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Mitigation of Arsenic by Water Hyacinths (*Eichhornia crassipes*) Plant

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Abstract: Water hyacinth (*Eichhornia crassipes*) plant removes arsenic remarkably both from artificial arsenic solution and naturally arsenic contaminated ground water. Two clay containers (locally known as “Chari”), one with water hyacinth plant in distilled water as a control and another with water hyacinth plant in artificial arsenic solution (0.3 mg/l) was used to set up the experiment. The arsenic concentration of the water was tested over multiple trails using a Hach colorimetric test kit. It was observed that water hyacinth reduced arsenic level from 0.3 mg/l to 0.01 mg/l for one trail, 0.05 mg/l for two trails and lost all ability to remove arsenic after five trails. Again, water hyacinth plant was placed in a clay container in which naturally arsenic contaminated (0.8 mg/l) ground water was used for a period of one month. Sampling was conducted in every two successive days. Rate of arsenic extraction through water hyacinth plant was higher in first two weeks and after that it seems to be constant. All laboratory tests were performed by SDDC method to determine arsenic content in root, bladder and leaves of hyacinth plant. About 40-50% arsenic was removed through water hyacinth from arsenic contaminated ground water. Roots, bladders and leaves of hyacinth plant absorbed most of the removed arsenic.

Key words: Groundwater, WHO guideline, clay container, calorimetric test.

Introduction

Research has demonstrated that plants are effective in extracting arsenic from soil and water (Wenzel et al., 1999). Phytoremediation is a general term for using plants to remove pollutants such as arsenic from water (Brady and Weil, 1999). Plants used to phytoremediate metals, like arsenic, are called hyperaccumulators. Hyperaccumulators are plants that accumulate metals within their biomass in higher concentrations than the concentrations in their resident soil (Sengupta, 1997). Phytoremediation by water hyacinth (*Eichhornia crassipes*) represents a potential solution to the arsenic problem. In particular, water hyacinths (*Eichhornia crassipes*) have been found to be accumulators of chromium and copper and hyperaccumulators of cadmium, mercury, lead and arsenic (McCutcheon, 2003). Water hyacinths are free-floating aqueous weeds that multiply very quickly (Ingole and Bhole, 2003). They have very fibrous roots and get all of their nutrients from the water. They have pinkish purple flowers and grow in dense mats in tropical and subtropical freshwater rivers, lakes, and reservoirs. They can tolerate extreme temperatures, pH and nutrient levels. They have been found to grow well in nutrient-rich waters (Batcher, 2004). Several studies suggest that it may be possible to use water hyacinth effectively to remove the arsenic from the ground water that is poisoning the people of Bangladesh. Thus, water hyacinths may be a practical solution to the arsenic problem in Bangladesh because using them as a treatment method has a very little cost. Water hyacinths grow naturally in ponds, lakes and rivers in Bangladesh. The farmers of Bangladesh have clay containers, locally known as Chari, that they use for animal feed. These containers could be used to hold water hyacinth and arsenic contaminated water for treatment. The aim of this study were to determine for how long the same water hyacinths plant can be used effectively to reduce arsenic concentrations and to determine where in the plant structure the arsenic is stored.

Materials and Methods

Mitigation of Arsenic from Artificial Arsenic Solution Water through Water Hyacinths

Experimental Design

One purpose of this study was to determine how much arsine water hyacinths can phytoaccumulate before losing their ability to phytoaccumulate arsenic efficiency. Definition of effective phytoaccumulation is the ability of the plant to reduce arsenic levels from 0.3 mg/l, a typical concentration in Bangladeshi well water to 0.01 mg/l, as recommended by WHO standards, in an approximately twentyfour-hour period (Chowdhury, 2004). The control was water hyacinths living in the same conditions as the arsenic plants, but without the arsenic in their water.

Safety when Working with Arsenic

While working with arsenic, safety was very important. Protective gloves were worn always when necessary during experiment. Any waste solutions as well as anything that came into contact with an arsenic solution above WHO drinking water standard were put in hazardous waste disposal. The arsenic solutions were kept in the locked chemical storeroom. Finally, to protect other students and animals, a placard was placed adjacent to clay pot containing the arsenic solution (Figure 1).

Figure 1: Experimental set up for artificial arsenic solution by water hyacinths.

Creating Initial Arsenic Solution and Control

The experimental system was set up to mimic the treatment system a Bangladeshi family might use. Clay container filled with arsenic solution and water hyacinth plants were put therein. Water level was always maintained 2.54 cm below the top of the clay container. For the control, the second clay container was filled with distilled water (Figure 1) up to same level. Sodium arsenate ($Na_2HAsO_4.7H_2O$) and sodium arsenite ($NaAsO_2$) powder (Anstiss et al., 2001) created a 0.3 mg/l (as arsenic) arsenite solution and a 0.3 mg/l (as arsenic) arsenate solution using distilled water. Also, sodium hydroxide was added to make the arsenic powder dissolve and neutralized the solution with acetic acid. For control, a solution containing the same amounts of sodium hydroxide and acetic acid was created and added to the arsenic solution. Ten ml each of the arsenite solution and the arsenate solution was added to the arsenic clay container to create 0.15 mg/l arsenite (as arsenic) and 0.15 mg/l of arsenate (as arsenic) for a total of 0.3 mg/l (as arsenic) arsenic level. Then the water was stirred well. Ten ml of the sodium hydroxide-acetic acid mixture was added to the control clay container to match the sodium acetate concentration in the arsenic clay container and stirred well.

Testing Arsenic Levels in Water

The sampling processes were carried on Tuesdays through Fridays by stirring the arsenic from the clay container. Fifty ml sample from the clay container was taken and tested for the arsenic level using Hach colorimetric test kit, following all of the instructions. In the Hach procedure the inorganic arsenic gets converted to arsine gas by sulfamic acid and zinc and the arsine gas reacts with the mercuric bromide coating on the test strips to cause discolouration which is compared to the colours and levels shown on the test kit bottle. Importantly, because this was a field test kit, it only indicated levels of 0, 0.01, 0.03, 0.05, 0.07, 0.3 and 0.5 mg/l (Hach. Arsenic Test Strip, 100 Tests. Arsenic concentration was determined from clay container through this test. The arsenic concentration of the clay container was recorded and then the amount of arsenite and arsenate solution needed to raise the arsenic level back up to 0.30 mg/l added, always using equal amounts of arsenite and arsenate solution. After adding the arsenic solutions, the same amount of sodium hydroxide-acetic acid solution to the control clay container was measured as the amount of arsenite solution added to the clay container. The solutions to the clay container were added and stirred well. These measurements and addition of more arsenic were repeated until the arsenic level was no longer reduced below 0.3 mg/l after at least twenty-four hours. As needed, re-fill the clay container with distilled water upto 2.54 cm below top of the clay container. Once during the experiment, the arsenic level of the control clay container was tested to make sure that the solution and calculations were correct for restoring the arsenic level to 0.3 mg/l. They were both at the corrected level.

Data Analysis

To validate the primary question about phyto-accumulation of arsenic by plants, the arsenic levels were reduced from 0.30 mg/l to 0.10 mg/l. Also the removal of arsenic in subsequent trails was recorded, even though the arsenic levels were not reduced to 0.10 mg/l. To estimate the arsenic concentration in the roots, firstly the total mass of arsenic extracted by multiplying the arsenic concentration was measured in the water extract (in mg/l) by 0.1 litre (because of the dilution of extract with 100 ml water). Next the arsenic mass was divided by the mass of the plant sample from which it had been extracted and converted the result to milligram arsenic per litres of plant. Same procedure was done for the stems/leaves/bladders. This calculation assumes 100 percent extraction into the water and negligible water loss in the extraction processes although this is not likely because the plant tissues strongly binds the arsenic, a known property of metal accumulators.

Mitigation of Arsenic from Arsenic Contaminated Groundwater through Water Hyacinths

Experimental Procedure

Initially high arsenic contaminated tube wells were selected through MERCK test kit in which arsenic concentration was more than 0.5 mg/l. After that, water samples were sent to arsenic testing laboratory to know the exact value of arsenic concentration. Before placement of water hyacinths into clay container, all hyacinth plants were stored two weeks in a bucket filled with distilled water. Stored hyacinth plants were washed by distilled water and all spoiled root, stem and leaves were separated just before placement of clay container that was filled with naturally arsenic contaminated ground water. Water hyacinth plants were taken out from clay container after four weeks of placement.

Water that was extracted by hyacinth plants was analyzed in laboratory immediately after collection. After analyses, it was observed that about fifty percent arsenic was removed by hyacinth plants. Then, steps were taken for analysis of selected parts of the water hyacinth plants to observe which part of water hyacinth plant extract arsenic from arsenic contaminated water. To create the extract, three water hyacinth plants have been taken from the clay container and washed off well, first with tap water and then with distilled water. These plants were dried very well and the roots separated from the stems and leaves. After that weighed root sample were cut into small pieces. The root sections were put with 100 ml distilled water into a blender. Chopped mixture was liquefied for about seven minutes, stopping occasionally to scrape down the side of the container, until it was all pureed. A funnel over the mouth of a beaker was put and was lined with a piece of filter paper. The puree was poured into the funnel and all of the water was allowed to drip through over-night. After about 24 hours, sample of the extract was taken and sent for laboratory analysis. The same procedure was repeated for the stems and leaves for the same plant. All samples were acidified before laboratory analysis and five numbers of sampling were conducted during experiment. The Silver Diethyldithiocarbamate (SDDC) method was applied for determining exact arsenic concentration in water sample before and after extraction of water hyacinth plants in water sample and roots, stem and leaf of hyacinth plants.

Results and Discussion

Mitigation of Arsenic from Artificial Arsenic Solution through Water Hyacinths

The water hyacinths reduced the arsenic level from 0.3 mg/l to below 0.045 mg/l for one trial. They continued to remove arsenic in the next four trials, but only down to 0.07 mg/l (second trial) and 0.07 mg/l (third through fifth trial), before ceasing to be effective at the removal of arsenic. This indicates that water hyacinths might have been able to reduce the levels of arsenic in the water from 0.3 mg/l (the arsenic concentration of water in typical wells in Bangladesh) to 0.01 mg/l or less (US EPA's drinking water standard, effective 2006) for many trials, but they did this for only one trial. In the first twenty-four hours, trial one, water hyacinths reduced the arsenic level from 0.3 mg/l to 0.1 mg/l. In the second 24-hour period, the water hyacinths reduced the arsenic level from 0.3 mg/l to 0.05 mg/l, which meets the Government of Bangladesh's drinking water standard, but not the US EPA's standard. During the third 24-hour period, the water hyacinths only reduced the arsenic level from 0.3 mg/l to 0.07 mg/l. During trial four, the plants again reduced the arsenic level from 0.3 mg/l to 0.07 mg/l. Any more arsenic was not added, thinking that the water hyacinths might be able to remove the rest of the arsenic if they had more time. However, 48 hours later the arsenic level was still 0.07 mg/l; the water hyacinths had not removed any more arsenic. To start trial five, again arsenic concentration was increased up to 0.3 mg/l. In the next 24-hour period, the water hyacinths reduced the arsenic level from 0.3 mg/l to 0.07 mg/l. During the final trial, the water hyacinths did not reduce the arsenic level from 0.3 mg/l at all. Three weeks later, when the arsenic level of the water was tested again, the arsenic level was still at 0.3 mg/l (Figure 2).

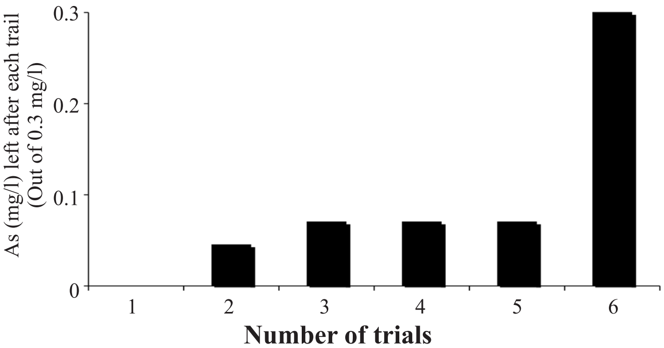

Figure 2: Arsenic (mg/l) left in each trial, starting with 0.3 mg/l in each trial.

Under the experimental condition, the water hyacinths reduced the arsenic level from a typical Bangladeshi well water concentration (0.3 mg/l) to EPA's proposed drinking water standard (0.01 mg/l) for one trial, to the Bangladeshi drinking water standard (0.05 mg/l) for two trials and lost all ability to remove arsenic after five trials. This means the arsenic is tightly bound at a molecular level so that, even when finely chopped, the arsenic did not leach out of the plants. Because of this, when the plants are removed from treatment, they would not leach large amounts of arsenic into the environment and could be stored safely for disposal in an area away from drinking water, at least until they started to decompose. There are important questions regarding the use of water hyacinths to remove arsenic from the artificial arsenic solution as because, at some point, the water hyacinths will no longer reduce arsenic levels effectively. The people will need to remove the plants from the water before they lose their ability to remove arsenic effectively and replace them with fresh plants. At that point, if all of the arsenic is stored in the roots, then the stems and leaves could be used as animal feed.

Mitigation of Arsenic from Natural Arsenic Contaminated Water by Water Hyacinth Plants

Figure 3 unfolds the extraction pattern of arsenic removed by water hyacinth plants. From this figure, it can be clearly observed that arsenic can be removed 50% to 60% by water hyacinth plants from arsenic contaminated groundwater. It can be clearly said that more arsenic is being stored in the roots than in the stems and leaves of water hyacinth plants. These are important questions to be resolved if this system is to be used in Bangladesh because, at some point, the water hyacinths are available everywhere in Bangladesh. Numerous studies have investigated the possibility of using a variety of plant types to remove arsenic and other metals from water with different results. Ahsan (2002) found that most aquatic plants could have an arsenic level up to 3,000 mg/l even though the water they are in has an arsenic level of less

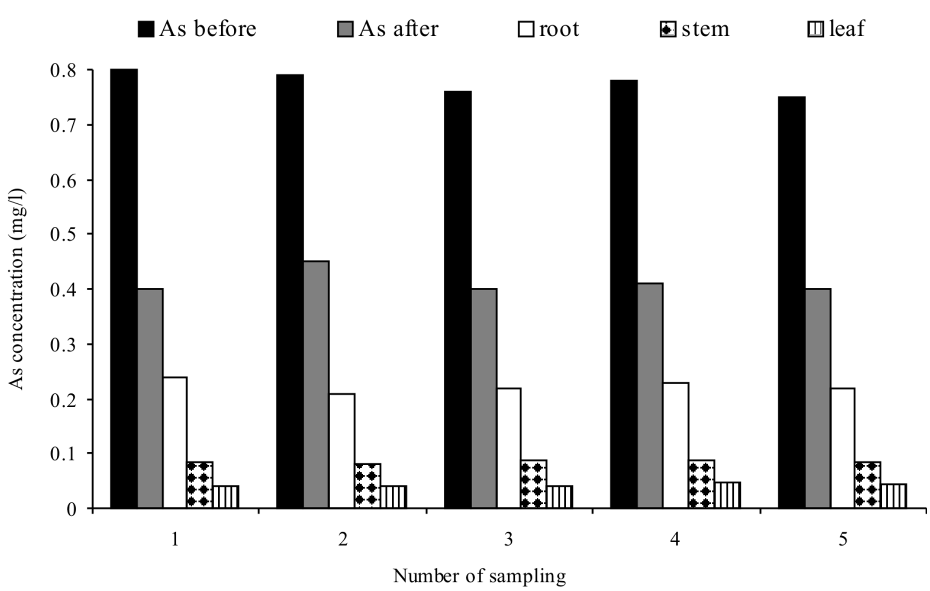

Figure 3: Arsenic absorption pattern by water hyacinths.

than 1 mg/l. In particular, water hyacinths (*Eichhornia crassipes*) have been found to be accumulators of chromium and copper and hyperaccumulators of cadmium, mercury, lead and arsenic (Zhu et al., 2004).

Several scientists have looked at water hyacinths' ability to remove arsenic from water, with somewhat differing results. Some studies have reported water hyacinths to be very effective at removing arsenic from contaminated water. Misbahuddin and Fariduddin (2002) found that just the roots of water hyacinths removed 81% from the 0.4 mg/l arsenic solution they were in. (Note: this would still leave an arsenic concentration of 0.076 mg/l, which is above both Bangladesh and US EPA 2001 drinking water standards.) The entire water hyacinth plant (roots, leaves, stems, etc.) was reported in the same study to have removed cent per cent of the arsenic, and to have done so in only three to six hours. Other scientists have reported that water hyacinths do not have very high arsenic removal capabilities. Zhu et al. (1999) reported that water hyacinths do not accumulate arsenic well and that most of the arsenic they take up is stored in their roots. Saha et al. (2004) reported that water hyacinths in water with an arsenic level of 10,000 mg/l remove 45% of the arsenite and 70% of the arsenate. Zhu et al. (2004) reported that water hyacinths convert a large portion of the arsenate they remove to the more toxic form of arsenic, arsenite, within the plant itself.

Rate of arsenic removal through water hyacinth plant is shown in Figure 4. Every two alternative day's arsenic concentration was sampled. Initially arsenic removal rate was higher. But at the end of sampling week, arsenic removal rate seems to be constant. It means that arsenic extraction through water hyacinth plant is higher and later is in decreasing trend. This transient characteristic indicates practical feasibility of arsenic removal through water hyacinth plant. Within two weeks period arsenic removal rate is so high. So, water hyacinth plant can be used effectively for arsenic removal in case of animal drinking water at small scale.

Conclusion

Experimental results showed that water hyacinths reduced the arsenic level from a Bangladeshi well water concentration (0.3 mg/l) to EPA's proposed drinking water standard (0.01 mg/l) for one trial, to the Bangladeshi drinking water standard (0.05 mg/l) for two trials and lost all ability to remove arsenic after five trials. Even water hyacinth plants also removed 50-60% arsenic from arsenic contaminated groundwater. Although there was more arsenic extracted from the roots of the arsenic plants than from the upper part of the plants, arsenic was present both in the roots and upper plant. All removed arsenic stored in roots, stems and leaves of water hyacinth plants. Out of them maximum amount of arsenic was extracted by roots than stems and leaves of water hyacinth plants. That means the arsenic is tightly bound at a molecular level so that, even when finely chopped, the arsenic did not leach out of the plants. Although, phytoremediation is slower than traditional methods of removing arsenic from water but much less costly in the perspective of Bangladesh. Prevention of arsenic contamination is far less expensive than any kind of remediation and much better for the environment.

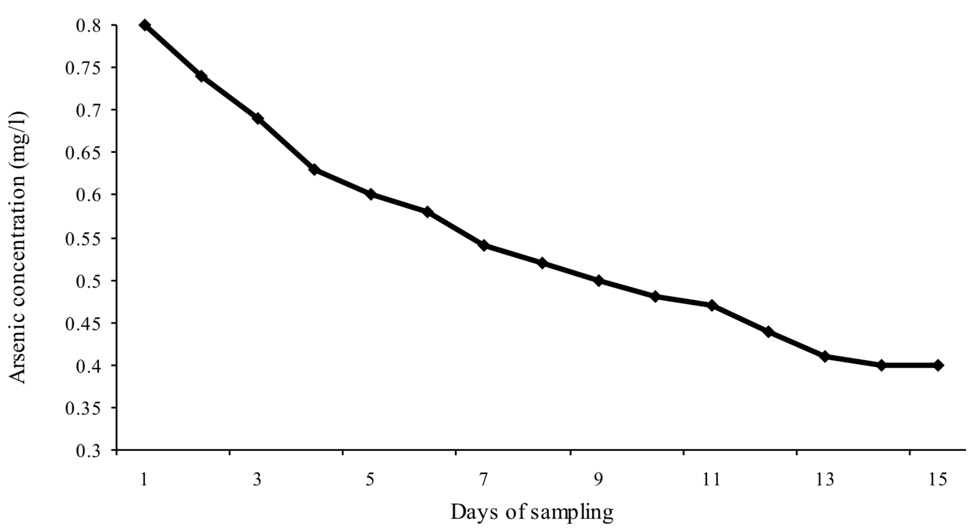

Figure 4: Rate of arsenic concentration (mg/l) removal by water hyacinth.

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