

## ***Eichhornia crassipes* (Mart.) Solms. Application of Macrophyte in Heavy Metals Removal**

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The present study tested the remediation potential of *Eichhornia crassipes* (water hyacinth), for the removal of chromium (Cr) and Zinc (Zn) and Nickel (Ni). Fresh and young plants of equal size were grown in hydroponic medium and supplemented with 300, 600, 1200 and 2400 µg/L of Cr and 600, 1200, 2400 and 6000 µg/L of Zn and 300, 600, 1200 and 2400 µg/L of Ni individually for 15 days. The bioaccumulation pattern was reported high in Zn culture. Metal toxicity in the floating macrophyte showed a significant reduction ( $P < 0.001$ ) on phytomass, chlorophyll,  $\text{NO}_3\text{-N}$  and  $\text{PO}_4\text{-P}$  uptake inhibition in comparison to control. The rate and amount of Cr uptake were minimum as compared to Zn and Ni. The rate of uptake increased with concentration and decreased with increasing time duration. The uptake and accumulation of Cr in the root were always higher than that of shoot except between 2 h to 72 h period at an initial concentration of test metal. The lowest and the highest tolerance indices in *Eichhornia crassipes* were recorded for Cr and Zn respectively. Bioconcentration factor (BCF) for Zn, Ni, and Cr were 14.6, 12.5 and 10.2 respectively, indicates that *Eichhornia crassipes* can be a moderate accumulator of heavy metals and the ubiquitous weed could be used to clean aquatic bodies threatened with pollutants.

**Keywords:** BCF, *Eichhornia crassipes*, Phytoremediation.

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Macrophytes are a distinct feature of an aquatic ecosystem and play important roles in wetland biogeochemistry through their active and passive transport of elements. Through their action as the nutrient reservoir<sup>1</sup>, active uptake of elements into plant tissue may promote immobilization in plant tissues, as reported in wetlands constructed for wastewater treatment<sup>2</sup> and in the use of wetland plants in remediation technology. Wetlands are often used as contaminants storage basins, and there are many cases in which wetland plants perform as a pollutant hyperaccumulators for removal of contaminants, including metals.

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Macrophytes are hyperaccumulators of heavy metals and capable of improving water quality by accumulating heavy metals with their efficient root system. Phytoremediation is an attractive economic cleanup method for moderately contaminated areas. Heavy metal removal from the industrial and domestic polluted stream via bio-absorption is marked beneficial because of releasing negligible secondary pollutants in comparison to conventional physicochemical water treatments plants. Technological advancements and industrial progress have widely disrupted the aquatic ecosystems by various pollutants damaging the ecosystem balance and water quality. Heavy metals penetrate from an aquatic medium into a biological system through water–plant–human or water–plant–animal–human biological network<sup>3</sup> herefore

finding a solution to overcome the problem of toxicity tolerance in an aquatic body is necessary for an ecosystem and its components. Several reports are describing the effects of heavy metals on water and hydrophytes and their properties, their enzymatic activity, and nutrition pattern<sup>4</sup>. A negative connection was revealed between heavy metal concentration in growth medium and plants' submerged organs and green biomass<sup>5</sup>. Low molecular weight proteins e.g. metallothioneins and phytochelatins seem to work against metal toxicity and other physiological processes to protect plant cells from environmental strain<sup>6</sup>. Plants work as a machine serving the function of both "accumulation" and "exclusion". Accumulator plants can survive despite gathering contaminants in their shoot system. They biodegrade or biotransform the contaminants into inactive substances in their tissues. The excluders confine the contaminant uptake into their biomass as stored content. Zinc (Zn) and nickel (Ni) are categorized as essential trace elements needed for the normal growth and healthy metabolism of plants and may produce toxicity if the concentration limit is exceeded<sup>7</sup>. Whereas, other metals e.g. chromium (Cr) and cadmium are nonessential and pose extreme toxicity to plants even at low supply<sup>8</sup>.

The suitability of aquatic macrophytes for heavy metal removal has been investigated and reviewed extensively<sup>9, 10</sup>. Bioaccumulative and persistent nature of heavy metals signifies them as one of the major water pollutants<sup>11,12</sup>. Implementing phytoremediation technology in environmental remediation is an economical energy saving technology. Macrophytes represent the base of the aquatic food chain they consume metals from water and sediment and subsequently releasing them on senescence and decomposition<sup>13, 14, 15</sup>. Metal suspension in soil and water are major environmental and human threats. Living plants represent a mechanical system working under the solar energy, consuming certain elements from the biosphere. Phytofiltration of heavy metals and their retention by aquatic vegetation represent the green technology where extensiveness of the root structure consumes the toxic metals from polluted water via evapotranspiration over an extended period.

*Eichhornia crassipes*, has well-established root, considered as the suitable option

for phytoremediation in the aquatic ecosystems for heavy metals and wastewater remediation than terrestrial plants as their rapid growth and significant biomass processing supports higher pollution uptake and better purification method due to direct contact with the water column. It is evident that there is a great scope to explore the potentialities of aquatic plants for heavy metal remediation from the metal contaminated wastewater. Therefore, the present investigation was carried out to study the phytoremediation of Cr, Zn and Ni by *Eichhornia crassipes*.

## MATERIALS AND METHODS

### Experimental Procedures

*E. crassipes* plants were collected from a local pond outside the city of Patna, from the Indian subcontinent and washed with tap water to remove attached impurities and insect larval growth on test plant. The plants were grown in cement tanks with tap water under natural sunlight for one week to provide them the natural environment, and then the plants of the same size were selected for the further experiment. A stock solution (1000 µg/L) each was prepared in distilled water with analytical grade  $K_2Cr_2O_7$ ,  $ZnCl_2$ , and  $NiCl_2 \cdot 6H_2O$  that was later, diluted as required. The test metals (Cr, Zn, and Ni) were introduced into the experimental trays at various concentrations (Zn: 600, 1200, 2400 and 6000 g/L and Cr: 300, 600, 1200 and 2400 µg/L, Ni: 300, 600, 1200 and 2400 µg/L). Growth was measured concerning dry weight (dw) at the end of the experiment. Chlorophyll a was estimated using methods of Broody & Broody<sup>16</sup>.  $NO_3^-$ -N uptake was calculated by phenol-di sulphonic acid method<sup>19</sup> and  $PO_4^-$ -P uptake was estimated by phosphomolybdenum blue color method<sup>20</sup>. Metal uptake was calculated by the method of Martin<sup>21</sup> with the help of an Atomic Absorption Spectrophotometer (Perkin-Elmer 2380). A control experiment without plant was also planned simultaneously with the experimental batch. All experiments were performed in triplicates. The test durations were 2 hours, 3, 5, 10 and 15 days. All the trays were exposed to enough sunlight. Everyday water was added to maintain the same level of water in each tray, to compensate the loss of water through plant transpiration, sampling, and evaporation. At the end of 15<sup>th</sup> day, plants were harvested. They

were separated into roots and shoot and were analyzed for metal accumulation. The specific objective of the study was to examine the uptake of Zn and Cr and Ni at various concentrations for 15 days by *Eichhornia crassipes*, the effect of metals on chlorophyll, plant biomass, nitrate and phosphate uptake. Also, the metals remained in the solution were measured to assess the removal potential of water hyacinth. The bioconcentration factor (BCF) works as an indicator of the plant ability to accumulate the metal concerning the concentration of metal in the experimental solution. It is calculated as the ratio of the trace element concentration in the plant tissues during harvesting to the concentration of the element in the external environment and is dimensionless<sup>6</sup>. The BCF was calculated as follows,

$$\text{BCF} = \frac{\text{Metal concentration in plant tissue}}{\text{Metal concentration in external solution}}$$

## RESULTS

### Metal accumulation

Uptake of metals by *Eichhornia crassipes* was dependent on time and concentration (Fig 1, 2 and 3). Metal uptake and accumulation in the test plants were estimated in roots and shoots separately. At the beginning of the growth phase, absorption was rapid in all the metals supply, and there was a gradual reduction in uptake rate with increasing time and concentration. For Zn, significant differences ( $P < 0.001$ ) between control and treated plants were found at all metal supply (Fig 1A). The minimum uptake of Zn was 1.6  $\mu\text{g}/\text{mg}$  d.w. of *Eichhornia crassipes* at 600  $\mu\text{g}/\text{L}$  at a 2h time interval of which 41% was concentrated by the shoot and almost 60% by the root. The uptake amount increased about fivefold after 15 days at the above concentration of test metal (Fig-1 A). There was a less absorption of metal via shoot system when compared with the root, but at the end of the experiment, shoot concentration increased up to 57 % at the initial concentration of test metal. In the beginning rate of metal, uptake was quite high, and it gradually declined. The amount and rate of uptake in root increased with increasing test metal concentration, and a maximum amount of Zn uptake was 18.2  $\mu\text{g}/\text{mg}^{-1}$  d.w. at 6000 $\mu\text{g}/\text{L}$  test metal level after 15 days of treatment. A significant

difference ( $P < 0.001$ ) in Cr accumulation with the passage of time at all concentrations except for 0 and 0.5  $\mu\text{g}/\text{L}$ . Plants treated with 1200  $\mu\text{g}/\text{L}$  of Cr on the 10th day, accumulated the highest level of metal in shoots (15.4  $\mu\text{g}/\text{mg}$ ; Fig 2A) and roots (14.3  $\mu\text{g}/\text{mg}$ ; Fig 2B). Plants treated with 2400  $\mu\text{g}/\text{L}$  of Zn on day five accumulated the highest level of metal in shoot region of the plant (10.5  $\mu\text{g}/\text{mg}$ ; Fig 1A). The ratio of root and shoot Ni uptake varied with time and concentration. At the first two concentration of test metal, the percentage of root uptake was high in most of the time duration except longer term shoot uptake was either high or equal to the root uptake. At 1200  $\mu\text{g}/\text{L}$  concentration of test metal between 2 h to days duration root uptake was low but at 7 and 15 days equilibrium exists between roots and shoot uptake. The rate and amount of Ni uptake were comparatively lower than that of Zn. The minimum amount of Ni uptake was 2.5  $\mu\text{g}/\text{mg}$  d.w. Ni at 3000  $\mu\text{g}/\text{L}$  of test metal after 2 hours and the maximum amount of Ni uptake was 11.4  $\mu\text{g}$  Ni  $\text{mg}^{-1}$  d.w. at 300  $\mu\text{g}/\text{L}$  of test metal after 15 days. The rate of uptake of Ni was higher at shorter time duration, and it gradually declined with time and concentration (Fig-2B). Cr uptake and accumulation was always greater in the roots than that of shoot except between 2 hr to 72 hr duration at an initial concentration of test metal. After two hr 54 % to 59 % uptake of Cr was done by the root, and after 15 days 49 to 60 % uptake of Cr was done by the shoot.

### Root and shoot absorption in *Eichhornia crassipes*

Floating aquatic plants have a well-designed root system, provides them growth substrates from metal contaminants through rhizofiltration mechanism, adsorption, or precipitation onto plant roots or absorption into the roots of contaminants available in root zone solution. Metal uptake through root systems of aquatic macrophytes and subsequent release of metal during decomposition of plant material represent a cycle between plant biology and metals in aquatic ecosystems. Such a mechanism could have a substantial change in intensity of metal toxicity in aquatic systems and therefore could exert some restrictions on the toxicity of these metals to sensitive organisms.

There are studies on estimation of the metal concentration of macrophytes growing in

natural and metal-enriched water bodies<sup>22, 23, 24, 25</sup>. Several reports are on metal uptake and their toxicity to macrophytes<sup>26, 27, 28, 29, 30</sup>. There are studies on shoot vs. root phosphorus storage in *Pistia stratiotes*<sup>31</sup> and *Eichhornia crassipes*<sup>32, 31</sup>. The

uptake of P by leaves or root of aquatic plants was investigated by several authors<sup>33, 34, 35, 36</sup>. Roots of aquatic plants help absorb nitrogen as an essential nutrient and translocate it to shoots and leaves<sup>37</sup>. Sutton & Blackburn<sup>26</sup> reported that when plants that

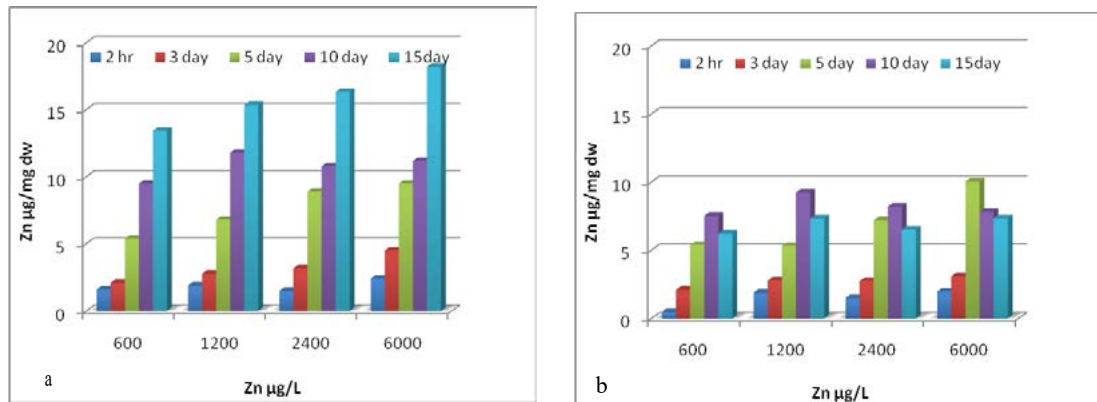


Fig. 1. Zn uptake by *Eichhornia crassipes* [Root (A) and Shoot (B)]

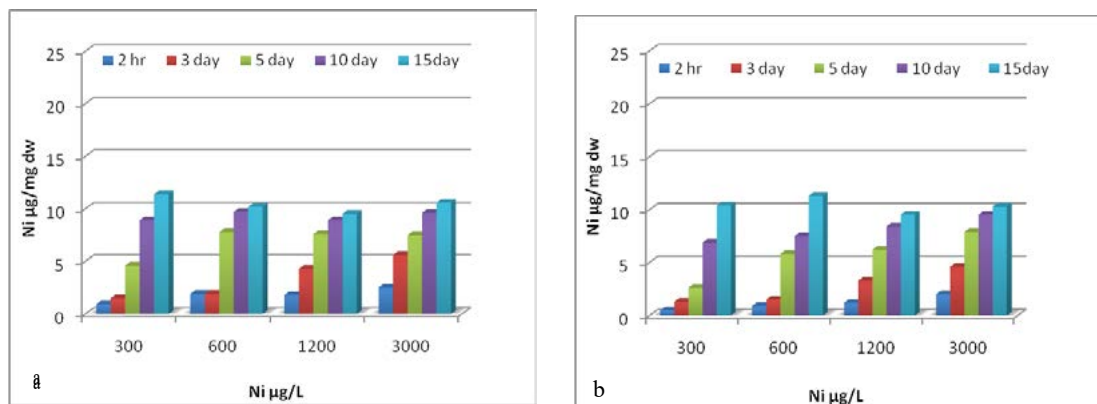


Fig. 2. Ni uptake by *Eichhornia crassipes* [Root (A) and Shoot (B)]

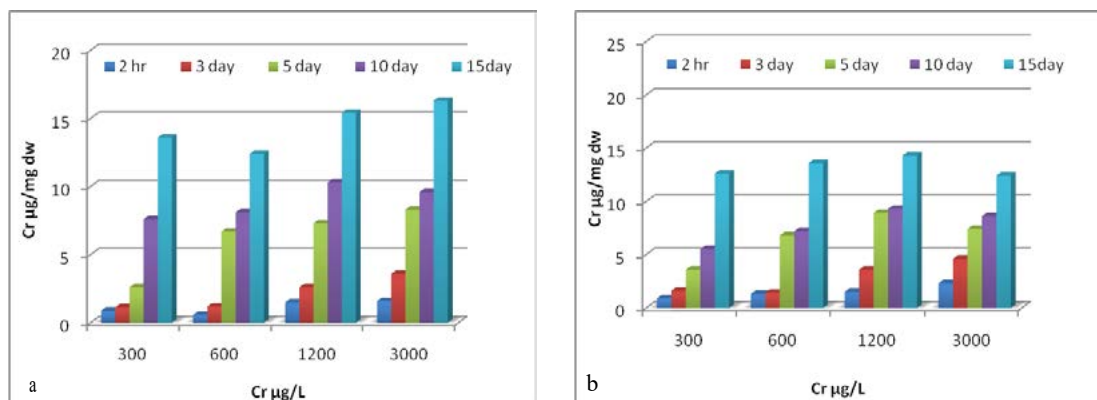


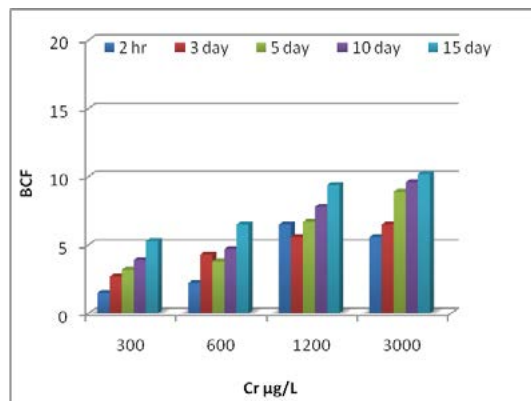
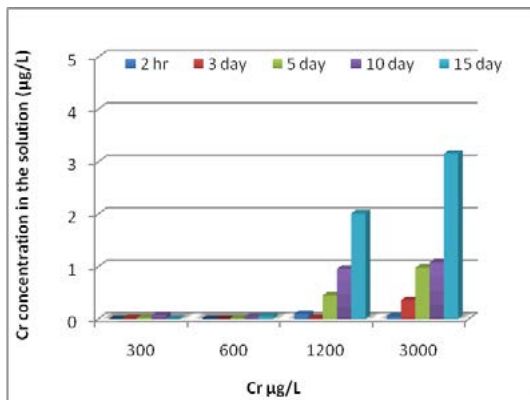
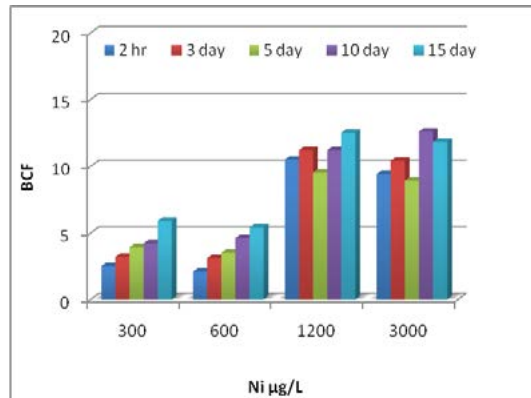
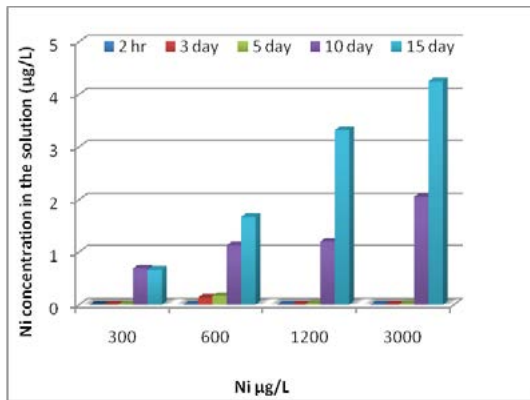
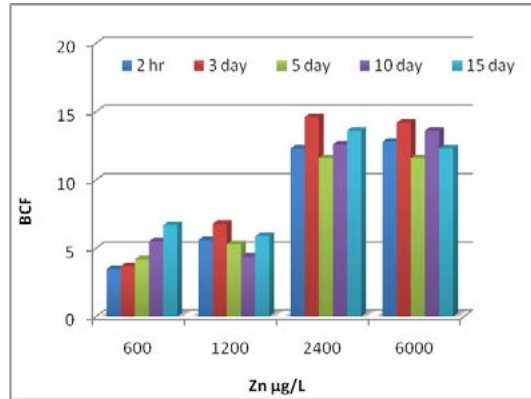
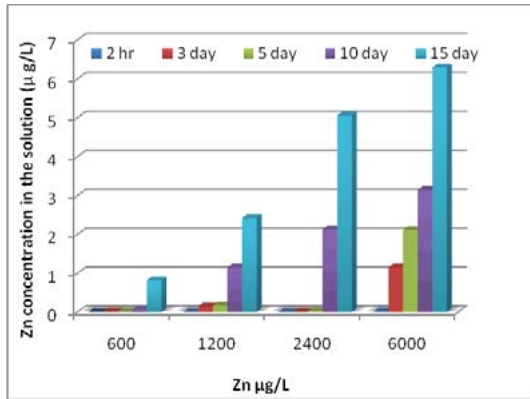
Fig. 3. Cr uptake by *Eichhornia crassipes* [Root (A) and Shoot (B)]

had accumulated high levels of copper were placed into water containing no copper, showed a decrease in the metal concentration in the plants; evidently, demonstrated the potential role of hydrophytes in metal cycling.

**Metals residual in the experimental basins**

The amounts of remaining dissolved

metals in the remaining metal solutions were shown in Fig 2. They were significantly decreased ( $P < 0.001$ ) when the exposure times were increased. The concentrations of dissolved Zn in the solutions at 600, 1200, 2400 and 6000  $\mu\text{g/L}$  were 0.82, 2.42, 5.06 and 6.29  $\mu\text{g/L}$ , respectively on day 15 (Fig 2 A). The concentration of Ni in the culture solution



**Fig. 4.** Zn (A), Ni (B) and Cr (C) concentrations in the experimental solution after 15 days

**Fig. 5.** The bioconcentration factor (BCF) values of Zn (A), Ni (B) and Cr (C) in *E. crassipes* at different metal concentrations and exposure times.

at 300, 600, 1200 and 3000  $\mu\text{g/L}$  were 0.67, 1.67, 3.324, and 4.25  $\mu\text{g/L}$  respectively on the 15th day of the exposure (Fig 2 B). The concentrations of dissolved Cr in the solutions at 300, 600, 1200 and 3000  $\mu\text{g/L}$  were 0.004, 0.006, 0.097 and 0.176  $\mu\text{g/L}$ , respectively on day 15 (Fig 2 C).

#### Bioconcentration of metal in *Eichhornia crassipes*

The BCF values for Zn, Ni, and Cr at different concentrations and exposure times were shown in Fig 3 (A, B, and C). In general, the BCF values for Zn, Ni, and Cr increased with the passage of time ( $p < 0.001$ ). The BCF values for Zn significantly increased ( $p < 0.001$ ) with increased

Zn dilutions in the test solution at each exposure time and then decreased when the Zn concentration was over 2400  $\mu\text{g/L}$  (Fig 3A). The maximum BCF of 14.6 was obtained in plants treated with 2400  $\mu\text{g/L}$  of Zn on day 3. The BCF values for Ni and Cr decreased ( $p < 0.001$ ) with Ni and Cr concentrations in the basin solutions at each exposure time and the maximum BCF of 12.6 was found in plants treated with 3000  $\mu\text{g/L}$  of Ni on day 10 (Fig 3B). The comparison of maximum BCF of *Eichhornia* exposed to Cr was 10.2 (3000  $\mu\text{g/L}$ ) on day 15 (Fig 3C), over 2400  $\mu\text{g/L}$  (Fig 3A). The maximum BCF of 14.6 was obtained in plants treated with 2400

**Table 1.** Effect of Zn, Ni, and Cr on Biomass (dw), chlorophyll a and  $\text{NO}_3\text{-N}$  and  $\text{PO}_4\text{-P}$  uptake of shoot and root of *Eichhornia crassipes* after 15 days exposure time

Metal concentration $\mu\text{g/L}$	DW mg/g	Chlorophyll $\mu\text{g/mg dw}$	$\text{NO}_3\text{-N}$ $\mu\text{g/mg dw}$	$\text{PO}_4\text{-P}$ $\mu\text{g/mg dw}$
Shoot				
Control	226±13	3.2±0.11	120±4	90±6
Zn				
600	165±9	0.91±0.03	72±3	46±2
1200	139±8	0.55±0.05	63±4	36±2
2400	90±8	0.46± 0.03	38±3	22±2
6000	56±5	0.32± 0.06	30±2	14±1
Ni				
300	182±8	0.35± 0.03	86±9	54±5
600	158±8	0.21± 0.02	64±3	34±5
1200	93±5	0.61± 0.01	39±3	22±2
3000	39±4	0.11± 0.01	29±3	16±2
Cr				
300	183±10	0.22± 0.02	66±5	44±5
600	146±14	0.15± 0.01	32±2	21±1
1200	83±6	0.11± 0.01	18±1	12±1
3000	28±2	0.07± 0.01	11±1	7±1
Root				
Control	126 ± 10	-	122±6	89±4
Zn				
600	91±4	-	66±6	49±3
1200	82±3	-	55±3	38±3
2400	42±3	-	30±2	22±2
6000	32±2	-	16±2	16±2
Ni				
300	91±5	-	83±6	55±3
600	68±5	-	55±5	35±3
1200	42±1	-	37±2	24±2
3000	24±2	-	13±2	11±2
Cr				
300	99±7	-	63±6	41±3
600	68±2	-	47±7	24±2
1200	38±3	-	22±3	20±2
3000	21±1	-	13±1	9±1

**Table 2.** Two way ANOVA to test for uptake of metals in shoot and root of the species between time (hours), concentration and interaction between hours and concentration

Shoot Metals	Time	F- values concentration	Time* Concentration
Zn	541*	690*	30*
Cr	519*	94*	8*
Ni	771*	386*	42*
Root			
Zn	523*	902*	47*
Cr	1328*	176*	18*
Ni	905*	419*	64*

\* All the F values are significant at  $p < 0.001$ , at time 15, concentration 3 and time and concentration 45

$\mu\text{g/L}$  of Zn on day 3. The BCF values for Ni and Cr decreased ( $p < 0.001$ ) with Ni and Cr concentrations in the basin solutions at each exposure time and the maximum BCF of 12.6 was found in plants treated with 3000  $\mu\text{g/L}$  of Ni on day 10 (Fig 3B). The comparison of maximum BCF of *Eichhornia* exposed to Cr was 10.2 (3000  $\mu\text{g/L}$ ) on day 15 (Fig 3C).

## DISCUSSION

Plants are the primary producers occupying the autotrophic level of the ecosystem and have the ability to accumulate essential elements from the abiotic medium. Matagi *et al.*,<sup>38</sup> have extensively reviewed on the heavy metal removal mechanisms in wetlands. Denny<sup>23,24</sup> noted that the main route of heavy metal uptake in wetland plants was from the roots in the case of emergent and surface-floating plants like water hyacinth. In locating the sites of mineral uptake in plants, Arisz<sup>39</sup> found that ions enter the plants in passive mode, mostly by substitution of cations, occupying place in the cell wall. Denny<sup>24</sup> concluded that plants used heavy metals by absorption and translocation, in their metabolism to some degree and released by excretion. Sharpe and Denny<sup>40</sup> and Welsh<sup>41</sup> reported, however, that maximum uptake of metals by plant tissues is by absorption to anionic sites located in the cell walls and the metals do not penetrate the living plant. This acknowledges why wetland plants can have a very high magnitude of

heavy metal concentration in their tissues compared to their surrounding environment<sup>42,43</sup>. Physiology of root pressure and transpiration from the aerial parts of the plants, primarily control pathway of cell sap mixed with metal, from the root to the shoot called translocation<sup>44</sup>. Accumulation of some metals in roots may be due to some physiological obstacle preventing metal transportation to the stem and leaf part, while others can readily transported in the plants. In the present study, although Cr, Ni and Zn translocation to the plant aerial parts occurred and continued to go on during the whole experiment, the process of sorption was slower than by roots. Translocation of trace elements from roots to shoots could be a limiting factor for the bioconcentration of elements in shoots<sup>45</sup>. Water hyacinth successfully removes a remarkable quantity of heavy metals (Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn) from water bodies especially at low concentrations<sup>46</sup>. Usually, macrophytes root concentrates metals 10 (or more) times higher in root than in shoot. Soltan and Rashed<sup>46</sup> while studying with water hyacinth and heavy metals (Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn) observed that water hyacinth accumulated higher concentrations of heavy metals in the roots in comparison to aerial parts.

Growth and morphological changes are often the first and most evident reactions of plants to heavy metal stress<sup>47</sup>. In plants treated with Zn, macrophyte growth increased in (600 and 1200  $\mu\text{g/L}$ ) treatments but decreased in (2400 and 600  $\mu\text{g/L}$ ) concentrations. The addition of Zn at low concentration had a favorable effect on the growth of water hyacinth, which may be attributed to the fact that the Zn concentration could encourage plants' growth and plants utilize Zn as an essential element for their growth<sup>48</sup>. Delgado *et al.*,<sup>49</sup> found that in long-term experiment (24 days), water hyacinth treated in (9mg/L) of Zn resulted in 30% reduction in weight. Schat *et al.*,<sup>50</sup> reported that Zn toxicity was first visible in the form of reduced root growth. As soon as the saturation state was reached, it seemed a little difficult for plants to absorb Cd or Zn further. Still, the concentration decreased with the metal exposure time.

Metals are required by the plants in different phases of their growth and development. Degradation of heavy metals does not follow the same pattern like organic pollutants<sup>51</sup>. When

the metal deposition in plant tissues reach above optimal levels, they start damaging cell structure by phytotoxicity. *E. crassipes* in the aquatic system is an efficient cosmopolitan, metal hyperaccumulator because its extensive root system that favors the selective metal uptake. A linear trend was observed in the metal bioabsorption by *E. crassipes*, indicating more uptake of Zn in comparison to Cr (Fig-1). The root zone technology in floating weed has significant performance in phytoremediation. *E. crassipes* has submerged, and the extensive root set that can absorb greatest concentrations of heavy metals because of greater root surface area<sup>52</sup> and thereby higher heavy metal adsorption capacity of the roots compared to the shoots. Studies revealed the role of cumulative ecosystem effects, involving not only macrophytes but also sediments and another biota necessary to provide a complete picture of the effects of heavy metals on aquatic ecosystems. Metal uptake comprises various factors surrounding the ecosystem such as the availability and amount of contaminants, plants ability to interrupt the process of metal uptake, bioabsorption of metals in the shoot system via root zone, an interaction between metals in the aqueous medium and sediment and biota. Many studies have reported the usage of floating aquatic macrophytes (FAM) design vegetated with *Eichhornia*<sup>53</sup>, *Pistia*<sup>54</sup> and *Lemna*<sup>55</sup> as an appropriate heavy metal accumulator. It has been reported that metal accumulating plant species can concentrate heavy metals in proportion to 100 or 1000 times compared to non-accumulator plants. Microorganisms bacteria and fungi associated with the rhizosphere of the plants helps mobilization of metal ions and enhances the bioavailability of the same<sup>3</sup>.

Phytotoxicity at high degree limits the plant growth and causes various physiological anomalies<sup>48</sup>. Toxicity of heavy metals is thought to be related with ions and not with their concentration<sup>48</sup>. There was a reduction in metal treated plant biomass particularly in a high dose of Zn, Ni, and Cr (Table-1). Heavy metal translocation was negligible in the old age plants in the leaves of eelgrass while pectic compounds from the cell wall material thought to play a significant role in the absorption of ions<sup>56</sup>. *E. crassipes* population showed a high reduction in biomass when compared to control at a concentration of (1200 µg/L) of Zn

and (300 µg/L) of Cr solution. The reason behind a reduction in biomass could be root deformity causing reduced transport of nutrients and water to the shoots. The results obtained demonstrate that the ion exchange is the mechanism solely responsible for the ions uptake. The photosynthetic plastid is one of the most studied biological characteristics used to determine the physiological disorders as a result of metal phytotoxicity. It is reported that some metals decreased chlorophyll content in many plant species<sup>58</sup>. *E. crassipes* plant exposed to the metal culture of Zn, Ni and Cr for long duration affected the chlorophyll biosynthesis and thereby resulted in visible symptoms of chlorosis, petiolar chlorosis and necrosis leading to plant decay in the experimental tray (Table-1). Metal toxicity degrades the chlorophyll synthesizing substance and hinders the chlorophyllase activity by Cr metal<sup>59</sup>.

Among the various forms of nitrogen  $\text{NO}_3^-$  and  $\text{NH}_4^+$  are mostly utilized by plants<sup>60</sup>. The increase metal concentration reflected the inhibition of  $\text{NO}_3^-$  uptake by leaf and root tissues. Nitrate is an essential component of chlorophyll molecule<sup>61</sup> gradual decrease in N uptake may be due to binding of metals with the enzyme, which finally resulted in damage to catalytic functions<sup>62</sup>. The decaying organic matter of the aquatic macrophytes enters detritivores food chains<sup>63</sup> and the heavy metals bound in the biomass may be released to higher trophic levels. P was found to decrease heavy metal uptake but in the presence of excess Fe phosphorus inhibition was reported<sup>64</sup>. Bioconcentration factor (BCF) serves the purpose of evaluating plant potential in the accumulation of metals, this value was calculated on dry weight basis. In aquatic stream, accumulation of metals by macrophytes are under the influence of metal availability in water and sediments<sup>65</sup>. The surrounding metal concentration in water is the major key factor affecting the metal uptake efficiency<sup>66</sup>. In general, the BCF values for metals increased with the exposure time ( $P < 0.001$ ). In general, the metal concentration in water is in direct proportion to the amount of metal accumulation in plants tissues, whereas the BCF value goes inversely<sup>67</sup>. In the present study BCF values decreased when Zn concentration increased, Ni and Cr followed the same pattern except at (1200 µg/L) Ni concentration was high. A report from Jain *et*



*al.*,<sup>48</sup> showed the BCF values for floating species; *Azolla pinnata* and *Lemna minor* growing with Pb and Zn gradually decreased with increasing metal concentration in the test solution. A study in the floating macrophytes, *Pistia* and *Salvinia* showed BCF of Zn 15.1 and 11.6<sup>66</sup> respectively. Zhu *et al.*,<sup>45</sup> found that the BCFs of water hyacinth were very high for Cd, Cu, Cr and Se at externally supplied low concentration, and found to decrease as the external supply increased. In the present study, BCF values for Zn were a little higher than those of Cr for the same duration in most cases, indicating that the accumulation potential of Zn by water hyacinth was slightly greater than that of Ni and Cr. The maximum BCF values for Zn, Ni and Cr were 14.6, 12.5 and 10.2, respectively, indicating that *E. crassipes* is an average accumulator of Zn, Cr and Ni<sup>66</sup>. Brix *et al.*,<sup>67</sup> found that the BCF values for Cd and Zn in the aboveground parts of eelgrass (*Zostera marina*) were only 0.62 and 78, respectively. Overall, the floating aquatic macrophytes exhibited better bioconcentration factor for metals was in the following order: Zn>Ni>Cr. This uptake behavior is explained by Zn and Ni as they belong to essential nutrients, unlike the Cr, which can be toxic for photosynthetic activity and production and chlorophyll synthesis. In another study, water hyacinth accumulated higher concentrations of Cu, Ni and Zn in the roots. Highest accumulation in root tissues (from 24.75 to 660.0 mg/kg dry wt.) was recorded for Zn, while Cu accumulation was in the range of 18.75 & 115.0 mg/kg dry wt. On the other side, the least accumulation of 5.65 to 16.0 mg/kg dry wt. was observed for Ni; these values showed that the affinity of water hyacinth in Zn accumulation is more than that for Cu and Ni. In shoot tissues, also Zn recorded the highest level of collection (9.26 - 112.5 mg/kg dry wt.) followed by Cu (2.5 - 19.0 mg/kg dry wt.) then by Ni (0.5 - 2.2 mg/kg dry wt.). This demonstrated that Zn is more mobile from roots to shoots than Cu and Ni<sup>68</sup>. Lu *et al.*,<sup>70</sup> reported that the accumulation of metals in the roots and shoots of water hyacinth had been shown in many field studies in which water hyacinth was used as a biological monitor for metal pollution. Stratford *et al.*,<sup>71</sup> found that the metals' accumulations in water hyacinth were mono-dimensional only in the culture solution, exhibiting the order of accumulation in leaves < stems < roots. This study

also demonstrated a pattern of metal uptake similar to that of Stratford *et al.*,<sup>71</sup>.

Metal uptake in the rooted emergent plants is entirely dependent on the roots while in surface floating plants select their leaves for metal uptake.

Free-floating rooted plants have the mechanism of metal uptake involving both roots and leaves. In Submerged macrophytes, metal uptake occurs through roots and leaves growing under the water column. These submerged plants have some potential for the extraction of metals from sediments as well as water.

## CONCLUSION

Toxic metal contaminated aquatic bodies, ground waters are becoming a threat to the economy and public health safety. Monitoring of the surface water quality is, therefore, required to evaluate the condition of surface water of the water bodies all over the world. The use of plants to remove these pollutants would provide an efficient, low cost, in situ cleanup technology, which can readily scavenge toxic metals from the site leaving it intact for normal ecosystem functioning and development. The bioaccumulative and rhizofiltration capacity of *Eichhornia*, an aquatic weed, helps infiltration of the metallic contaminants from the water systems. Maintenance of proper density of the weed in the water body can be managed by controlled harvesting followed by disposal to regulate the heavy metal contamination in the lake ecosystem without introducing any foreign chemical substance. The phytotoxicity of *Eichhornia* was noticeable in the presence of metals (Zn, Ni and Cr) Culture and can be ideal for the heavy metal pollutant monitoring agent in eco-technology.

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