Biosorption of Mercury by Selected Plants – a Preliminary Study*

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Abstract

Traditionally, mercury (Hg) is considered among the most toxic elements with several major health issues and serious environmental challenges. With the frequent release of Hg from artisanal and small-scale gold mining (ASGM) operations, aquatic plants or staple crops in environments polluted with mercury may accumulate significant amounts of mercury. Thus, result in mercury entering the food supply chain posing health challenges to humans. In order to ascertain the bio-sorption characteristics of some staple crops for mercury; beans, millet, corn and groundnut were tested. The plants were contacted with 10 mg/L and 50 mg/L solution of mercury concentration for 7 days followed by subsequent metal analysis of residual solution. The results delineate that, metal uptake ranges of 4.6-9.3 mg/l, 3.2-9.6 mg/l, 4.7-9.3 mg/l and 3.0-7.7 mg/l for beans, corn, groundnut and millet respectively for the 10 ppm Hg solution. In addition, 16.2-42.0 mg/l, 18.2-35.7 mg/l, 17.6-34.2 mg/l and 26.0-30.2 mg/l are the Hg metal uptake ranges for the 50 ppm concentration. This shows that the plants have the capacity to uptake mercury metal to certain degree. This also confirms that beans, corn, millet, and groundnut are potential bio-accumulators of mercury in mercury contaminated sites. Notably, the findings from this study affirm the hypothesis that in situations where the mercury is bioavailable, some food items harvested in such polluted areas may eventually enter the food chain.

Keywords: Mercury, Small-scale mining, Staple crops, Sorption

1 Introduction

One heavy metal contaminant of concern on the global scale is mercury (Hg). Both artificial and natural processes contribute to Hg emissions (Addai-Arhin *et al.*, 2022; Xia *et al.*, 2020; Li *et al.*, 2017; Driscoll *et al.*, 2013; Yin *et al.*, 2022). In Ghana, the main source of Hg contamination is artisanal and small-scale gold mining (AGSM) operations. Hg is used in small-scale gold mining to recover gold particles from the concentrates (Amankwah *et al.*, 2010; Valenzuela and Fytas, 2002). Amalgamation is the generally used technique by these miners, where the ability of mercury to amalgamate gold is utilized to capture fine gold particles, whether from placer deposits or hard rock deposits (Amankwah and Ofori-Sarpong, 2014). The gold amalgam is heated causing the mercury to evaporate as gold is left behind. (Amankwah *et al.*, 2010).

Mercury may remain in the metallic state in the environment and may not be bioavailable. However, disposed mercury may be carried downstream and dispersed where it transforms into methylmercury in the sediments at the bottom of the rivers, streams or lakes (Boening, 2000). Mercury is toxic and when methylated, it becomes extremely toxic and considered a global environmental pollutant due to its atmospheric capacity to undergo long-distance transport (Wang *et al*, 2003; Boening, 2000).

In areas where sulphide minerals are available, an acid mine drainage situation may cause mercury to dissolve in the acidic environment and become bioavailable to plants and animals.

Crops grown in Hg-contaminated locations have variable capacities to bioaccumulate Hg from the soil and atmosphere (Addai-Arhin *et al.*, 2022; Lima *et al.*, 2019), and the consumption of food from such crops can have negative health impacts (Yin *et al.*, 2022; Arvay *et al.*, 2017; Xia *et al.*, 2020). Remediation of agricultural soil contaminated with Hg is crucial for lowering Hg intake through diet.

In Ghana, crop farming, like artisanal and small-scale mining is a major economic activity (Addai-Arhin *et al.*, 2022). Consequently, crop farming is mostly practiced in rural communities where ASGM activities take place. Hence it is likely that various plants like plantain, cassava, corn, millet, beans, groundnut, sugarcane, etc., planted in these soils and along such water bodies may contain appreciable Hg concentrations (Cargnelutti *et al*., 2006; Patra *et al.*, 2004). Despite the fact that numerous remediation techniques have been created for Hg-contaminated soils, none of them have been applied on a broad scale because of financial and environmental restrictions (Addai-Arhin *et al.*, 2022; Xu *et al.*, 2015). The short- to medium-term needs of the local residential communities in Hg-contaminated areas cannot be satisfied by currently available technologies, such as thermal desorption or phytoextraction, because they are prohibitively expensive or take an excessive amount of time to

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decontaminate soils (Wang *et al.*, 2012). Due to their inefficiency in terms of cost, most cleanup procedures do not succeed in appealing to landowners' interests. In order to make it possible for Hg-contaminated farmlands to be safely used for crop production, a practical and affordable solution is urgently required. Such, a possible solution to this problem is to avoid planting crops with high Hg-accumulation capacity in Hg-contaminated areas (Yin *et al.*, 2022; Xia *et al.*, 2020). It can be accomplished by cultivating crops with edible parts that collect Hg at levels below the allowable limit. It will provide benefits for the landowners and reduce dietary Hg exposure, among others.

In this study, an acid mine drainage situation was simulated by dissolving mercury in dilute sulphuric acid and the solution contacted with selected plants of staple crops (corn, millet, groundnut and beans) to confirm mercury sorption ability. The plants did not grow long enough to generate fruits as this preliminary study considered the capacity of the staple plants to uptake and accumulate Hg.

2 Resources and Methods Used

2.1 Materials

Seeds of the various plants; groundnut, corn and millet were obtained from an agricultural shop in Tarkwa and planted on black soil for four weeks.

2.2 Sample Preparation

After this initial period, the crops showed significant growth and were then harvested for further investigations at the laboratory. Deionised water was used to prepare dilute mercury solution in acidic media of pH 5.5 at 10 ppm and 50 ppm.

2.3 Experimental Setup

The crops were planted in the plastic containers with mercury solution of concentration 10 ppm and 50 ppm for seven days as shown in Fig. 1.

Fig. 1 Experimental Setup

Solution samples were taken from the bulk every 24 hours for the initial four days and on the seventh day. The samples were analysed using the iCAP™ 7400 Inductively Coupled Plasma-Optical Electron Spectroscopy (ICP-OES) Duo to determine the residual mercury concentrations remaining in the solution after sorption per day so as to ascertain the concentration of metal uptake by the staple crop plants.

3 Results and Discussion

3.1 Mercury Intake

In this study, the mercury sorption ability of selected plants (corn, millet, groundnut and beans) and their rates of sorption were analysed. Percent metal removal after seven days was 93.2%, 92.9%, 91.6% and 29.9% for groundnut, beans, corn and millet, respectively for the 10 ppm concentrations (Fig. 2). At 50 ppm, 83.9%, 60.5%, 52.2% and 35.3% Hg removal was achieved for beans, corn, millet and groundnut respectively (Fig. 3). Laboratory investigations indicated that beans, corn, groundnut staple crops can significantly uptake mercury whiles millet showed minimal uptake of mercury at the end of the experiment (Day 7).

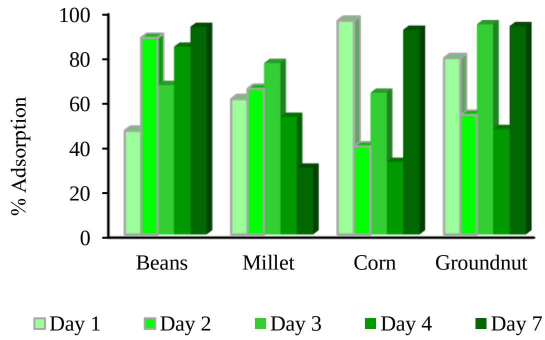

Fig. 2 Percentage Sorption of Mercury by Beans, Millet, Corn and Groundnut (10 ppm)

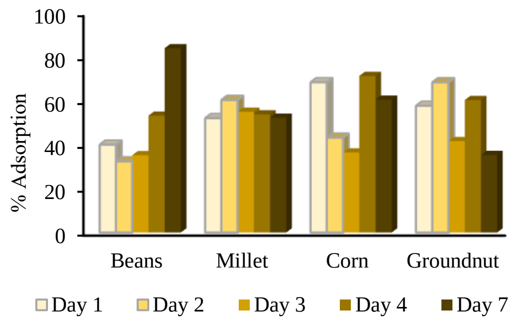

Fig. 3 Percentage Sorption of Mercury by Beans, Millet, Corn and Groundnut (50 ppm)

From the graphs, the high sorption values observed for the first day, shows the availability of active sites within each staple plant. The corn plant gave the highest sorption percentages of 95.7% and 68.4% for the first day for both 10 ppm and 50 ppm respectively. Following the absorption pattern in the first day, the sequence in mercury uptake for both (10 ppm and 50 ppm mercury concentration) was groundnut plant followed by millet plant and then finally beans plant. The difference that occurred between the 50 ppm and 10 ppm concentrations of mercury on the first day was that, the staple crops were able to sorb a higher degree of mercury at the lower than at the higher concentration. This shows their various affinity for mercury metals in varying solution strength.

From the graphs, the millet plant shows a marginal increase in absorption within the initial 3 days to a maximum of 76.7% in the 10 ppm mercury solution and 54.9% within the initial 2 days for the 50 ppm mercury solution. This pattern followed with a rapid and gradual fall in absorption in Fig. 2 and Fig. 3 respectively.

This observation can be associated with an exhaustion of active sites due to metal filling capacity. Since adsorption is an equilibrium process, the fall in absorption can be associated with release of the mercury from the plant back into solution as well as possible volatilization of mercury from the plant (Kumar *et al.*, 1995; McGrath *et al.*, 2001; Reeves and Baker, 2000). This observation might also be as a result of reverse osmosis; by which, as the plant absorb the metal from the solute solution, it reverses the Hg metal from the plant back into the solution by osmotic pressure. After day 4 at 10 ppm, three plants; corn, groundnut and beans increased rapidly to the maximum above 90% while millet decreased drastically to it minimum of 29.9%.

In addition, at 50 ppm, percent sorption in beans increased rapidly but to a maximum of 83%. This is to be expected, since sorption of metals from a solution of lower strength is faster and preferred than higher solution strength. Nevertheless, each plant absorbed Hg metals to certain degree. It can also be conferred from the graphs that, contact time affects the absorption of Hg metals by the staple crop plants.

4 Conclusion

This study reports that the plants of staple crops; beans, corn, millet and groundnut can uptake and accumulate mercury from solutions. When these plants are harvested for consumption from Hg polluted areas where the metal is bioavailable, Hg can enter the food chain to cause health challenges and risks to both humans and animals.

The beans, corn and groundnut plants showed significant sorption characteristics for mercury whiles millet showed lower sorption capacity at the end of the study. Sorption for groundnuts, beans, corn and millet plants after 7 days of contact with 10 ppm mercury solution were 93.2%, 92.9%, 91.6% and 29.9% respectively and 83.9%, 60.5%, 52.2% and 35.3% Hg removal at 50 ppm concentration.

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