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The potential of *Zea mays*, *Commelina bengelensis*, *Helianthus annuus* and *Amaranthus hybridus* for phytoremediation of waste water

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ABSTRACT

Waste-water from domestic use and from industrial effluent burden the water systems with high levels of heavy metal hence there is need to remove these heavy metals so that the waste water can be recycled for use for household or irrigation. The present study has screened *Zea mays* (maize), *Commelina bengelensis* (wondering jew), *Helianthus annuus* (sunflower) and *Amaranthus hybridus* (amaranthus) for their ability to bioaccumulate Pb, Cu, Cd and Zn metals. The results obtained show that the *H. annuus* and *C. bengelensis* plant have promising potential for removal of Pb, Cu and Cd from wastewater though their ability to remove Zn from contaminated solutions is not much different from that of *Z. mays* and *A. hybridus.*

Keywords*:* AAS, lead, copper, zinc, cadmium.

O potencial de *Zea mays, Commelina bengelensis, Helianthus annuus e Amaranthus hybridus* para fitorremediação de águas residuárias

RESUMO

Nas águas residuárias de origem doméstica ou esgoto sanitário, níveis elevados de metais tóxicos poluem os sistemas hídricos e, por conseguinte, há necessidade de eliminar esses elementos para que as águas residuárias possam ser recicladas para uso doméstico ou irrigação. O presente estudo avaliou a capacidade das espécies *Zea mays* (milho), *Commelina bengelensis* (trapoeraba), *Helianthus annuus* (girassol) e *Amaranthus hybridus* (amaranto) para bioacumulação de Pb, Cu, Cd e Zn. Os resultados revelaram que o *H. annuus* e a *C. bengelensis* têm potencial para remoção do Pb, Cu e Cd de águas residuárias, entretanto, a capacidade delas para remoção de Zn não é muito diferente das espécies *Z. mays* e *A. hybridus.*

Palavras-chave: AAS, chumbo, cobre, zinco, cádmio.

1. INTRODUCTION

Heavy metals are major pollutants in marine, ground, industrial and even treated wastewater (Valdman et al., 2001). The heavy metals may come from natural sources, leached from rocks and soils according to their geochemical mobility or come from anthropogenic sources, as a result of human land occupation and industrial pollution (Espinoza-Quiñones et al., 2005).

Industrial waste constitutes the major source of various kinds of metal pollution in natural waters. The important toxic metals Cd, Zn, Ni and Pb find their way to the water bodies through waste waters Ajmal et al. (1998). Due to their non- biodegradability and persistence, heavy metals can accumulate in the environment such as in food chains and thus may pose a significant danger to human health (Bakkaloglu et al., 1998).

Rhizofil tration, the use of plants both terrestrial and aquatic to absorb, concentrate and precipitate contaminants from polluted aqueous sources with low contaminant concentration in their roots, can partially be used to treat industrial discharge. It can be used for Pb, Cd, Cu, Ni, Zn and Cr, which are primarily retained within roots (Chaudhry et al., 1998). For example plants like sunflower, Indian mustard, tobacco, rye, spinach and corn have been studied for their ability to remove Pb from effluent, with sunflower having the greatest ability (Ghosh and Singh, 2005). Indian mustard has proven to be effective in removing a wide concentration range of lead (4-500 mg L^{-1}) (Raskin and Ensley, 2000).

The technology has been tested in the field with uranium-contaminated water at concentrations of 21-874 µg L^{-1}; the treated uranium concentration reported by Dushenkov et al. (1995) was < 20 µg L^{-1} before discharge into the environment.

This plant-assisted bioremediation is most effective if groundwater is within 10 feet of the surface (Cunningham et al., 1997) and is applicable to sites with large volumes of groundwater with low levels of contamination that have to be cleaned to low (strict) standards (Salt et al., 1997).

In this study, the efficiency of *Helianthus annuus* (sunflower), *Commelina bengelensis* (wondering Jew), *Zea mays* (maize) and *Amaranthus hybridus* (amaranth) has been studied in the process of heavy metal removing from both single metal solutions and various mixtures. Metals of interest were Cd, Pb, Cu and Zn based on their industrial applications and potential pollution impact on the environment. Cd and Pb are cumulative poisons, highly toxic to humans, plant and animals (Low et al., 2000). Cu and Zn play major roles in modern industry and in the vicinity of extraction or processing plants, the emissions arising are certainly capable of causing an undesirable contamination of agricultural products and therefore recommended not to omit these metals from scrutiny.

2. MATERIALS AND METHODS

This study was conducted in a greenhouse as pot experiments on distilled water at Jomo Kenyatta University of Agriculture and Technology in Kenya. The experiment was carried out during 2008 – 2011 period. The experimental layout for single metal solutions comprised 8 treatments, a control with no metal added, and 7 treatments for which the dose of heavy metal was increasingly higher (Table 1). Heavy metals were added as salts of $Pb(NO_3)_2$, $Cu(NO_3)_2 5H_2O$, $Zn(NO_3)_2.7H_2O$ and $Cd(NO_3)_2.4H_2O$. The experiment was carried out in triplicate and stratified sampling was done to identify the pot but at each pot random sampling was employed in choosing the plant for analysis.

To compare the uptake of these metals from single solutions (uncombined state) and uptake from mixture solutions (combined state), the mixture solutions were prepared by dissolving the salts of the heavy metals in distilled water in order to achieve the same concentrations as those of single solutions as per Table 1.

Zea mays and *Helianthus annuus* were germinated on a tray in the green house for 14 days while *Amaranthus hybridus* seedlings and *Commelina bengelensis* cuttings were obtained from the university farm, transplanted on tray in the greenhouse for the same number of days. The plants were uprooted and three seedlings per pot were suspended in the contaminated solutions with the roots completely immersed. Every four days for twelve days, one plant was removed from each pot, put in polyethylene bag immediately sealed and transported to the laboratory for analysis.

Table 1. Dose of heavy metals (mg L^{-1}) added to distilled water for treatments 0 – VII.

Treatment	Cd	Cu	Zn	Pb
Control	0	0	0	0
I	10	20	50	30
II	20	40	100	60
III	40	80	200	120
IV	80	160	400	240
V	160	320	800	480
VI	320	640	1600	960
VII	640	1280	3200	1920

In the laboratory, samples were washed with distilled water, bench dried for 5 days then oven dried at 105^{o} C for 12 hours and each separately ground to a powder in a porcelain mortar. The powder was then stored in plastic bottles ready for analysis.

The digestion of samples was carried out as follows: 0.1g of the oven-dried powder was put in a 100 mL conical flask and 5 mL of the tri-acid mixture (nitric, perchloric and sulfuric) in the ratio 3:1:1 was added and let to digest on a hot plate until brown fumes disappeared and white fumes observed. The samples were then cooled, diluted with a 4% nitric acid and filtered into 100 mL volumetric flasks. These were then made up to the mark with distilled water and analyzed using Atomic Absorption Spectrophotometer (AAS).

3. RESULTS AND DISCUSSION

Table 2 presents the Pb concentrations in the A. *hybridus*, *Z. mays*, *C. bengelensis* and *H. annuus* were in the range of (0.061-1.211), (0.046-3.921), (1.354-7.632) and (1.168-8.558) g kg^{-1}, respectively.

These different values show that the uptake of Pb is plant dependent and also depends on the concentration of Pb in solution. The Pb concentration in *C. bengelensis* and *H. annuus* were above the value used to define hyper accumulation (1.0 g kg^{-1}), hence these plants in solutions can be referred to as hyperaccumulators of Pb. These values are comparable to values of 0.009-4.561 g kg^{-1}obtained by Lombi et al. (2001) in roots of *Z. mays* grown in soils with EDTA. In another research by Podar et al. (2004), the concentration of Pb ranged from 0.001-0.030 g kg^{-1} in *H. annuus* and 0.000-0.018 g kg^{-1} in Z. mays grown in soil contaminated with mine spoils. These values are lower than those obtained in this study. The results obtained in the current study are higher than those of Carlson et al. (1975), who found that the amount of Pb in leaves of *H. annuus* and *Z. mays* treated with up to 500 mg/l of Pb, as $PbCl_2$, averaged 0.004 g kg^{-1} Pb and was not statistically different from the Pb concentration in the control (untreated) plants.

No toxicity was observed for the four plants for all the treatments under investigation. This observation is in agreement with findings of Vyslouzilova et al. (2003) who found out that willow plants grew without any physiological symptoms of phytotoxicity in soil supplied with 2.000 g kg^{-1}. The lack of Pb toxicity is probably due to its immobilization in roots as reported by Vyslouzivola et al. (2003) and Stoltz and Greger (2002).

Table 2. Concentration of lead (g kg^{-1}) in *Z. mays*, *C. bengelensis* and *A. hybridus* grown in contaminated soil for the first, second and third harvests over three months period.

Metal Pb	**1st (Month)**				**2nd (Month)**				**3rd (Month)**			
Treat.	***A. hybridus***	***Z. mays***	***C. bengelensis***	***H. annuus***	***A. hybridus***	***Z. mays***	***C. bengelensis***	***H. annuus***	***A. hybridus***	***Z. mays***	***C. bengelensis***	***H. annuus***
0	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
30	0.272 ± 0.039	0.046 ± 0.016	1.535 ± 0.030	1.702 ± 0.014	0.167 ± 0.040	0.061 ± 0.015	1.607 ± 0.037	4.250 ± 0.053	0.061 ± 0.0305	0.101 ± 0.023	1.354 ± 0.066	4.773 ± 0.045
60	0.231 ± 0.046	0.096 ± 0.049	1.842 ± 0.051	2.767 ± 0.173	0.070 ± 0.048	0.151 ± 0.027	3.293 ± 0.067	4.038 ± 0.045	0.117 ± 0.018	0.222 ± 0.077	1.851 ± 0.054	5.634 ± 0.046
120	0.222 ± 0.053	0.237 ± 0.026	2.067 ± 0.018	2.067 ± 0.020	0.206 ± 0.038	0.174 ± 0.050	3.456 ± 0.067	5.614 ± 0.074	0.1917 ± 0.035	0.202 ± 0.038	2.712 ± 0.093	4.865 ± 0.028
240	0.634 ± 0.097	0.671 ± 0.046	4.321 ± 0.029	1.168 ± 0.046	0.530 ± 0.046	0.771 ± 0.026	3.932 ± 0.098	4.815 ± 0.010	0.827 ± 0.114	0.630 ± 0.109	3.867 ± 0.022	5.084 ± 0.028
480	0.817 ± 0.066	0.671 ± 0.023	7.236 ± 0.037	1.461 ± 0.019	0.530 ± 0.031	1.295 ± 0.023	7.632 ± 0.048	4.460 ± 0.038	0.832 ± 0.085	0.913 ± 0.068	5.029 ± 0.148	5.360 ± 0.016
960	0.883 ± 0.023	3.921 ± 0.070	2.043 ± 0.025	1.715 ± 0.017	0.923 ± 0.015	1.789 ± 0.023	4.090 ± 0.032	4.967 ± 0.054	1.211 ± 0.001	0.857 ± 0.032	6.177 ± 0.070	8.558 ± 0.010
1920	0.615 ± 0.057	0.217 ± 0.083	6.002 ± 0.020	3.567 ± 0.045	1.064 ± 0.044	2.077 ± 0.031	3.290 ± 0.017	3.881 ± 0.049	0.358 ± 0.038	1.215 ± 0.061	7.187 ± 0.062	PD

Note: PD-Plant died.

From Table 2, it can be seen that *H. annuus*, was the highest accumulator of lead in solutions, followed by *C. bengelensis*, *Z. mays* and finally *A. hybridus*. The accumulation of Pb in *H. annuus* was not statistically different from that of *C. bengelensis* for all the three harvests (P= 0.5) even though Pb concentration in these plants was statistically different from that of *Z. mays and A. hybridus*. In our study, *H. Annuus* and *C. bengelensis* have shown a high ability to remove Pb from waste water effluent but the ability of *Z. Mays* and *A. Hybridus* is low. These results are in agreement with findings recorded by Ghosh and Singh (2005), where several plants were investigated for their bioaccumulation of Pb from waste water; *H. annuus* was found to have the greatest ability.

3.1.Cadmium

Table 3 presents the range of Cd concentrations as (0.138-19.690), (0.082-22.367), (2.482-9.146) and (0.201-9.972) g kg^{-1} for *Z. mays, A. hybridus, H. annuus* and *C. bengelensis* respectively. The concentration of Cd obtained for these treatments were greater than the value used to define Cd hyperaccumulation (0.1 gkg^{-1}).

Table 3. Concentration of cadmium (gkg^{-1}) in *Z. mays*, *C. bengelensis* and *A. hybridus* grown in contaminated soil for the first, second and third harvests over three months period.

Metal Cd	1st (Month)				2nd (Month)				3rd (Month)			
Treat.	***A.* *hybridus***	***Z.* *mays***	***C.* *bengelensi***	***H.* *annuus***	***A.* *hybridus***	***Z.* *mays***	***C.* *bengelensis***	***H.* *annuus***	***A.* *hybridus***	***Z.*** mays	***C.* *bengelensi***	***H.* *annuus***
0	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
10	0.163 ± 0.013	0.273 ± 0.052	0.474 ± 0.008	2.555 ± 0.013	0.082 ± 0.002	0.138 ± 0.010	0.201 ± 0.007	2.626 ± 0.001	0.206 ± 0.010	0.326 ± 0 017	0.289 ± 0.006	2.482 ± 0 .005
20	0.455 ± 0.013	0.450 ± 0.007	0.796 ± 0.009	3.266 ± 0.011	0.439 ± 0.008	0.774 ± 0.007	1.365 ± 0.008	5.701 ± 0.030	0.636 ± 0.011	0.751 ± 0 021	1.287 ± 0.009	3.159 ± 0.020
40	0.683 ± 0.012	0.602 ± 0.025	2.129 ± 0.010	5.321 ± 0.014	0.435 ± 0.012	1.005 ± 0.010	2.121 ± 0.011	6.414 ± 0 .007	0.395 ± 0.018	PD	1.632 ± 0.010	5.669 ± 0 .006
80	2.576 ± 0.093	2.734 ± 0.100	2.964 ± 0.023	6.402 ± .066	1.538 ± 0.003	2.632 ± 0 .100	5.912 ± 0.016	6.965 ± 0.018	1.369 ± 0.003	PD	3.950 ± 0.004	7.046 ± 0.018
160	4.419 ± 0.014	6.001 ± 0.015	3.668 ± 0.016	7.513 ± 0.023	5.246 ± 0.084	7.754 ± 0.063	7.337 ± 0.054	8.887 ± 0.001	6.560 ± 0.056	PD	6.811 ± 0.009	PD
320	10.200 ± 0.070	10.677 ± 0.035	5.706 ± 0.048	8.966 ± 0.010	16.567 ± 0.049	PD	8.874 ± 0.064	9.052 ± 0.006	15.807 ± 0.119	PD	7.035 ± 0.005	PD
640	19.233 ± 0.179	19.690 ± 0.208	5.901 ± 0.019	9.132 ± 0.004	22.367 ± 0.248	PD	9.972 ± 0.020	9.146 ± 0.004	PD	PD	8.729 ± 0.007	PD

Note: PD-Plant died.

In a research done by Antonkiewicz and Jasiewicz (2002) in contaminated soils, the Cd content in *Z. mays* and *A. hybridus* was 0.000-0.070 g kg^{-1} and 0.001-0.060 g kg^{-1} respectively while in another study by Lombi et al. (2001), a range of 0.60-0.576 g kg^{-1} was obtained for *T. caerulescens*. The highest value of Cd concentration of 1.800 g kg^{-1} was recorded in leaves of *T. caerulescens* in a research carried out by Baker and Walker (1990). The values obtained in the current study are higher than those recorded in these studies. Cd concentrations above 20 mg/l, 80 mg/l and 320 mg/l were found to be toxic for the growth of *Z. mays*, *H. annuus* and *A. hybridus* respectively. *C. bengelensis* did not show any toxicity signs to Cd which gives the plant an added advantage over the other plants in phytoremediation of wastewater containing higher concentrations of Cd.

From table 3, the high uptake of Cd by *H. annuus* is comparable to that of *C. bengelensis* while the uptake of Cd by *Z. mays* is lower than that of *A. hybridus*. Similar trend was observed by Antonkiewicz and Jasiewicz (2002), where the Cd content in the top parts of *A. hybridus* was found to be higher than that of *Z. mays*.

H. annuus has the highest removal of Cd from solutions, followed by *C. bengelensis,* then *A. hybridus* and finally *Z. mays.*

3.2. Copper

Table 4 presents the range of copper concentration (0.213-35.770) g kg^{-1} for *Z. mays*, (0.230-43.273) g kg^{-1} for *A. hybridus*, (1.786-15.995) g kg^{-1} for *H. annuus* and (0.514-

20.807) g kg^{-1} for *C. bengelensis*. These values are higher than those obtained in earlier studies where the range of Cu values indicated as 0.001-0.0075 g kg^{-1} in aquatic macrophytes (Espinoza-Quiñones et al., 2005), 0.0015-0.0189 g kg^{-1} in *Z. mays* and 0.085-0.0327 g kg^{-1} in *H. annuus* (Podar et al., 2004) and 0.0413- 0.806 g kg^{-1} in *Z. mays* roots with EDTA (Lombi et al., 2001). The values obtained for all the four plants at treatments of 640 and 1280 ppm are above the value of a Cu hyperacumulator, *Ipomea alpina* of 12.300 g kg^{-1} (Baker and Walker, 1990). However the plants were found to suffer from Cu phytotoxicity at Cu concentrations higher than 80 ppm. This implies that although the plants can be used for phytoremediation of wastewater contaminated with Cu, their remediation potential would be limited by phytotoxicity of Cu. It was also noted that in the uptake of Cu by *C. bengelensis*, the initial (1^{st} harvest), was not as high as in the other plants and this is probably why it was possible to obtain the 2^{nd} harvest for all treatments.

Table 4: Concentration of copper (gkg^{-1}) in *Z. mays*, *C. bengelensis* and *A. hybridus* grown in contaminated soil for the first, second and third harvests over three months period.

Metal Cu	**1^{st} (Month)**				**2^{nd} (Month)**				**3^{rd} (Month)**			
Treat.	***A. hybridus***	***Z. mays***	***C. bengelensis***	***H. annuus***	***A. hybridus***	***Z. mays***	***C. bengelensis***	***H. annuus***	***A. hybridus***	***Z. mays***	***C. bengelensis***	***H. annuus***
0	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
20	0.230 ± 0.016	0.493 ± 0.026	0.514 ± 0.009	1.786 ± 0.018	0.257 ± 0.043	0.213 ± 0.047	0.699 ± 0.023	2.099 ± 0.013	0.319 ± 0.009	0.371 ± 0.019	0.839 ± 0.013	2.987 ± 0.020
40	0.596 ± 0.017	1.389 ± 0.024	1.548 ± 0.009	2.664 ± 0.016	0.333 ± 0.014	1.943 ± 0.119	3.425 ± 0.024	4.278 ± 0.026	0.697 ± 0.020	0.866 ± 0.024	1.115 ± 0.020	3.476 ± 0.022
80	1.900 ± 0.022	2.384 ± 0.265	2.150 ± 0.023	4.502 ± 0.053	3.019 ± 0.0136	3.504 ± 0.042	5.553 ± 0.012	6.647 ± 0.007	0.958 ± 0.016	3.087 ± 0.049	6.675 ± 0.013	PD
160	1.918 ± 0.069	3.325 ± 0.060	2.958 ± 0.027	5.851 ± 0.018	5.486 ± 0.099	4.347 ± 0.346	5.876 ± 0.038	8.308 ± 0.047	1.858 ± 0.028	PD	PD	PD
320	6.072 ± 0.023	8.080 ± 0.147	5.122 ± 0.126	7.025 ± 0.028	9.966 ± 0.166	PD	12.115 ± 0.074	10.782 ± 0.068	PD	PD	PD	PD
640	26.753 ± 0.121	24.013 ± 0.085	6.581 ± 0.016	12.875 ± 0.006	PD	PD	11.697 ± 0.049	PD	PD	PD	PD	PD
1280	43.273 ± 0.145	35.770 ± 0.185	7.960 ± 0.052	15.995 ± 0.031	PD	PD	20.807 ± 0.147	PD	PD	PD	PD	PD

From Table 4, the Cu concentration in *H. annuus*, *C. bengelensis*, *Z. mays* and *A. hybridus* was found to increase as the concentration in the solution increased. The first and second harvests did not show much difference in their accumulation for the four plants and by third harvest, most of the plants had died in solutions containing high levels of Cu contamination. In phytoremediation, due to Cu phytotoxicity at high concentrations, the plants should be removed from the contaminated aqueous solutions on the 4^{th} day.

Comparison of the uptake of Cu by the four plants at the end of the first four days reveals that at Cu concentrations below 640 mg L^{-1}, *H. annuus* has the highest uptake of Cu, while at concentrations of 640 and 1280 mg L^{-1}, *Z. mays* and *A. hybridus* have the highest uptake.

3.3. Zinc

Table 5 presents the Zn concentration in *Z. mays*, A. *hybridus*, *H. annuus* and *C. bengelensis* were found to be in the range (2.282-8.307), (1.141-7.593), (2.674-6.992) and (1.876-7.770) g kg^{-1}, respectively. These values are lower than the value used to define a Zn hyper accumulator (10.0 g kg^{-1}), (Lasat, 2000), and much lower than a value of 38.055 g kg^{-1} obtained by Hinchman et al. (1996) in the roots of hybrid poplar. The values are comparable to those obtained by Lombi et al. (2001) and Gremion et al. (2004) that is 1.868-9.187 g kg^{-1} and 1.600-10.000 g kg^{-1} respectively for *T. caerulescens* which is a documented Zn hyperaccumulator. However, the values are lower than the greatest Zn uptake of 39.600 g kg^{-1} in *T. caerulescens* leaves. This means that the Zn uptake by these plants is quite significant though they cannot be said to be hyperaccumulative in solutions.

Table 5: Concentration of zinc (g kg^{-1}) in *Z. mays*, *C. bengelensis* and *A. hybridus* grown in contaminated soil for the first, second and third harvests over three months period.

Metal Zn	**1st (Month)**				**2nd (Month)**				**3rd (Month)**			
Treat.	***A.*** *hybridus*	***Z.*** *mays*	***C.*** *bengelensis*	***H.*** *annuus*	***A.*** *hybridus*	***Z.*** *mays*	***C.*** *bengelensis*	***H.*** *annuus*	***A.*** *hybridus*	***Z.*** *mays*	***C.*** *bengelensis*	***H.*** *annuus*
0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.000 ± 0.000	0.00 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
50	1.141 ± 0.006	2.417 ± 0.007	2.303 ± 0.007	2.674 ± 0.020	1.327 ± 0.007	2.282 ± 0.007	1.876 ± 0.005	4.456 ± 0.007	1.743 ± 0.021	3.084 ± 0.016	2.014 ± 0.006	4.301 ± 0.024
100	1.398 ± 0.002	4.246 ± 0.007	3.134 ± 0.011	4.520 ± 0.012	5.293 ± 0.002	4.679 ± 0.013	4.390 ± 0.051	5.552 ± 0.003	4.455 ± 0.011	4.912 ± 0.013	3.056 ± 0.008	5.251 ± 0.004
200	3.943 ± 0.006	5.967 ± 0.004	3.491 ± 0.009	5.921 ± 0.027	6.181 ± 0.012	6.456 ± 0.006	5.306 ± 0.024	6.141 ± 0.005	6.662 ± 0.006	6.447 ± 0.014	3.22 1± 0.009	5.704 ± 0.006
400	5.734 ± 0.009	6.572 ± 0.007	5.170 ± 0.029	5.740 ± 0.028	6.087 ± 0.007	6.813 ± 0.014	6.367 ± 0.012	6.353 ± 0.075	6.509 ± 0.007	7.981 ± 0.012	7.148 ± 0.004	PD
800	7.114 ± 0.003	7.263 ± 0.003	5.469 ± 0.027	6.137 ± 0.009	7.188 ± 0.013	PD	7.272 ± 0.012	5.986 ± 0.001	PD	PD	7.489 ± 0.014	PD
1600	7.730 ± 0.009	7.813 ± 0.006	6.496 ± 0.021	6.559 ± 0.117	PD	PD	7.410 ± 0.014	6.602 ± 0.011	PD	PD	PD	PD
3200	7.593 ± 0.010	8.307 ± 0.010	7.121 ± 0.049	6.861 ± 0.014	PD	PD	7.770 ± 0.003	6.992 ± 0.015	PD	PD	PD	PD

Table 5 presents the Zn concentration in *Z. mays*, A. *hybridus*, *H. annuus* and *C. bengelensis* with increase in the metal concentration in solution. The uptake of Zn by the four plants for the 1st harvest (first 4 days) did not show much difference in concentration.

H. annuus and *C. bengelensis* were found to be more tolerant to high Zn concentration since it was possible to obtain data for all the 8 treatments up to the second harvest (8th day) while at high concentration *Z. mays* and *A. hybridus* died off by first harvest (4th day). Due to their tolerance of high levels of Zn and high uptake, *C. bengelensis* and *H. annuus* would be the best out of the four plants to be used to remove zinc from solutions contaminated with zinc.

4. CONCLUSIONS

In this study it was found out that the heavy metal uptake by the four plants analyzed was different regarding the metal contamination. In solutions, the uptake of metals by plants may be ranked from the highest to the lowest in the following order:

Lead:	*Helianthus, Commelina, Zea mays, Amaranthus;*
Cadmium:	*Helianthus, Commelina, Amaranthus, Zea mays;*
Copper:	*Helianthus, Commelina, Zea mays, Amaranthus;*
Zinc:	*Helianthus, Zea mays, Amaranthus, Commelina;*

Helianthus, Commelina and *Zea mays* have shown a high ability to remove Pb from waste water.

The comparison of individual elements indicates much higher accumulation of Cd, Cu, and Zn in the plants than that of Pb.

Helianthus, Commelina, Zea mays and *Amaranthus* have been found to take up a lot of these heavy metals especially Zn, Cd and Cu as compared to Pb, hence these plants can be used for phytoremediation of these heavy metals at moderate concentration. These can be effectively done if the levels of concentration are below 960, 800, 40 and 20 mg L^{-1} of solution of Pb, Zn, Cu and Cd, respectively. From the current study it was noted that the period of planting does not really matter since the concentrations of the heavy metals after 4, 8 and 12 days were not significantly different.

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