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ORIGINAL ARTICLE

Lead and cadmium removal from water using duckweed – *Lemna gibba* L.: Impact of pH and initial metal load

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Abstract The aim of this study was to investigate the potential of duckweed (*Lemna gibba*) in heavy metal (Pb and Cd) from water under different pH and metal loads. A total of three (2, 5 and 10 mg/L) strengths of Pb and Cd were used with varying pH (5, 7 and 9) and changes in metal concentration and metal uptake yield of system were recorded. The Pb and Cd removal ranged between 60.1% (2 mg/L at 9 pH) and 98.1% (10 mg/L at 7 pH) and 41.6% (10 mg/L at pH 9) and 84.8% (2 mg/L at pH 7), respectively. The duckweed set-up with pH 7 showed the optimum metal removal. The metal removal rate showed an inverse relationship with pH ($r^2 > 0.60$, for all). Bioconcentration factor (BCF) and metal uptake yield per unit of dry biomass (q_m) were recorded: 403–738 and 445–616, respectively for BCF_{Pb} and BCF_{Cd}. The q_m suggest the dose (mg/L) 5 and 10 at pH 5 as the best combinations for the optimum removal. Results, thus suggest that *L. gibba* can be a suitable candidate for removal of heavy metals from pollutant water bodies.

1. Introduction

The contamination of heavy metals in terrestrial and aquatic ecosystem has been appeared as a global environmental problem. The mining and unsafe disposal of industrial solid/liquid wastes is the prime source of heavy metals in the environment. In the urban areas the load of heavy metals in freshwater resources is at alarming level probably due to disposal of untreated or partially treated sewerage and industrial wastewaters. Due to acute toxicity associated with heavy metals, these are considered as environmental priority pollutants and are targeted for cleanup processes. The conventional metal remediation technologies involve the following: chemical precipitation (hydroxide precipitation and sulfide precipitation), ion-exchange, adsorption (activated carbon adsorbents, carbon nanotubes adsorbents, bioadsorbents), membrane filtration (ultrafiltration, reverse osmosis, nanofiltration and electrodialysis), coagulation–flocculation, flotation and electrochemical methods [1]. These technologies offer several advantages such as flexibility in design and operation, huge treatment capacity, high removal efficiency, and fast kinetics but also showcases limitations such as, generation of toxic sludge or other by-products, high operation and maintenance cost and high energy requirements [2,3]. Therefore, there is an urgent need to adopt technology with optimum efficacy

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and low capital investment and can be acceptable for wide range of metal contamination [3].

Phytoremediation is a plant-based cleanup process of any contaminated environment [4]. It is designated as quite simple and versatile technology to achieve specific remedial goals. There are several advantages of this process, such as technologically feasible, low operating costs, least possible sludge generation, and competitive performance [5]. The plenty of plant species (e.g., water hyacinth – *Eichhornia* sp., duckweeds - *Lemna* sp. and *Spirodella* sp., small water fern – *Azolla* sp., water lettuce – *Pistia* sp.) is known for heavy metal removal from aquatic media and for producing an internal concentration of metal several times greater than the surroundings [6]. *Lemna gibba,* belonging to the family – Lemnaceae, is a rooted free-floating aquatic plant consisting of small fronds. Due to the high growth rate and large uptake metal potential, members of Genus *Lemna* have been appeared as potential candidates for designing a duckweed-based heavy metal phytoremediation set-up. Few earlier workers have demonstrated high potency of *L. gibba* in heavy metals removal from the aquatic environment [7–9]. In metal uptake and chemical kinetic process the role of initial metal load and pH of medium are very critical factors. Such parameters need to be optimized in order to design an industrial-scale duckweed pond system for wastewater treatment process designing. As pH deemed to offer a very decisive role in bio-remediation process, there is an urgent need to address this research issue. After reviewing the available scientific literature it was realized that studies on role of metal loads and pH of media are not well undertaken by previous researchers. The contributory effect of metal load and pH performance on achieving maximum removal will further help to target metal pollution problem efficiently. Therefore, the aim of this study was to investigate the impact of pH and concentration of metals in aquatic media on removal efficiency of the duckweed system containing *L. gibba* as test species. The role of such parameters in plant growth and metal uptake yield was also studied using laboratory-based batch set-ups.

2. Methodology

2.1. Plant material and growth conditions

L. gibba L. was collected from a freshwater body located nearby to the campus of the Doon University, Dehradun (India). The plant material was collected in a plastic circular container and brought to the laboratory. In laboratory the plant material was washed carefully to remove dirt, sludge and other adhesive debris from it. To avoid any contamination the second generation of *L. gibba* was obtained by culturing original individual in 1/10 diluted Hoagland solution for 10 days as per standard methodology described by Penningsfeld and Kurzman [10] and Eliasson [11]. The composition of Hoagland's solution was as (all in mg/L): KNO_3, 1515.0; KH_2PO_4, 680.0; $Ca(NO_3)_2$–$4H_2O$, 1180.0; $MgSO_4$–$7H_2O$, 492.0; $ZnSO_4$–7H2O, 0.22; H_3BO_3, 2.85; Na_2MoO_4–$2H_2O$, 0.12; $CuSO_4$–5H2O, 0.08; $MnCl_2$–$4H_2O$, 3.62; $FeCl_3$–$6H_2O$, 5.4; tartaric acid, 3.0 [12]. Nutrient solution was renewed twice every week. Prior to the experiment, containers were disinfected by immersion in 1% (v/v) NaClO for 3–5 min. The prominent and healthy plants were screened out to be used in further experimentations. All cultures, stock and experimental set-ups were kept at a temperature of 26 ± 2 °C, with a light intensity of 1120 Lx and a day–night cycle of 16:8 h.

2.2. Experimental design

The batch scale experimentation set-ups were designed in triplicates and the average results were reported. The pre-cleaned beakers of 500 ml capacity were used as experimental set-up. A total of three strengths (2, 5 and 10 mg/L) of cadmium and lead were prepared in double deionized water. The stock solution of cadmium and lead was prepared using cadmium (II) sulfate ($3CdSO_4{\cdot}8H_2O$) and lead (II) nitrate [Pb $(NO_3)_2$], salts respectively. AR grade chemical was used for stock preparation. The selected metal concentrations were considered to be sublethal for *L. gibba*. In the literature the LC_{50} (Lethal concentration 50) for *L. gibba* is 500 ± 23.4 mg/l for lead [13] and 50 ± 31.5 mg/l for cadmium [14]. To investigate the effect of pH on Cd and Pb removal by duckweed, three pH ranges, i.e. 5, 7 and 9 (slightly acidic to alkaline) were taken into account. The selection of pH range was done on the basis of the survival potential of duckweed for on different pH as reported in earlier literature (1; 13). The selection of pH was done on the basis of competitive growth dynamics of duckweed plant [15–17]. The initial pH of the solution was adjusted with 1 N HCl and 1 N NaOH solutions. For experimentation, 2.5 g live plant material was inoculated in 250 ml solution of metal in glass beaker (500 ml capacity) under the aforementioned conditions for period of 7 days. The load of inoculation biomass was calculated on the basis of total plant biomass required to cover the whole surface of the reactor (with approximately a single layer of fronds). The duckweed plant biomass was rinsed with distilled water before inoculation in experimental set-ups. In order to see the removal efficiency of duckweed live biomass the residual concentration of Pb and Cd was determined in inoculation media of all set-ups at the end of experimentation. The plant biomass was also analyzed in order to see the biological accumulation of concern metals in tissues of inoculated duckweed biomass. For that live specimens of duckweed were harvested from each experimental set-up and further processed for heavy metal load estimation. The plant samples were dried at 70 °C to determine the dry weight (X_m).

The metal solutions without plants acted as experimental control. Duplicates of all experimental set-ups were kept in triplicate as experimental control. The control set-up media were also analyzed for metal concentration changes by assuming that whether there was any adsorption of metals on flask wall.

2.3. Plant growth and BCF estimation

To measure the changes in the total biomass of *L. gibba* in experimental set-ups the plant biomass (mg) was measured at end of experimentation. The growth rate was measured using following formula (1)

$$\text{Plant growth rate(in\%)} = \frac{\text{Final biomass} - \text{initial Biomass}}{\text{Final biomass}} \times 100 \qquad (1)$$