Accumulation coefficient and translocation factor of heavy metals through *Ochradenus baccatus* plant grown on mining area at Mahad AD'Dahab, Saudi Arabia

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Abstract

The plant species *Ochradenus baccatus*, which naturally grows around the Mahad AD'Dahab Mine, has been selected for study due to its ability to accumulate heavy metals (As, Cd, Cu, Pb, Zn). Five samples from shoots and others from roots of *Ochradenus baccatus* were collected. Moreover, five soil samples were collected from an area such as to make a representative soil sample. Plant and soil samples were analyzed for As, Cd, Cu, Pb, and Zn. The results showed a high concentration of soil heavy metal content with respect to As, Cd, Cu, Pb, and Zn (30, 7, 479, 355 and 1481 mg kg^{-1} respectively). The concentration of Cd, Cu, Pb, Zn in shoots of *Ochradenus baccatus* were 1.7, 30.8, 10.2, 169.5 mg kg^{-1}, respectively. On the other hand, the concentration of heavy metals in the roots was as follows (mg kg^{-1}): Cd: 3.9; Cu: 114; Pb: 43; Zn: 430. With the exception of As, heavy metals (Cd, Cu, Pb, Zn) tend to be accumulated in the roots rather than the shoots. The accumulation coefficient of heavy metals in the shoots was low (0.03-0.25), while it was higher in the roots (0.04-0.58). Based on the accumulation coefficient, heavy metals can be ordered as follows: Cd> Zn> As> Cu> Pb for shoots and Cd> Zn> Cu> Pb> As for roots. Statistical analysis was performed to examine the heavy metals accumulation in *Ochradenus baccatus* at a 0.01 level. A highly significant difference was found between Cd and other metals in both the shoots and roots, while the difference was highly significant between Zn and other metals, with the exception of As and Cu, in shoots and roots respectively. From the above, *Ochradenus baccatus* should be described as not-excluder and can be explored further for phytoremediation of metal polluted soils. On the other hand, the practice of providing foliage and pods as fodder for livestock should be avoided in the Mahad AD'Dahab area.

Keywords: heavy metals, Ochradenus baccatus, Mahad AD'Dahab, Saudi Arabia, gold mining.

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1 Introduction

The contamination of soils or plants with heavy metals is one of the most dangerous types of pollution [1]. A high accumulation of heavy metals was found on the surface of the soil in areas of mining and industrial activity [2], which leads to environmental problems, including the arrival of a concentration of these metals toxic to plants, animals and humans, which resulted in serious health problems [3].

There are a number of studies on the plant uptake of heavy elements. Kathleen et al. [4] found some species of plants reduce the mercury in water by absorption through the roots and accumulation in plants. It was also proved that the species belonging to the six of *Thlaspi* sp (Brassicaceae) can accumulate 0.1% Cd, 3% Zn, 0.5% Pb in their branches [5, 6]. The ability of plants to accumulate elements depends on the size of plant and speed of its growth [7].

Thangavel et al. [8] mentioned that *P. juliflora* could be used in the remediation of soils contaminated with aluminium. Moreover, *P. juliflora* was found to absorp nickel, chromium and lead [9, 10]. In addition, many types of ragweed were used to remove lead, while *thlapsi rotundifolium* was used for removing zinc and cadmium [11]. These plants are good for Phytoremediation, but their use becomes dangerous when they are within the pastoral areas.

Chelates, such as EDTA and DTPA, have been used to try to evaluate the bioavailability of heavy metals. The DTPA has been widely used in calcareous soils [12]. However, Ortiz and Alcañiz [13] found that DTPA extraction gave a very low correlation coefficient with leaf concentration of *Dactylis glomerata* of Pb, Ni, Cu, Cd. Vandecasteele et al. [14] found that EDTA is stronger than DTPA in the extraction of Zn, Cd, Cu, Pb and Ni. Moreover, they concluded that DTPA does not give a good indication of the extraction of zinc absorption by the plant. Also, DTPA was poorly correlated with lead and cadmium.

There are several mining projects in Saudi Arabia, including gold mining at Mahad AD'Dahab area, the production of which began in 1988. A recent study shows that the soil surrounding the gold mine is contaminated with respect to cadmium, copper, lead, zinc and mercury. The percentage of samples of soil contaminated with one or more heavy metal, depending on the Enrichment Factor (EF), is 99% of the studied soil samples (139 samples) [15].

Al-Farraj and Al-Wabel [16] studied the concentration of heavy metals in the branches of ten plants that grow around the Mahad AlD'Dahab Mine. They found *Pergularia tomentosa* had the highest concentration of heavy metals, while *Ochradenus baccatus* had the lowest accumulation. Therefore, those plants could be described as tolerant of soil contaminated by heavy metals, but they have different mechanisms.

From the above, it is very important to study the behaviour of those plants in the contaminated areas, which help in the perception of bio-remediation of soils contaminated with heavy metals, as well as to avoid their use in grazing areas because of the seriousness of transmission to humans. Nevertheless, there are only a few studies examining the levels of heavy metals in mining areas in Saudi Arabia, as well as their effects on the ecosystem (human, animal, plant).

Therefore, the objective of the current research is mainly to study the accumulation of heavy metals (Cd, Cu, Pb, Zn, As) in *Ochradenus baccatus* grown in the gold mining area at Mahad AD'Dahab, Saudi Arabia. *Ochradenus baccatus* is one of the plants that feeds cattle and birds.

2 Materials and methods

2.1 Study area and collection of plant and soil samples

The *Ochradenus baccatus* and soil samples used for this research were collected in 2007 from the surrounding area (100 m^2) of the Mahad AD'Dahab Mine (23º30$^=$ N; 40º30$^=$ E). Mahad AD'Dahab has the largest and oldest gold mine in Saudi Arabia. A completely random design was applied to choose plant samples. The sites of the samples were chosen because of their high contamination with respect to heavy metals (Cd, Cu, Pb, Zn … etc) [15]. Different branches (leaves and stems) and roots were collected from five plants of *Ochradenus baccatus*. These branches (shoots) and (roots) were mixed separately and then dried at 60ºC. The air-dried plant samples were powdered homogenously for further analysis. Also, five representative surface soil samples (0-20 cm) were collected from the studied area.

2.2 Heavy metals analysis

Dried and powdered plant samples were acid digested with HNO_3 & $HClO_4$ [17]. The soil sample was digested with HNO_3-$HClO_4$-HF [18]. Moreover, the DTPA extractable fraction was obtained by mechanical shaking of the soil sample (4 g) with 40 ml of 0.5 M DTPA, 0.01 M CaCl2, 0.1 M TEA (triethanolamine) buffered at pH 7.3 for 2 h [19]. Soil analysis was done with two replicates. Plant and soil samples, after being digested or extracted, were analyzed for heavy metal concentration (As, Cd, Cu, Pb, Zn) using ICP-AES (Perkin elemer, 4300 DV). Due care was taken to avoid metal contamination in the process of sampling, washing, drying and grinding. Moreover, all analysis of plant samples was done on three replicates

2.3 Coefficient and translocation factor of heavy metals

Plant–soil relationships were assessed for heavy metal accumulation in shoots and roots. The accumulation coefficient (AC), defined as the plant/soil concentration quotient [20], was calculated.

$$AC=(C_{\text{root or shoot}}/C_{\text{soil}})$$

where $C_{\text{root or shoot}}$ = Concentration of heavy metal in *Ochradenus baccatus* aerial or root part (mg kg^{-1}) and C_{soil} = Concentration in soil (mg kg^{-1}). Moreover, the translocation factor (TF) was calculated to estimate the transfer of heavy metals from roots to shoots of *Ochradenus baccatus* TF=(C_{shoot}/C_{root}) [21].

3 Results and discussion

3.1 Contaminated soil sample

The basic physicochemical properties of the studied soil sample are summarized in table 1. Table 2 shows the concentration of heavy metals of Mahad AD’Dahab's soil compared to the average concentrations and the normal ranges in soils. The soil has a greater concentration compared with the average in soils. Furthermore, the soil has a concentration much higher than the maximum of Cd, Cu, Pb and Zn in soils, according to Lindsay [22]. Therefore, the soil of Mahad AD’Dahab could be described as contaminated soil with respect to As, Cd, Cu, Pb and Zn. This result agreed well with the results of Al-Farraj and Al-Wabel [15]. A high concentration of heavy metals in soil results in increasing extraction of DTPA. The concentration of heavy metals extracted by DTPA follow this order: Cu (8.3%); Pb (7.7) Cd (7.5%); Zn (2.2%) (table 2).

3.2 Accumulation coefficient

Table 3 and figure 1 show the concentration of heavy metals in shoots and roots, the accumulation coefficient (AC) of each metal and translocation (TF) within *Ochradenus baccatus*. The total concentration of arsenic in shoots is 2.5 mg kg^{-1}, cadmium is 1.7 mg kg^{-1}, copper is 30.8 mg kg^{-1}, lead is 10.2 mg kg^{-1} and zinc is 169.5 mg kg^{-1}. The accumulation coefficient was determined for heavy metals to measure the relative difference in the bioavailability of metals to *Ochradenus baccatus*.

The accumulation coefficient of the heavy metals in roots ranged between 0.04-0.58, while it was 0.03-0.25 in shoots. With the exception As, the concentrations of studied heavy metals in the roots of *Ochradenus baccatus* was two to four times higher than their concentrations in shoots. Those results show that Cd, Cu, Pb and Zn tend to be accumulated in the roots rather than the shoots. On the other hand, the accumulation coefficient of As in shoots was doubled compared to roots (0.08 and 0.04, respectively).

The order of the accumulation coefficient of heavy metals in roots and shoots was as follows: Cd> Zn> Cu> Pb> As, except for As, which came third in the shoots before the Cu. Statistical analysis showed significant differences between the average accumulation coefficient of heavy metals, where there was a significance difference between Cd and other metals in both the roots and shoots, while there was a significant difference between Zn and other metals, except As and Cu, in the shoots and roots, respectively (Fig. 1). The results agreed with several previous studies [23–26]. In a study [26] the accumulation coefficient of Pb and As was low in leaves (<0.03) for a number of wood trees, while Cu was higher than that (0.2), in contrast, Zn was 0.9 and Cd was 2.0.

In general, the accumulation coefficient of heavy metals in both roots and shoots of *Ochradenus baccatus* was low (> 0.58). This result could be explained by the fact that the plants that were collected and analyzed had completed their life cycle, but growth was weak compared to what it should be (Fig. 2). Weak growth may be due to the sampling period, the drought or another reason, and the weakness may affect the absorption and accumulation of heavy metals. The accumulation coefficient of both roots and shoots shows that Cd was greater than other metals. This observation could be due to the nature of Cd, since Cd is recognized to be less retained by the soil than others [27].

3.3 Translocation factor

The shoot/root metal concentration ratio was calculated for each metal. This quotient shows the translocation factor (TF) of heavy metals from the roots to the shoots. Table 3 and figure 1 show the translocation factor of heavy metals. Arsenic has the highest translocation factor (1.88), compared with the others. The TF was less than 1 for other metals. With the exception of As, there was no significant difference between the translocation factor of other heavy metals, which could be arranged in the following order: Cd> Zn> Cu> Pb. This result stood in agreement with Gupta and Sindn [28], who found the accumulation of heavy metals (Fe, Zn, Cr, Mn, Cu, Pb, Ni, Cd) was more in roots compared with shoots of *Sesamum indicum*. Furthermore, McLaughlin et al. [29] found a strong correlation between the concentration of Cd and Zn in leaves of two species of *Salix* and their concentration in soil. Also, they found the most accumulation of Cu, Cr, Pb, Fe, Mn and Ni was in the roots.

3.4 DTPA extractable

DTPA extract was proposed to extract available forms of micro-elements and heavy metals in calcareous soils; our study did not find any relation between the concentration of heavy metals in *Ochradenus baccatus* and DTPA extract. Zinc extraction was very weak (2.2%) compared to metals (Cu, Pb, Cd), but it was most absorbed by *Ochradenus baccatus* (431 and 169 mg kg^{-1}, in shoots and roots, respectively) (table 2; figure 3).

The result suggests that the efficiency of DTPA to extract metals does not mean efficiency in assessing the available form. Many previous studies have agreed with our proposal here. Gupta and Sinha [28] found a better relationship between Zn extracted by the DTPA, EDTA and NH_4NO_3, which was absorbed by the plant *Sesamum indicum*, while there was no link with Ni, Cu and Pb. Ortiz and Alcañiz [13] also found a relationship between the total concentration and extraction by DTPA of Zn, Cr and the concentration in leaves of plant *Dactylis glomerata*. On the other hand, they did not find DTPA suitable for Ni, Cu and Cd and did not find any relationship between the concentration of those metals in the roots and the total concentration in the soil or that extracted by DTPA. In another study, researchers found that the DTPA is less efficient than the significance of EDTA to absorb heavy metals of the plant, despite the recent decline in pH [28]. From the above, we can say that although DTPA is considered suitable for calcareous soils, our results reflecting the observation of McLaughlin et al. [29]: that DTPA may over-estimate plant-available metals.

4 Conclusion and recommendations

The studied soil of Mahad AD'Dahab is considered to be contaminated with heavy metals (cadmium, copper, lead, zinc, arsenic). Moreover, heavy metals (Cd, Cu, Pb, Zn) tend to be accumulated in the roots of *Ochradenus baccatus* rather than the branches, while the accumulation factor of arsenic in the branches doubled compared to the roots.

Table 1: The basic properties of Mahad AD'Dahab's soil.

pH	Cations mg kg^{-1}				Anions mg kg^{-1}				SAR	Particles size (%)			Textural	$CaCO_3$	OM	CEC
	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4		Clay	Silt	Sand	Class	%	%	Cmo kg^{-1}
8.2	53.3	3.45	2.1	6.3	nd	61	29	189	7.2	17.6	6	76.4	SL	2.9	0.14	8.3

Table 2: Total heavy metal concentration of Mahad AD'Dahab's soil in comparison with the common range in soils (mg kg^{-1}), DTPA extracted and EF[a].

Element	Total Concentration mg kg^{-1}	DTPA Extracted		EF	Common range in soils[b]		
		mg kg^{-1}	%		Max	Min	Average
As	30.0	nd	nd	11	50	1	5
Cd	6.8	0.5	7.5	64	0.7	0.01	0.06
Cu	479	39.7	8.3	13	100	2	30
Fe	26940	2.2	0.01	1	55000	7000	38000
Pb	354.5	27.1	7.7	42	200	2	10
Zn	1481	32.5	2.2	35	300	10	50

[a] EF: Enrichment factor $= \dfrac{(C_m / C_{Fe})_{Soil}}{(C_m / C_{Fe})_{Earth's Crust}}$

[b] Lindsay [22].

Table 3: The average concentration of heavy metals in the roots and shoots of *Ochradenus baccatus*, the accumulation coefficient and the translocation factor.

Element	Concentration (mg kg^{-1})		Accumulation Coefficient (AC)		Translocation Factor (TF)
	Roots	Shoots	Root/Soil	Shoot/Soil	Shoots/Roots
As	1.3	2.5	0.04	0.08	1.88
Cd	3.9	1.7	0.58	0.25	0.44
Cu	113.5	30.8	0.24	0.06	0.27
Pb	42.8	10.2	0.12	0.03	0.24
Zn	430.6	169. 5	0.29	0.11	0.39

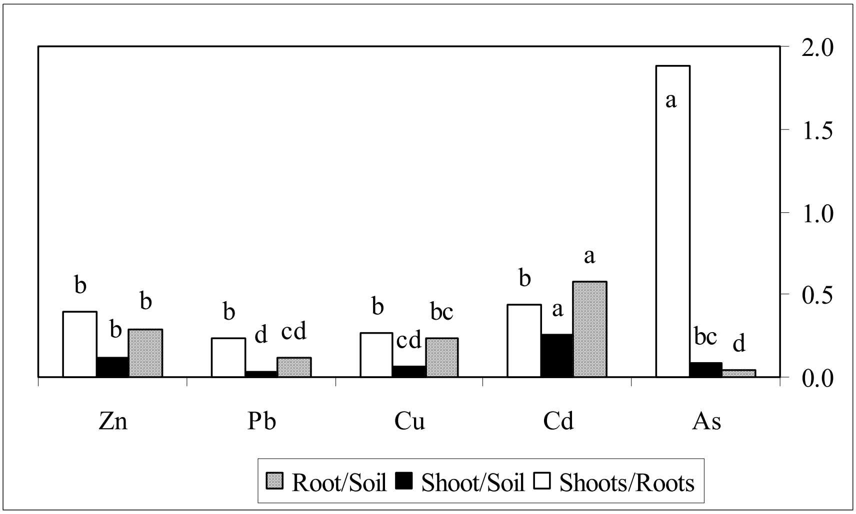

Figure 1: Accumulation coefficient in roots and branches and the translocation factor of *Ochradenus baccatus*, the similarity or different letters show the significant difference between heavy metals.

The main part of our recommendation is that *Ochradenus baccatus* should be described as a not-excluder. Furthermore, it can be explored further for the phytoremediation of metal polluted soils. Moreover, since the area is open to be used for livestock, the practice should be avoided.

Figure 2: Pictures of *Ochradenus baccatus*; left is from study area; right is regular *Ochradenus baccatus*.

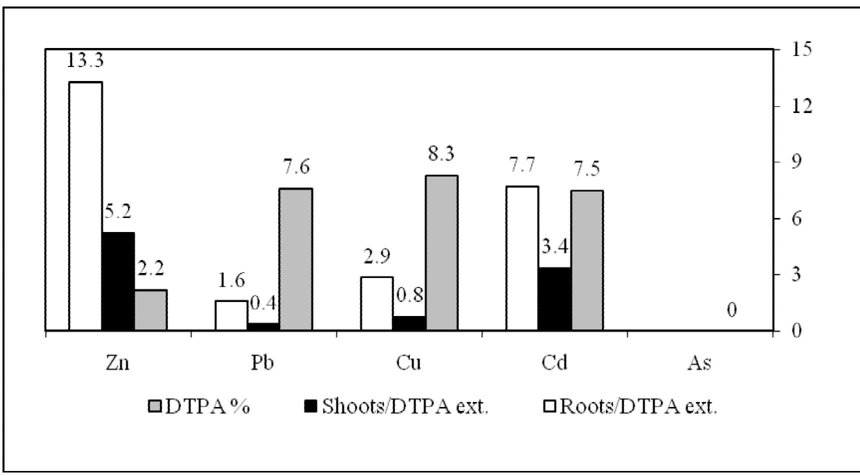

Figure 3: The percentage of heavy metals (%) extracted by DTPA compared with the ratio of their concentrations in both roots and branches.

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