Available online at www.ewijst.org

ISSN: 0975-7112 (Print)
ISSN: 0975-7120 (Online)

Environ. We Int. J. Sci. Tech. 4 (2009) 23-27

Environment & We
an International
Journal of Science
& Technology

Salvinia: an Aquatic Fern with Potential Use in Phytoremediation

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Abstract

Salvinia exhibit capacity for removing contaminants such as heavy metals, inorganic nutrients, explosives from wastewaters. Properties such as high productivity, high sorption capacity and high metal removal potential establish *Salvinia* as an aquatic fern with immense potential for use in phytoremediation technologies. Realizing capabilities of *Salvinia,* its role for mass scale use in phytoremediation technology needs to be highlighted.

Key words: Heavy metals, phytoremediation, *Salvinia,* wastewater.

Introduction

The role of aquatic plants in phytoremediation technology is well established (Dushenkov *et al*., 1995; Rai *et al*., 1995; Schneider and Rubio, 1999; Skinner *et al*., 2007). Aquatic ferns in particular exhibit exorbitant potential to remove various contaminants including heavy metals, organic compounds, radionuclides from the environment (Olguín *et al*., 2002, Benaroya *et al*., 2004, Stepniewska *et al*., 2005; Suněe *et al*., 2007). Among various species, *Salvinia*, a free-floating aquatic fern holds a distinct position because of several advantages including high productivity and tolerance to a wide range of temperatures (Olguín *et al*., 2002). Several species of *Salvinia* including *S. herzogii*, *S. minima*, *S. natans*, *S. rotundifolia* show potential to remove various contaminants including heavy metals from wastewaters (Nichols *et al*., 2000; Olguín *et al*. 2002; Suněe *et al*., 2007; Sánchez-Galván *et al*., 2008; Xu *et al*., 2009).

Heavy metal removal

The potential of *Salvinia* for heavy metal removal has been studied extensively (Srivastav *et al*., 1993; Banerjee and Sarkar, 1997; Olguín *et al*. 2002, 2005; Hoffman *et al*., 2004; Espinoza-Quinones *et al*., 2005; Mukherjee and Kumar, 2005; Molisani *et al*., 2006; Suñe *et al*., 2007) (Table 1). The heavy metal removal and compartmentalization in *Salvinia* is primarily a function of the presence of certain nutrients and chelants, with secondary dependence on environmental conditions (Olguin *et al*., 2003), though the mode of metal uptake varies depending upon the plant species and metal. The metal uptake in *Salvinia* occurs through a biological or physical mode. The metal (Cr, Pb) uptake by physical processes is fast and involves adsorption, ionic exchange and chelation, while biological processes such as intracellular uptake (transported through plasmalemma into cells) is comparatively slow but help in subsequent translocation of metals (Cd) from roots to leaves (Suñe *et al*., 2007). The maximum uptake occurs during the first few hours, though sorption capacity is limited by availability of adsorption sites. Studies involving scanning electron microscopy microanalysis suggest direct sorption of heavy metals through leaves as they are in direct in contact with the solution (Suñe *et al*., 2007) and propose that as the main cause of increase in metal in the aerial parts (Maine *et al*., 2004). It has been postulated that uptake of heavy metals is driven by secondary transport proteins viz. channel proteins or H^+ coupled carrier proteins where negative membrane potential inside the plasma membrane drives the uptake of cations through secondary transporters. Free carboxylic groups present on the cell surface provide the sites for metal binding (Olguin *et al*., 2005). High metal removal capacity of *Salvinia* biomass has been attributed to great specific surface (264 $m^2 g^{-1}$) that is rich in carbohydrates (48.50%) and carboxyl groups (0.95 mmol g^{-1}) (Sánchez-Galván *et al*., 2008). Proteins behave as important ligand atoms and also play an important role in metal sorption. The kinetics for the metal removal exhibit first order rate and equilibrium data fit well to both Langmuir and Freundlich's isotherms (Mukherjee and Kumar, 2005). Among various *Salvinia* species, *S. minima,* is considered as a hyperaccumulator of lead and cadmium because it shows high bioconcentration factor (BCF) (Olguin *et al*., 2002) which can reach in the range of 2000–2600 in batch systems and 4134 to 17170 in continuous systems (Olguin *et al*., 2005).

Non-living biomass of *Salvinia* exhibit equivalently high potential to remove heavy metals. The higher concentration of lipids and carbohydrates present on the plant surface act as the cationic weak exchanger groups that contribute to metal sorption by ion exchange reactions. Sorption of heavy metals by dry biomass also follows the Langmuir isotherm (Schneider and Rubio, 1999).

Removal of other contaminants

Another *Salvinia* species, *S. rotundifolia* show capacity for treating groundwater contaminated with explosives such as TNT. The removal of TNT by plants is rapid and result in accumulation of metabolic products such as aminodinitrotoluene (ADNT) (Jacobson *et al*., 2003). *Salvinia minima* show capacity to treat high-strength synthetic organic wastewater (HSWW). The plants raised in HSWW depict potential for fast consumption of inorganic nutrients such as ammoniumï nitrogen and nitrateï nitrogen and significant increase in relative growth rate (RGR) and productivity (2.3 fold increase) (containing ammoniumï nitrogen concentration of 70 mg L^{-1}) (Olguín *et al*., 2007). The greater sorption capacity of *Salvinia* biomass can be explored to use it as oil filter for removal of oil from oil/water emulsions. The superiority of the *Salvinia* sp. for removing oil (approx. 90% of the oil was retained by the biomass) from such emulsions appears to be due to large surface area, hydrophobicity of the aquaphyte biomass and hair-like surface that results in space between the hairs to hold oil (Ribeiro *et al*., 2003).

Advantages

Several advantages establish *Salvinia* as an important species for use in phytoremediation technologies. These mainly include (i) wide geographical distribution within the tropical and sub-tropical regions of the world; (ii) very high productivity around 5.8 to 11.4 g dw m^{-2} day^{-1} when cultivated in a chemically defined Hoagland medium, and around 20-120 kg^{-1} $ha^{-1}day^{-1}$ under natural conditions (Schneider and Rubio 1999); (iii) physico-chemical properties such as a high surface area (264 m^2g^{-1} d.w.) and high carboxylic content (ligands) (0.95 mmol H^+g^{-1} biomass); (iv) efficiency for nutrient or pollutant removal from wastewater, throughout different seasons; (iv) higher rate of metal removal per surface unit and higher recovery of metals after suitable treatment (Olguin *et al*., 2005); (v) easy to harvest as it has bigger fronds (from 0.5 to 1.0 cm); (vi) the possible use of the harvested biomass (Olguin *et al*., 2003).

Conclusions

In light of these advantages, *Salvinia* can be recommended as a plant species with greater potential for use in phytoremediation of contaminants including heavy metals. Though protocols need to be developed and further studies are required to understand the mechanisms involved in the uptake/removal of contaminants so that maximum potential can be utilized for use in phytoremediation technology.

Table 1 *Salvinia* species depicting potential for removing heavy metals.

Plant species	Heavy metal	Reference
S. minima	As, Pb, Cd, Cr	Hoffman *et al*. 2004, Olguin *et al*. 2002, 2005
S. auriculata	Hg	Molisani *et al*. 2006
S. herzogii	Cd, Cr	Maine *et al*. 2004, Suněe *et al*. 2007
S. rotundifolia	Pb	Banerjee and Sarkar, 1997
S. natans	Ni, As, Cu	Sen and Mondal, 1990, Sen and Bhattacharya, 1994, Mukherjee and Kumar, 2005

Acknowledgements

The financial assistance from Department of Science and Technology to Bhupinder Dhir is gratefully acknowledged.

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