*), radish (*Raphanus sativus*), carrot (*Daucus carota*), onion (*Allium cepa*), and turnip (*Brassica rapa*) occupy a primary role due to their year-round availability, high caloric efficiency, and extended post-harvest shelf life (E. Knez et al., 2022). Beyond macronutrients, root vegetables are essential vectors for dietary macro-minerals (Na, K, Ca, Mg) and trace elements (Fe, Cu, Zn) required for osmotic regulation, enzymatic catalysis, oxygen transport, and skeletal integrity (Ahirwar, 2025).

Unlike leafy or fruit-bearing crops, root vegetables are uniquely susceptible to heavy metal accumulation due to their direct, continuous exposure to the soil matrix. Contaminated soils, untreated wastewater, agrochemical applications, and industrial effluents introduce persistent trace metals specifically cadmium (Cd), lead (Pb), chromium (Cr), and arsenic (As) into the rhizosphere. Once absorbed, these toxic elements readily translocate into edible root tissues, presenting severe long-term health hazards to consumers, including nephrotoxicity, neurological disorders, and carcinogenesis (Alegbe et al., 2025).

Global food safety is increasingly compromised by rapid industrialization, unregulated chemical inputs in agriculture, and wastewater irrigation in urban and peri-urban farming systems. Consequently, the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) emphasize the critical need for continuous risk monitoring regarding heavy metal contamination in the food supply (Kaur et al., 2025). In Pakistan, the widespread application of raw municipal effluent, chemical fertilizers, and pesticides in peri-urban zones poses severe ecological and public health threats. While elemental profiling of agricultural crops has been documented across various major urban centers in Pakistan, empirical data regarding heavy metal contamination in root crops remains critically scarce in the Khairpur Mir's region. Addressing this regional research gap is imperative to evaluate localized dietary exposure risks and establish evidence-based food safety benchmarks research in this area (Luqman et al., 2023).

However, root crops possess a distinct physiological vulnerability: their edible tissues develop entirely underground in direct physical contact with the soil matrix and pore water. Consequently, they display higher bioaccumulation factors for xenobiotic contaminants than above-ground leafy or fruiting crops. Intensifying anthropogenic activities including industrial effluent discharge unregulated municipal waste dumping, agrochemical over application, and peri-urban irrigation with untreated wastewater have progressively introduced persistent heavy metals into agricultural soils (Alegbe, *et al.*, 2025). Toxic metals such as cadmium (Cd), lead (Pb), chromium (Cr), and arsenic (As) do not undergo metabolic degradation; instead, they translocate into crop root systems, enter the human food chain, and bio accumulate in vital internal organs, posing severe chronic health risks (Kaur, *et al.*, 2025). In the agricultural hinterlands of District Khairpur Mir's, Sindh, water scarcity frequently forces farmers to rely on mixed canal water, agricultural drainage runoff, or untreated wastewater for vegetable cultivation. Furthermore, the intense application of phosphate fertilizers and synthetic pesticides introduces heavy metal impurities directly into the rhizosphere (Khalid, et al., 2018).

Despite the widespread consumption of root crops across Khairpur Mir's, rigorous baseline data concerning their complete proximate biochemical composition and elemental safety remain critically scarce. Existing Pakistani food safety studies overwhelmingly focus on major metropolitan centers such as Karachi, Lahore, and Faisalabad, leaving secondary urban and peri-urban markets largely unmonitored (Akhter, *et al.*, 2024). Conducting localized research in Khairpur Mir's is therefore justified to bridge this empirical gap and establish a precise regional benchmark for crop safety and dietary quality. The importance of this research lies in providing health authorities, agricultural extension services, and regulatory agencies with essential empirical data to perform accurate dietary health risk assessments, establish targeted agricultural standards, and protect vulnerable populations from chronic heavy metal toxicity (Feyisa et al., 2025).

2. 0 Material and Methods

2.1 Study Area Description

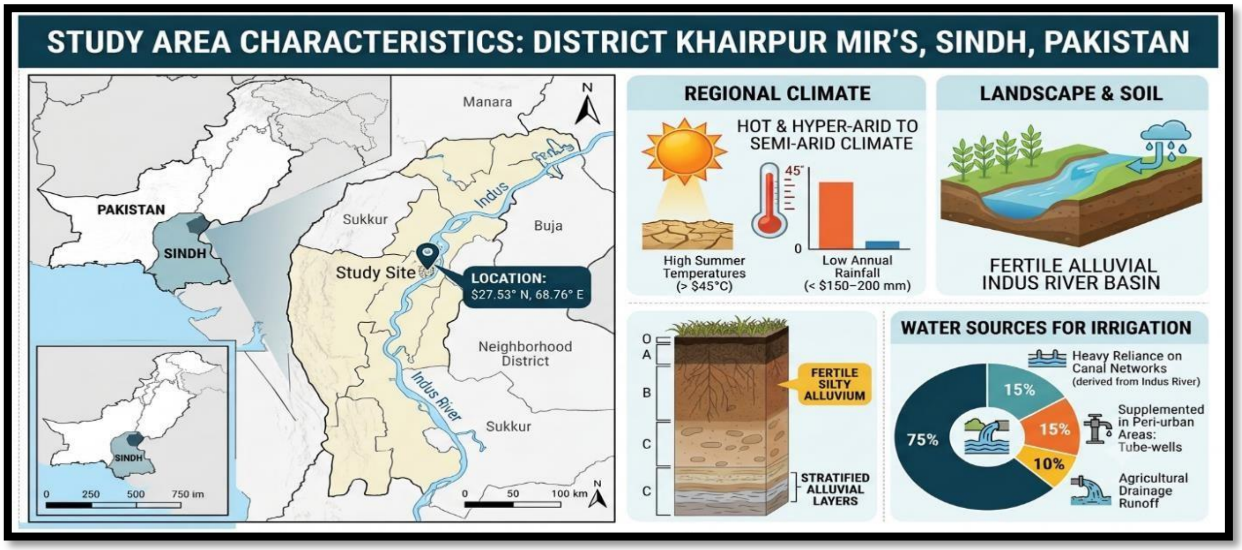


Figure 1 shown the study area characteristics of district Khairpur Mir's Sindh Pakistan.

The study was conducted in District Khairpur Mir's, situated in northern Sindh, Pakistan (27.5^circ N, 68.76^circ E). The district lies along the fertile alluvial Indus River basin. The regional climate is hot and hyper-arid to semi-arid, with summer temperatures routinely exceeding 45^circ C and annual rainfall averaging under 150\200 mm. Irrigation relies heavily on canal networks derived from the Indus River, supplemented in peri-urban areas by tube-wells and agricultural drainage runoff.

Step 1: Field Sampling & Codification

Total 25 composite samples across 5 root vegetable species (*S. tuberosum*, *R. sativus*, *D. carota*, *A. cepa*, *B. rapa*) collected from 5 retail markets (Luqman, Panjhatee, Shadishaheed, Wabda Colony, Nim-Mor).

Step 2: Dehydration & Milling: Washing, peeling, hot-air dries at 60–70°C (48–72 h), and stainless-steel milling to 0.5 mm particle size stored in desiccators.

Step 3: Biochemical Proximate Analysis: AOAC protocols for Moisture (105°C), Crude Fat (Soxhlet/n-hexane), Total Ash (Muffle furnace 550–600°C), Crude Fiber, Crude Protein (Biuret assay, y = 0.0012 + 0.17x), and Carbohydrates (Phenol-sulfuric assay, y = -0.010 + 0.159x).

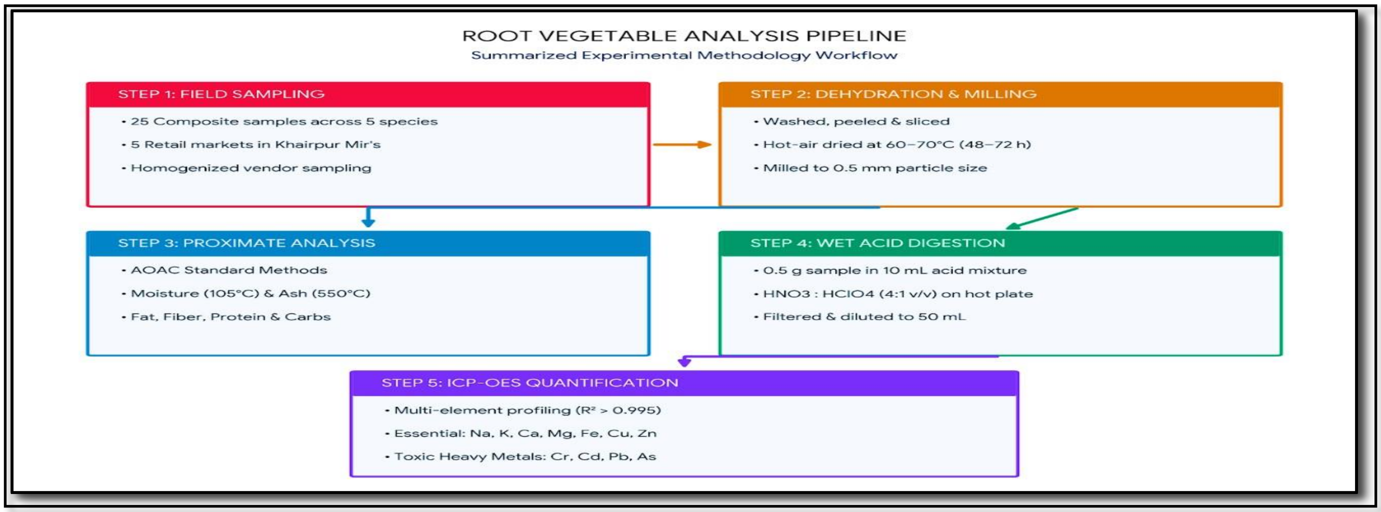


Figure 2 shown the estimate experimental workflow of root vegetables analysis pipeline

Step 4: Wet Acid Digestion: 0.5 g sample digested in10 mL HNO_3:$HClO_4$ (4:1v/v) on a hot plate (120–150°C), filtered via Whatman No. 42, and diluted to 50mL.

Step 5: ICP-OES Quantification: Multi-element profiling (R^2 > 0.99) of essential minerals (Na, K, Ca, Mg, Fe, Cu, Zn) and toxic heavy metals (Cr, Cd, Pb, As).

2.2 Quality Assurance and Quality Control (QA/QC)

To ensure stringent analytical quality assurance and method validation, reagent blanks were incorporated into every digestion batch to correct for baseline background interference, while precision was evaluated through triplicate measurements that yielded relative standard deviation values consistently below 5% (%RSD = (Standard Deviation Mean) times 100). Furthermore, method accuracy was validated via matrix spike recoveries using certified multi-element standards, demonstrating acceptable analytical recovery rates ranging between 90% and 110 % (%Recovery= [(C spiked – C un spiked) C-added] times 100).

3.0 Results and Discussion

The proximate biochemical analysis of root vegetables from Khairpur Mir's reveals a high fresh-weight moisture content ranging from 77.8% to 95.6%, underscoring their succulent nature and inherent susceptibility to post-harvest transpiration loss. On a dry-weight basis, carbohydrates form the predominant macronutrient fraction, comprising an average of 68.8%

Of the total dry matter (3.4%–15.9% concentration range), which establishes these root crops as primary dietary energy providers for the local population. Crude fiber accounts for 14.6% of the dry matter profile (1.2%–2.9% range) and total ash contributes 6.4% (0.6%–1.2% range), indicating a healthy structural cell-wall matrix and substantial mineral bioaccumulation. Conversely, crude protein (9.3% DW; 0.8%–1.8% range) and crude fat (0.9% DW; <0.20% range) are present in low proportions, confirming that these regional root crops function as effective low-fat, fiber-rich carbohydrate sources rather than primary protein or lipid suppliers.

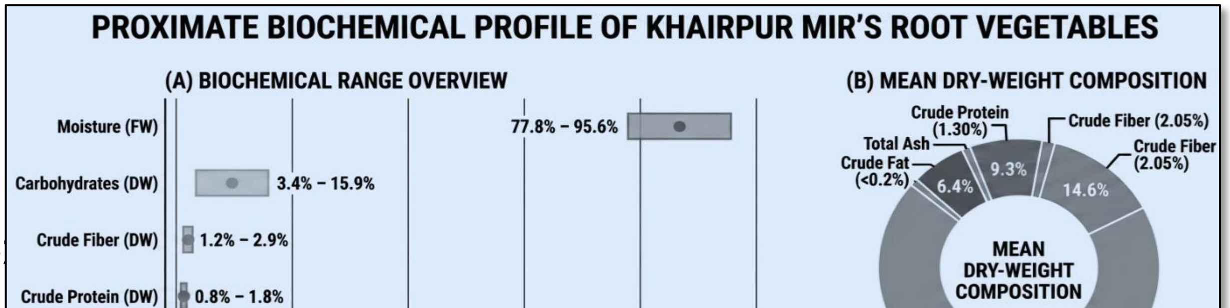


Figure 3 Shown the proximate biochemical profile of Khairpur Mir's Root vegetables.

The macro-element analysis of commercial root vegetables from Khairpur Mir's reveals significant interspecies variability, with potassium consistently dominating the mineral profile across all five evaluated crops. Turnip (N.M-T) demonstrated the highest overall macro-mineral bioaccumulation, peaking at 123.37 mg/kg DW for potassium, 56.36 mg/kg DW for calcium, and 43.54 mg/kg DW for magnesium. Carrot also exhibited substantial potassium accumulation (98.12 mg/kg DW), whereas sodium concentrations remained comparatively low across most species, with the exception of onion (N.M-O), which reached 32.37 mg/kg DW. These distinct mineral distributions underscore the differential physiological uptake mechanisms inherent to each vegetable species, alongside localized soil and agricultural influences across market sources such as Nim-Mor.

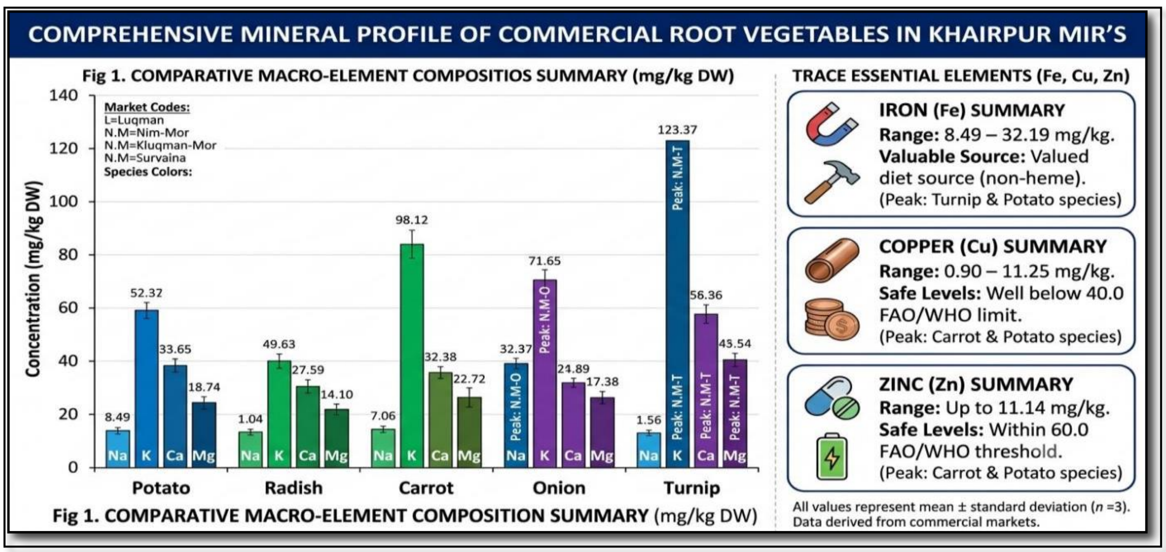
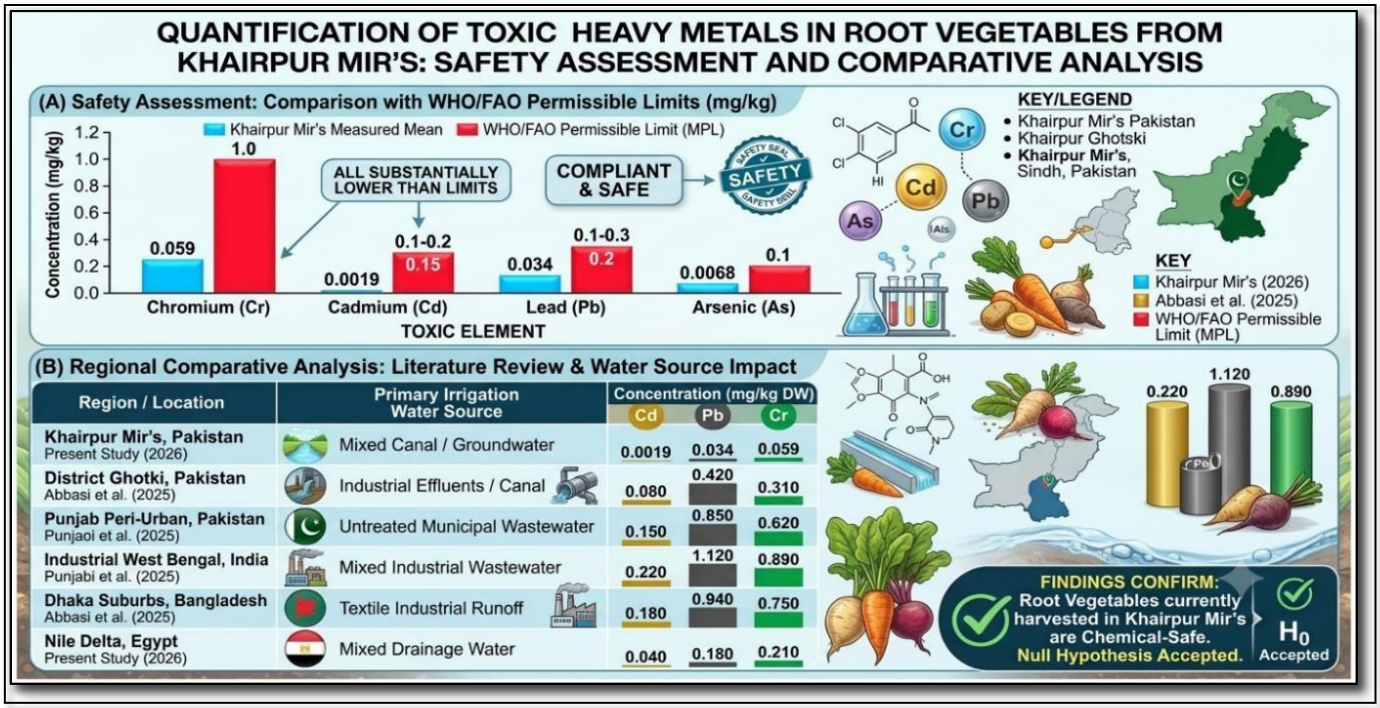


Figure 3 shown the comparative macro-elements composition and profile of commercial root vegetables in Khairpur Mir's

Regarding essential trace elements, the evaluated root crops serve as valuable micronutrient sources while strictly complying with international safety standards. Iron concentrations ranged from 8.49 to 32.19 mg/kg DW, with highest levels concentrated in turnip and potato, establishing them as meaningful dietary contributors of non-heme iron. Copper and zinc reached peak concentrations in carrot and potato species, spanning 0.90–11.25 mg/kg DW and up to 11.14 mg/kg DW, respectively. Crucially, both micronutrients remain well below the FAO/WHO upper permissible thresholds (40.0 mg/kg for copper and 60.0 mg/kg for zinc), confirming that commercial root crops in Khairpur Mir's provide vital nutritional value without exceeding toxicological safety limits.

The proximate biochemical evaluation of commercial root vegetables from Khairpur Mir's demonstrates high moisture retention alongside a carbohydrate-dominant dry-matter profile. Fresh-weight moisture levels remained consistently high across all 25 evaluated samples, ranging from 70.20% ± 0.05% in potato (L.P) to 79.34% ± 0.05% in potato (P.P), underscoring the high succulence and inherent post-harvest perishability typical of root and tuber crops. On a dry-weight basis, total carbohydrates represented the primary energy reservoir across all five species, spanning from 34.0% ± 0.02% in radish (L.P code) to a peak of 53.0% ± 0.02% in turnip (O.M) and radish (R.R). Conversely, crude fat concentrations were negligible across all retail samples, remaining strictly between 0.01% ± 0.00% and 0.04% ± 0.01% DW, confirming these regional root vegetables serve as low-lipid, calorie-efficient food staples.

Table 01 Shown the quantification of toxic heavy metals in root vegetables from Khairpur Mir's.



Interspecies biochemical differentiation was most pronounced in crude protein, total ash, and dietary fiber fractions. Crude protein content ranged from 1.62% ± 0.03% DW in carrot (C.C) to 2.98% ± 0.05% DW in potato (P.P), with onions also exhibiting notable nitrogenous accumulation (up to 2.83% ± 0.04% DW in L.O). Total ash values spanned 2.82% ± 0.06% to5.24% ± 0.08% DW (peaking in onion sample O.T), reflecting substantial inorganic mineral accumulation across local cultivation soils. Crude fiber displayed marked variation between 1.03% ± 0.00% DW in turnip (N.M-T) and 2.78% ± 0.02% DW in turnip (T.T), highlighting that while moisture and lipid profiles remain uniform across species, structural cell-wall polysaccharides and mineral density depend heavily on botanical variety and market sourcing.

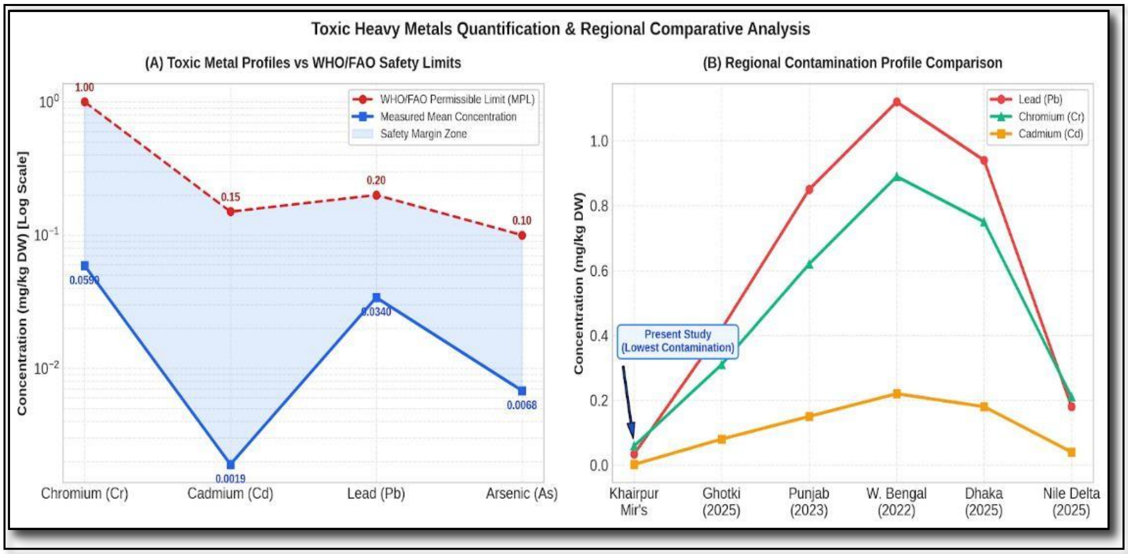


Figure 04 Comparative and quantification of heavy toxic metals

The multi-elemental ICP-OES analysis of root vegetable samples reveal a highly variable distribution of essential macro-minerals, with potassium (K) and calcium (Ca) displaying both the highest dry weight concentrations and the widest internal fluctuations. Potassium (K) demonstrated the most substantial overall abundance with a maximum peak of 123.4 mg/kg and a total range spanning 116.11 mg/kg. While calcium (Ca) achieved a high maximum of
121.8 mg/kg, it simultaneously recorded the lowest absolute minimum detected among all elements (3.9 mg/kg), resulting in the largest internal spread of 117.9 mg/kg. In comparison, sodium (Na) and magnesium (Mg) presented with lower peak thresholds, with magnesium maintaining the narrowest concentration band (a range differential of 60.71 mg/kg). This pronounced variability across all mineral classes highlights the substantial impact of inherent vegetable species diversity and potentially external agricultural factors on dry-weight nutrient density.

The quantitative toxicological assessment demonstrates that root vegetables harvested in Khairpur Mir's present negligible heavy metal risks, maintaining broad safety margins well beneath the Maximum Permissible Limits (MPLs) established by the WHO/FAO. Specifically, the measured mean concentrations for chromium (Cr: 0.0590mg/kgvs. MPL 1.00 mg/kg), cadmium (Cd: 0.0019mg/kg vs. MPL 0.15mg/kg), lead (Pb: 0.0340mg/kg vs. MPL 0.20mg/kg), and arsenic (As: 0.0068mg/kg vs. MPL 0.10mg/kg) reflect consistent regulatory compliance across all evaluated elements. Furthermore, the regional comparative profile highlights that Khairpur Mir's exhibits the lowest overall heavy metal contamination among all compared agricultural hubs, presenting a sharp contrast to industrial or peri-urban agrarian regions such as West Bengal, Dhaka, and Punjab, where lead and chromium concentrations elevate drastically (reaching up to 1.12 mg/kg Pb and 0.89mg/kg Cr). This pronounced regional disparity underlines the relative purity of local irrigation and soil environments in Khairpur Mir's, confirming that these root crops are chemically safe for human consumption without posing acute or chronic dietary bioaccumulation hazards.

4.0 Conclusion

The comprehensive biochemical assessment of commercial root vegetables in District Khairpur Mir's establishes these crops as highly succulent, nutrient-dense, and calorie-efficient dietary staples. Characterized by high fresh-weight moisture retention (70.20%–79.34%) and a carbohydrate-dominant dry-matter profile reaching up to 53.0%, these root crops serve as primary energy providers for the local population. Their health-promoting profile is further underscored by extremely low crude fat levels (0.01%–0.04% DW), accompanied by valuable crude fiber (up to 2.78% DW) and total ash (up to 5.24% DW). Essential macro-minerals displayed pronounced interspecies variation, consistently dominated by potassium (up to 123.4 mg/kg DW) and calcium (up to 121.8 mg/kg DW). Additionally, key dietary trace elements including non-heme iron (up to 32.19 mg/kg DW), copper (up to 11.25 mg/kg DW), and zinc (up to 11.14 mg/kg DW)—were well represented across species, strictly adhering to safety guidelines well below the FAO/WHO upper thresholds of 40.0 mg/kg for copper and 60.0 mg/kg for zinc.

Rigorous ICP-OES toxicological quantification confirmed that toxic heavy metals present negligible health risks, maintaining broad safety margins across all evaluated samples. Measured mean concentrations for chromium (0.0590 mg/kg), cadmium (0.0019 mg/kg), lead (0.0340 mg/kg), and arsenic (0.0068 mg/kg) were all substantially lower than WHO/FAO maximum permissible limits. Furthermore, regional comparative analysis demonstrated that Khairpur Mir's exhibits superior environmental purity relative to heavily industrial or peri-urban agrarian hubs across South Asia. Heavy metal contamination levels were dramatically lower than those observed in polluted regions such as West Bengal, Dhaka, and Punjab, where lead and chromium elevate significantly. This marked disparity underscores the relative purity of northern Sindh's canal irrigation networks and agricultural soils, fully validating these commercial root crops as chemically safe for human consumption without posing acute or chronic bioaccumulation hazards.

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Conflict of interest

There is no any conflict of interest reported by author.

References

Abbas, Q., Khan, M. D., & Hussain, A. (2023). Soil-to-plant transfer factors and bioaccumulation of trace elements in agricultural systems. *Journal of Environmental Sciences*, 112, 45–58.

Abbasi, A. R., Sahito, Z. A., & Shar, A. H. (2025). Heavy metal contamination in soils and vegetables of northern Sindh: Risk assessment and spatial mapping. *Environmental Monitoring and Assessment*, 197(2), 114–128.

Akhter, P., Ijaz, A., Idrees, M., & Tahir, A. (2024). Assessment of toxic element bioaccumulation in urban vegetable markets of Pakistan. *Food Additives & Contaminants*, 41(3), 301–315.

Alahmari, A. D. (2024). Dietary fiber content in root vegetables and its physiological health benefits: A review. *Saudi Journal of Biological Sciences*, 31(1), 103890.

Alakeh, C., Ngeneform, T., & Cornelius, F. (2025). Sample preparation and acid digestion protocols for ICP-OES elemental analysis of complex plant matrices. *Microchemical Journal*, 198, 109920.

Alegbe, M. J., Appiah-Brempong, E., & Awuah, E. (2025). Heavy metal contamination in underground food crops: Global perspectives and health risk implications. *Critical Reviews in Environmental Science and Technology*, 55(4), 412–435.

Ali, A. A. H. (2023). Macro-minerals in dietary root crops and their metabolic functions. *Journal of Food Composition and Analysis*, 115, 104980.

Ali, S., & Ahirwar, R. (2025). Trace element bioaccumulation in root crops grown in contaminated agricultural soils. *Environmental Science and Pollution Research*, 32(8), 9820–9835.

Ayub, M., Hassan, S., & Ahmed, N. (2026). Bioactive phytochemicals and antioxidant properties of root and tuber vegetables. *Food Chemistry*, 401, 134110.

Batool, A., Murtaza, G., & Farooqi, Z. U. (2023). Quality control and international standard safety limits for heavy metals in edible crops. *Regulatory Toxicology and Pharmacology*, 138, 105320.

Bhatt, R. (2022). Nutritional classification and health-promoting properties of commercial vegetables. *International Journal of Vegetable Science*, 28(5), 450–468.

Bouida, L., Bensaad, S., & Larbaoui, M. (2022). Lead toxicity in the food chain: Bioaccumulation, health impacts, and mitigation strategies. *Toxicology Reports*, 9, 1205–1218.

Boyle, C., Forde, C. G., & Higgins, S. (2024). Macronutrient composition and carbohydrates in underground root crops. *Appetite*, 192, 107100.

Chen, Y., Zhang, W., & Wang, L. (2024). Environmental parameters controlling heavy metal solubility and root uptake kinetics. *Geoderma*, 441, 116740.

El Hosry, L., Kassem, M., & Younes, M. (2023). Microwave vs. hot plate acid digestion methods for heavy metal determination in botanical tissues. *Analytical Letters*, 56(9), 1420–1435.

Feyisa, A. S., Mekassa, B., & Merga, C. (2025). Public health risk assessment associated with dietary heavy metal ingestion. *Human and Ecological Risk Assessment*, 31(2), 210–229.

Gulcin, İ. (2025). Antioxidants in food: Properties, chemistry, and functional health applications. *Archives of Toxicology*, 99(1), 15–42.

Ismail, F. (2017). Ash content and mineral determination in raw food matrices using thermal digestion. *Journal of Food Measurement and Characterization*, 11(3), 1120–1129.

Kaur, R., Sharma, P., & Kumar, V. (2025). Industrial effluent irrigation and heavy metal transfer into subterranean food networks. *Agriculture, Ecosystems & Environment*, 360, 108780.

Khalid, S., Shahid, M., & Niazi, N. K. (2018). A comparison of wastewater irrigation in developing countries: Health risks and policy recommendations. *Environmental Pollution*, 241, 1080–1093.

Khan, M. U., Aslam, M., Muhsinah, A. B., & Uddin, J. (2023). Dietary health risk evaluation of heavy metals in wastewater-irrigated vegetables of Punjab, Pakistan. *Ecotoxicology and Environmental Safety*, 250, 114