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Chromium tolerance capacity by *Ceratophyllum demersum* (L.) and *Eichhornia crassipes* (L.) from Salim Ali Lake, Aurangabad.

Suvarna Ubale*[1], Sangeeta Ahuja[2]

[1,2] Department of Botany, Sir Sayyed College, Aurangabad

Abstract

The present study was carried out to evaluate the potential use of *Ceratophyllum demersum* (L.) and *Eichhornia crassipes* (L.) to tolerate and remediate chromium given in the form of hexavalent chromium (CrO_3), that is the more toxic form. Plants from Salim Ali Lake were treated with different chromium concentrations (hexavalent- CrO_3) in plastic containers containing E and W medium along with no chromium (control). The plants were harvested randomly on 3, 7, and 10 days for the first plant and 10, 20, and 30 days for the latter plant to study different tolerance parameters. In both plant species, a significant decrease in growth as the chromium concentration increased ($p<0.05$). However, growth showed an initial increase with exposure time up to a certain threshold. Beyond this threshold, not only did growth decline with increasing chromium concentration, but it also decreased over time. In *Ceratophyllum demersum* (L.), Growth threshold: 5 mg/L; beyond this, negative relative growth rate, leading to 100% mortality at 12.5 and 15 mg/L. Maximum removal efficiency: 46.61% at 1 mg/L on day 10. Maximum accumulation: 556.11 µg/g dry weight at 5 mg/L. Maximum Bioconcentration Factor (BCF): 466.05. In *Eichhornia crassipes* (L.), Growth threshold: 10 mg/L; beyond this, reduced growth but no mortality. Maximum removal efficiency: 93.21% at 5 mg/L on day 30. Maximum accumulation: 8610 µg/g dry weight at 10 mg/L. Maximum BCF: 932 at 5 mg/L. Higher chromium translocation in roots than shoots. Both plants efficiently remediated chromium from water, with *Eichhornia crassipes* (L.) showing superior performance over *Ceratophyllum demersum* (L.).

Keywords: Bioconcentration factor, *Ceratophyllum demersum* (L.), Chromium, *Eichhornia Crassipes* (L.), Salim Ali Lake, Translocation factor.

Introduction

In recent times, environmental pollution stemming from heavy metals has gained substantial attention, primarily due to their widespread industrial applications. Among these metals, chromium has emerged as a significant environmental pollutant, as highlighted by Nriagu and Nieboer (1988). Despite its status as a non-essential micronutrient for normal plant metabolism, chromium is notorious for its high toxicity. It is frequently found in wastewater discharges from diverse industries like electroplating, dye and pigment manufacturing, wood preservation, and leather tanning. Regrettably, in numerous industrial sites, the leaching

and seepage of chromium from soil into groundwater pose significant health risks. Chromium is present in various forms, with hexavalent chromium (Cr (VI)) being highly toxic and carcinogenic, while trivalent chromium (Cr (III)) is less hazardous but still poses risks to aquatic ecosystems (Monga *et al.*, 2022). Beyond its high toxicity, Cr is characterized by its mobility and prolonged residence time in both surface water and groundwater (Chandra & Kulshreshtha, 2004). Considering the detrimental effects of heavy metals on both human health and aquatic organisms, the effective treatment of heavy metals in wastewater remains of utmost importance.

Typically, the removal of these pollutants necessitates the utilization of various technologies, including reverse osmosis, ion exchange, electrodialysis, adsorption, and more. However, it's important to note that most of these treatment technologies come with significant drawbacks. They tend to be expensive, energy-intensive, and often designed to target specific metals. Consequently, none of these methods can assertively claim to efficiently treat all heavy metals in a cost-effective manner (Singh *et al.*, 1996). This situation is particularly challenging for developing countries like India, where competing investment priorities exist. As a result, these nations often find it financially burdensome to invest in the removal of heavy metals from wastewater due to the high associated costs. Macrophytes possess a unique capability to accumulate pollutants in concentrations several thousand times higher than those found in the surrounding water and higher affinities, provided that the appropriate chemical form of the pollutant is present in the water (St-Cyr et al., 1994). Aquatic plants such as water hyacinth (*Eichhornia* sp.), duckweeds (*Lemna* sp., *Spirodella* sp.), a small water fern (*Azolla* sp.), and water lettuce (*Pistia* sp.) have gained considerable recognition for their capacity to remove heavy metals from wastewater (Abdallah, 2012).

Ceratophyllum demersum (L.) and *Eichhornia crassipes* (L.) are two aquatic plant species that are known to exhibit rapid growth rates and high biomass production. Despite being commonly viewed as invasive weeds, research has demonstrated their valuable potential for phytoremediating various pollutants including heavy metals through hyperaccumulation (Rezania *et al.*, 2015). In a prior study conducted by Garg and Chandra (1990), coontail was examined as a proficient accumulator of chromium (Cr). This specific macrophyte is preferred for research in phytoremediation of polluted waters due to its unique characteristics. It is a submerged, floating, rootless macrophyte known for its delicate and feathery leaves (Duman *et al.*, 2014). Its high surface-to-volume ratio allows for efficient uptake of chromium from the water column. Furthermore, the plant's high transpiration rates facilitate the movement of chromium to the shoot tissues, where it can be sequestered or detoxified. This capacity is enhanced by the presence of metal-binding ligands, such as phytochelatins, in *Ceratophyllum demersum* (L.) (Mishra *et al.*, 2006). These ligands can chelate chromium ions, rendering them less toxic and facilitating their storage within vacuoles.

Eichhornia crassipes (L.), on the other hand, is a floating aquatic plant with broad, thick leaves. This plant's tolerance to heavy metals like chromium is partly attributed to its ability to accumulate metals in its root tissues (Ndimele *et al.*, 2011). Additionally, *Eichhornia crassipes* has an extensive root system that can help stabilize sediments, reducing the release of chromium back into the water column. Its rapid growth also promotes the removal of chromium by increasing the overall biomass of the plant. Furthermore, water hyacinth has demonstrated a remarkable capacity for trace element bioconcentration when exposed to low external

concentrations of all six elements, with particularly notable bioconcentration factors (BCF) for Cd (highest BCF=2150), Cr (1823), and Cu (595). This suggests that water hyacinth is exceptionally efficient at phytoextracting trace elements and toxic pollutants from wastewater characterized by low concentrations of these elements (Zewge *et al.*, 2011).

The scientific literature regarding the suitability of coontail and water hyacinth plants for chromium-contaminated water treatment is notably scarce, particularly in Aurangabad, Maharashtra. This study is designed to address this gap by conducting a comprehensive investigation into the chromium tolerance capacity of *Ceratophyllum demersum* (L.) and *Eichhornia crassipes* (L.) through controlled experiments. The current objectives include assessing these plants' capabilities in removing, accumulating, translocating, and tolerating various concentrations of chromium across different time intervals. By gaining insights into the mechanisms these aquatic plants employ to combat chromium-induced stress, we aim to unlock their potential for effective phytoremediation in chromium-contaminated aquatic ecosystems.

Material and Method

Collection of plant material and acclimatization

In July 2021, two aquatic plant species, *Ceratophyllum demersum* (L.) and *Eichhornia crassipes* (L.), from Salim Ali Lake in Aurangabad (coordinates: 19°53′57.26″N 75°20′32.23″E), were collected based on their distinct morphological characteristics in fresh and healthy condition. These plants were authenticated at the Babasaheb Ambedkar Marathwada University laboratory in Aurangabad. They were carefully washed with tap water to eliminate any solid particles and then transported to the laboratory in sterilized polythene bags. The plants were maintained in the greenhouse with an average temperature of 26.9°C and a relative humidity level of 22.1%.

Experimental setup

To prepare a one-liter chromium stock solution with a concentration of 1000 ppm (parts per million), 1.9232 grams of chromium trioxide (CrO_3) was dissolved. The calculation to determine the required weight of chromium trioxide was done using the following formula:

$$\text{Weight of CrO3 (mg)} = \left(\frac{\text{Molecular Weight of } CrO3}{Atomic \text{ weight of Cr}}\right) \text{x Number of ppm of Cr required}$$

Five plant stems weighing 1 gram each *Ceratophyllum demersum* (L.) were placed in plastic beakers containing 1000 mL of E & W medium prepared in distilled water. The medium was supplemented with varying concentrations of chromium in the form of hexavalent chromium (CrO_3- Chromium trioxide), including 1, 2.5, 5, 7.5, 10, 12.5, and 15 ppm. The plants were incubated for 10 days, and all the chromium tolerance parameters were studied by harvesting water and plant samples on 3 days, 7 days, and 10 days. Three plants of 170 grams each of *Eichhornia crassipes* (L.) plant stems were placed in plastic buckets containing 10 L of E & W media. The medium was supplemented with same varying concentrations of hexavalent chromium. These plants were incubated for 30 days, and all the chromium tolerance parameters were studied by harvesting water and plant samples on 10 days, 20 days, and 30 days, respectively. Additionally, a control group was included, which did not receive any chromium supplementation. All the concentrations of

hexavalent chromium containing both the plants were kept in triplicates. During the chromium tolerance studies of *Ceratophyllum demersum* (L.), all the plants within the beaker were aggregated and pooled together before being dried to facilitate the data reading process. This was done considering the small size of the plant.

Fresh weight, dry weight, and relative growth rate

The determination of Fresh Mass (FM) and Dry Mass (DM) for the plants was carried out according to the standard protocol described by Matindi *et al.* (2022).

To calculate the Relative Growth Rate (RGR), the final biomass weight was compared to the initial biomass weight, and this comparison was made over a specified timeframe. The RGR for plant biomass was calculated using the formula provided below, where W_2 represents the weight of the final plant biomass, W_1 corresponds to the weight of the initial plant biomass, and t_2 and t_1 denote the respective time points. It is noteworthy that this formula has been widely utilized in various studies related to plant growth, including research conducted in aquatic and wetland plant ecosystems (Sudiarto *et al.*, 2019).

$$Relative\ Growth\ Rate\ (RGR) = \frac{(\ln W2 - \ln W1)}{t2 - t1}$$

Chlorophyll content

Fresh samples of the plants were collected and whole plants of *Ceratophyllum demersum* (L.) and leaves of *Eichhornia crassipes* (L.) were selected for the analysis. The plant samples were washed with deionized distilled water and dried by blotting on filter paper. Chlorophyll content was determined by crushing 0.5 gram of each plant sample with 20 ml of chilled aqueous acetone (80%) and refrigerating it at 40°C for a duration of 6 hours. Subsequently, the samples underwent centrifugation at 5000 rpm for 5 minutes, resulting in the separation of the supernatant. This process was repeated iteratively until the residue became colorless. This solution was kept in dark for 12 hours at 20 °C. a portion of the supernatant, was taken and transferred in cuvette to find the absorbance. Finally, the volume of the supernatant was adjusted to 100 ml and utilized for measuring optical density at 663 nm and 645 nm using a UV spectrophotometer (Arnon, 1949) and the total chlorophyll was calculated using the formula stated by Su *et al.* (2010).

Chromium removal efficiency in water

After harvesting water hyacinth and coontail plant samples, the water levels in the growth tanks were restored to their initial levels. Water samples, each measuring 500 mL, were collected from all treatment tanks, each containing varying concentrations of heavy metals (ranging from 1 to 15 mg/L). These water samples were subsequently filtered using Whatman filter paper No. 41, known for its 0.45 µm pore size. To determine the percent removal efficiency of the water hyacinth plants in each treatment tank, the heavy metal content in the samples was analyzed. For this purpose, 100 mL of each collected water sample was transferred into a 250 mL round-bottom flask. To these samples, 2 mL of HNO_3 and 1 mL of HCl were added. The flask was placed on a hot plate, covered with a raised watch glass, and heated to approximately 85°C. After 2 hours and 30 minutes, the sample volume was reduced to 20 mL. Subsequently, the flask was allowed to cool for 15 minutes, and then the volume was adjusted to the mark on a 50 mL volumetric flask using de-ionized water. A blank solution was prepared by digesting a mixture of reagents (69–72% HNO_3 and H_2O_2) using the same digestion

and dilution procedures as described above. This blank solution served as a control for the analysis (Klumpp *et al.*, 2002).

Chromium accumulation in plants

The analysis involved determining the chromium metal content in various parts of the plant. *Ceratophyllum demersum* (L.) was harvested on 3rd, 7th, and 10th days of exposure to hexavalent chromium and *Eichhornia crassipes* (L.) was harvested on 10th, 20th, and 30th day of exposure to hexavalent chromium.

The harvested plants underwent a series of preparatory steps, starting with wiping them using 0.01 N HCl, followed by thorough washing with tap water and then a final rinse with distilled water to eliminate any adsorbed ions. Subsequently, the plants were divided into roots, and stems, for water hyacinth and whole plants for coontail and they were subjected to oven drying at 150°C for an hour. Afterward, the dried samples were ground using a pestle and mortar, sieved, and digested with a mixture of HNO3 and HCl in a 7:5 ratio. The resulting solution was brought up to a total volume of 100ml using a Standard Measuring Flask and then filtered through Whatman No.1 filter paper. Finally, the filtered solution was placed in plastic bottles and analyzed using Atomic Absorption Spectrophotometry (AAS) (Zewge *et al.*, 2011).

Bioconcentration factor (BCF)

The plant's ability to accumulate heavy metals concerning the initial metal concentration in the surrounding substrate is quantified using the Bioconcentration Factor (BCF). The BCF is computed by dividing the metal concentration in the plant tissue (µg/g) by the initial concentration (mg/L) of the metal in the nutrient solution (Zayed *et al.*, 1998).

Translocation factor

The Translocation Factor (TF) is used to assess the plant's ability to transfer metal species from its roots to its shoot at varying concentrations. The translocation factor was determined for *Eichhornia crassipes*. It was calculated using the following formula described by (Zayed *et al.*, 1998):

$$TF = \frac{Cr\ content\ of\ the\ root \mu \frac{g}{g}}{Cr\ content\ of\ the\ shoot\ \mu \frac{g}{g}}$$

Statistical analysis

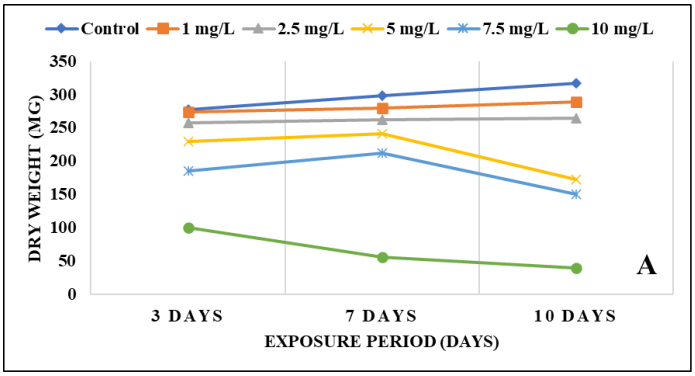
The statistical analysis employed in this study involved the use of One-Way ANOVA to assess whether significant differences existed among the various Cr (VI) concentration treatments across different time points. Additionally, multiple comparisons among these treatments were conducted using Tukey's tests. It's important to note that all statistical analyses were conducted using IBM SPSS Amos 27 software, ensuring a robust and reliable evaluation of the data.

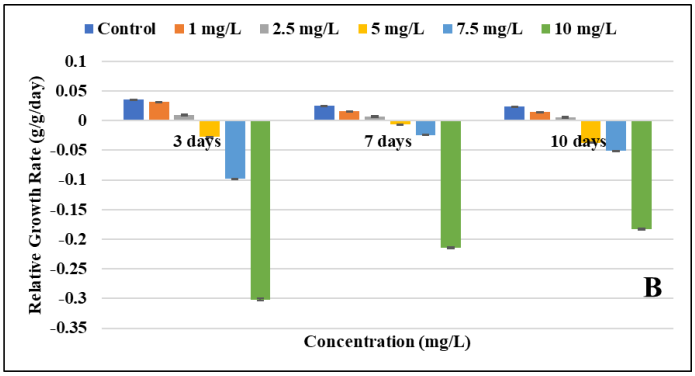
Results and Discussion

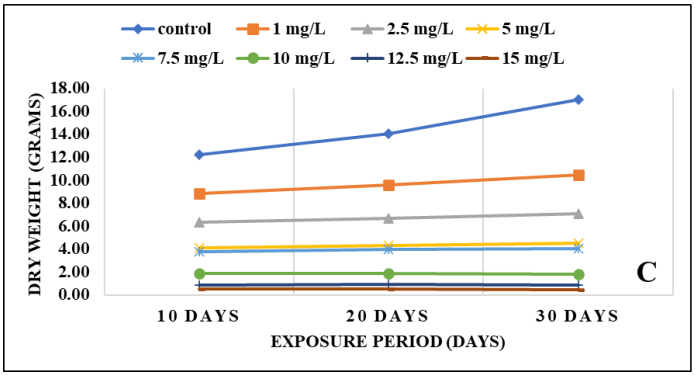
Fresh mass and Dry mass

In the present study, the growth of the plants in the presence of chromium was assessed through fresh mass, and dry mass (Table 1). Various concentrations of chromium used in the study showed significantly gradual reduction in fresh weight, and dry weight compared to the control ($p<0.05$). The control and 1 mg/L concentration showed similar values. The reduction increased with increasing metal concentration. The fresh mass increased with increase in the exposure time till the concentration of 5 mg/L on day 7 after which it decreased with the increasing time. This suggest that plants can survive and continue to grow at higher concentrations of chromium up to 3 days, but further exposure time may lead to slower growth. Fresh mass at the lowest concentration of 0 mg/L (control), increased from 5.56 ± 0.03 g at day 3 to 6.34 ± 0.04 g at day 10. On day 10, the fresh mass decreased reaching to 3.45 ± 0.02 g. Conversely, at the highest concentration of 10 mg/L, the fresh mass decreased from 2.02 ± 0.01 g at day 3 to 0.8 ± 0.00 g at day 10. This trend suggests a concentration-dependent effect on the growth of the *Ceratophyllum demersum* (L.).

A similar pattern was observed for dry mass measurements, which significantly increased with the increasing period at lower concentrations and decreased at higher concentrations ($p<0.05$). In control, the plant displayed an increase in dry mass over the 10-day observation period. Specifically, the dry mass increased from an initial value of 278 ± 1.61 mg at day 3 to 317 ± 1.83 mg at day 10. At concentrations of 1 mg/L and 2.5 mg/L, although there was a slight decrease in dry mass observed over the 10-day period, it's noteworthy that these values remained relatively close to the dry mass recorded in the control group. Conversely, at the highest experimental concentration of 10 mg/L, the dry mass exhibited a distinct decline (







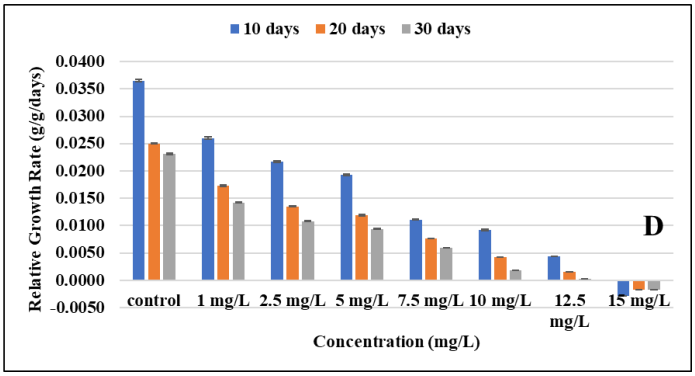


Figure *1*). The dry mass decreased from 101.17 ± 0.58 mg at day 3 to 40 ± 0.23 mg at day 10, signifying a substantial reduction in structural biomass. This notable reduction in dry mass indicates that higher concentrations of the experimental substance had an adverse impact on the plant's ability to accumulate structural biomass. No fresh mass and dry mass were recorded at concentrations of 12.5 mg/L and 15 mg/L as

the plants experienced mortality, resulting in the shedding of all leaves and the deterioration of the plant material. The results obtained in the current study are nearly similar to those obtained by Al-Nabhan (2022) that reported fresh weight of 6 g and dry weight of 400 mg with 3 mg/L chromium concentration. They also reported that the plants are unable to tolerate chromium concentrations above 3 mg/L. However, the results obtained by Aasim *et al.* (2020) reported efficient fresh weight and dry weight till 15 mg/L of chromium concentration. Such variations can be dependent on the variety of the plant species, seasonal changes, and the location from where the plants are harvested for the study (Wang *et al.*, 2012). In the current study, with the increasing concentration of chromium, leaf shedding and stem yellowing were more prominent. Chlorosis was observed. These symptoms are observed to be similar to those found by (Muhammet Doğan1, 2017) that reported similar chlorosis in coontail plants when exposed to chromium.

The results of fresh mass and dry mass of *Eichhornia crassipes* (L.) observed under different chromium concentrations is summarized in

Table **2**. The average fresh weight of the plants was seen to be significantly increased with increasing exposure time in a period of 30 days ($p<0.05$) indicating natural growth of the plants with time. However, the fresh weight reduced with increasing concentration of chromium. The initial biomass of the plant was 170 gram each. In control, on day 10 the fresh weight was 245.1 ± 1.42 g, increasing to 280.4 ± 1.62 g and reaching to the maximum of 340 ± 1.96 g. with 10 mg/L concentration, the fresh weight reduced to 165.1 ± 0.95 g on day 10 to 161.1 ± 0.93 g. In the current study, the fresh weight increased with increasing time up to 10 mg/L on day 20 but reduced after that concentration at higher levels. The results in the present study are in correlation with those obtained by Singh *et al.* (2022) that reported maximum fresh weight of 260 g with 25 % chromium concentration and later decreased with increasing concentration. Parwin and Karar Paul (2019) also recorded maximum fresh weight of 349 g with effluent and kitchen wastewater containing chromium. Same trend was observed with dry weight analysis, where around 90 % moisture was lost from the fresh mass (

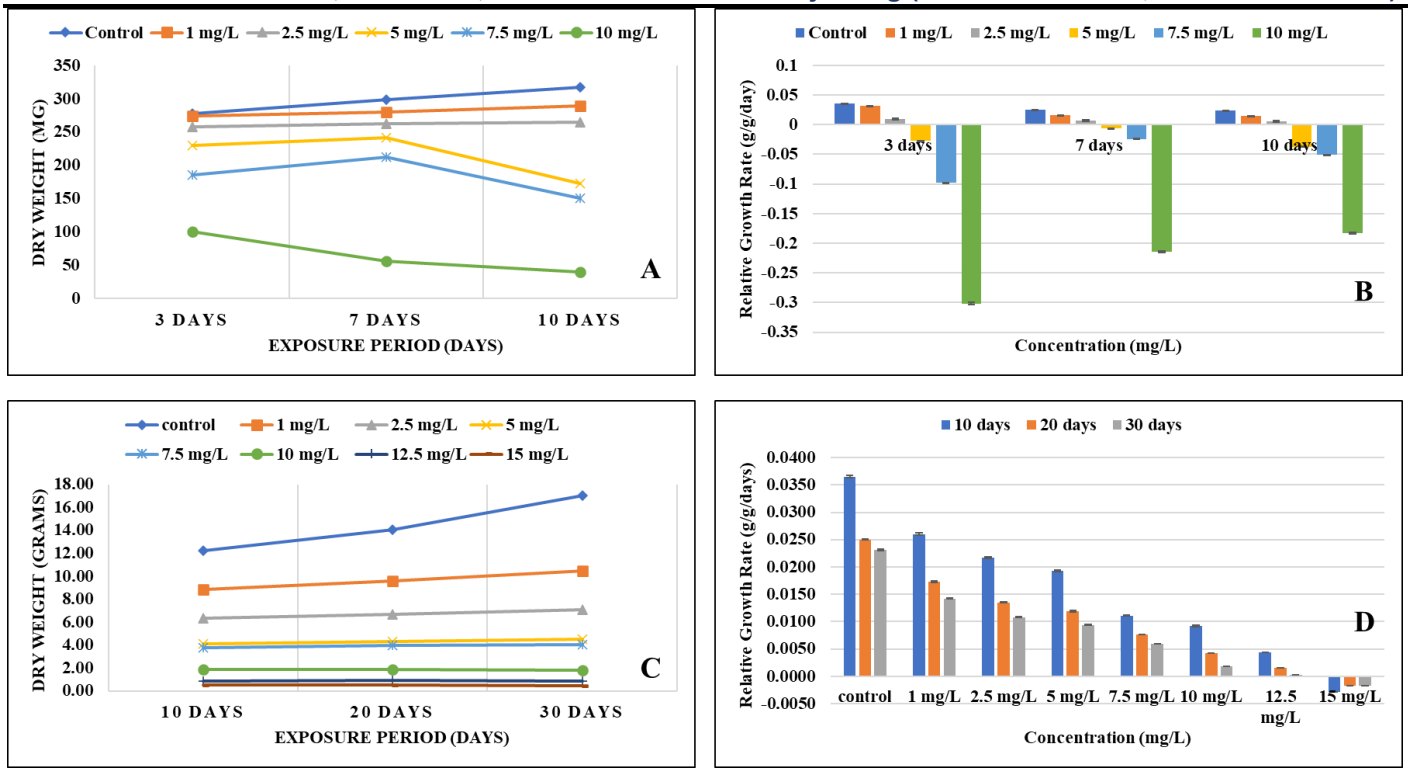


Figure *1*).

The decline in both fresh weight and dry weight can be attributed to various factors. The metals may have affected the components of the plasma membrane, leading to alterations in its functional and structural integrity by free radicals (Van Assche & Clijsters, 1990). These changes could result in the inhibition of liquid transport between the cell after a certain threshold concentration (Angulo-Bejarano *et al.*, 2021). The enzyme activity within the plant may have been altered as a response to the stress induced by the presence of metals (Cho & Park, 2000). Additionally, decrease in the mitotic index is more in chromium compared to other heavy metals (Mahdi & Al-Abbawy, 2019).

Relative Growth Rate (RGR)

The Relative Growth Rate (RGR) exhibited fluctuations in response to the experimental concentrations in *Ceratophyllum demersum* (L.). In control, the RGR ranged from 0.035 ± 0.0002 g/g/day at day 3 to 0.024 ± 0.0001 g/g/day at day 10. The growth density decreased significantly ($p<0.05$) with the increasing concentration compared to the control. Conversely, at 10 mg/L, the RGR displayed a more pronounced decline, reaching -0.302 ± 0.000 g/g/day at day 3 and -0.183 ± 0.000 g/g/day at day 10 (

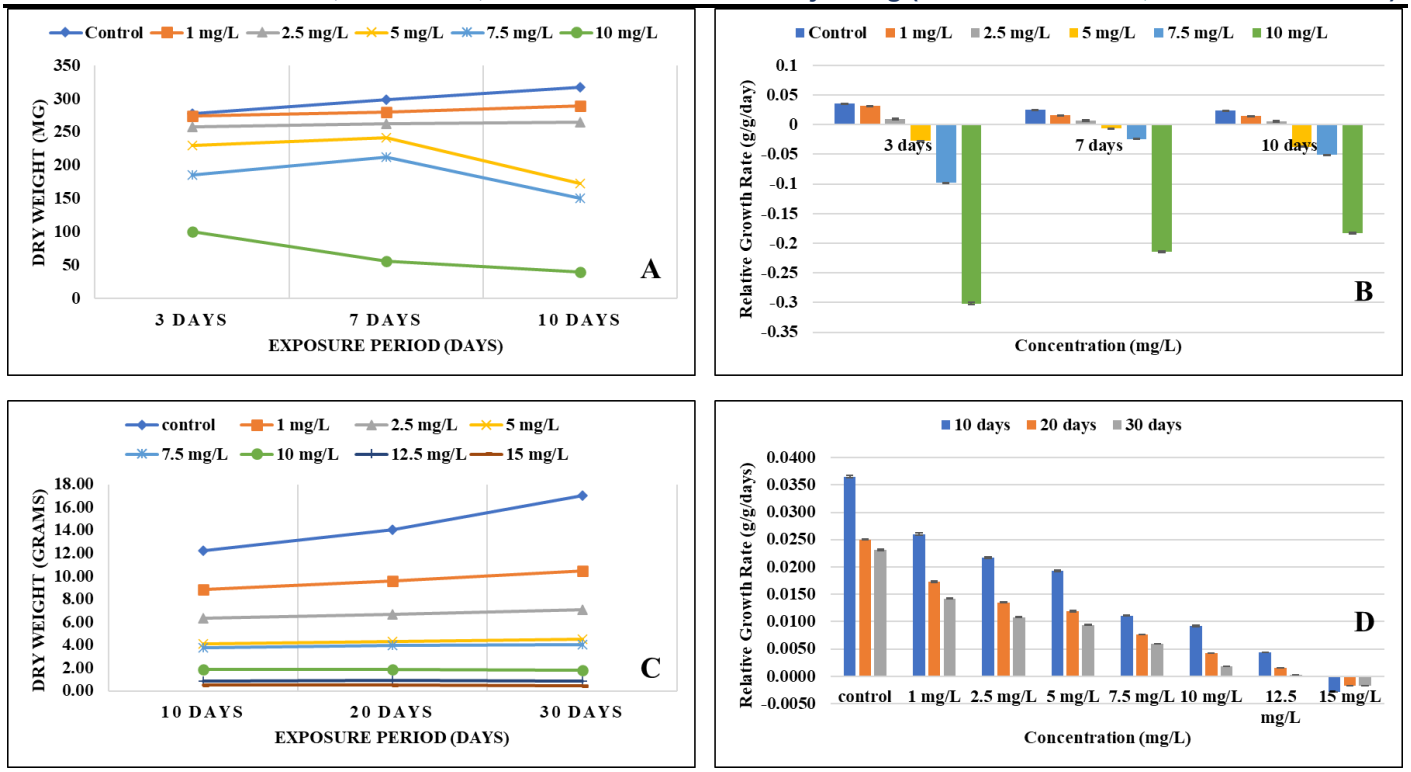


Figure *1*). These negative RGR values suggest inhibited growth and potential adverse effects at higher concentrations of the experimental substance. From concentration of 5 mg/L onwards, a negative growth rate was observed till 10 mg/L with complete growth inhibition at 12.5 mg/L and 15 mg/L, respectively. Such relative growth rate pattern have been reported by Duman *et al.* (2009) and Kumar (2011) when aquatic plants like azolla and watercress were exposed to higher chromium concentrations.

For *Eichhornia crassipes* (L.), in the control group, the RGR exhibited a range from 0.037 ± 0.0002 g/g/day on day 10 to 0.023 ± 0.0001 g/g/day on day 30. This decline in growth density over time was statistically significant ($p < 0.05$) across the days. Conversely, in the presence of a 15 mg/L concentration of the chromium, the RGR displayed a more pronounced and concerning decline. On day 10, it reached -0.003 ± 0.000 g/g/day, and by day 30, it was -0.002 ± 0.000 g/g/day (as shown in Figure 1). Similar pattern of RGR was found by Zewge *et al.* (2011).

The relative growth rate is relative to many parameters, like nutrients and growth conditions and may vary (Tholen *et al.*, 2004). The relative growth rates in these experiments were relatively different from other observations, but the difference is considerable, with regards to the genotype and growing conditions.

Chlorophyll content

The levels of total chlorophyll content found in *Ceratophyllum demersum* (L.) is shown in. The chlorophyll content significantly decreased with increasing concentration and increased with increasing exposure period till 5 mg/L after which the content decreased with time ($p<0.05$). The total chlorophyll content in control plants and 1 mg/L were similar showing 4.7 ± 0.027 and 4.3 ± 0.025 mg/g of dry weight on day 10 indicating the concentration is not very toxic for the plant growth (Table 3). From 2.5 mg/L and 5 mg/L concentration, a sudden decline in the chlorophyll content with 2.65 ± 0.015 and 1.73 ± 0.010 mg/g of dry weight was observed. From 7.5 mg/L and 10 mg/L concentration, chlorophyll content was further decreased

to 0.76 ± 0.004 and 0.20 ± 0.001 mg/g of dry weight. For the starting three concentrations, an efficient content of chlorophyll was observed for up to 10 days indicating the plant can survive in the chromium concentration of up to 5 mg/L. Suryani *et al.* (2017) reported increased chlorophyll content in coontail plant even at high concentration of 17 mg/L showing that the plant has the potential to survive in the extreme environment.

Eichhornia crassipes (L.) was comparatively resistant to higher concentrations of chromium. There was a significant decline in chlorophyll content of the plant as the concentration of chromium increased. But, with the relative growth, the chlorophyll content was found to increase with time until 10 mg/L concentration of chromium. The plant was found to lose chlorophyll at 12.5 and 15 ppm concentration as the plant grew. The results showed that 10 mg/L concentration was suitable for growth of *Eichhornia crassipes* with regards to chromium removal. Mishra and Tripathi (2009) and Zewge *et al.* (2011) found similar chlorophyll content at similar concentrations of chromium.

The decline in chlorophyll content is regarded as a significant toxic symptom resulting from metal-induced stress on plants following exposure to varying metal concentrations. The chlorophyll content in the present study clearly demonstrate that the total chlorophyll content was adversely affected with higher chromium concentration levels when compared to the control group. Furthermore, this reduction in chlorophyll content exhibited a direct correlation with the increasing metal concentrations. According to Panda *et al.* (2002), a plant accumulating heavy metals would experience an oxidative stress including decreased level of chlorophyll. The decrease in total chlorophyll content happens because chromium could lower the ∂-aminolaevulinic acid dehydratase (ALA) essential in the biosynthesis of chlorophyll. Besides, chromium VI can change most Mg+ ions and drain the chlorophyll content.

Chromium removal efficiency

The Table 5 displays the data regarding the total chromium content, hexavalent chromium content, and the removal efficiency achieved by *Ceratophyllum demersum* (L.). The one-way ANOVA performed yielded statistically significant differences among the chromium concentration treatments ($p < 0.05$). Notably, the chromium removal efficiency decreased with increasing chromium concentration indicating that the higher chromium concentrations were toxic for the plant. The removal efficiency of *Ceratophyllum demersum* (L.) was found to be maximum with 1 mg/L on day 10 exhibiting 46.61 ± 0.269 % after which it decreased with increasing concentration and reached to a minimum of 3.39 ± 0.02 % with 10 mg/L on day 10. Of the total chromium analysed, 70 % was present in the form of hexavalent chromium. Similar results were obtained by Suryani *et al.* (2017) who reported maximum removal efficiency of 1.7 % at 7.74 mg/L chromium concentration in tannery wastewater in 14 days and negative efficiency was obtained at higher chromium concentrations of 17 and 23 mg/L, respectively. The results however, contradicted to those obtained by Abdallah (2012) who reported a maximum removal of 84 % at 15 mg/L to as low as 13 % at 4 mg/L. Such variations might be because of different varieties of plant species exhibiting variable tolerance capacities, different conditions and growth medium provide. There is a limited study in the remediation of heavy metals through this plant which it an ideal subject for pollution tolerance studies in future.

The Table 6 describes the data relating to the total chromium content, hexavalent chromium content, and the removal efficiency by *Eichhornia crassipes* (L.). The chromium removal efficiency increased with the

increasing concentration up to 5.0 mg/L after which it decreased gradually at the higher concentrations. The highest removal efficiency was observed to be 93.21 ± 0.538 % with 5 mg/L concentration on day 30. The lowest removal was found to be 62.45 ± 0.361 % with 15 mg/L concentration on day 30. Similar results have been obtained by Saha *et al.* (2017) who reported chromium removal efficiency of 99 % in 15 days.

Both the plants exhibited increased chromium removal at the lower concentrations while showed a consistent and stagnant removal when treated with high chromium Figure 2. Of the total chromium content, hexavalent chromium was found in the majority form consisting of 60 to 70 %. As reported by various authors, wetland plants like *Eichhornia crassipes* (L.) have the capacity to convert highly toxic hexavalent chromium into the significantly less harmful trivalent chromium. This conversion can occur either within their tissues following the assimilation of Cr (VI) or externally through the release of root exudates (Fibbi *et al.*, 2012). They also reported that of the total hexavalent chromium, 40 % was reduced to trivalent chromium. However, some researchers report that the trivalent chromium is reduced from hexavalent chromium at different pH levels indicating more reduction at low to moderate pH (Park *et al.*, 2004).

Accumulation of chromium

The data for accumulation of chromium in *Ceratophyllum demersum* (L.) grown in different chromium concentrations and different exposure time is given in Table 7 and Figure 3. The chromium concentration accumulated in both the plants significantly increased with increasing concentration and exposure time ($p<0.05$). The accumulation increased with increasing concentration and exposure time till 5 mg/L after which the uptake decreased with 7.5 mg/L and 10 mg/L chromium concentration, respectively. The highest accumulation of 556.11 µg/g of dry weight was noted when plant was exposed to 5 mg/L concentration on 10^{th} day. The plants were unable to uptake chromium and exhibited accumulation of 488.81 ± 2.822 µg/g of dry weight with 7.5 mg/L concentration and 338.56 ± 1.955 µg/g of dry weight with 10 mg/L concentration on day 10, respectively. The results are in agreement with those obtained by Abdallah (2012). According to Garg and Chandra (1990), coontail plants can survive chromium concentrations up to 2 mg/L and showed maximum uptake of 867.80 µg/g of dry weight.

The data for accumulation of chromium in different plant parts like shoot and root of *Eichhornia crassipes* (L.) grown in different chromium concentrations and exposure time is mentioned in Table 8 and Figure 3. The rate of accumulation of the plants exhibited significantly increasing trend with increasing concentration and exposure period ($p<0.05$) till 10 mg/L where the plant showed maximum chromium uptake of 8630 ± 49.71 µg/g of dry weight on day 30. Among the plant parts, it was observed that roots accumulated more chromium than shoots. The analytical results in this study pertaining to chromium concentration in root and shoot of plants revealed that highest uptake of chromium by the shoot was 2411 ± 13.92 µg/g of dry weight and root was 6199 ± 35.79 µg/g of dry weight on day 30 with 10 mg/L chromium, respectively. Similar results were obtained by Tabinda *et al.* (2018) and Zewge *et al.* (2011) who also reported maximum chromium uptake at 10 mg/L.

High accumulation of chromium is usually reported in the roots both in terrestrial and aquatic plants. *Ceratophyllum demersum* (L.) being a rootless plant has shown efficient potential for chromium accumulation. However, the higher chromium concentrations of 12.5 mg/L and 15 mg/L had negative impact on the plant

since the plants experienced mortality. Additionally, the present study shows that the overall high accumulation of chromium was found to be superior in water hyacinth plants than coontail plants. However, it is essential to note that the absorption of metals by plants can be influenced by various factors, including pH, temperature, and chemical components present in the environment. In our study, we specifically manipulated exposure duration and chromium (Cr) concentration, while other potentially influential variables were not considered. We recognize that these unexamined factors might have had some impact on the outcomes of our study.

Bioconcentration factor (BCF)

The bioconcentration factor for different chromium concentrations and different exposure period is shown in Table 9. In general, the BCF values increased significantly ($p \leq 0.05$) with the increase in the exposure time for *Ceratophyllum demersum* (L.). However, it was observed that with the increasing concentration of the chromium, the BCF values decreased for this plant. The highest BCF value obtained was 466.05 ± 2.69 with 1 mg/L chromium concentration at day 10, while the lowest BCF was obtained on day 3 at 10 mg/L exhibiting 12.02 ± 0.07, respectively. The higher concentrations of 12.5 mg/L and 15 mg/L did not exhibit any values since the plants were completely degraded at such high chromium concentration. The plant was able to concentrate and accumulate chromium efficiently till 5 mg/L concentration (111.22 ± 0.64) after which the BCF values drastically reduced at 7.5 mg/L and 10 mg/L exhibiting 65.17 ± 0.38 and 33.86 ± 0.2 at day 10, respectively. Similar results were obtained by Abdallah (2012) who reported that the maximum BCF value for chromium was at 2 mg/L exhibiting 297.1 on day 12. Additionally, they reported a maximum BCF of 700 was reported with 15 mg/L chromium on day 4. Al-Abbawy *et al.* (2021) also recorded a BCF value of 255.76 with *Ceratophyllum demersum* (L.) against chromium. The studies have reported high BCF values with coontail plant against chromium exceeding above 1000 however, in the present study comparatively lower BCF values were observed. This could depend on the variety of the species studies, seasonal variation,

On the other hand, the BCF value of *Eichhornia crassipes* (L.) significantly increased with increasing concentration and increasing time ($p<0.05$) till the concentration reached 5 mg/L where highest BCF value was recorded 932 ± 5.38 Table 10. From 7.5 mg/L concentration, the BCF value significantly decreased with higher concentration ($p<0.05$) till it reached the minimum of 357 ± 2.06 at 15 mg/L on day 30. In the initial four concentrations (1 mg/L, 2.5 mg/L, 5 mg/L, and 7.5 mg/L), notably high Bioconcentration Factor (BCF) values exceeding 900 were observed. However, some BCF values exhibited similarities in their magnitude, such as the BCF values for concentrations 2.5 mg/L and 12.5 mg/L on day 10, as well as concentrations 1 mg/L and 12.5 mg/L, along with 5 mg/L and 10 mg/L on day 20, which showed comparable BCF values. This observation underscores the dependence of heavy metal accumulation on the plant's efficiency, where certain concentrations and time points may yield similar levels of accumulation due to variations in the plant's uptake mechanisms. Generally, the plants that have high BCF values above 1000 are good phytoaccumulators and indicate a greater potential for bioaccumulation. Similar studies have been obtained by Giri and Patel (2011) with *Eichhornia crassipes* (L.) showing BCF value of above 500 at 4 mg/L against hexavalent chromium. Zewge *et al.* (2011) reported maximum BCF value of 506 at 3 mg/L concentration and the values tend to be in decreasing trend with increasing concentration. The study conducted by Odjegba and Fasidi (2007) reported

a BCF exceeding 1000 in *Eichhornia crassipes* (L.) for a Cr (VI) concentration of 15 mg/L after 21 days of experimental exposures. This finding suggests that extended exposure over a prolonged period, even at relatively low to moderate contamination levels, may result in significant accumulation of chromium in the plant tissue. However, differences in BCF values might depend upon the plant species being used in the phytoremediation, the concentration of the heavy metal, and the exposure time. Apart from this, seasonal variations also greatly influence the bioconcentration factor of the plants (Al-Abbawy *et al.*, 2021).

The Bioconcentration Factor (BCF) stands as a valuable parameter for assessing the capacity of plants to accumulate metals, and it was computed based on the dry weight of the plant material. The uptake of metals by macrophytes is subject to influence from both water and sediment metal concentrations (Lu *et al.*, 2004). Notably, the metal concentration in ambient water emerges as a prominent factor governing metal uptake efficiency. Generally, as the metal concentration in the water rises, the amount of metal accumulated in plants increases, but the BCF values exhibit a declining trend (Sinha *et al.*, 2002).

Translocation factor (TF)

The results in show that the translocation factor of the water hyacinth plant decreased with the increasing concentration of chromium up to 7.5 mg/L exhibiting 1.4 ± 0.01 (42 %) on day 30 (Table 11). All the results showed $p<0.05$ level of significance when analysed through one way ANOVA except TF of 2.5 mg/L and 12.5 mg/L on day 10 showed similar value. This similarity in values might be attributed to the distinct concentrations tested and their respective translocation efficiencies, which could potentially lead to overlapping results. From 10 mg/L concentration, the translocation factor started to increase and reached a maximum of 5.7 ± 0.03 (18 %) with 15 mg/L concentration on day 30. High translocation factor implies poorer translocation capability (Zayed *et al.*, 1998). This implies that the translocation of the heavy metal from root to shoot increased with increasing concentration up to 7.5 mg/L and later decreased with higher concentrations. The chromium metal was found to be translocated to the shoots in the range of 21 % to 38 %. The study noted a decrease in the translocation factor as the exposure period increased, suggesting improved translocation efficiency over a longer incubation time. This pattern persisted up to 10 mg/L, where a translocation factor of 2.1± 0.01 (32%) was observed on day 20. However, beyond this critical concentration threshold, translocation started to decline with increasing concentration. Such similar results were obtained by Zewge *et al.* (2011) where their chromium translocation was maximum at 7 mg/L and minimum at 10 mg/L and 20 mg/L, respectively. Soltan and Rashed (2003) suggested that the water hyacinth plant mostly uptakes chromium and translocate only 6 to 25 % of the heavy metal to the shoots. In the present study, the accumulation of the chromium was found to be higher in the roots than in shoots.

The fine lateral roots of water hyacinth exhibit a remarkable ability to convert highly toxic Cr (VI) into less toxic Cr (III) and subsequently transport the relatively non-toxic Cr (III) to the leaf tissues. This efficient mechanism results in lower metal accumulation in the shoot compared to the root, which is essential for safeguarding the plant's photosynthetic tissue from the harmful effects of trace elements (Lytle *et al.*, 1998). This root-to-shoot partitioning strategy is a common adaptation employed by the plant to sequester harmful ions in the roots, thereby shielding the leaves the sites of photosynthesis and other vital metabolic processes from toxicity (Sinha *et al.*, 2002). However, as the concentration of chromium in the environment increased,

the plant's capacity to uptake Cr decreased. This decline in uptake could be attributed to the fact that the chromium concentration in the water surpassed the plant's tolerance threshold, potentially leading to damage to the plant tissues. This suggests that the chromium can be optimally remediated from the water bodies or effluent water at maximum of 10 mg/L concentration through water hyacinth.

Conclusion

The current study has successfully demonstrated the potential of two aquatic plant species, *Ceratophyllum demersum* (L.) and *Eichhornia crassipes* (L.), in both tolerating and remediating chromium contamination under varying concentrations and exposure durations. The study revealed that the removal and uptake of chromium exhibited an upward trend as the concentration of chromium in the water increased, reaching a specific threshold concentration. Beyond this threshold, which varied for each plant species, the remediation efficiency started to decline. Additionally, the translocation was higher in roots than in shoots. Based on the findings from our study, it is apparent that *Eichhornia crassipes* (L.) outperforms *Ceratophyllum demersum* (L.) as a more effective phytoaccumulator of chromium. *Eichhornia crassipes* (L.) demonstrated the ability to tolerate elevated chromium concentrations while maintaining a favorable Bioconcentration Factor (BCF). Additionally, it exhibited efficient chromium removal, exhibited fewer toxic symptoms, and displayed better growth parameters compared to *Ceratophyllum demersum* (L.). *Ceratophyllum demersum* (L.), being a small and rootless aquatic plant, exhibits efficient heavy metal remediation capabilities at lower concentrations. Higher concentrations of heavy metals might prove to be lethal and toxic for this plant, limiting its effectiveness in such environments. These results contribute to the understanding of the capabilities of aquatic plants in mitigating heavy metal pollution and highlight the importance of selecting the appropriate plant species and concentration levels for effective phytoremediation efforts.

Table 1 Effect of different concentrations and exposure time of Total Chromium on growth of *Ceratophyllum demersum* (L.)

Initial Concentration (mg/L)	Fresh mass (g)			Dry mass (mg)			Relative Growth Rate RGR (g/g/days)		
	3 days	7 days	10 days	3 days	7 days	10 days	3 days	7 days	10 days
0 (Control)	5.56 ± 0.03[a]	5.97 ± 0.03	6.34 ± 0.04	278 ± 1.61[b]	298.5 ± 1.72	317 ± 1.83	0.035 ± 0.0002	0.0250 ± 0.0001	0.024 ± 0.0001
1	5.49 ± 0.03[a]	5.61 ± 0.03	5.79 ± 0.03	274.5 ± 1.58[b]	280.5 ± 1.62	289.5 ± 1.67	0.031 ± 0.0002	0.016 ± 0.0001	0.015 ± 0.0001
2.5	5.15 ± 0.03	5.24 ± 0.03	5.29 ± 0.03	257.5 ± 1.49	262 ± 1.51	264.5 ± 1.53	0.010 ± 0.0001	0.007 ± 0.0000	0.006 ± 0.0000
5	4.61 ± 0.03	4.78 ± 0.03	3.45 ± 0.02	230.5 ± 1.33	241 ± 1.39	172.5 ± 1.00	-0.027 ± 0.000	-0.006 ± 0.000	-0.037 ± 0.000
7.5	3.72 ± 0.02	4.22 ± 0.02	3.02 ± 0.02	186.17 ± 1.07	213 ± 1.23	151 ± 0.87	-0.098 ± 0.000	-0.024 ± 0.000	-0.050 ± 0.000
10	2.02 ± 0.01	1.12 ± 0.01	0.8 ± 0.00	101.17 ± 0.58	55.95 ± 0.32	40 ± 0.23	-0.302 ± 0.000	-0.214 ± 0.000	-0.183 ± 0.000
12.5	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance. The values with common superscript are similar.

Table 2 Effect of different concentrations and exposure time of Total Chromium on growth of Eichhornia crassipes (L.)

Initial Concentration (mg/L)	Fresh mass (g)			Dry mass (g)			Relative Growth Rate RGR (g/g/dry weight)		
	10 days	20 days	30 days	10 days	20 days	30 days	10 days	20 days	30 days
0 (Control)	245.1 ± 1.42	280.4 ± 1.62	340 ± 1.96	12.26 ± 0.07	14.02 ± 0.08	17 ± 0.10	0.037 ± 0.0002	0.025 ± 0.0001	0.023 ± 0.0001
1	220.5 ± 1.27	240.3 ± 1.39	260.8 ± 1.51	8.82 ± 0.05	9.61 ± 0.06	10.43 ± 0.06	0.026 ± 0.0002	0.017 ± 0.0001	0.014 ± 0.0001
2.5	211.2 ± 1.22[a]	223.1 ± 1.29	235.7 ± 1.36	6.34 ± 0.04	6.69 ± 0.04	7.07 ± 0.04	0.022 ± 0.0001	0.014 ± 0.0001	0.011 ± 0.0001
5	206.3 ± 1.19[a]	215.8 ± 1.25	225.4 ± 1.30	4.13 ± 0.02	4.32 ± 0.02	4.51 ± 0.03	0.019 ± 0.0001	0.012 ± 0.0001	0.009 ± 0.0001
7.5	190.1 ± 1.10[b]	198.5 ± 1.15	203.7 ± 1.18	3.80 ± 0.02	3.97 ± 0.02	4.07 ± 0.02	0.011 ± 0.0001	0.008 ± 0.0000	0.006 ± 0.0000
10	186.4 ± 1.08[b]	189.32 ± 1.09	179.5 ± 1.04	1.86 ± 0.01	1.89 ± 0.01	1.80 ± 0.01	0.009 ± 0.0001	0.004 ± 0.0000	0.002 ± 0.0000
12.5	177.7 ± 1.03	179.21 ± 1.03	171.3 ± 0.99	0.89 ± 0.01	0.90 ± 0.01	0.86 ± 0.00	0.004 ± 0.0000	0.002 ± 0.0000	0.0002 ± 0.0000
15	165.1 ± 0.95	163.8 ± 0.95	161.1 ± 0.93	0.50 ± 0.00	0.49 ± 0.00	0.48 ± 0.00	-0.0030.0000	-0.002 0.0000	-0.002 0.0000

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance. The values with common superscript are similar.

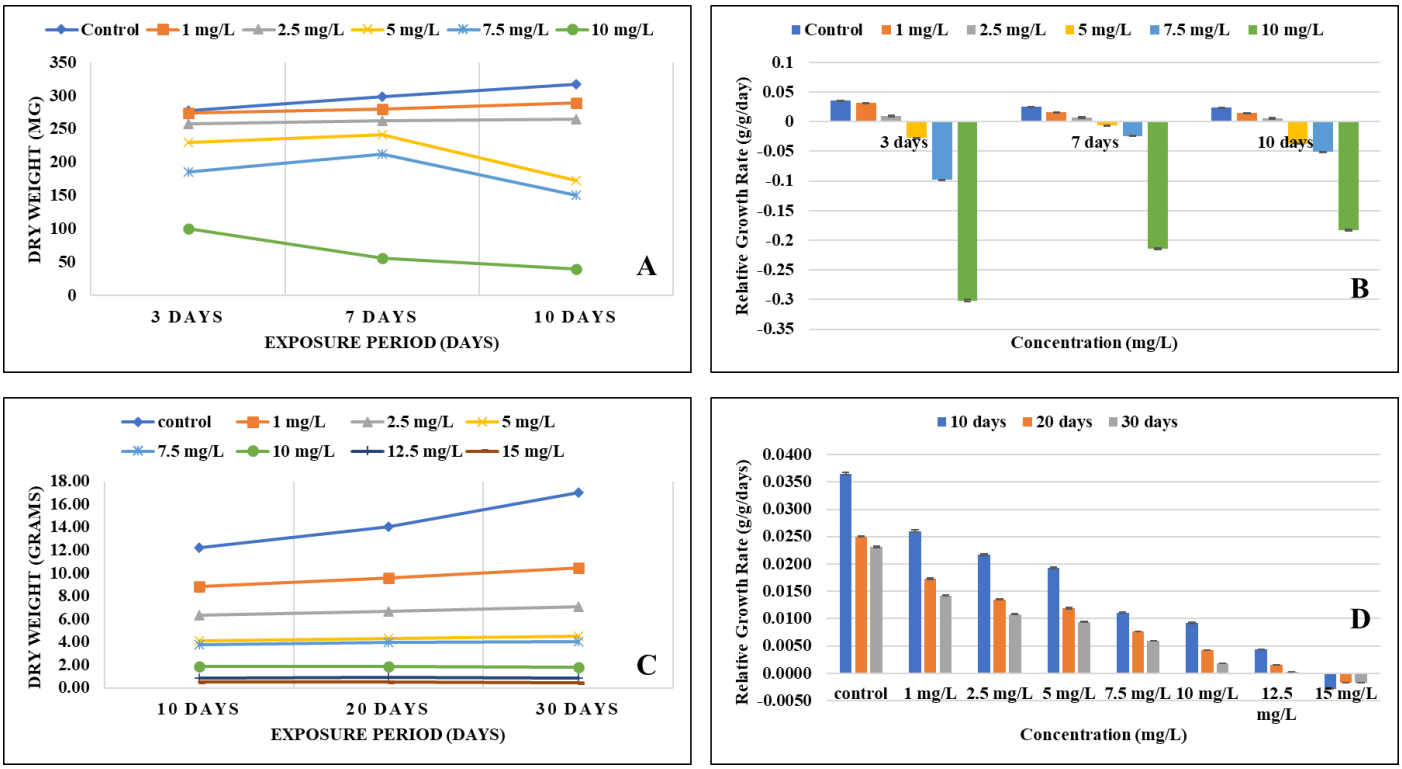


Figure 1 Dry weight and Relative Growth Rate of *Ceratophyllum demersum* (L.) and *Eichhornia crassipes* (L.). A and B are dry weight and relative growth rate of *Ceratophyllum demersum* (L.) and C and D are dry weight and relative growth rate of *Eichhornia crassipes* (L.)

Table 3 Effect of total chromium on the chlorophyll content of *Ceratophyllum demersum* (L.)

Chlorophyll content (mg/g of dry weight)			
Initial Concentration (mg/L)	**3 days**	**7 days**	**10 days**
0	4.17[a] ± 0.024	4.48 ± 0.026	4.76 ± 0.027
1	4.12[a] ± 0.024	4.21 ± 0.024	4.34 ± 0.025
2.5	2.58 ± 0.015	2.62 ± 0.015	2.65 ± 0.015
5	2.31 ± 0.013	2.41 ± 0.014	1.73 ± 0.010
7.5	0.93 ± 0.005	1.06 ± 0.006	0.76 ± 0.004
10	0.51 ± 0.003	0.28 ± 0.002	0.2 ± 0.001
12.5	-	-	-
15	-	-	-

Any value followed by ± is the Standard Error of the mean. Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance. The values with common superscript are similar

Table 4 Effect of total chromium on the chlorophyll content of *Eichhornia crassipes* (L.)

Chlorophyll content (mg/gram of dry weight)			
Initial Concentration (mg/L)	**10 days**	**20 days**	**30 days**
0	306.38 ± 1.77	350.5 ± 2.02	425 ± 2.45
1	220.5 ± 1.27	240.3 ± 1.39	260.8 ± 1.51
2.5	158.4 ± 0.91	167.33 ± 0.97	176.78 ± 1.02
5	82.52 ± 0.48	86.32 ± 0.50	90.16 ± 0.52
7.5	76.04 ± 0.44	79.4 ± 0.46	81.48 ± 0.47
10	37.28 ± 0.22	37.86 ± 0.21	35.9 ± 0.21
12.5	13.33 ± 0.08	13.44 ± 0.08	12.85 ± 0.07
15	3.47 ± 0.02	2.95 ± 0.02	1.93 ± 0.01

Any value followed by ± is the Standard Error of the mean. Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance

Table 5 Total and hexavalent chromium content in water and removal efficiency by *Ceratophyllum demersum* (L.)

Initial Concentration (mg/L)	Total chromium (mg/L)			Hexavalent chromium (mg/L)			Removal efficiency of total chromium (%)		
	Day 3	Day 7	Day 10	Day 3	Day 7	Day 10	Day 3	Day 7	Day 10
0 (Control)	-	-	-	-	-	-	-	-	-
1	0.89 ± 0.005	0.73 ± 0.004	0.53 ± 0.003	0.62 ± 0.004	0.51 ± 0.003	0.37 ± 0.002	11.02 ± 0.064	27.06 ± 0.156	46.61 ± 0.269
2.5	2.37 ± 0.014	2.2 ± 0.013	2 ± 0.012	1.66 ± 0.01	1.54 ± 0.009	1.4 ± 0.008	5.39 ± 0.031	12.1 ± 0.07	19.99 ± 0.115
5	4.85 ± 0.028	4.66 ± 0.027	4.44 ± 0.026	3.39 ± 0.02	3.26 ± 0.019	3.11 ± 0.018	3.01 ± 0.017	6.76 ± 0.039	11.12 ± 0.064
7.5	7.35 ± 0.042	7.18 ± 0.041	7.01 ± 0.04	5.14 ± 0.03	5.02 ± 0.029	4.91 ± 0.028	2.05 ± 0.012	4.32 ± 0.025	6.52 ± 0.038
10	9.88 ± 0.057	9.77 ± 0.056	9.66 ± 0.056	6.92 ± 0.04	6.84 ± 0.039	6.76 ± 0.039	1.2 ± 0.007	2.33 ± 0.013	3.39 ± 0.02
12.5	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance.

Table 6 Total and hexavalent chromium content in water and removal efficiency by *Eichhornia crassipes* (L.)

Initial Concentration (mg/L)	Total chromium (mg/L)			Hexavalent chromium (mg/L)			Removal efficiency of total chromium (%)		
	Day 10	Day 20	Day 30	Day 10	Day 20	Day 30	Day 10	Day 20	Day 30
0 (Control)	-	-	-	-	-	-	-	-	-
1	0.59 ± 0.003	0.37 ± 0.002	0.09 ± 0.001	0.413 ± 0.002	0.259 ± 0.001	0.063 ± 0	40.68 ± 0.235	62.71 ± 0.362	90.54 ± 0.523
2.5	1.04 ± 0.006	0.55 ± 0.003	0.22 ± 0.001	0.728 ± 0.004	0.385 ± 0.002	0.154 ± 0.001	58.39 ± 0.337	78.02 ± 0.45	91.25 ± 0.527
5	1.73 ± 0.01	0.92 ± 0.005	0.34 ± 0.002	1.211 ± 0.007	0.644 ± 0.004	0.238 ± 0.001	65.47 ± 0.378	81.69 ± 0.472	93.21 ± 0.538
7.5	2.16 ± 0.012	0.95 ± 0.005	0.55 ± 0.003	1.512 ± 0.009	0.665 ± 0.004	0.385 ± 0.002	71.23 ± 0.411	87.33 ± 0.504	92.65 ± 0.535
10	1.97 ± 0.011	1.7 ± 0.01	1.39 ± 0.008	1.379 ± 0.008	1.19 ± 0.007	0.973 ± 0.006	80.32 ± 0.464	82.96 ± 0.479	86.12 ± 0.497
12.5	5.07 ± 0.029	4.86 ± 0.028	4.68 ± 0.027	3.549 ± 0.02	3.402 ± 0.02	3.276 ± 0.019	59.41 ± 0.343	61.12 ± 0.353	62.45 ± 0.361
15	10.48 ± 0.061	10.11 ± 0.058	9.64 ± 0.056	7.34 ± 0.042	7.08 ± 0.041	6.75 ± 0.039	30.12 ± 0.174	32.57 ± 0.188	35.76 ± 0.206

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance.

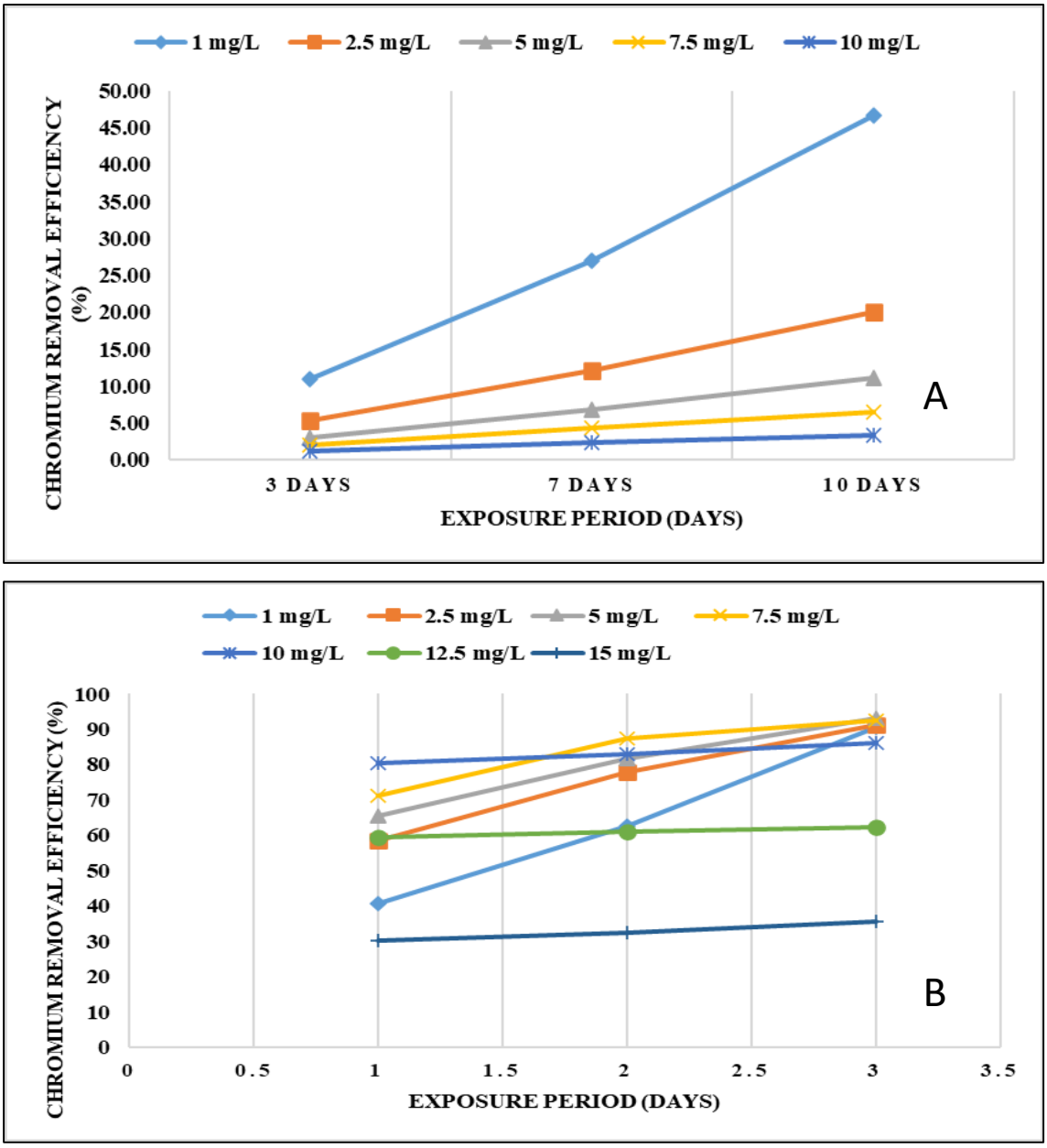


Figure 2. A and B are the chromium removal efficiencies (%) at different concentrations and different exposure periods of *Ceratophyllum demersum* (L.) and *Eichhornia crassipes* (L.), respectively.

Table 7 Accumulation/uptake of total chromium by *Ceratophyllum demersum* (L.)

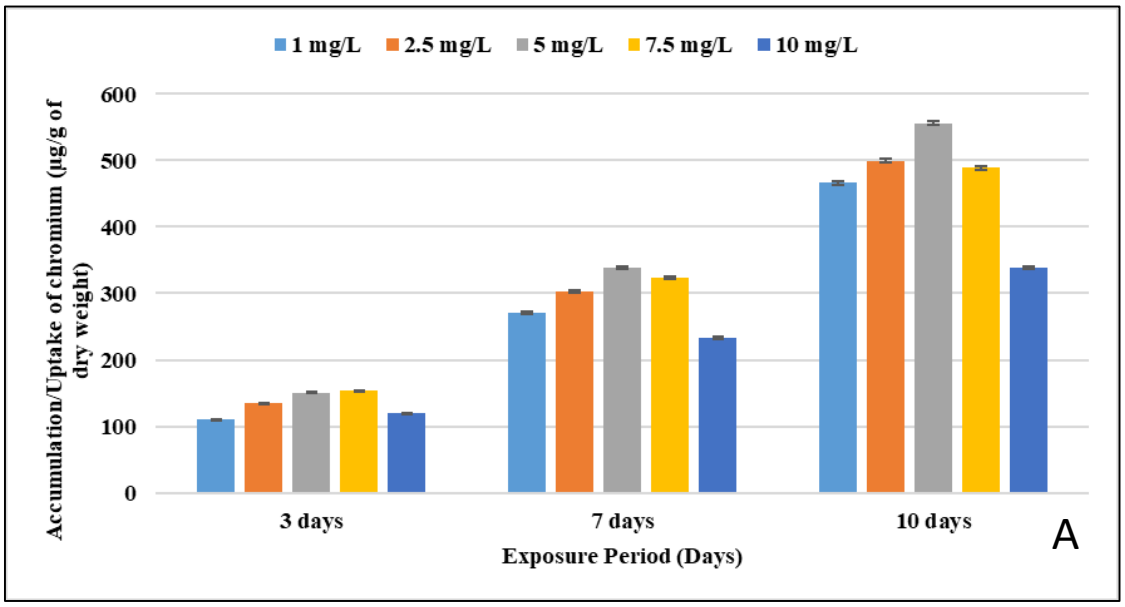
Initial Concentration (mg/L)	3 days (µg/g of dry weight)	7 days (µg/g of dry weight)	10 days (µg/g of dry weight)
0 (control)	-	-	-
1	110.23 ± 0.636	270.58 ± 1.562	466.05 ± 2.691
2.5	134.74 ± 0.778	302.55 ± 1.747	499.78 ± 2.885
5	150.63 ± 0.87	337.99 ± 1.951	556.11 ± 3.211
7.5	153.58 ± 0.887	323.8 ± 1.869	488.81 ± 2.822
10	120.15 ± 0.694	233.11 ± 1.346	338.56 ± 1.955
12.5	-	-	-
15	-	-	-
Control	-	-	-

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance.

Table 8 Accumulation/uptake of total chromium by *Eichhornia crassipes* (L.)

Initial Concentration (mg/L)	Total chromium in plant (µg/g of dry weight)			Shoot (µg/g of dry weight)			Root (µg/g of dry weight)		
	Day 10	Day 20	Day 30	Day 10	Day 20	Day 30	Day 10	Day 20	Day 30
0 (control)	-	-	-	-	-	-	-	-	-
1	410 ± 2.37	630 ± 3.64	910 ± 5.25	86 ± 0.5	145 ± 0.84	228 ± 1.31	324 ± 1.87	485 ± 2.8	773 ± 4.46
2.5	1460 ± 8.43	1950 ± 11.26	2280 ± 13.16	394 ± 2.28	546 ± 3.15	661 ± 3.82	1066 ± 6.15	1404 ± 8.11	1619 ± 9.35
5	3270 ± 18.88	4080 ± 23.56	4660 ± 26.9	1014 ± 5.85	1346 ± 7.77	1584 ± 9.15	2256 ± 13.03	2734 ± 15.78	3076 ± 17.76
7.5	5340 ± 30.83	6550 ± 37.82	6950 ± 40.13	1869 ± 10.79	2489 ± 14.37	2919 ± 16.85	3471 ± 20.04	4061 ± 23.45	4031 ± 23.27
10	8030 ± 46.36	8300 ± 47.92	8610 ± 49.71	2409 ± 13.91	2656 ± 15.33	2411 ± 13.92	5621 ± 32.45	5644 ± 32.59	6199 ± 35.79
12.5	7430 ± 42.9	7640 ± 44.11	7820 ± 45.15	2006 ± 11.58	1986 ± 11.47	1877 ± 10.84	5424 ± 31.31	5654 ± 32.64	5943 ± 34.31
15	4520 ± 26.1	4890 ± 28.23	5360 ± 30.95	1220 ± 7.04	1075 ± 6.21	964 ± 5.57	3300 ± 19.05	3815 ± 22.03	4396 ± 25.38

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance.



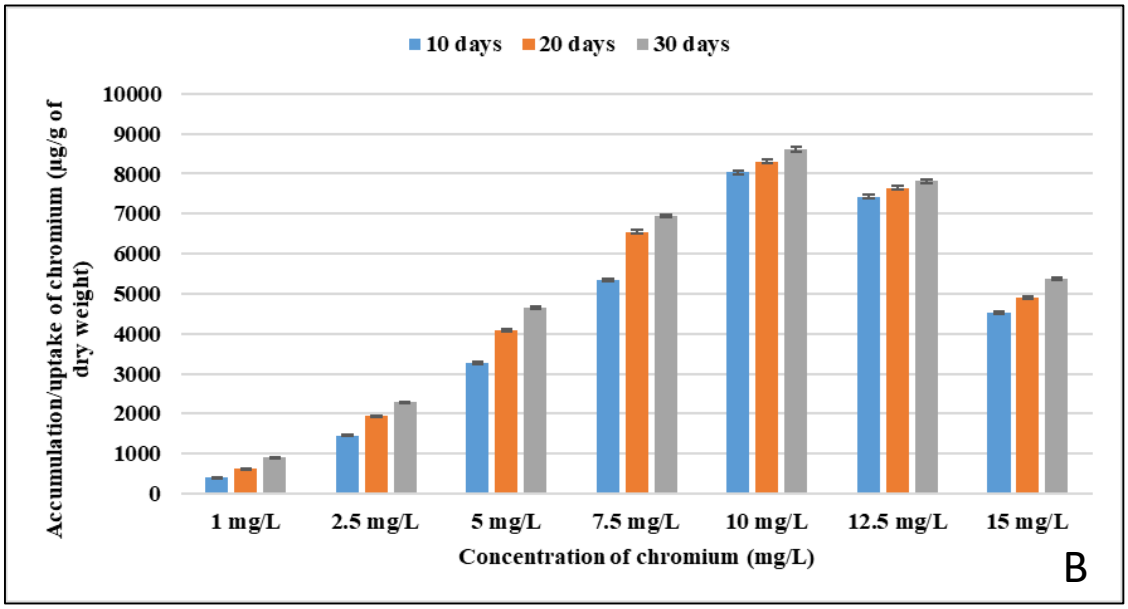


Figure 3. A and B are the accumulation/uptake of chromium in µg/g of dry weight of *Ceratophyllum demersum* (L.) and *Eichhornia crassipes* (L.), respectively.

Table 9 Bioconcentration factor (BCF) of *Ceratophyllum demersum* (L.)

Initial Concentration (mg/L)	3 days	7 days	10 days
1	110.23 ± 0.64	270.58 ± 1.56	466.05 ± 2.69
2.5	53.9 ± 0.31	121.02 ± 0.7	199.91 ± 1.15
5	30.13 ± 0.17	67.6 ± 0.39	111.22 ± 0.64
7.5	20.48 ± 0.12	43.17 ± 0.25	65.17 ± 0.38
10	12.02 ± 0.07	23.31 ± 0.13	33.86 ± 0.2
12.5	-	-	-
15	-	-	-

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance.

Table 10 Bioconcentration factor (BCF) of *Eichhornia crassipes* (L.)

Initial Concentration (mg/L)	Day 10	Day 20	Day 30
1	410 ± 2.37	630 ± 3.64[b]	910 ± 5.25[d]
2.5	584 ± 3.37[a]	780 ± 4.5	912 ± 5.27[d]
5	654 ± 3.78	816 ± 4.71[c]	932 ± 5.38[d]
7.5	712 ± 4.11	873 ± 5.04	927 ± 5.35[d]
10	803 ± 4.64	830 ± 4.79[c]	861 ± 4.97
12.5	594 ± 3.43[a]	611 ± 3.53[b]	626 ± 3.61
15	301 ± 1.74	326 ± 1.88	357 ± 2.06

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance. The values with common superscript are similar.

Table 11 Translocation Factor and percentage of *Eichhornia crassipes* (L.)

Initial Concentration (mg/L)	Translocation factor			Translocation %		
	Day 10	Day 20	Day 30	Day 10	Day 20	Day 30
1	3.8 ± 0.02	3.3 ± 0.02	3.4 ± 0.02	21	23	25
2.5	2.7 ± 0.02[a]	2.6 ± 0.01	2.4 ± 0.01	27	28	29
5	2.2 ± 0.01	2 ± 0.01	1.9 ± 0.01	31	33	34
7.5	1.9 ± 0.01	1.6 ± 0.01	1.4 ± 0.01	35	38	42
10	2.3 ± 0.01	2.1 ± 0.01	2.6 ± 0.01	30	32	28
12.5	2.7 ± 0.02[a]	2.8 ± 0.02	3.2 ± 0.02	27	26	24
15	3.7 ± 0.02	4.6 ± 0.03	5.7 ± 0.03	27.4	22	18

Any value followed by ± is the Standard Error of the mean. All the means were significantly different at $p<0.05$ level of significance. The values with common superscript are similar.

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