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Heavy metal accumulation patterns and phytoremediation potential of three indigenous Fabaceae species in Zimbabwe

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ABSTRACT

Heavy metal contamination poses significant ecological and public health challenges owing to their persistence and toxicity in soil. This study evaluated the partitioning patterns of three indigenous Zimbabwean Fabaceae species namely; *Indigofera setiflora*, *Pterocarpus angolensis* and *Pericopsis angolensis* under natural conditions by determining essential and toxic metals (Al, Ca, Mg, Mn, Fe, Zn, Cu, Pb, Cd, and Cr) in leaves, bark and roots using atomic absorption spectrophotometry. *Indigofera setiflora* showed the highest aluminium content in the bark (0.88 ± 0.16 ppm) as well as calcium in leaves (38.32 ± 5.13 ppm) and roots (23.45 ± 2.14 ppm). Iron and zinc levels were higher in *Indigofera setiflora* bark (Fe: 16.95 ± 2.58 ppm) and roots (Fe: 14.90 ± 1.07 ppm; Zn: 16.03 ± 2.61 ppm). *Pterocarpus angolensis* exhibited a moderate aluminium concentration (0.58 ± 0.14 ppm), elevated leaf magnesium levels (47.88 ± 5.04 ppm), leaf zinc levels (19.67 ± 3.32 ppm), and bark zinc levels (21.08 ± 3.25 ppm) compared to other species. *Pericopsis angolensis* accumulated the highest amount of aluminium in the roots (0.42 ± 0.07 ppm). Copper and manganese were present in trace amounts across all species (Cu: < 6 ppm; Mn: < 3 ppm). Toxic metals (Pb, Cd, and Cr) were below the detection limits in all species, indicating a low ecological risk.

Keywords: heavy metals, Fabaceae, *Indigofera setiflora*, *Pterocarpus angolensis*, *Pericopsis angolensis*, atomic absorption spectroscopy, bioaccumulation, phytoremediation

INTRODUCTION

Heavy metal contamination is a global environmental concern arising from mining operations, industrial effluents, urbanization, agrochemical use and improper waste disposal (Ali et al., 2019; Sharma et al., 2015). They enter the environment through corrosion, atmospheric deposition, erosion, groundwater leaching, sediment resuspension, and water evaporation. Although essential micronutrients such as zinc, copper, and iron are required by plants in small quantities, toxic metals, including lead, cadmium, mercury, and arsenic, pose serious ecological and human health risks, even at low concentrations (Lee et al., 2023). Excessive metal content deteriorates soil structure, fertility, and crop productivity, ultimately threatening food security and environmental sustainability (Ahmad, 2024; Deng et al., 2024).

Soil degradation leads to the loss of crucial ecosystem services, such as nutrient cycling and water filtration. This loss of ecosystem services negatively impacts human health and the quality of life. Consequently, the resulting environmental damage has immediate, profound, and multifaceted consequences for both ecosystems and human health (Oubohssaine & Dahmani, 2024). Traditional remediation techniques, such as soil excavation, washing, and chemical stabilization, are often costly, disruptive, and unsuitable for large-scale applications (Mohamed et al., 2025). Phytoremediation has gained prominence as an environmentally friendly and cost-effective technology for mitigating heavy metal pollution (Ahmad, 2024; Kanwal et al., 2019; Shen et al., 2022). Plants can remove, stabilize, or transform contaminants through various mechanisms, including phytoextraction, phytovolatilization, phytostabilization, and phytofiltration. The efficiency of these processes depends largely on plant biomass, root morphology, metal bioavailability, and species-specific physiological responses (Jiang et al., 2022; Shen et al., 2022).

Members of the Fabaceae family are widely recognized for their heavy metal tolerance, nitrogen-fixing capacity, and ability to thrive in nutrient-deficient and contaminated soils (Jach et al., 2022; Sommer et al., 2025). Consequently, Fabaceae species exhibit diverse phytoremediation strategies. For example, *Bauhinia purpurea*, *Vachellia campechiana*, and *Acacia karroo* effectively accumulate metals such as Zn, Cu, Pb, and Cr their shoots, making them strong phytoextractors

(Kanwal et al., 2019; Santoyo-Martínez et al., 2020). In contrast, species such as *Acacia auriculiformis*, *Sesbania virgata*, and *Lonchocarpus cultratus* accumulate metals primarily in their roots, thus favouring phytostabilization (Heckenroth et al., 2022; Oliveira et al., 2021; Rodriguez et al., 2023).

Despite extensive global research on Fabaceae phytoremediation, there has been limited research on heavy metal accumulation patterns in indigenous Zimbabwean species. Understanding their ecological roles and phytotechnology potential is essential for developing local solutions for soil rehabilitation, biodiversity conservation, and safe utilization in food, herbal, and cosmetic applications. Therefore, the present study investigated the inferred bioaccumulation and phytoremediation capacities of three native Zimbabwean Fabaceae species, *Indigofera setiflora var. setiflora*, *Pterocarpus angolensis* DC, and *Pericopsis angolensis* van Meeuwen under natural conditions. This study provides a baseline assessment of metal accumulation and partitioning patterns in indigenous Fabaceae species in natural, minimally contaminated soil conditions. The phytoremediation indices discussed in this present study are inferred and require further validation in contaminated environments.

MATERIALS AND METHODS

Reagents

All reagents used were of analytical grade and obtained from Sigma-Aldrich, Merck, and Sisco Laboratories. The metal standards for calibration included calcium chloride ($CaCl_2$), magnesium metal (Mg), iron chloride ($FeCl_2$), aluminium chloride ($AlCl_3$), cadmium chloride ($CdCl_2$), manganese chloride ($MnCl_2$), zinc metal (Zn), lead nitrate ($Pb(NO_3)_2$), and chromium nitrate ($Cr(NO_3)_3$). Nitric acid (HNO_3) and hydrochloric acid (HCl) were used to digest the samples. Deionized water (18.2 MΩ·cm) was used for all analyses. Lanthanum chloride ($LaCl_3$) was added as a releasing agent during Ca and Mg determination to minimize chemical interference.

Instruments

Metal quantification was performed using a Varian Spectra A50B Flame Atomic Absorption Spectrophotometer (FAAS) equipped with element-specific hollow cathode lamps, an air-acetylene flame atomizer, and an automated background correction feature. The instrumental parameters (wavelength, slit width, lamp current, and fuel/oxidant ratios) were optimized individually for each analyte. The detection limits, calibration sensitivity, and instrument stability were verified before the analysis.

Sample Collection

Plant and soil samples were collected from the Mapfungautsi Forest (18^{o}26'41.0''S 28^{O}51'19.9''E), located in the Gokwe South District of Zimbabwe. Samples were collected from three indigenous Fabaceae species namely *Indigofera setiflora* var. *setiflora*, *Pterocarpus angolensis* DC, and *Pericopsis angolensis van Meeuwen.* For each species, leaves, barks, and roots were collected from healthy, mature plants using non-destructive sampling and placed in labelled paper envelopes. Leaves were collected from sun-exposed branches facing south by selecting fully developed, hardened leaves from the mid-canopy or top third of the tree. Soil samples (0-20 cm depth) were obtained from the rhizosphere of each plant using soil probes. A chisel and hammer were used to remove small, thin pieces of the outer and inner bark, including the cambium layer. Root samples were collected from active and fine roots located near the edge of the tree canopy in all directions around the plant species using a soil auger. All plant specimens were botanically authenticated, voucher specimens were deposited, and voucher numbers were assigned for *Indigofera setiflora*, *Pericopsis angolensis*, and *Pterocarpus angolensis* as follows: Garanganga, P: Voucher Number 1, Garanganga, P: Voucher Number 2, and Garanganga, P: Voucher Number 3. Each sample type was collected in triplicates to ensure representativeness.

Sample Preparation

Plant samples

Plant materials were cleaned with running tap water and rinsed with deionized water to remove dust and soil residue. Samples were oven-dried at 60°C for 48 h, ground using a pestle and mortar, and sieved to less than 1 mm particle size. A 0.5 g subsample of each powdered material was digested in 10 mL of concentrated nitric acid (HNO_3, 65%) using a hot plate digestion method adapted from (US Environmental Protection Agency (EPA), 2024). The samples were digested at 95°C for 2 h. After cooling, the digests were diluted to 50 mL with deionized water, filtered through Whatman No. 42 filter paper, and reserved for analysis by FAAS.

Soil samples

Soil samples were air-dried, ground, and passed through a 2 mm mesh sieve. A 10 g portion was digested using HNO_3 and HCl (3:1 aqua regia) adapted from the EPA Method 3050B. The samples were digested at 95°C for 2 h. The digests were similarly diluted to 50 mL, filtered with deionized water through Whatman No. 42 filter paper, and reserved for analysis by FAAS.

Physicochemical Tests for Soil Samples

Soil samples were tested for pH, electrical conductivity (EC), moisture, texture, bulk density, silt, clay, sand, organic matter (OM), phosphate (P_2O_5), initial mineral nitrogen (IMN), and exchangeable cations using standard methods described in the literature (Soil Survey Staff, 2022).

Heavy Metal Determination

All digested samples were analyzed for aluminium (Al), calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), lead (Pb), cadmium (Cd), and chromium (Cr) using FAAS (Tawfik et al., 2024; Zvěřina et al., 2024). Calibration curves for each element were constructed using freshly prepared multi-element standard solutions at five concentration levels. The calibration curve linearity exceeded R^2 = 0.995 for all metals. The instrument detection limits (IDLs) and limits of quantification (LOQs) were calculated based on three and ten times the standard deviation of the blank measurements, respectively (Ferreira et al., 2018). The

Table 1. Physicochemical properties for Mapfungautsi Forest soil

pH	EC	OM	Exchangeable cations (meq/100g)				Bulk density	IMN	P_2O_5	Silt	Clay	Sand
	μS/cm	%	Ca	Mg	Na	K	g/cm³	μg/g	μg/g	%	%	%
6.51 ±0.01	410 ±0.02	4.98 ±0.03	7.27 ±0.04	2.68 ±0.03	0.84 ±0.02	0.54 ±0.01	1.38 ±0.01	10 ±0.02	<0.01	20 ±0.03	14 ±0.01	66 ±0.02

Table 2. Enrichment factor for Mapfungautsi Forest soil

Metal	Al	Ca	Mg	Mn	Fe	Zn	Cu	Pb	Cr
EF	0.94	0.98	0.99	0.99	1	1.01	1	1.01	0.99

sample concentrations were automatically corrected for the dilution factors. Metal concentrations were expressed in ppm (dry weight) for both plant and soil samples.

Quality Assurance (QA) and Quality Control (QC)

A comprehensive QA/QC protocol was implemented to ensure accuracy and reliability. Certified reference materials for plant and soil matrices were analyzed alongside samples, and the recoveries ranged between 95-105%. Reagent and procedural blanks were included in each digestion batch. All analyses were performed in triplicates to assess precision. Spike recovery tests were conducted for the selected samples, yielding recoveries within acceptable limits (±10%). The results were compared with the permissible limits (European Commission 2023, 2023; US Environmental Protection Agency (EPA), 2024).

Quantitative Phytoremediation Indices

The following equations were used to calculate the Bioaccumulation Factor (BAF), Bioconcentration Factor (BCF), Translocation Factor (TF), and Enrichment Factor (EF) (Bandiera et al., 2016; Buat-Menard & Chesselet, 1979; Lu et al., 2024; Muller, 1969; Muzerengi, 2019; Reimann & de Caritat, 2000; Shingadgaon & Chavan, 2019; Sutherland, 2000; Zoller et al., 1974):

$$Bioaccumulation\ Factor = \frac{Metal\ content\ in\ aerial\ parts}{Metal\ content\ in\ soil} \quad (1)$$

$$Bioconcentration\ Factor = \frac{Metal\ content\ in\ root}{Metal\ content\ in\ soil} \quad (2)$$

$$Translocation\ Factor = \frac{Metal\ content\ in\ shoot}{Metal\ content\ in\ root} \quad (3)$$

$$Enrichment\ Factor = \frac{Cx/\ Cref}{Bx/\ Bref}\ sample \quad (4)$$

Where *Cx* is the content of the examined element in the examined environment, *Cref* is the content of the examined element in the reference environment, *Bx* is the content of the reference element in the examined environment, and *Bref* is the content of the reference element in the reference environment. Fe in the same environment (1 m deep) was used as the reference.

Statistical Analysis

Statistical analysis using two-way analysis of variance (ANOVA) followed by Post Hoc Tukey's test to evaluate differences between plant species, plant parts, and heavy metals was performed on SPSS 2024. Statistical significance was set at p-value < 0.05. The experiments were performed in triplicate (n = 3), and the standard deviation was reported as the error.

RESULTS AND DISCUSSION

Physicochemical Properties of Soil

Under the relatively uncontaminated conditions of the Mapfungautsi Forest, the observed metal accumulation patterns reflect inherent physiological responses rather than stress-induced phytoremediation performance. The physicochemical properties of the Mapfungautsi Forest soil are presented in **Table 1**.

The slightly acidic to near-neutral pH of 6.51 ± 0.01 is reported to decrease the solubility of many trace metals, limiting their bioavailability (Zeng et al., 2011). The non-saline environment, indicated by an electrical conductivity of 410 μS/cm, suggests that the effects of ionic competition on metal uptake are weak. The OM content of 4.98% is relatively high and may contribute to metal complexation and immobilization through humic substances. This reduces the concentration of free metal ions in the soil solution (Rieuwerts et al., 1998). The soil exhibited an intermediate cation exchange capacity with exchangeable bases mainly consisting of Ca (7.27 meq/100 g), Mg (2.68 meq/100 g), Na (0.84 meq/100 g), and K (0.54 meq/100 g). The total exchangeable base content of 11.33 meq/100 g indicates moderately fertile soil with reasonable buffering capacity, which may further reduce metal mobility. Maintaining such a moderate exchangeable capacity is indicative of a possible retention range for cationic metals with limited mobility. Moreover, the sandy texture (66% sand, 20% silt, and 14% clay) alludes to low adsorption compared to clay soils; however, this limitation is partially compensated by the moderate OM content. The bulk density (1.38 g/cm³) indicates relatively dense soil. Low nutrient profiles (IMN = 10 μg/g, P_2O_5 = <0.01 μg/g) demonstrated low phosphorus availability.

The EF values (0.94-1.01) for all tested elements (Al, Ca, Mg, Mn, Fe, Zn, Cu, Pb, and Cr) in **Table 2** show that most of the metals belong to the geogenic group and that no significant source of enrichment is anthropogenic. EF values around unity are naturally occurring levels rather than indicators of contamination (Reimann & de Caritat, 2005). This is consistent with the low accumulation rates of the studied Fabaceae species (Pastor et al., 2024).

Heavy Metal Distribution in Soil Samples

The concentrations of heavy metals in the soils of the Mapfungautsi Forest are presented in **Figure 1**. Aluminium,

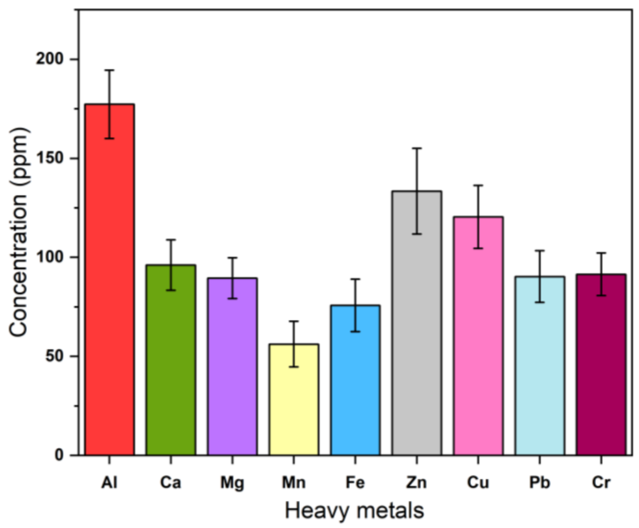

Figure 1. Heavy metal distribution in Mapfungautsi Forest soil (Source: Authors' own elaboration)

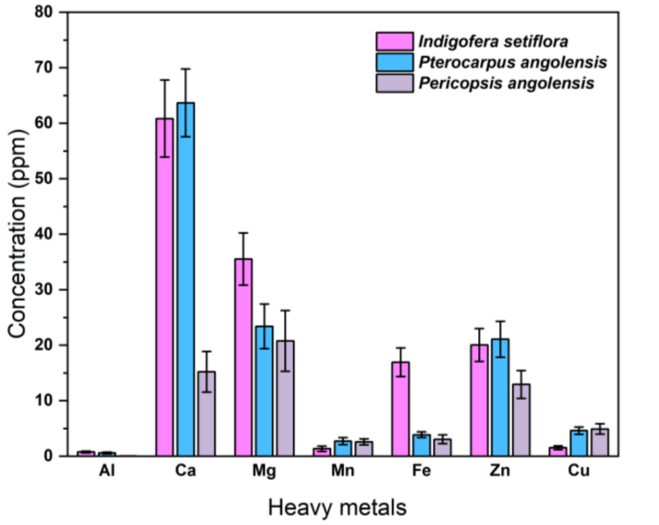

Figure 3. Heavy metal distribution in bark (Source: Authors' own elaboration)

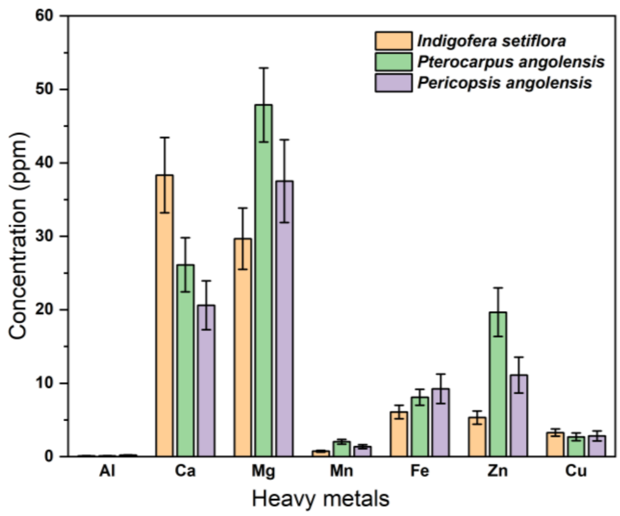

Figure 2. Heavy metal distribution in leaves (Source: Authors' own elaboration)

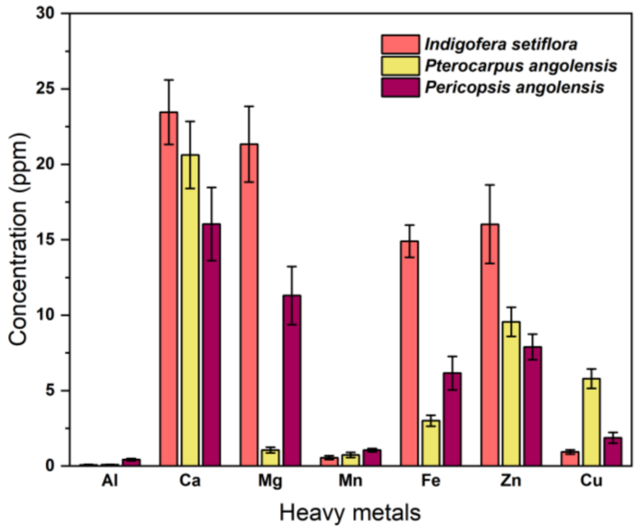

Figure 4. Heavy metal distribution in roots (Source: Authors' own elaboration)

zinc, and copper were the most abundant essential metals, occurring at 177.27 ± 17.24 ppm, 133.41 ± 21.62 ppm, and 120.38 ± 15.90 ppm, respectively. These metals are present in Zimbabwean forest soils and contribute to nutrient cycling and enzymatic processes that are essential for plant growth. Toxic heavy metals, lead, and chromium (<100 ppm) were below the permissible limits for soil (European Commission, 2023; US Environmental Protection Agency (EPA), 2024). The cadmium content was below the detection limit.

The relatively high levels of essential metals provide a suitable environment for studying species-specific bioaccumulation under natural conditions.

Heavy Metal Distribution in Plant Samples

Figures 2-4 illustrate the distribution of metals in the leaves, bark, and roots of the three Fabaceae species. Distinct metal partitioning patterns were observed among species and plant parts, reflecting their varying physiological responses and tolerance mechanisms. These findings align with previous studies highlighting the capacity of Fabaceae plants to regulate metal uptake and compartmentalization (Santoyo-Martínez et al., 2024; Varun et al., 2017).

Aluminium

Aluminium accumulated predominantly in the bark and roots, with the highest concentration in *Indigofera setiflora* bark (0.88 ± 0.16 ppm). *Pterocarpus angolensis* stored a moderate amount of Al in the bark (0.58 ± 0.14 ppm), whereas *Pericopsis angolensis* showed higher root accumulation (0.42 ± 0.07 ppm). All plant Al concentrations were much lower than those reported for other Fabaceae species growing in contaminated soils (Kang et al., 2018; Kochian et al., 2015; Yousaf et al., 2019).

Calcium

Indigofera setiflora exhibited higher Ca concentrations, particularly in the leaves (38.32 ± 5.13 ppm) and roots (23.45 ± 2.14 ppm). The Ca levels observed in *Indigofera setiflora* were within the same average range as those reported for other

Table 3. Two-way ANOVA results for the effect of species and plant part on metal concentrations

Metal	Species effect (*p*-value)	Plant part effect (*p*-value)	Significant factors
Al	< 0.001	< 0.001	Species, plant Part
Ca	< 0.001	< 0.001	Species, Plant Part
Mg	< 0.001	< 0.001	Species, Plant Part
Mn	< 0.001	< 0.001	Species, Plant Part
Fe	< 0.001	0.02	Species, Plant Part
Zn	< 0.001	< 0.001	Species, Plant Part
Cu	< 0.001	0.43	Species only

Fabaceae species. *Prosopis laevigata* growing in the mine tailings accumulated more than 20 ppm Ca in their roots (Muro-González et al., 2020), and *Vachellia campechiana* demonstrated a leaf Ca concentration of more than 45 ppm (Santoyo-Martínez et al., 2020). The root Ca content of *Indigofera setiflora* was comparatively higher than that reported for *Sesbania virgata* in Cr-contaminated soils (Rodriguez et al., 2023).

Magnesium

Mg accumulation was maximal in *Pterocarpus angolensis* leaves (47.88 ± 5.04 ppm). The Mg levels in *Pterocarpus angolensis* leaves are similar to those in other legumes. In both contaminated and control sites, Mg concentrations in leaves of *Robinia pseudoacacia* (black locust) were 38-52 ppm (Liu et al., 2024; Xue et al., 2024), while *Acacia karroo* accumulated 41-58 ppm from contaminated soil (Maphuhla & Oyedeji, 2024). Mg values for *Pterocarpus angolensis* reported in the current study are within the optimal ranges for photosynthetic functioning in legumes (35-60 ppm), which have been confirmed in earlier studies (Alejandro et al., 2020).

Manganese

Mn was present in all species at concentrations of less than 3 ppm. These concentrations are below the reported toxicity threshold (> 500 ppm) for most legumes (Alejandro et al., 2020; Rashed et al., 2021). Mn plays a major role in photosystem II activity, oxidative stress protection, enzymatic activation, and improving the availability of phosphorus and calcium (Alejandro et al., 2020; Rashed et al., 2021). Consistent Mn accumulation patterns have been observed in *Crotalaria pumila* leaves growing in heavy metal-damaged soils (Santoyo-Martínez et al., 2024) and in *Lathyrus sativus* under Cd-contaminated conditions (Abdelkrim et al., 2019).

Copper

All plant parts indicated the presence of Cu (< 6 ppm). Cu activates enzymes, protein synthesis, and catalysis in plant growth systems (Tripathi et al., 2022). The observed Cu levels in the present study were well below the phytotoxic threshold (> 20 ppm for most legumes) and within the optimal range (5-15 ppm) for Cu-dependent enzymes, such as plastocyanin, cytochrome oxidase, and superoxide dismutase (Tripathi et al., 2022). The Cu concentrations corresponded to those of other Fabaceae species obtained from contaminated and uncontaminated sources. In multi-metal-polluted soils from gold mining regions, *Mucuna deeringiana* was reported to contain 4.8-12.4 ppm Cu in leaves (Boechat et al., 2017). The Cu concentrations in *Vachellia campechiana* growing in the mine tailings were 5.2-15.6 ppm (Santoyo-Martínez et al., 2020).

Iron and zinc

Iron and zinc were present in all species, with *Indigofera setiflora* showing distinctly higher concentrations in the bark (Fe: 16.95 ± 2.58 ppm) and roots (Fe: 14.90 ± 1.07 ppm; Zn: 16.03 ± 2.61 ppm). *Pterocarpus angolensis* showed the highest Zn concentrations in the leaves (19.67 ± 3.32 ppm) and bark (21.08 ± 3.25 ppm). The accumulation of Fe and Zn in *Indigofera setiflora* and *Pterocarpus angolensis* may be attributable to micronutrient uptake mechanisms (García-Carrillo et al., 2024; Kanwal et al., 2019; Shahid et al., 2017; Xue et al., 2024). The concentration of Fe in *Pterocarpus angolensis* leaves is typical of Fabaceae species (Abdul Rashid & Arzuri, 2024; Oliveira et al., 2021; Zhang et al., 2021).

Toxic metal uptake

Pb, Cd, and Cr were below the detection limits in all plant species, which could be attributed to the following three factors: (1) the relatively uncontaminated Mapfungautsi Forest soils, where toxic metals are below bioavailable thresholds (Shahid et al., 2017); (2) effective selective exclusion mechanisms involving root exudates and a mycorrhizal link in Fabaceae species (Jach et al., 2022; Zheng et al., 2023); and (3) preferential uptake of nutrients relative to toxic metals, as documented in *Sesbania virgata* and *Coronilla juncea* (Heckenroth et al., 2022; Rodriguez et al., 2023).

Statistical Analysis

Significant species-specific and tissue-specific distributions of Al, Ca, Mg, Mn, Fe, and Zn ($p < 0.001$) were demonstrated in the present study (**Table 3**), except for Cu. Cu content varied only by species ($p < 0.001$). Significant differences between species demonstrate varying metal uptake mechanisms due to genetic, physiological, and environmental phenomena.

Al exhibited the highest variability. Tukey's HSD post-hoc comparisons revealed significant species vs tissue interactions for Al (**Table 4**). The highest Al concentrations were observed in *Pericopsis angolensis* tissues. Non-significant comparisons ($p > 0.05$) occurred between *Indigofera setiflora* and *Pterocarpus angolensis* in the leaves and roots.

Comparative Phytoremediation Indices

The following phytoremediation indices: Bioaccumulation Factor (BAF), Bioconcentration Factor (BCF), and Translocation Factor for plant samples are presented in **Table 5**.

In *Indigofera setiflora*, the bioaccumulation factors (BAF: 0.00-0.40) and bioconcentration factors (BCF: 0.00-0.24) of all metals were below 1, implying low absorption from soil to

Table 4. Tukey HSD Post Hoc summary of significant pairwise comparisons for Al

Plant Part	Key Significant Comparisons (p <0.05)	Non-Significant Comparisons (p ⩾ 0.05)
Bark	Significance in all species-part comparisons ($p < 0.001$)	None
Leaves	*Indigofera setiflora* vs *Pericopsis angolensis* (0.08 ppm, $p = 0.015$)	*Indigofera setiflora* vs *Pterocarpus angolensis* ($p = 0.999$); *Indigofera setiflora leaves* vs roots ($p = 0.61$)
Roots	*Indigofera setiflora* vs *Pericopsis angolensis* (0.34 ppm, $p < 0.001$); *Pericopsis angolensis* vs *Pterocarpus angolensis* ($p < 0.001$)	*Indigofera setiflora* vs *Pterocarpus angolensis* comparisons ($p > 0.05$)

Table 5. Bioaccumulation Factor (BAF), Bioconcentration Factor (BCF), and Translocation Factor for plant samples

Sample	Metal	BAF	BCF	TF
Indigofera setiflora	Al	0.00	0.00	1.50
	Ca	0.40	0.24	1.63
	Mg	0.33	0.24	1.39
	Mn	0.01	0.01	1.35
	Fe	0.08	0.06	1.33
	Zn	0.04	0.08	0.49
	Cu	0.03	0.01	3.53
Pterocarpus angolensis	Al	0.00	0.00	1.33
	Ca	0.27	0.21	1.27
	Mg	0.54	0.01	45.17
	Mn	0.04	0.01	2.78
	Fe	0.11	0.04	2.69
	Zn	0.15	0.07	2.06
	Cu	0.02	0.05	0.47
Pericopsis angolensis	Al	0.00	0.00	0.48
	Ca	0.21	0.17	1.29
	Mg	0.42	0.13	3.32
	Mn	0.02	0.02	1.30
	Fe	0.12	0.08	1.50
	Zn	0.08	0.06	1.41
	Cu	0.02	0.02	1.51

roots (Ali et al., 2013). Despite the low uptake, TF > 1 for Ca (1.63), Mg (1.39), Mn (1.35), Fe (1.33), and Cu (3.53) demonstrate efficient internal transfer from roots to shoots and metal uptake. In contrast, Zn exhibited an opposing pattern with TF < 1 (0.49) and BCF (0.08) > BAF (0.04) (Kar et al., 2021).

Pterocarpus angolensis displayed poor BAF (0.00-0.54) and BCF (0.00-0.21) relative to all metals, indicating low uptake performance. Nevertheless, this species presented high translocation factors especially those for Mg (TF = 45.17), and high TF values were also detected for Mn (2.78), Fe (2.69), and Zn (2.06). Mg exhibits very high TF suggesting efficient root-to-shoot transport. Similar trends were observed for Mn, Fe, and Zn, indicating that these elements were actively mobilized to the leaves. In comparison to Zn, Cu had a TF < 1 (0.47) and a higher BCF (0.05) (Yoon et al., 2006). Hence, *Pterocarpus angolensis* is an effective translocator and weak accumulator.

The BAF (⩽ 0.42) and BCF (⩽0.17) values in *Pericopsis angolensis* were below 1. This is slightly more efficient than that in other species when considering Ca, Mg, and Fe. The translocation factors were above 1 for all metals such as Ca (1.29), Mg (3.32), Mn (1.30), Fe (1.50), Zn (1.41), and Cu (1.51), which confirms that metals migrate effectively from roots to shoots. No effective root retention (TF < 1, BCF > BAF) was observed (Yoon et al., 2006).

CONCLUSION

This study illustrates distinct heavy metal accumulation patterns among three indigenous Zimbabwean Fabaceae species: *Indigofera setiflora*, *Pterocarpus angolensis*, and *Pericopsis angolensis*. *Indigofera setiflora* exhibited high uptake and translocation of essential metals, particularly Fe and Zn, underscoring its strong potential as a metal excluder for the remediation of metal-enriched soils. In contrast, *Pterocarpus angolensis* and *Pericopsis angolensis* showed preferential retention of metals in root tissues and complete exclusion of toxic metals, indicating their suitability for soil reinforcement. The absence of detectable Pb, Cd, and Cr across all species implies low risk for the analyzed metals under the studied conditions; however, comprehensive safety evaluation requires assessment of additional contaminants such as Hg, As and Ni as well as long-term accumulation and site variability. Quantitative phytoremediation indices were determined using EF values, indicating naturally occurring quantities; BCF and BAF, indicating low absorption or uptake and phytoextraction or accumulation capacity, respectively; and TF, indicating efficient internal metal transfer from roots to leaves. This study provides a baseline assessment of metal partitioning patterns under natural conditions. Overall, these findings provide a primary baseline for the potential integration of indigenous Fabaceae species into engineered phytoremediation programs and broader ecological restoration efforts in Zimbabwe. However, studies on the bioaccumulation and phytoremediation potential of indigenous Fabaceae species in heavily contaminated areas are required for further validation.

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AI statement: The authors have not used any generative AI or AI-assisted technologies.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

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