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ACCUMULATION OF PB, FE, MN, CU AND ZN IN PLANTS AND CHOICE OF HYPERACCUMULATOR PLANT IN THE INDUSTRIAL TOWN OF VIAN, IRAN

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Abstract - Various industrial activities contribute heavy metals to the soil environment directly or indirectly through the release of solid wastes, waste gases, and wastewater. Phytoremediation can be potentially used to remedy metal-contaminated sites. A major step towards the development of phytoremediation of heavy metal-impacted soils is the discovery of the heavy metal hyperaccumulation in plants. This study evaluated the potential of 7 species growing on a contaminated site in an industrial area. Several established criteria to define a hyperaccumulator plant were applied. The case study was represented by an industrial town in the Hamedan province in the central-western part of Iran. This study showed that most of the sampled species were able to grow in heavily metal-contaminated soils and were also able to accumulate extraordinarily high concentrations of some metals such as Pb, Fe, Mn, Cu and Zn. Based on the obtained results and using the most common criteria, *Camphorosma monospeliacum* for Pb and Fe, and *Salsola soda* and *Circium arvense* for Pb can be classified as hyperaccumulators and, therefore, they have suitable potential for the phytoremediation of contaminated soils.

*Key words***:** Enrichment factor, heavy metals, hyperaccumulator, industrial town, phytoremediation, translocation factor

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INTRODUCTION

Heavy-metal pollution of soil is mainly attributed to anthropogenic sources, including various human activities such as mining, smelting, and various industrial activities (Krishna et al., 2005; Li et al., 2007; Wang et al., 2005). With the development of urbanization and industrialization, soils have become increasingly polluted by heavy metals which threaten ecosystems, surface, and ground waters, food safety, and human health (Moon et al., 2000; Chen et al., 2005; Davydova, 2005; Krishna et al., 2005; Kachenko et al., 2006). Phytoremediation is a relatively new approach to removing contaminants from the environment. It may be defined as the use of plants to remove, destroy or sequester hazardous substances from environment. It has become a topical research field in the last decades as it is safe and potentially cheap compared to traditional remediation techniques (Salt et al., 1998; Mitch, 2002; Glick, 2003; Pulford et al., 2003). The basic idea that plants can be used for environmental remediation is very old, and cannot be traced to any particular source. However, a series of fascinating scientific discoveries combined with an interdisciplinary research approach have allowed the development of this idea into a promising, cost-effective, and environmentally friendly technology (Baker et al., 1991). Phytoremediation is currently divided into many types: phytoextraction (hyperaccumulator), phytodegradation, rhizofiltration, phytostabilization and phytovolatilization (Salt et al., 1998). Although phytoremediation has received considerable attention recently and there are an increasing number of reports suggesting that it should become the technology of choice for the cleanup of various types of environment contamination, this technology is still in its infancy (Glick, 2003). Most reviews focus on the phytoremediation of the metallic pollutants in soil, particularly the area of metal hyperaccumulator, which is the area of major scientific and technological progress in the past years (Brown et al., 1995; Cunningham et al., 1995; Cunningham et al., 1996). There have been many reports of hyperaccumulating plant (Berti and Cunningham, 1993; Brown et al., 1995; Shen et al., 1998; Ozturk et al., 2003). A hyperaccumulator has been defined as a plant that can accumulate 1000 mg/kg of Cu, Co, Cr, Ni and Pb, or 10000 mg/kg of Fe, Mn and Zn in their shoot dry matter (Baker et al., 1989; Market, 2003). Other authors included, besides the first previous requirements, three others: 1) in hyperaccumulator plants, the metal concentrations in shoots are invariably greater than that in roots, showing a special ability of the plant to absorb and transport metals and store them in their aboveground part (Baker, 1989; Baker et al., 1994; Brown et al. 1994; Wei et al., 2002); 2) in hyperaccumulators, the plant aboveground metal concentrations must be 100-500 times higher than those of the same plant species from non-polluted environments (Yanqun et al., 2005); 3) a hyperaccumulator is regarded as a plant in which the concentrations of heavy metal in the shoots are greater than that in soils, meaning higher metal concentrations in the plant than in the soil, which emphasizes the degree of plant metal uptake (McGrath et al., 2003; Yanqun et al., 2005). To some extent, it will be useful to find some plants that have the accumulating ability of heavy metals. In this study, we investigated the concentrations, translocation and enrichment factors of Pb, Fe, Mn, Cu and Zn of 7 plant species in a industrial town with the objective to (1) get a better knowledge of the accumulating capacity of 7 plant species of Pb, Fe, Mn, Cu and Zn, and (2) choose a hyperaccumulator that could be used for the remediation of soil polluted by heavy metals.

MATERIALS AND METHODS

Site description

The plant and soil samples used in this study were collected from a known industrial town called Vian of Hamedan city, north of Hamedan (Fig. 1). The site of the industrial town Vian is: east longitude 48° 51', north latitude 35° 7', altitude 1635 m; it has an annual average temperature 10.5°C, annual rainfall 318 mm, and the area is 50 ha. There was no treatment plant for the purification of wastewater. and therefore the discharging of industrial wastewater contaminated by toxic heavy metals is a serious concern. Contamination by heavy metals was mainly concentrated in the top 20 cm of the soil.

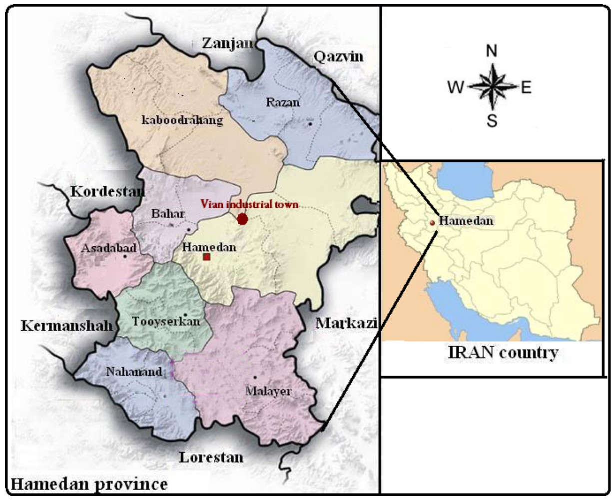

Fig 1. Location of the study area

Sampling

Samples of plant and soil were collected from the surrounding area of Vian. The collected plant species grow very well and were dominant in the industrial area. Seven plant species were collected from June to August 2009. The studied species consisted of 7 genera and 4 families, of which 4 species belonged to Chenopodiaceae, forming the most dominant component in studied site (Table 1). At least six individual plants of each plant species were randomly collected within the sampling area; they were then mixed to give a composite whole plant sample. The soils in which the plants were growing were representative of the surface horizon, maximum sampling depth was about 20 cm. Soil samples were composite mixtures of soils from the rhizosphere of each plant.

Table 1. Species composition in the surrounding area of Vian industrial town

Species No.	Scientific name	Family
1	*Suaeda altissima* (L.) Pall.	Chenopodiaceae
2	*Chenopodium album* L.	Chenopodiaceae
3	*Camphorosma monospeliacum* L.	Chenopodiaceae
4	*Salsola soda* L.	Chenopodiaceae
5	*Hordeum glaucum* Steud.	Poaceae
6	*Circium arvense* (L.) Scop.	Asteraceae
7	*Lepidium perfoliatum* L.	Brassicaceae

Plant analysis

The plant samples were carefully washed with deionized water and oven-dried at 70°C for 30 min, then ground into fine powder and sieved through a 1 mm nylon sieve. The concentrations of Pb, Fe, Mn, Cu and Zn in the plants were determined in the environment laboratory of the Islamic Azad University, Hamedan branch (Hamedan, Iran). 1-gram plant samples were digested by HNO_3:$HClO_4$ (3:1). The concentrations of Pb, Fe, Mn, Cu and Zn were determined by an Inductively Coupled Plasma Emission Spectroscopy (ICP-ES-710 Varian, Australia). Standard materials were included for assurance control. Standard materials were $Pb(NO3)_2$, $MnCl_2$, $Cu(NO3)_2$, $Fe(NO3)_2$ and $ZnCl_2$. Means of Pb, Mn, Cu, Fe and Zn were calculated from triplicate.

Soil analysis

The soil samples were air-dried at room temperature for 3 weeks, then ground into fine powder and sieved through a 2 mm nylon sieve. The concentrations of Pb, Fe, Mn, Cu and Zn in the soils were determined in the environment laboratory of the Islamic Azad University, Hamedan branch (Hamedan, Iran). 0.5 gram soil samples were digested by HNO_3:HCl:$HClO_4$ (1:2:2) to obtain a total extraction of the heavy metals. The total concentrations of Pb, Fe, Mn, Cu and Zn were determined by Inductively Coupled Plasma Emission Spectroscopy (ICP-ES-710 Varian, Australia). Standard materials were included for assurance control. Standard materials were $Pb(NO3)_2$, $MnCl_2$, $Cu(NO3)_2$, $Fe(NO3)_2$ and $ZnCl_2$. Means of Pb, Mn, Cu, Fe and Zn were calculated from triplicate.

Enrichment and translocation factors

The definition of metal hyperaccumulation has to take into consideration not only the metal concentration in the aboveground biomass, but also the metal concentration in the soil. Both enrichment factor (EF) and translocation factor (TF) have to be considered while evaluating whether a particular plant is a metal hyperaccumulator (Ma et al., 2001). The enrichment factor is calculated as the ratio plant shoot concentration to soil concentration ($[Metal]_{shoot}/[Metal]_{Soil}$) (Branquinho et al., 2006) and the translocation factor is the ratio of metal concentration in the shoot to the root ($[Metal]_{Shoot}/[Metal]_{Root}$). Therefore, a hyperaccumulator plant should have EF or TF> 1.

RESULTS

Concentrations of Pb, Fe, Mn, Cu and Zn in plants

Total lead concentrations in the plant samples collected from the site were variable, ranging from 260 mg/kg to 3420 mg/kg in roots and 15 mg/kg to 2880 mg/kg in shoots, with the maximum level in the roots of *C. arvense* and shoots of *S. soda*. The iron concentrations in the plant roots differed among the species at the polluted site from 349.6 mg/kg to 22645.3 mg/kg and in shoots from 309.6 mg/kg to 10604.9 mg/kg, with the maximum content in the roots of *S. soda* and shoots of *C. monospeliacum*. Total manganese concentrations in the plant roots ranged from 3.3 mg/kg to as high as 656.7 mg/kg, and in plant shoots from 6.2 mg/kg to as high as 603.7 mg/kg, with the maximum level in the roots of *S. soda* and shoots of *C. monospeliacum*. Copper concentrations in the plant roots differed among the species at the polluted site from 1.6 mg/kg to 25.6 mg/kg and in shoots from 2.0 mg/kg to 20.0 mg/kg, with the maximum content in the roots and shoots of *L. perfoliatum*. Zinc concentrations in the plant roots differed among the species at the polluted site from 25.8 mg/kg to 1695 mg/kg, and in shoots from 53 mg/kg to 1458 mg/kg, with the maximum content in the roots of *C. album* and shoots of *S. soda*. For average concentrations in roots, Cu was the lowest (10.5 mg/kg), followed by Mn (144.5 mg/kg), Zn (674.1 mg/kg), Pb (1233.0 mg/kg), and Fe (7844.4 mg/kg). Average concentrations in shoots showed the same condition (Cu: 10.5 mg/kg, Mn: 144.5 mg/kg, Zn: 718.2 mg/kg, Pb: 945 mg/kg and Fe 3976.3 mg/kg). Concentrations of Pb, Fe, Mn, Cu and Zn in the collected plant species are provided in Table 2.

Concentrations of Pb, Fe, Mn, Cu and Zn in soils

Table 2 shows the values of the heavy metals in different localities in the vicinity of Vian industrial town. Here were detected the average values of 1188.3 mg/kg, 17084.1 mg/kg, 794.4 mg/kg, 26.0 mg/kg and 1204.4 mg/kg for Pb, Fe, Mn, Cu and Zn, respectively. Of all the heavy metals examined in the soil from the studied area, the average concentration of Cu (26.0 mg/kg) was the lowest, followed by Mn (794.4 mg/kg), Pb (1188.3 mg/kg), Zn (1204.4 mg/kg), and Fe (17084.1 mg/kg).

Enrichment and translocation factors of Pb, Fe, Mn, Cu and Zn in plants

For the enrichment factor of the five heavy metals in the plants, the average of Mn was the lowest (0.17), followed by Fe (0.23), Cu (0.41), Zn (0.59), and Pb (0.78). For the different plant species, the enrichment factors of Pb, Fe, Mn, Cu and Zn were different. The enrichment factor maximum for Pb was 2.35 of *S. soda*, and minimum was 0.01 of *C. album*. The enrichment factors were greter than 1 in *S. soda* and *C. arvense* for Pb. For the translocation factor of the measured heavy metals in the plants, the average of Pb was the lowest (1.54), followed by Cu (1.92), Fe (2.46), Zn (2.54), and Mn (2.68). For the different plant species, the translocation factors of Pb, Fe, Mn, Cu and Zn were different, respectively. For example, the translocation factor, maximum of Pb was 8.35 *S. soda*, and the minimum was 0.08 of *C. arvense*. The translocation factors were greater than 1 in *S. soda* for Pb, *C. album*, *C. monospeliacum* and *L. perfoliatum* for Fe, *S. altissima*, *C. album*, *C. monospeliacum*, *H. glaucum*, *C. arvense* and *L. perfoliatum* for Mn, *S. altissima*, *C. album*, *H. glaucum* and *C. arvense* for Cu and *S. altissima*, *C. monospeliacum*, *C. arvense* and *L. perfoliatum* for Zn. Enrichment and translocation factors of Pb, Fe, Mn, Cu and Zn in 7 collected plant samples are listed in Table 3.

DISCUSSION

This is the first report about the concentrations, translocation and enrichment capacities of Pb, Fe, Mn, Cu and Zn of 7 plant species and hyperaccumu-

Table 2. Concentrations of Pb, Fe, Mn, Cu and Zn of 7 plants and soils in Vian industrial town

Samples No.	Pb (mg/kg)			Fe (mg/kg)			Mn (mg/kg)			Cu (mg/kg)			Zn (mg/kg)		
	Shoot	**Root**	**Soil**	**Shoot**	**Root**	**Soil**	**Shoot**	**Root**	**Soil**	**Shoot**	**Root**	**Soil**	**Shoot**	**Root**	**Soil**
1	235	1190	1202.6	1781.3	4375.7	17019.8	112.0	17.9	829.7	9.7	2.6	23.4	489	258	1160.5
2	15	260	1137.3	2271.8	349.6	16353.7	84.5	17.7	604.5	18.6	3.4	24.1	1458	1695	1186.2
3	1060	2020	1179.3	10604.9	10383.7	17012.6	603.7	254.3	898.0	2.0	16.7	23.9	297	25.8	1198.3
4	2880	345	1175.0	4282.3	22645.3	16854.2	115.7	656.7	637.7	2.2	13.3	28.9	1256.3	1289	1296.2
5	155	985	1214.3	309.6	2381.3	17414.5	6.2	3.3	839.3	2.3	1.6	29.3	53	163	1211.2
6	1880	3420	1201.3	1108.6	13938.6	17631.0	35.3	17.0	883.9	18.5	10.4	27.1	685	616	1155.3
7	390	415	1208.7	7476.0	837.0	17303.2	54.0	44.5	867.6	20.0	25.6	24.8	789	672	1223.5
Average	945	1233.6	1188.3	3976.3	7844.4	17084.1	144.5	144.5	794.4	10.5	10.5	26.0	718.2	674.1	1204.4
Maximum	2880	3420	1214.3	10604.9	22645.3	17631.0	603.7	656.7	898.0	20.0	25.6	29.3	1458	1695	1296.2
Minimum	15	260	1137.3	309.6	349.6	16353.7	6.2	3.3	604.5	2.0	1.6	23.4	53	25.8	1155.3

Table 3. Enrichment and translocation factors in the selected plants

Samples No.	Enrichment factor *(EF)					Translocation factor **(TF)				
	Pb	Fe	Mn	Cu	Zn	Pb	Fe	Mn	Cu	Zn
1	0.19	0.10	0.13	0.41	0.42	0.20	0.41	**6.26**	**3.73**	**1.90**
2	0.01	0.14	0.14	0.77	**1.23**	0.06	**6.50**	**4.77**	**5.47**	0.86
3	0.90	0.62	0.67	0.08	0.25	0.52	**1.02**	**2.37**	0.12	**11.51**
4	**2.35**	0.25	0.18	0.08	0.97	**8.35**	0.19	0.18	0.16	0.89
5	0.13	0.02	0.01	0.08	0.04	0.16	0.13	**1.88**	**1.44**	0.32
6	**1.56**	0.06	0.04	0.68	0.59	0.55	0.08	**2.08**	**1.78**	**1.11**
7	0.32	0.43	0.06	0.81	0.64	0.94	**8.93**	**1.21**	0.78	**1.17**
Average	0.78	0.23	0.17	0.41	0.59	**1.54**	**2.46**	**2.68**	**1.92**	**2.54**
Maximum	2.35	0.33	0.67	0.81	1.23	8.35	**8.93**	**6.26**	**5.47**	**11.51**
Minimum	0.01	0.02	0.01	0.08	0.25	0.06	0.08	0.18	0.12	0.32

lator choice in the industrial town of Vian, Hamedan, Iran. The discussion concentrates on the uptake and accumulation of Pb, Fe, Mn, Cu and Zn and the choice of hyperaccumulator plants.

Uptake and accumulation

Heavy metals are currently of great environmental concern. They are harmful to humans, animals and tend to bioaccumulate in the food chain. Activities such as the mining and smelting of metal ores, industrial emissions and applications of insecticides and fertilizers have all contributed to elevated levels of heavy metals in the environment (Alloway, 1994). The threat that heavy metals pose to human and animal health is aggravated by their long-term persistence in the environment.

The present study showed that some plants can colonize sites with a wide range of metal concentrations in the soils. According to Istvan and Benton (1997) and Kabata-Pendias and Pendias (1984), 300 mg/kg Pb, 3800 mg/kg Fe, 545 mg/kg Mn, 20 mg/kg Cu and 200 mg/kg Zn can be considered to be normal concentrations based on total fractions in soil. The average metal contents (Pb, Fe, Mn, Cu and Zn) in the surrounding area of Vian greatly exceeded these ranges (Table 2).

Metal concentrations in plants vary with plant species (Alloway et al., 1990). According to Istvan and Benton (1997), toxic concentrations of heavy metals for various plant species are 300, 500, 300, 20 and 100 mg/kg for Pb, Fe, Mn, Cu and Zn, respectively; therefore the average contents of Pb, Fe and Zn in the sampled plants were higher than the toxic levels.

Identification of hyperaccumulator plants in study area

When categorizing plants that can grow in the presence of toxic elements, the terms “tolerant” and “hyperaccumulator” are used. A tolerant species is one that can grow on soil with concentrations of a particular element that are toxic to most other plants (Assuncao et al., 2001; Bert et al., 2003; MacNair et al., 1999), therefore most of the plant species grown in Vian were tolerant to the measured heavy metals.

The concept of phytoremediation was first proposed by Chaney (1983) and involves the use of plant hyperaccumulators of heavy metals to remove pollutants from soils or waters. Hyperaccumulators accumulate appreciable quantities of metal in their tissue, regardless of the concentration of metal in the soil (Prasad et al., 2003). More than four hundreds plants are known as hyperaccumulators of metals which can accumulate high concentrations of metals into their aboveground biomass. These plants include trees, vegetable crops, grasses and weeds (Yoon et al., 2006). Considering the hyperaccumulator definition of Baker and Brooks (1989) and Market (2003), none of the plant species were hyperaccumulator for Mn, Cu and Zn. *C. monospeliacum* for Pb and Fe with 1060 mg/kg and 10604.9 mg/kg, and *S. soda* and *C. arvense* with 2880 mg/kg and 1880 mg/kg for Pb were hyperaccumulator species in the study area. However, when applying the requirements of McGrath and Zhao (2003), it can be considered an unusual number of accumulators. There is 1 species that has been identified as a Pb accumulator, 3 species as Fe accumulators, 6 species as Mn accumulators and 4 species as Cu and Zn accumulators based on this definition. In fact these plant species are able to accumulate unusually high concentrations of heavy metals in their aboveground parts. In this study, *S. soda* and *C. arvense* for Pb and *C. album* for Zn showed EFs > 1 in respect to total soil composition, i.e. they were hyperaccumulators according to McGrath and Zhao (2003) and Yanqun et al. (2005). Another requirement for classifying a hyperaccumulator plant is that the concentrations found in plants must be 10-500 times higher than the ones growing in unpolluted environments (Yanqun et al. 2005), but in this study this requirement cannot be tested due to the lack of the sampled plants on other locations and soils. EF and TF values> 1 are in bold font at Table 3.

CONCLUSION

The heavy metal input through anthropogenic activities increases the total contents of the metals, which may result in the increase of potential environmental risk. Phytoremediation is the use of living plants to mop-up pollution in the environment like metal contaminants in the soil. This study was conducted to screen plants growing on a contaminated site to determine their potential for metal accumulation. According to the above-mentioned criteria, *S. soda* and *C. arvense* can be classified as hyperaccumulators for some of the measured heavy metals and they are good candidates to be used in the phytoremediation of contaminated soils. Further investigations under controlled environmental conditions are required for evaluating the usefulness of these species in phytoremediation technologies.

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