



RESEARCH ARTICLE

Macro- and microelement composition of *Cichorium intybus* L. from Uzbekistan

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Abstract

The present study investigates the distribution of macro- and microelements in *Cichorium intybus* L. collected from different ecological sites within the Samarkand region of Uzbekistan. Elemental analysis was performed separately for aboveground organs (leaves and stems) and underground parts (roots) following standardised sample preparation protocols. Quantitative determination of elemental composition was carried out using X-ray fluorescence spectroscopy (XRF, Rigaku, Japan). The analysis confirmed the accumulation of essential macroelements, including calcium, potassium, magnesium and sodium, along with a range of trace elements such as iron, zinc, copper, manganese, cobalt, nickel, chromium, lead and molybdenum. Distinct organ-specific patterns were observed: root tissues were characterised by elevated levels of calcium and potassium, while leaf samples showed comparatively higher concentrations of iron, zinc and manganese, which are closely associated with metabolic and photosynthetic activity. Variations in elemental content were also influenced by local environmental conditions. These results highlight the mineral richness of *C. intybus* and support its potential relevance for further phytochemical, nutritional and pharmacological investigations.

Keywords: *Cichorium intybus*; macroelements; microelements; Uzbekistan; X-ray fluorescence spectroscopy

Introduction

Cichorium intybus L. (common chicory) is a perennial herbaceous species belonging to the family Asteraceae and is widely distributed throughout Uzbekistan. The plant commonly occurs in regions such as Samarkand, Tashkent, Fergana and Kashkadarya, where it grows under both natural and cultivated conditions (1). Owing to its high ecological plasticity and ability to adapt to diverse environmental factors, chicory has become a stable component of regional plant communities and an important biological resource, as demonstrated in studies reporting its wide ecological amplitude and tolerance to variable soil and climatic conditions. The species has long been valued for its wide range of applications in traditional medicine, food technology and pharmaceutical industries (2). Chicory roots are recognised as a rich source of inulin, a polysaccharide with pronounced prebiotic properties that stimulates the growth of beneficial intestinal microbiota. In addition to inulin, various biologically active compounds including bitter glycosides, phenolic substances, organic acids and pectic compounds have been reported in different plant organs, enhancing its nutritional and therapeutic relevance (2).

Mineral elements represent another critical group of constituents in medicinal plants. Both macro- and microelements are involved in essential physiological processes such as

photosynthesis, respiration, enzymatic regulation, protein synthesis and antioxidant defense mechanisms (3). Their accumulation in plant tissues is strongly influenced by environmental conditions, including soil geochemistry, moisture availability, pH level and overall ecological characteristics, which collectively determine element uptake and spatial distribution within the plant (4).

Previous international studies have described the mineral composition of *C. intybus* grown in European and Mediterranean regions, reporting relatively stable patterns of macro element accumulation alongside moderate variability of trace elements depending on soil type and climatic conditions. Regional investigations conducted in different parts of Central Asia have likewise indicated organ-specific differences in mineral accumulation; however, these studies have largely focused on cultivated populations or have provided generalised data without detailed regional differentiation (5).

In Uzbekistan, available studies have demonstrated variability in the mineral composition of chicory roots and leaves, yet comprehensive data on plants growing in natural habitats under specific local ecological conditions remain limited. In particular, the Samarkand region characterised by distinct soil climatic features have not been sufficiently examined in terms of its influence on the macro- and microelement profiles of

Cichorium intybus L. Thus, comparative evaluation of mineral accumulation patterns in naturally growing populations represents an important gap in current knowledge.

Therefore, the present study provides new region-specific data on the macro- and microelement composition of *C. intybus* collected from natural habitats of the Samarkand region. By comparing the obtained results with previously reported regional and international data, this research highlights distinctive accumulation patterns associated with local ecological conditions. These findings expand existing knowledge on the mineral nutrition of chicory and contribute to a more accurate assessment of its nutritional value, ecological adaptability and suitability as a source of phytotherapeutic raw material.

Materials and Methods

Study area and environmental characteristics

Plant material of *C. intybus* was collected in 2024 during the middle stage of the vegetative period from natural populations located in the Pstdargom and Nurobod districts of the Samarkand region, Uzbekistan. The investigated areas are situated within a sharply continental climatic zone, where summer air temperatures commonly reach 32–38 °C, while winter temperatures decrease to approximately -2 to -4 °C.

Soil cover in both locations is represented mainly by alluvial loam and sandy-loam soils with a slightly alkaline reaction (pH 7.1–7.5). Such edaphic conditions are considered favourable for the development of mineral-rich and metal-accumulating herbaceous plant species (6). However, it should be noted that the present study did not include direct elemental analysis of soil samples. Therefore, the interpretation of mineral accumulation patterns in *C. intybus* is based on general soil physicochemical characteristics rather than quantitative soil mineral data. This limitation should be considered when evaluating plant–soil element relationships and indicates the need for integrated soil–plant elemental analyses in future investigations.

Geographical coordinates of all sampling sites were recorded using a global positioning system (GPS). At each locality, three independent microplots were established to ensure spatial representativeness (7). Within each microplot, five mature and morphologically uniform plants were randomly selected, resulting in a total of 15 individual plants per site. Plant material was collected separately from roots, stems, and leaves of each individual plant, providing 15 biological replicates per organ for elemental analysis. This sampling design enabled a robust comparative assessment of organ-specific elemental accumulation and enhanced the reproducibility of the obtained results.

Sample preparation

Immediately after collection, fresh plant samples were placed in sterile polyethylene bags and transported to the laboratory. The material was thoroughly washed with distilled water to remove adhering soil particles and airborne contaminants, followed by a final rinse to eliminate residual impurities. Drying was carried out under shaded conditions at room temperature (approximately 25 °C) for 72 hr. This procedure was selected to prevent thermal degradation of plant tissues and redistribution of mineral elements, in accordance with commonly accepted protocols for plant elemental analysis (7, 8).

Grinding and particle size homogenisation

After drying, plant tissues were mechanically ground using a laboratory ball mill for 15–20 min until a homogeneous powder was obtained. The resulting material was passed through laboratory sieves to standardise particle size within the range of 0.5–2.0 mm. Particle size uniformity is a critical requirement for X-ray fluorescence analysis, as it reduces matrix-related variability and enhances measurement accuracy (8).

X-ray fluorescence analysis

Quantitative determination of macro- and microelements was performed using an energy-dispersive X-ray fluorescence spectrometer (Rigaku, Japan). Prior to analysis, powdered samples were placed into plastic sample cups sealed with 4 µm polypropylene X-ray-transparent films, which are suitable for biological matrices (9). For each measurement, approximately 2–3 g of sample was introduced into the cup and gently compressed to obtain a flat and uniform surface.

The analytical conditions were set as follows: X-ray tube voltage of 50 kV and tube current of 1 mA; measurements for light elements (Na–Mg) were conducted under vacuum conditions. The energy range was 0–40 keV, with a counting time of 200 s per sample. Element detection was performed using a Si-PIN energy-dispersive detector. Spectral processing, including background correction, peak separation, and matrix correction, was carried out automatically using the fundamental parameters (FP) method incorporated in the Rigaku software.

Calibration and quality assurance

Instrument accuracy and analytical reliability were assessed using the certified reference material NIST SRM 1573a (Tomato leaves), which is widely applied in plant elemental studies. To minimise instrumental drift, recalibration was performed after every 10 measurements. Detection limits and analytical precision complied with internationally accepted standards (2), with limits of detection ranging from 5 to 10 mg/kg for macroelements and from 0.5 to 5 mg/kg for microelements. Measurement repeatability was maintained within an error margin of less than 3%.

Statistical Analysis

All samples were analyzed in triplicate, and the results were expressed as mean ± standard deviation (SD). Differences in elemental concentrations among plant organs were evaluated using one-way analysis of variance (ANOVA). When statistically significant differences were detected ($p < 0.05$), Tukey's honestly significant difference (HSD) post hoc test was applied to identify pairwise differences between organs. Statistical calculations and graphical visualisation were performed using OriginPro 2021 software.

Results

X-ray fluorescence analysis demonstrated that the roots of *C. intybus* accumulate a broad spectrum of mineral elements, including more than fourteen macro- and microelements ranging from sodium (Na) to heavier essential trace metals. The detected elemental profile indicates that root tissues represent a mineral-enriched plant organ with considerable physiological and nutritional relevance.

Elemental composition of roots

Among the detected elements, potassium (K) and calcium (Ca) were dominant, accounting for the highest mass fractions in root samples. Potassium constituted 49.2 % of the total elemental content, while calcium represented 26.5 %, confirming their quantitative predominance in root tissues. The high potassium content reflects its role in osmotic regulation, enzyme activation and ion transport, whereas calcium is essential for maintaining cell wall integrity, membrane stability and intracellular signal transduction (5).

Iron (Fe), phosphorus (P) and magnesium (Mg) were present at appreciable concentrations, jointly contributing 4.5–12.0 % of the total mineral content. Quantitative analysis revealed iron concentrations of approximately 45 mg kg⁻¹, phosphorus 38 mg kg⁻¹ and magnesium 62 mg kg⁻¹ in root tissues. Iron plays a key role in electron transport chains and redox reactions, phosphorus is essential for ATP synthesis and nucleic acid formation and magnesium functions as a central component of chlorophyll molecules and photosynthetic enzymes (6, 10). The proportional distribution of macro- and microelements in root tissues is summarised in Fig. 1.

Sodium was detected only at trace levels (<1.0 mg kg⁻¹), indicating limited accumulation in root tissues (Fig. 2), which is consistent with previously reported data. Quantitative assessment of trace elements showed concentrations of 28 mg kg⁻¹ for zinc, 12 mg kg⁻¹ for manganese, 6 mg kg⁻¹ for copper and 2 mg kg⁻¹ for molybdenum. In leaf tissues, the contents of Fe, Zn and Mn were 1.3–1.6 fold higher than those observed in roots, highlighting their increased involvement in photosynthetic and enzymatic processes.

Trace elements such as Cl, Br, S, Zn, As, Mn, Cr and Cu were detected at concentrations ranging from 0.01 % to 6.0 % of the total elemental composition (Fig. 3), indicating selective accumulation patterns across different element groups.

Spectral characteristics

The XRF spectra of root samples exhibited distinct emission peaks corresponding to both macro- and microelements (Fig. 4). In the low-energy region (1.0–3.0 keV), pronounced K α peaks of Na, Mg, P and Cl were observed, reflecting their presence at lower atomic masses. Secondary K β ₁ emissions of Zn and Cl were also detected within this region. Strong K α and K β ₁ peaks of potassium and calcium appeared in the 3.0–4.0 keV range, consistent with their high quantitative abundance. Transition metals, including Cr, Cu, Zn, As and Br, displayed characteristic K α peaks in the mid-energy region, confirming their trace-level occurrence. Iron exhibited a prominent

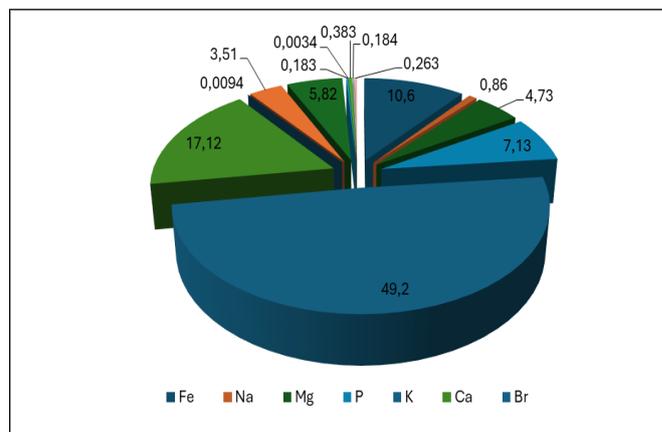


Fig. 2. Macro- and microelement composition of *Cichorium intybus* root samples (expressed as mass %).

K α peak between 6.0 and 7.0 keV, accompanied by a smaller K β ₁ peak, reflecting its relatively elevated concentration. The complete mass percentage distribution of detected elements is presented in Fig. 5.

Elemental composition of seeds

XRF analysis of *C. intybus* seeds revealed high concentrations of potassium and calcium, which together accounted for more than 65 % of the total mineral content, indicating substantial energetic and physiological value (11). Iron and zinc were also present at elevated levels, reaching approximately 52 mg kg⁻¹ and 34 mg kg⁻¹, respectively. These elements serve as essential cofactors in antioxidant systems, enzymatic regulation and immune-related functions (12).

The seed mineral profile included major macroelements (K, Ca, Mg and Na) along with essential microelements such as Fe, Zn, Cu and Mn. The relatively balanced distribution of these elements supports the high biological value of chicory seeds and their potential use as raw material for nutraceuticals, dietary supplements and phytopharmaceutical products (11, 12). In particular, the increased Fe and Zn contents are of practical importance due to their frequent incorporation into functional food formulations and pharmaceutical preparations.

Variations in the mineral composition of seeds are influenced by environmental and edaphic factors, including soil pH, moisture availability, temperature regime and soil texture. These ecological parameters regulate mineral uptake and accumulation in higher plants (10, 12), which corresponds well with the heterogeneous environmental conditions observed across different regions of Uzbekistan (11).

Analyzed result(FP method)							
No.	Component	Result	Unit	LLD	LLQ	Element line	Intensity(cps/ μ A)
1	Na	0,86	mass%	0,236	0,709	M:Mg-K α	0,00451
2	Mg	4,73	mass%	0,831	2,49	L:Mg-K α	0,00421
3	Br	0,0094	mass%	0,0496	0,0021	M:Br-K α	2,61912
4	P	7,13	mass%	0,0241	0,0722	L:P-K α	2,94210
5	S	3,51	mass%	0,0132	0,0396	L:S-K α	6,44701
6	Cl	5,82	mass%	0,0119	0,0358	L:Cl-K α	18,45726
7	K	49,2	mass%	0,123	0,369	M:K-K α	1,46032
8	Ca	17,12	mass%	0,220	0,659	M:Ca-K α	1,01329
9	Fe	10,6	mass%	0,0093	0,0279	M:Fe-K α	3,07119
10	Zn	0,183	mass%	0,0023	0,0070	M:Zn-K α	0,29681
11	As	0,0034	mass%	0,0653	0,196	M:As-K α	0,04888
12	Mn	0,383	mass%	0,0157	0,0470	M:Mn-K α	0,09333
13	Cr	0,184	mass%	0,0143	0,0430	M:Cr-K α	0,00432
14	Cu	0,263	mass%	0,0034	0,0101	M:Cu-K α	0,29129

Fig. 1. Analysed elemental composition of *Cichorium intybus* root samples using the fundamental parameters (FP) method.

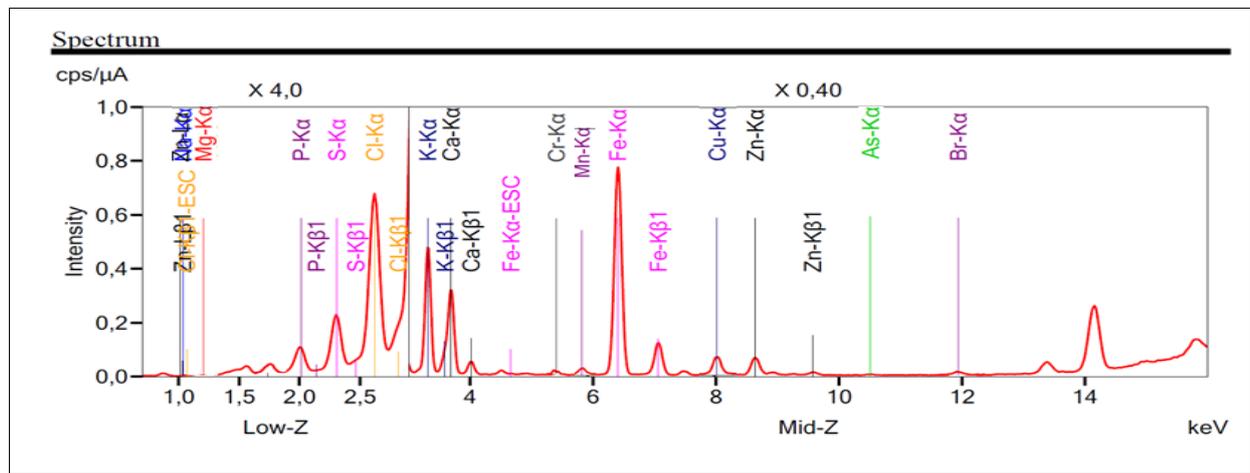


Fig. 3. X-ray fluorescence spectrum of *Cichorium intybus* root samples.

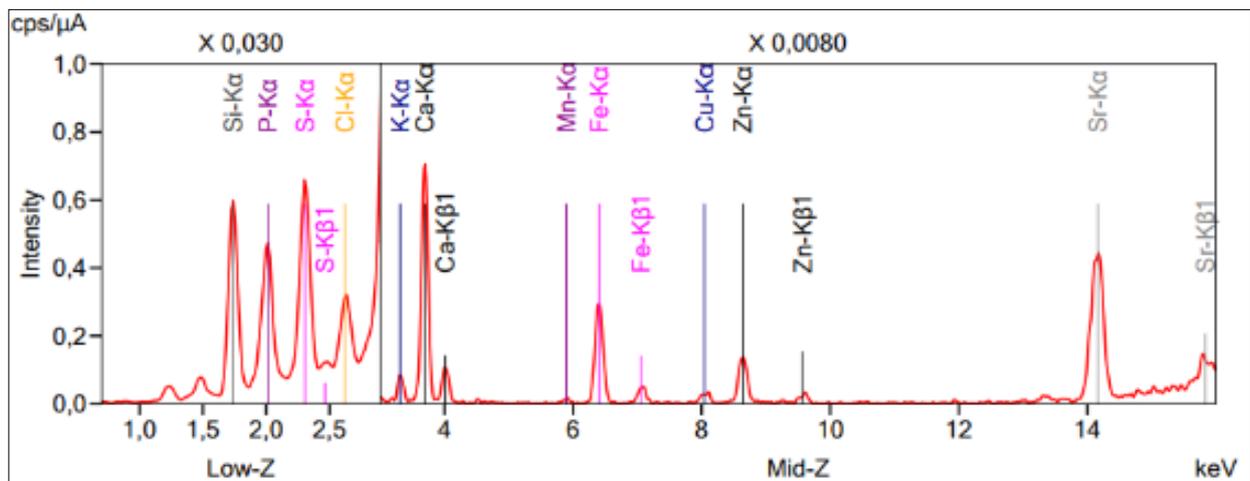


Fig. 4. X-ray fluorescence spectrum of *Cichorium intybus* seed samples.

Meas. cond.							
Diaphragm	DE-1mm	Atmosphere	Helium	Sample spin	None	Meas. order optimization	Yes
Condition name	Primary filter	Tube voltage(kV)	Tube current(μA)	ST(μsec)	Meas. time(sec)	Dead time(%)	
Mid-Z	C	35,0	342	1,6	100	0,3	
Low-Z	Open	6,5	999	1,6	100	1,6	
Analyzed result(FP method)							
No.	Component	Result	Unit	LLD	LLQ	Element line	Intensity(cps/μA)
1	S	3,10	mass%	0,0216	0,0648	L:S-Kα	0,15408
2	Cl	0,779	mass%	0,0240	0,0720	L:Cl-Kα	0,05676
3	Zn	0,804	mass%	0,0196	0,0587	M:Zn-Kα	0,01196
4	Mn	(0,311)	mass%	0,135	0,405	M:Mn-Kα	0,00070
5	Cu	0,245	mass%	0,0291	0,0872	M:Cu-Kα	0,00248
6	Br	ND	mass%				
7	Na	ND	mass%				
8	Mg	ND	mass%				
9	K	5,84	mass%	0,793	2,38	M:K-Kα	0,00400
10	Ca	67,8	mass%	0,572	1,71	M:Ca-Kα	0,04869
11	P	4,17	mass%	0,0574	0,172	L:P-Kα	0,09294
12	Si	9,55	mass%	0,0524	0,157	L:Si-Kα	0,11175
13	Fe	6,82	mass%	0,0793	0,238	M:Fe-Kα	0,02451
14	Co	ND	mass%				
15	Ni	ND	mass%				
16	Sr	0,624	mass%	0,0097	0,0291	M:Sr-Kα	0,05481
Spectrum							

Fig. 5. Mass percentage composition of macro- and microelements in *Cichorium intybus* seed samples (calculated relative to a total elemental content of 100 %).

Discussion

The present findings confirm that *C. intybus* accumulates a wide spectrum of essential macro- and microelements in both underground and reproductive organs, highlighting its nutritional

and physiological relevance. The predominance of potassium and calcium in roots and seeds emphasises their fundamental roles in ionic homeostasis, osmotic adjustment and maintenance of structural integrity in plant tissues (2-4). Similar elemental distribution patterns have been consistently reported for

herbaceous species, in which potassium represents the major intracellular cation, while calcium contributes to mechanical strength and resistance to environmental stress factors (5–7).

Considerable levels of iron, zinc, manganese and copper observed in the analysed samples are in good agreement with earlier investigations conducted under the ecological conditions of Uzbekistan (2–5) as well as with international data on chicory and other mineral-rich members of the family Asteraceae (1–3). Among these elements, iron and zinc are of particular importance due to their involvement in redox regulation, enzymatic activity and antioxidant defense systems. Their elevated concentrations in seeds substantially enhance the pharmacological and functional value of *C. intybus*, supporting its traditional medicinal use and expanding application in functional food and nutraceutical formulations (2, 3).

In addition to essential elements, trace amounts of potentially toxic metals, including lead (Pb), chromium (Cr), arsenic (As) and nickel (Ni), were detected. Importantly, the concentrations of these elements remained below internationally accepted permissible limits for medicinal plants and herbal raw materials as established by the World Health Organization and related regulatory frameworks. Specifically, Pb and As contents did not exceed recommended thresholds (typically ≤ 10 mg kg⁻¹ for Pb and ≤ 1 -2 mg kg⁻¹ for As), while detected levels of Cr and Ni were within ranges considered safe for nutraceutical and phytotherapeutic use. These findings indicate that, under the studied environmental conditions, *C. intybus* does not pose a toxicological risk associated with heavy metal accumulation and is suitable for use in food and pharmaceutical applications.

Organ-specific differences in elemental accumulation reflect the distinct physiological functions of roots, leaves and seeds. Root tissues preferentially accumulate calcium, magnesium and iron, which are associated with metabolic regulation, nutrient storage and electron transport processes. In contrast, higher concentrations of iron, zinc and manganese in aerial organs especially leaves, as reported in previous studies (9) are closely related to their roles in photosynthesis, chlorophyll biosynthesis and the activity of metalloenzymes involved in light-dependent reactions.

The uptake and distribution of mineral elements in *C. intybus* are strongly modulated by environmental parameters, including soil pH, moisture availability, temperature regime and mineral composition (9, 10). The ecological heterogeneity of the Samarkand region may therefore contribute to the pronounced mineral richness observed in the studied populations. Comparable trends have been described for metal-accumulating plants inhabiting semi-arid ecosystems, where edaphic characteristics and climatic stress conditions promote enhanced accumulation of nutrients and trace elements in different plant organs (9, 11).

From an applied perspective, the elemental profiles of chicory roots and seeds obtained by X-ray fluorescence analysis indicate that *C. intybus* represents a promising source of raw material for dietary supplements, nutraceuticals and phytopharmaceutical products. The substantial presence of biologically active microelements such as iron, zinc and manganese supports the potential use of chicory-based preparations in metabolic regulation and immune-related functions. Importantly, the XRF derived mineral composition established in this study provides a reliable and reproducible reference dataset for comparative evaluation of chicory populations growing under different ecological conditions.

X-ray fluorescence analysis offers a robust, non-destructive and multi-elemental approach for assessing mineral composition in medicinal plants, enabling simultaneous detection of macro- and microelements with sufficient sensitivity for nutritional and safety evaluation. Within this context, the application of XRF-based elemental profiling represents an effective strategy for characterising mineral richness and organ-specific accumulation patterns in *C. intybus*, thereby strengthening the scientific and practical relevance of the present study without reliance on additional analytical techniques.

Conclusion

This study demonstrates that *C. intybus* growing under the ecological conditions of the Samarkand region is characterised by a mineral-rich profile, with roots and seeds acting as the principal reservoirs of macro- and microelements. X-ray fluorescence analysis revealed the dominance of potassium and calcium, alongside nutritionally important trace elements such as iron, zinc, manganese and copper, which are directly involved in metabolic regulation and enzymatic processes.

From a practical perspective, the established elemental composition supports the suitability of chicory roots and seeds as raw materials for functional foods, nutraceuticals and phytotherapeutic products. The detection of potentially toxic elements at levels below internationally accepted limits further confirms the safety of the plant material studied for medicinal and food-related applications.

Future research should focus on integrated soil–plant elemental assessments, seasonal and geographical variability of mineral accumulation and the bioavailability of key elements in chicory-derived products. Such studies will contribute to a more comprehensive evaluation of *C. intybus* as a standardised and safe source of mineral-enriched plant-based materials.

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Authors' contributions

TJ conceptualised the study, designed the research framework and supervised the overall work; SR participated in field sampling and carried out sample preparation for elemental analysis; KK performed the X-ray fluorescence (XRF) measurements and instrumental analysis; UZ contributed to data processing, interpretation of macro- and microelement concentrations and statistical analysis; TS conducted the literature review and contributed to the interpretation of ecological and physiological aspects of the results; BB participated in methodological optimisation and validation of analytical procedures; IM assisted in data compilation and drafting of the manuscript; XB critically revised the manuscript for important intellectual content and contributed to final editing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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