USO DE MACRÓFITAS PARA REMEDIAÇÃO DE AMBIENTES AQUÁTICOS CONTAMINADOS

USING MACROPHYTES TO REMEDIATE CONTAMINATED AQUATIC ENVIRONMENTS

USO DE MACRÓFITOS PARA REMEDIAR MEDIOS ACUÁTICOS CONTAMINADOS

Renata Coura Borges1
Claudio Fernando Mahler2
Márcio Antonio Loredo Filho3
Cassiano Augusto Rolim Bernardino4

DOI: 10.54751/revistafoco.v16n11-046
Recebido em: 05 de Outubro de 2023
Aceito em: 09 de Novembro de 2023

RESUMO
A contaminação da água por elementos tóxicos vem despertando muita preocupação dos governantes e de toda população devido ao seu alto potencial de toxicidade a todos os seres vivos e ao ambiente. A fitorremediação tem sido considerada uma técnica limpa e de baixo custo para remoção dos poluentes. As macrófitas aquáticas têm sido estudadas para serem utilizadas como alternativas de recuperação desse ambiente, uma vez que possuem características favoráveis a esse processo. Este trabalho teve como objetivo verificar o potencial da Eichhornia crassipes para tolerar 3 níveis diferentes de contaminação por Pb, e quais mecanismos estão envolvidos nessa tolerância e explicar a estratégia de fitorremediação. As plantas foram cultivadas em solução de Hoagland em casa de vegetação. Foram avaliadas as modificações anatômicas das folhas e das raízes e as concentrações de Pb. As plantas não apresentaram modificações anatômicas para o Pb. As concentrações utilizadas não promoveram efeitos tóxicos e os mecanismos de tolerância demonstraram alto potencial dessa espécie para a fitorremediação de Pb.

Palavras-chave: Fitorremediação; contaminação aquática; eichhornia crassipes.

1 Doutora em Geoquímica Ambiental, Geociência pela Universidade Federal Fluminense. Universidade Federal do Rio de Janeiro (UFRJ). Avenida Pedro Calmon s/nº, Ilha do Fundão, Rio de Janeiro - RJ, CEP: 21941-596. E-mail: renatacouraborges@hotmail.com
2 Doutor em Geotecnia. Universidade Federal do Rio de Janeiro (UFRJ). Avenida Pedro Calmon s/nº, Ilha do Fundão, Rio de Janeiro - RJ, CEP: 21941-596. E-mail: mahler@coc.ufrj.br
3 Graduando em Engenharia Ambiental. Universidade Federal do Rio de Janeiro (UFRJ). Avenida Pedro Calmon s/nº, Ilha do Fundão, Rio de Janeiro - RJ, CEP: 21941-596. E-mail: loredo@eq.ufrj.br
4 Doutor em Geotecnia. Universidade Federal do Rio de Janeiro (UFRJ). Avenida Pedro Calmon s/nº, Ilha do Fundão, Rio de Janeiro - RJ, CEP: 21941-596. E-mail: cassianorolim@hotmail.com
ABSTRACT
The contamination of water by toxic elements has aroused great concern among
governments and the general public due to its high potential for toxicity to all living beings
and the environment. Phytoremediation has been considered a clean and low-cost technique for removing pollutants. Aquatic macrophytes have been studied for use as alternatives for recovering this environment, since they have favorable characteristics for this process. The aim of this work was to verify the potential of Eichhornia crassipes to tolerate 3 different levels of Pb contamination, and which mechanisms are involved in this tolerance and explain the phytoremediation strategy. The plants were grown in Hoagland's solution in a greenhouse. Leaf and root anatomical changes and Pb concentrations were assessed. The plants showed no anatomical changes to Pb. The concentrations used did not promote toxic effects and the tolerance mechanisms demonstrated the high potential of this species for Pb phytoremediation.

Keywords: Phytoremediation; aquatic contamination; eichhornia crassipes.

RESUMEN
La contaminación del agua por elementos tóxicos ha despertado gran preocupación entre los gobiernos y la población en general debido a su alto potencial de toxicidad para todos los seres vivos y el medio ambiente. La fitorremediación se ha considerado una técnica limpia y de bajo coste para la eliminación de contaminantes. Los macrófitos acuáticos han sido estudiados para su uso como alternativas para la recuperación de este medio, ya que presentan características favorables para contaminantes. Los Eichhornia crassipes han sido cultivados en solución de Hoagland en un invernadero. Se evaluaron los cambios anatómicos de hojas y raíces y las concentraciones de Pb. Las plantas no mostraron cambios anatómicos al Pb. Las concentraciones utilizadas no promovieron efectos tóxicos y los mecanismos de tolerancia demostraron el alto potencial de esta especie para la fitorremediación del Pb.

Palabras clave: Fitoremediación; contaminación acuática; eichhornia crassipes.

1. Introduction
The rapid increase in the world's population has led to a greater demand for food, water, energy, wood and other ecosystem services, promoting serious pressures on natural resources and the environment (KAMRAN et al., 2021; SALEEM et al., 2020c; ZAHEER et al., 2020). Anthropogenic activities such as accelerated urbanization, industrialization, agricultural intensification practices and mining activities are causing serious environmental pollution by heavy metals (ANYAKORA et al., 2013; HE et al., 2015; SU, 2014).

Water contamination is one of the most worrying because it is an indispensable input not only for living organisms, but also for production and social and economic development. With growing technological advances, this
natural resource has been the constant target of effluents from various anthropogenic activities, prompting the search for decontamination methods.

Heavy metals are considered toxic substances and have the ability to remain in the environment, as they are not biodegradable and can enter the food chain through cultivated plants, and possibly accumulate in the human body (SILVA, 2006). In order to avoid risks to human health and the environment, it is necessary to use appropriate and less expensive technologies that can remedy the toxicity of metals (LAMEGO; VIDAL, 2007). In the search for alternatives to clean up contaminated areas, solutions have been chosen that aim to decontaminate water through the use of living organisms, such as microorganisms and plants (PIRES et al., 2003).

Phytoremediation has emerged as a promising alternative for water remediation, which is less aggressive to the environment (ecologically correct) and more economically viable (HAQUE et al, 2008). Some of the advantages of phytoremediation are the low cost of investment and operation, its applicability in situ, and the minimal generation of degradation and destabilization of the area to be decontaminated (CHAVES et al, 2010).

2. Material and Methods

The experiment was conducted in a greenhouse located in the Environmental Geotechnics Sector of the Geotechnics Area of the Civil Engineering Program at COPPE/UFRJ (Federal University of Rio de Janeiro). The species used was a macrophyte called water hyacinth (*Eichhornia crassipes*), contaminated with Pb.

Cultivation was carried out in 9 buckets with a capacity of 10 liters, which received 9.8 liters of distilled water and 135 mL of nutrient solution (HOAGLAND & ARNON (1950). The plants underwent an adaptation period of approximately three weeks, and then the pots were contaminated with lead metal (Pb) on a weekly basis at the following doses: 0 mg kg\(^{-1}\) in treatment 1, 30 mg kg\(^{-1}\) in treatment 2 and 60 mg kg\(^{-1}\) for treatment 3 (Table1). During the period of the experiment, measurements such as plant and root mass and dimensions were taken on a weekly basis in order to monitor plant growth and behavior during
contamination.

Table 1. Concentrations of Pb applied in treatments T1, T2 and T3 (mg kg\(^{-1}\)). Pb concentration in groundwater, according to CONAMA resolution 420 (2009).

<table>
<thead>
<tr>
<th>Metal</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>COMANA 420</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead (PbNO(_3))</td>
<td>0</td>
<td>20</td>
<td>60</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Source: authors.

During the management of the experiment, the nutrient solution was renewed every week and the solution level was kept constant with the daily addition of distilled water. The pH was adjusted to close to 5.5.

After the cultivation period (four weeks), 20 mL of water was collected from each pot in the different contaminations using a volumetric pipette, then the water was filtered and the pH and concentration of heavy metals of interest were measured. The plants were also collected and stored in paper bags and their wet weight determined. The plants were then dried in a forced-air oven at a temperature of between 40 and 60 °C until they reached a constant weight. The plants were then weighed to determine their dry biomass.

The plants were then separated into the aerial part (AP) and the root system (RS) and ground in a mill. They were then weighed and digested using nitroperchloric opening (TEDESCO, 1995) and read using a Varian AA280FS Atomic Absorption Spectrometer.

The experimental design used in this experiment was entirely randomized. Before the usual parametric statistical analyses, all the parameters studied were subjected to the Lilliefors test (which is a derivation of the Kolmogorov-Smirnov test) and the Shapiro-Wilk test, to check whether or not the values of a given variable follow a normal distribution. The data was also subjected to the Cochran test, which is used to check the homogeneity of variances.

Subsequently, they were subjected to analysis of variance and comparison of means using the Tukey test at a 5% probability level, using the Statistic 7 statistical package (Copyright 1984-1987, StatSoft, Inc. 2300 East 14th Street Tulsa, OK 74104, USA).

3. Results and Discussion

In plant systems, the presence of lead (Pb) can cause biochemical,
morphological and physiological dysfunctions, affecting photosynthesis, DNA (SHAHID et al., 2011; GALLEG0 et al., 2012), the variety and quantity of organic acids secreted (RASCIO & NAVARIZZO, 2011; NIU et al., 2012), increases susceptibility to diseases such as chlorosis and leaf necrosis, as well as reducing the growth of roots and aerial parts (PEREIRA, 2014). In plants, Pb can also cause an increase in the activity of antioxidant enzymes (VERMA & DUBEY, 2003).

The application of increasing doses of Pb significantly increased the number of leaves after the first contamination. Meanwhile, treatment T1 without contaminant also had an increase in the number of leaves, but much less significantly than the other treatments T2 and T3. Therefore, it was noted that contamination rapidly influenced leaf growth in Eichhornia crassipes, demonstrating the plant's adaptability to Pb contamination, as can be seen in Figure 1. RPDRIGUES et al., 2016 believes that Eichhornia crassipes has the ability to tolerate environments contaminated by heavy metals, and attributes this fact to its ability to undergo changes in its physiology and anatomy, which lead to adaptation to the stressful environment.

Figure 1. Behavior of the variable number of leaves in the species Eichhornia Crassipes grown in hydroponic solution contaminated with Pb.
Figure 2 shows the development of the species after the third contamination with Pb. The behavior of *Eichhornia crassipes* after the first application of the contaminant was totally different from what was expected, there was a positive response to the increase in lead concentration, that is, there was an increase in the number of leaves and consequently in the mass of the treatments that received the contaminant, T2 and T3. In the second application of the contaminant (Pb), the response was the same as previously observed, there was an increase in the number of leaves in treatments T2 and T3, while the root began to show a negative response to the contamination, with very little growth or even a contraction in the size of the roots being observed in treatments T2 and T3 when compared to treatment T1 which did not receive the pollutant. In the third stage of contamination, the response was identical to that observed in the second application of Pb, but there was only one different observation, in relation to the coloration of the roots in treatments T2 and T3, which showed intense lightening when compared to treatment T1.
The increase in the number of leaves may be associated with the findings made by Rodrigues et al., 2016 who concluded that changes in anatomy, such as an increase in stomata density, leaf mesophyll thickness and spongy parenchyma, were observed in Eichhornia crassipes grown in the presence of Cd, which favored photosynthesis due to the greater capacity to enter and retain CO₂ and consequently the plant's development and tolerance to contamination. High rates of photosynthesis can increase vegetative reproduction, due to the production of energy and carbon skeletons, increasing the population growth of the species. Pereira, 2014 identified in his studies that Pb promoted an increase in the photosynthetic rate of Eichhornia crassipes, a fact that also corroborates the increase in biomass found in this work.
The Pb concentrations determined in *Eichhornia crassipes* can be seen in Figure 3.

**Figure 3** - Pb concentration in the aerial part and root system of *Eichhornia crassipes* grown in nutrient solution

![Graph showing Pb concentration](image)

Source: authors.

In this study with *Eichhornia crassipes*, more than 93% of all Pb absorbed by the macrophyte was accumulated in the roots, even though the leaves were in contact with the contaminated solution. It was observed that at low concentrations of this element no symptoms of damage were shown by the plant, but at high concentrations a lightening of the roots and a reduction in the emission of new roots were noticed. These symptoms may be related to disruption of the membrane, the primary target of Pb phytotoxicity.

The lead found in the roots of these plants may be associated with the negative charges of the cell walls, preventing its translocation to the aerial part and possible damage to this organ. The absorbed fraction is also resistant to translocation due to its complexation in the roots.

When the concentrations of Pb in the plants were evaluated, it was found that the behavior of this metal was the same in all the treatments applied, i.e. with the increase in the doses of Pb in treatments T2 and T3 there was an increase in the concentrations of the contaminant in *Eichhornia crassipes*.

The following Pb values were observed in treatment T1: 46 mg.kg\(^{-1}\) and 17 mg.kg\(^{-1}\) in the root and part of the plant, respectively. The presence of Pb in
this treatment, which did not receive the contaminant, is explained by the location of the greenhouse, which is close to the main highways in the city of Rio de Janeiro, the Yellow Line, the Red Line and Avenida Brasil. Environmental contamination by lead has been attributed mainly to the combustion of gasoline, so large quantities of lead continue to be spread in the environment as a result of its use as an additive in car fuels.

Treatment T2 showed much higher values of Pb in both the root and the aerial part when compared to treatment T1, 6576 mg kg$^{-1}$ in the root and 224 mg kg$^{-1}$ in the aerial part. However, the highest concentrations of Pb in *Eichhornia crassipes* were obtained in treatment T3, with 9838 mg kg$^{-1}$ found in the root and 621 mg kg$^{-1}$ in the aerial part.

These results indicate that the species has great potential for phytoremediation since it showed hyperaccumulation of Pb in the roots, and the accumulation was proportional to the exposure time and the concentration of the element in the solution. These results corroborate the study by GONÇALVES JR. et al. (2008) which also found an enormous capacity for Pb hyperaccumulation by *Eichhornia crassipes*.

The potential of plants to phytoremediate can be measured using certain indices or factors. The Translocation factor suggested by GALAL and SHEHATA, 2015, evaluates the species' ability to translocate contaminants from the root to the aerial part. Which was calculated according to the formula below and its results are presented in Table 2.

$$\text{FT(\%)} = \frac{\text{QPA (mg vase}^{-1})}{\text{QAR (mg vase}^{-1})} \times 100$$

Where:

- QPA = accumulated quantity of the elements in the aerial part, in mg vase$^{-1}$;  
- QAR = accumulated quantity of elements in the aerial part + root, in mg vase$^{-1}$.

In the case of *Eichhornia crassipes*, the translocation factor (FT) for Pb was very low, i.e. the vast majority of this contaminant remained associated with
the plant's roots. These rates varied between 26 for treatment T1, 2.8 for T2 and 5.9 for T3. Therefore, these results indicate that the phytoextraction potential of Pb does not occur in this species, since only species with a FT above 80 are classified as phytoextractors.

Table 2. Translocation factor for Pb in the different treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Eichhornia crassipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>26.8</td>
</tr>
<tr>
<td>T2</td>
<td>2.8</td>
</tr>
<tr>
<td>T3</td>
<td>5.9</td>
</tr>
</tbody>
</table>

Source: authors.

Thus, the roots of Eichhornia crassipes demonstrated the ability to maintain nutrient absorption and its conduction to the aerial part even in situations of stress, and are therefore considered an excellent mechanism for tolerance to Pb contamination. CASTRO et al., 2009, also found similar responses in their study, where Eichhornia crassipes was cultivated in water contaminated by Cd.

The bioconcentration factor (BCF) assesses the transfer of heavy metals from the substrate to the plants. When choosing remediation plants, it is essential that the BCF is as high as possible, indicating high absorption of heavy metals into the plant and, consequently, the possibility of removing these elements from the system. The bioconcentration factor was calculated using the formula below and the results of the calculation are shown in Table 3.

\[
\text{BCF} = \frac{\text{QTV} \text{ (mg vase}^{-1})}{\text{QS} \text{ (mg vase}^{-1})}
\]

Where:

\[
\text{QTV} = \text{accumulated quantity of the elements in the plant tissue, in mg vase}^{-1}; \\
\text{QS} = \text{accumulated quantity of elements in the substrate, in mg vase}^{-1}.
\]

Table 3. Bioconcentration factor for Pb in the different treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Eichhornia crassipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>63.7</td>
</tr>
<tr>
<td>T2</td>
<td>97.3</td>
</tr>
<tr>
<td>T3</td>
<td>104.5</td>
</tr>
</tbody>
</table>

Source: authors.
Treatment T3 absorbed the most lead from the water in relation to the mass of the plant, followed by treatment T2 with a slightly lower BCF. These results indicate that the plant has phytoremediation potential using the rhizofiltration technique, which differs from phytoextraction in that the accumulation of contaminants tends to be preferentially in the roots of aquatic plants. In rhizofiltration, metals are adsorbed on the root surface or absorbed by the roots. Root exudates can alter the pH of the rhizosphere, which leads to the precipitation of metals in plant roots (JAVED et al., 2019).

4. Conclusion

Eichhornia crassipes showed rapid growth, high absorption of available elements and high biomass production, even when subjected to Pb contamination. This may be associated with the development of different physiological mechanisms by the plant. The study demonstrated the possibility of using this macrophyte to decontaminate water bodies contaminated with Pb, as the species hyperaccumulates high concentrations of the metal in its roots.

REFERENCES


CONSELHO NACIONAL DO MEIO AMBIENTE (CONAMA). Resolução Nº 420, de 28 de dezembro de 2009.


GALAL, T.M.& SHEHATA, H.S. (2015). Bioaccumulation and translocation of heavy metals by Plantago major L. grown in contaminated soils under the effect of traffic pollution. Ecological Indicators v. 48, 244-251.
USO DE MACRÓFITAS PARA REMEDIAÇÃO DE AMBIENTES AQUÁTICOS CONTAMINADOS


PEREIRA, F. J. (2014). Características anatômicas e fisiológicas de aguapé e índice de fitorremediação de alface d’água cultivados na presença de arsênio, cádmio e chumbo. Tese de Doutorado, Lavras - MG.


RASCIO, N. and NAVARI-IZZO, F. (2011) Heavy Metal Hyperaccumulating


