Potential of *Pistia stratiotes* and *Eichhornia crassipes* in Rhizofiltration

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SUMMARY

Pistia stratiotes, and Eichhornia crassipes pleustophyta, hydrocharoid species among the most widely researched aquatic plants to treat industrial waste water containing heavy metals have been chosen for further biotransformation and translocation tests. Pistia stratiotes and Eichhornia crassipes showed elevated heavy metal accumulation, their biotransformation factor is high, confirming that both are potentially applicable for waste water treatment in hydroponies as part of a rhizofiltration technology. Especially Zn was accumulated in high extent, namely in 0.5% of the plant tissue. Accumulation preferably takes place in their root system, the translocation factors are accordingly high, only Sr was found among the examined elements to translocate to the shoots, probably playing the role of Ca substituent.

INTRODUCTION

Rhizofiltration represents a considerable, and recently widely researched „green" opportunity for using plants to clean up contaminated or waste water. Hundreds of plant species have been screened, and several are proved to effectively take up and accumulate certain heavy metal species, having the potential for the application in rhizofiltration technologies. Rhizofiltration is an approach of using hydroponically cultivated plant roots to absorb, concentrate, and precipitate certain contaminants. The roots take up the water and the contaminants dissolved in it. Many plant species naturally uptake heavy metals and excess nutrients for a variety of reasons: sequestration, drought resistance, disposal by leaf abscission, interference with other plants, and defence against pathogens (Raskin et al., 1997; Boyd, 1998).

Rhizofiltration may be applicable to the treatment of surface water and groundwater, industrial and residential effluents, downwashes from power lines, storm waters, acid mine drainage, agricultural runoffs, diluted sludge, and radionuclide-contaminated solutions. Plants suitable for rhizofiltration applications can efficiently remove toxic metals from a solution using rapid-growth root systems. Various terrestrial plant species have been found to effectively remove toxic metals such as Cu, Cd, Cr, Ni, Pb, and Zn from aqueous solutions. Plants should have considerable root mass, high root surface, and with good absorption capacity, however, with relatively low biotransformation factor, not resulting in more contaminated plant residue (Dushenkov et al., 1995).

Rhizofiltration is particularly effective in applications where low concentrations and large volumes of water are involved. For successful application, depth of contamination, types of heavy metal species present, and level of contamination must be determined and monitored. Vegetation should be aquatic, emergent, or submergent plants. Hydraulic detention time and sorption by the plant roots must also be considered (Schnoor, 1997).

In the plants, different processes undergo at the same time, including mobilization of contaminants by extracellular acidification and complexation, and in contrary, immobilization by iron-oxide precipitation on the root surface (Robinson, 1990; Ernst, 1996). When heavy metals get through the plant cell wall, different, even species-specific intracellular methods provide protection against adverse effects.

Recently, several potentially useful plant species have been identified and researched under different conditions, including both aquatic species, e.g. *Eichhornia crassipes* (Alvarado et al., 2008; Mishra and Tripathi, 2008), *Lemna minor* (Alvarado et al., 2008), *Spirodela polyrhiza* (Gaur et al., 1994; Mishra and Tripathi, 2008), *Azolla pinnata* (Gaur et al., 1994), *Phragmites australis* (Bragato, et al., 2006; Lesage, et al., 2007), *Bolboschoenus maritimus* (Bragato, et al., 2006), and terrestrial ones *Brassica juncea* (Niu et al., 2007) and *Helianthus annuus* (January et al., 2008).

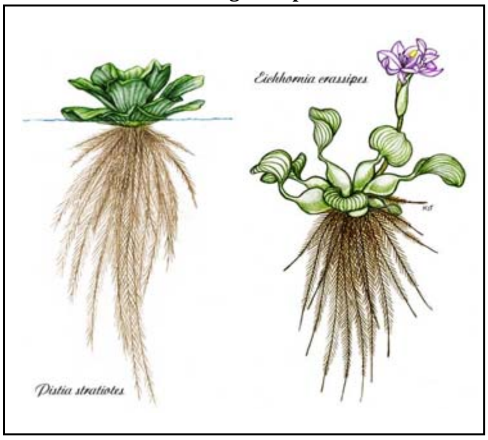
MATERIALS AND METHODS

Pistia stratiotes, and *Eichhornia crassipes* pleustophyta, hydrocharoid species among the most widely researched aquatic plants to treat industrial waste water containing heavy metals have been chosen for further biotransformation and translocation tests (Fig. 1).

Pistia stratiotes is a genus of aquatic plant in the family *Araceae*, often called water cabbage or water lettuce. Its native distribution is uncertain, but probably pantropical; it was first described from the Nile, in Africa. It has been reported to reduce COD, BOD, and ammonium-N from industrial waste water, considerably (Chen et al., 2006; Zimmels et al., 2006), in addition to heavy metal elimination from water phase (Tewari et al., 2008; Upadhyay et al., 2007). Its root system contributes to the precipitation of chromium, however, considerable amount is accumulated in the shoot as well (Sune et al., 2007). Its tolerance against mercury was found also high, with significant accumulation (Skinner et al., 2007), and also high elimination ratio from solution was reported for cadmium (Bhakta and Munekage, 2008).

Eichhornia crassipes belonging to the family *Pontederiaceae* and commonly known as Common Water Hyacinth is an invasive species of plant, which is native of Amazon basin. The plant is widely used for sewage treatment due to its high phosphorous accumulation ability (Hada and Maine, 2007). It shows high tolerance against cadmium, however, the translocation is also high resulting in high Cd content in the leaves (Toppi et al., 2007). In case of other heavy metals, like iron, zinc, copper and chromium, *Eichhornia crassipes* was also proved to have high elimination potential from industrial waste water (Mishra and Tripathi, 2008).

Figure 1: ***Pistia stratiotes*****, and** ***Eichhornia crassipes*** **investigated species**



To model a heavy metal containing aqueous media, two sampling sites from an abandoned mine tailing in Gyöngyösoroszi (Hungary) were chosen, since, the aim of the study was to investigate the plant species rather in a complex system than in pure water solutions. The samples differed in physical and chemical properties i.e. in particle size distribution and heavy metal concentrations, however, both were acidic in water suspension, and had elevated Zn, Cd, Pb, Ni, As contents from natural, partly weathered mineral sources. The solid phases were extracted till equilibrium with deionised water in m/m ratio of 1:2.5, for 48 h assuming no limitation for saturation. The solid phases were let settle down, during the tests, the solid and liquid phases were not separated.
Pistia stratiotes and *Eichornia crassipes* were grown for 6 weeks in greenhouse (T=25^{o}C) under natural light, in the system. The nutrients were supplied by adding NPK 15:15:15 fertilizer. Control test for *Pistia stratiotes* was carried out in a natural wetland.

Analysis of the liquid phase included pH, EC, and total salt content was carried out weekly, while the heavy metal concentration in the extract, and the accumulated heavy metal content in roots and shoots were measured last week. The growth intensity was also monitored by measuring the biomass at week 1 and 6 for both species.
The bioconcentration factors (*BCF*) were calculated based on the element concentration in the liquid phase (*l*) and the plant element concentration (*p*) (Eq. 1), while the translocation factors (*TLF*) were calculated from the root and shoot element concentrations (*r* and *s*, respectively) (Eq. 2).

$$BCF = element\ concentration_{(p)} / element\ concentration_{(l)} \quad (1)$$

$$TLF = element\ concentration_{(r)} / element\ concentration_{(s)} \quad (2)$$

RESULTS AND DISCUSSION

During the test period, the pH of both extracts does not change significantly, but remains in the slightly acidic range of 5.42-6.02, without trends, providing high solubility and potential bioavailability of the heavy metals. Based on the EC values, changing in the range of 2.07-4.08 mS cm^{-1}, the extracts moderately-highly salty. The high salt content in addition to acidic pH may increase the adverse effect on the plant species not having high tolerance against these conditions. However, the tolerable pH range is 5.5-9 for *Eichornia crassipes*, while for *Pistia stratiotes* it is 5-8. According to Toppi et al. (2007), salt content and pH affect plants more significantly than heavy metals in such systems.
In case of *Eichornia crassipes*, necrosis of the leaves ends was found, while in case of *Pistia stratiotes*, slight chlorosis was be observed for both extracts.
The element concentrations in the extracts were not detectable for Pb, Ni and As, however, Cu, Zn, Sr and Cd concentrations were measurable (Table 1). Values were higher in case when the solid phase itself contained higher heavy metal concentrations probably resulting from different chemical compositions of the mineral phases, and not from undersaturation of the liquid phase.

Table 1

Element concentration in the extracts of media with different physical types, mg l^{-1}

extract	As	Cd	Cu	Fe	Ni	Pb	Sr	Zn
sandy-loam	ND	0.033	0.019	0.181	ND	ND	0.745	1.95
sand	ND	0.010	0.017	0.144	ND	ND	0.49	0.842

ND: non-detectable (ICP-OES)

Considering the accumulation abilities of *Pistia stratiotes* and *Eichornia crassipes*, results confirm that the studied species highly tolerate and accumulate heavy metals even in media having high salt content and acidic pH (Table 2). Based on it, they are widely applicable for heavy metal elimination from industrial waste waters and other contaminated waters. Zn accumulation was considerable resulting in 0.5% in the plant tissues, due to the acidic conditions providing high bioavailable fractions. Pb, Mn, As and Cd were measured in elevated concentrations in the plants, as well. Comparing the two species for As accumulation, *Eichornia crassipes* was found a better accumulator, however, its overall heavy metal accumulating ability also better comparing to that of *Pistia stratiotes*.

Table 2

Element concentrations in the plant roots and shoots for different media, mg kg^{-1}

extract	species		*Pb*	*As*	*Zn*	*Cu*	*Ni*	*Mn*	*Cr*	*Cd*	*Sr*
sand	*Pistia stratiotes*	root	426	24.0	3480	245	20.9	2140	4.83	23.0	73.0
		shoot	70.6	5.12	367	23.0	3.95	256	2.51	3.31	90.9
	Eichornia crassipes	root	680	71.0	4290	473	22.3	1000	3.71	17.4	56.3
		shoot	297	34.0	1560	143	10.8	171	2.48	8.13	122
sandy-loam	*Pistia stratiotes*	root	1890	25.8	6100	378	23.9	744	4.21	82.4	58.5
		shoot	158	ND	1070	28.3	4.31	64.2	1.57	9.60	84.4
	Eichornia crassipes	root	1670	123	5080	363	26.7	1080	2.47	30.3	74.1
		shoot	437	26.2	1600	143	9.01	200	2.76	12.9	108
control	*Pistia stratiotes*	root	64.00	34.22	1174	ND	ND	284	ND	ND	ND
		shoot	ND	ND	836	ND	ND	ND	ND	ND	ND

ND: non-detectable (ICP-OES)

Based on the results for Zn, Cd and Cu concentration in the plants, BCFs show considerable accumulation and enhanced heavy metal up-take in both cases. TLFs reveal that both *Pistia stratiotes* and *Eichornia crassipes* accumulate heavy metals in their root systems, which confirms the results of Tewari et al. (2008).

An interesting finding is that Sr accumulation takes place rather in the shoots than in the roots for both species. It may be explained by the strontium biochemical properties similar to that of calcium. For *Pistia stratiotes*, higher TLFs were found revealing possibly different detoxification methods for the two species (Table 3).

Table 3

Bioconcentration factors and Translocation factors for *Pistia stratiotes* and *Eichornia crassipes*

element	extract	BCF		TLF	
		Pistia stratiotes	*Eichornia crassipes*	*Pistia stratiotes*	*Eichornia crassipes*
Pb	sand	ND	ND	6.0	2.3
	sandy-loam	ND	ND	12.0	3.8
As	sand	ND	ND	4.7	2.1
	sandy-loam	ND	ND	ND	4.7
Zn	sand	4568.9	6947.7	9.5	2.8
	sandy-loam	3676.9	3425.6	5.7	3.2
Cu	sand	14084.5	32432.7	10.6	3.3
	sandy-loam	23902.0	29740.2	13.4	2.5
Ni	sand	ND	ND	5.3	2.1
	sandy-loam	ND	ND	5.5	3.0
Mn	sand	NM	NM	8.4	5.9
	sandy-loam	NM	NM	11.6	5.4
Cr	sand	NM	NM	1.9	1.5
	sandy-loam	NM	NM	2.7	0.9
Cd	sand	2629.7	16388.5	6.9	2.1
	sandy-loam	2788.6	5415.2	8.6	2.4
Sr	sand	34.3	191.8	0.8	0.7
	sandy-loam	88.0	370.7	0.5	0.7

ND: non-detectable (ICP-OES)

NM: not measured

Even though adverse effect of the media was observed, biomass for both species was found increasing in time (Table 4). *Eichornia crassipes* showed a little bit more intense trend, which also confirms the results of Sooknah and Wilkie (2004).

Table 4

Biomass production (g)

extract	species	initial biomass	final biomass	growth potential
sand	*Pistia stratiotes*	625	866	1,39
	Eichornia crassipes	64	105	1,64
sandy loam	*Pistia stratiotes*	539	682	1,27
	Eichornia crassipes	69	94	1,36

CONCLUSIONS

According to the tests carried out in a complex system of mine tailing materials' extracts, both investigated species, *Pistia stratiotes* and *Eichhornia crassipes* showed elevated heavy metal accumulation, their biotransformation factor is high, confirming that both are potentially applicable for waste water treatment in hydroponies as part of a rhizofiltration technology. Especially Zn was accumulated in high extent, namely in 0.5% of the plant tissue. Accumulation preferably takes place in their root system, the translocation factors are accordingly high, only Sr was found among the examined elements to translocate to the shoots.

The investigations were carried out in simple extracts by no added complexing agents that can enhance the heavy metal up-take, and other materials, except nutrients, that may reduce the adverse effects of high salt content and acidic pH, thus further studies are required to optimize rhizofiltration technology with respect to the tested hydrocharoid species.

References

Alvarado, S., Guédez, M., Lué-Merú, M.P., Nelson, G., Alvaro, A., Jesús, A.C., Záray Gy. (2008): Arsenic removal from waters by bioremediation with the aquatic plants Water Hyacinth (*Eichhornia crassipes*) and Lesser Duckweed (*Lemna minor*). *Bioresource Technology* **99**(17), 8436-8440.

Bhakta, J.N., Munekage, Y. (2008): Role of ecosystem components in Cd removal process of aquatic ecosystem. *Ecological Engineering* **32**(3), 274-280.

Boyd, R. S. (1998): Plants That Hyperaccumulate Heavy Metals. Ed. R. R. Brooks. Willingford, U.K.: CAB International, 181-201.

Bragato, C., Brix, H., Malagoli, M. (2006): Accumulation of nutrients and heavy metals in *Phragmites australis* (Cav.) Trin. ex Steudel and *Bolboschoenus maritimus* (L.) Palla in a constructed wetland of the Venice lagoon watershed. *Environmental Pollution* **144**(3), 967-975.

Chen, T.Y., Kao, C.M., Yeh., T.Y., Chien, H.Y., Chao, A.C. (2006): Application of a constructed wetland for industrial wastewater treatment: A pilot scale study. *Chemosphere*, **64**, 497-502.

Dushenkov, V., Motto, H., Raskin, I., Kumar N. (1995): Rhizofiltration: the Use of Plants to Remove Heavy Metals From Aqueous Streams. *Environmental Science Technology* **30**, 1239-1245.

Ernst, W.H.O. (1996): Bioavailability of heavy metals and decontamination of soils by plants. *Applied Geochemistry* **11**, 163-167.

Gaur, J.P., Noraho, N., Chauhan, Y.S. (1994): Relationship between heavy metal accumulation and toxicity in *Spirodela polyrhiza* (L.) Schleid. and *Azolla pinnata* R. Br. *Aquatic Botany* **49**(2-3), 183-192.

Hada, H.R., Maine, M.A. (2007): Phosphorous amount in floating and rooted macrophytes growing in wetlands from the Middele Parana River floodplain (Argentina). *Ecological Engineering* **31**, 251-258.

January, M.C., Cutright, T.J., Keulen, H.V., Wei, R. (2008): Hydroponic phytoremediation of Cd, Cr, Ni, As, and Fe: Can *Helianthus annuus* hyperaccumulate multiple heavy metals? *Chemosphere* **70**(3) 531-537.

Lesage, E., Rousseau, D.P.L., Meers, E., Tack, F.M.G., De Pauw, N. (2007): Accumulation of metals in a horizontal subsurface flow constructed wetland treating domestic wastewater in Flanders, Belgium. *Science of The Total Environment* **380**(1-3), 102-115.

Mishra, V.K., Tripathi B.D. (2008): Concurrent removal and accumulation of heavy metals by the three aquatic macrophytes. *Bioresource Technology* **99**(15), 7091-7097.

Niu, Z.X., Sun, L.N., Sun, T.H., Li, Y.S., Wang, H. (2007): Evaluation of phytoextracting cadmium and lead by sunflower, ricinus, alfalfa and mustard in hydroponic culture. *Journal of Environmental Sciences* **19**(8), 961-967.

Raskin, I., Smith, R.D., Salt D.E. (1997): Phytoremediation of metals: using plants to remove pollutants from the environment. *Current Opinion in Biotechnology* **8**(2), 221-226.

Robinson, N.J. (1990): Metal-binding polypeptides in plants. In: Shaw, A.J. (Editor), Heavy Metal Tolerance in Plants: Evolutionary Aspects, CRC Press, Boca Raton, Forida, 195-215.

Schnoor, J.L. (1997): Phytoremediation, Technology Overview Report, Ground-Water Remediation Technologies Analysis Center, Series E, Vol. 1.

Skinner, K., Wright, N., Porter-Goff, E. (2007): Mercury uptake and accumulation by four species of aquatic plants. *Environmental pollution* **145**, 234-237.

Sooknah, R.D., Wilkie, A.C. (2004): Nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater. *Ecological Engineering* **22**, 27-42.

Sune, N., Sanchez, G., Gaffaratti, S., Maine, M.A. (2007): Cadmium and chromium removal kinetics from solution by two aquatic macrophytes. *Environmental pollution* **145**, 467-473.

Tewari, A., Singh, R., Singh, N.K., Rai, U.N. (2008): Amelioration of municipal sludge by *Pistia stratiotes* L.: Role of antioxidant enzymes in detoxification of metals. *Bioresource technology* **99**(18), *8715-8721*.

Toppi, L.S., Vurro, E., Rossi, L., Marabottini, R., Musetti, R., Careri, M., Maffini, M., Mucchino, C., Corradini, C., Badiani, M. (2007): Different compensatory mechanisms in two metal-accumulating aquatic macrophytes exposed to acute cadmium stress in outdoor artificial lakes. *Chemosphere* **68**, 769-780.

Upadhyay A.R., Mishra, V.K., Pandey, S.K., Tripathi, B.D. (2007): Biofiltration of secondary treated municipal wastewater in a tropical city. *Ecological engineering* **30,** 9-15.

Zimmels, Y., Kirzhner, F., Malkovskaja, A. (2006): Application of *Eichhornia crassipes* and *Pistia stratiotes* for treatment of urban sewage in Israel. *Journal of Environmental Management* **81**, 420-428.