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STUDY OF HEAVY METAL REMOVAL FROM AQUEOUS AND STOMACH SIMULATED MEDIUMS BY BANANA FRUIT

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Abstract

Bioaccumulation of heavy metals in living organisms poses significant health risks, particularly through exposure to contaminated food and water. The human stomach is susceptible to bioaccumulation, which can lead to various adverse effects. This study aimed to investigate the efficacy of a common fruit, banana in eliminating lead (II) and chromium (III) heavy metals from aqueous and simulated stomach mediums so that further study could be performed to identify the chelation capability of that fruit. Synthetic aqueous solutions of lead and chromium were prepared, and a stomach-conditioned medium was simulated to mimic human stomach conditions. Bananas were introduced into the mediums, and removal rates were measured at specific residence times using AAS. The results revealed removal efficiencies of 25-86% for lead and 18-44% for chromium in the aqueous medium. There was slight change observed in the result of stomach medium, as the removal efficiencies became 49-86% for lead and 7-32% for chromium. The formation of new bonds was identified by FTIR analysis. These findings contribute to understanding the potential of bananas in reducing heavy metal accumulation in the human body, providing a basis for further research in this field.

Keywords: Bioaccumulation, heavy metals, human stomach, banana, removal efficiency, aqueous medium

1. Introduction

Heavy metal pollutants are considered a serious problem in modern civilization as they accumulate inside organisms and are responsible for a variety of ailments (Malode & Shetti, 2023). Heavy metals are considered one of the major public health concerns of the modern day due to their bioaccumulative capacity across the food chain, availability, high toxicity, and longevity in the environment, (Santos et al., 2018). Among them, the most carcinogenic metals are arsenic (As), cadmium (Cd), hexavalent chromium (Cr), and nickel (Ni), and exposure to these substances causes alterations in the tumor suppressor gene expression, damage repair mechanisms, and enzyme functions involved in metabolism via damage caused by oxidation. (H. S. Kim et al., 2015; Rama Jyothi, 2021). Heavy metal poisoning occurs as a result of occupational exposure, polluted air, water, food chains, medications, and other factors (Verma & Kaur, 2016).

Chelation therapy is commonly used as a treatment for heavy metal poisoning in the human body. Deferasirox, deferiprone, EDTA are common chelating drugs that were introduced to prevent the complications of iron (Fe) and lead (Pb) overload. But chelation therapy with these drugs is associated with poor compliance due to slow parenteral infusions and poor long-term outcome (Ejaz et al., 2015). Traditional chelating agents, particularly aminopolycarboxylates (APCs) and phosphonates, have been widely utilized in both industrial and domestic applications. This is primarily preferred because of their strong metal-binding capabilities and their long-standing presence in the market. However, numerous studies have demonstrated that these chelating agents are not environmentally friendly (Asemave, 2018).

This study is focused to identify the nutraceutical value and application of a common fruit, Banana for the treatment of heavy metal in human body. The components of banana plants are all nutritious and therapeutic in nature. (Ranjha et al., 2022) Furthermore, banana contains aminocarboxylate compounds and these are commonly used to derive chelating agents to treat heavy metal contamination in the industries (Asemave, 2018).

This study utilizes banana fruit body to assess its heavy metal reduction in aqueous and simulated stomach mediums. There is future scope to identify the specific proteins and components that bind with heavy metal so that nutraceuticals can be developed and applied for the treatment of heavy metal poisoning.

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2. Methodology

For the preparation of the aqueous medium of lead and chromium respectively lead (II) acetate, $Pb(C_2H_3O_2).3H_2O$, and chromium (III) nitrate, $Cr(NO_3)_3.9H_2O$ were selected as they are model compounds for lead and chromium related studies. (Khanafari et al., 2008). The volume of the aqueous medium was selected to be 100mL, based on the relaxed state of the human stomach (Li & Jin, 2021). The temperature of the aqueous medium was selected to be 25°C (room temperature). For the preparation of the stomach medium, a gastric buffer of pH 2 was prepared by mixing 13mL 0.2M HCl with 50 mL of a 0.2M KCl and brought to a total volume of 200mL with ultrafiltered water (Gawad & Fellner, 2019). The volume for the gastric buffer solution was taken to be 100mL similar to that of the aqueous medium. 37°C was selected to be the temperature of the stomach medium to mimic the temperature of the human body (Chen et al., 2016).

For the removal process for aqueous medium, bananas were collected from a local shop in Dhaka and mashed into a paste. A predetermined amount of banana paste (20g) was weighed and added into a certain concentration of lead and chromium solution in the aqueous medium. Then the mixture was left to sit for 1h after which the solid content of the banana was separated from the mixture using a strainer, Whatman grade 42 filter paper and 0.45-micron filter paper to remove any impurities.

The concentration of metal (lead or chromium) in the resulting solution was measured using flame based Atomic Absorption Spectroscopy (AAS). Then the removal percentage was calculated. The procedure was repeated varying the concentration of lead and chromium from 5 to 900 ppm in an aqueous medium. Furthermore, the amount of banana paste was varied for different concentrations to study the effect of mass variation in the removal process of lead. The concentration of lead in the aqueous medium was varied keeping the amount of banana constant at 10g and 30g as well.

For the removal of lead and chromium in the stomach medium, 20g of banana paste was taken for both lead and chromium solutions. The gastric buffer was kept in an oven at 37°C and the measured banana paste was added to the gastric buffer solution of pH 2. Then similar procedure of the aqueous medium was followed to attain the removal percentage and removal capacity. FTIR analysis (455.13-3495.26 cm^{-1}) was performed for various banana paste samples.

3. Results and Discussion

3.1. FTIR Spectroscopy

FTIR spectra of banana pulp sample treated with lead in aqueous and stomach medium (Figure 1) shows that the peak in the range 860-750 cm^{-1} disappears. So, aromatic rings might be involved in the removal process. The shift in the peak 1039 cm^{-1} indicates the involvement of C=O (unconjugated carbonyl) (Azam et al., 2021).

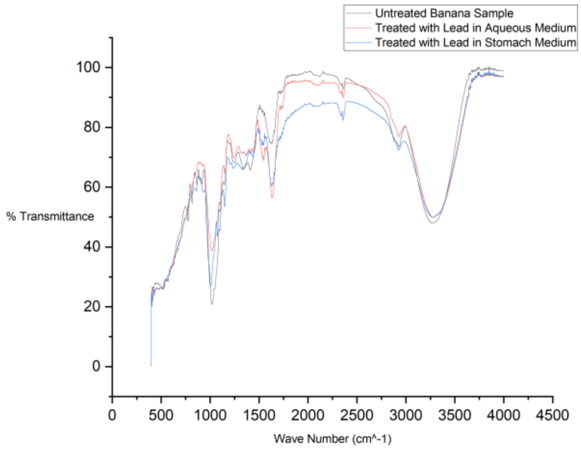


Figure 1. FTIR results for untreated banana pulp and treated with lead in aqueous and stomach medium.

In the case of both aqueous and stomach medium shift in the peak of 1023 cm^{-1} is observed. This might suggest the involvement of carbonyl groups as well. Shift in the transmittance of 1631.45 cm^{-1} establishes the participation of carboxyl and amide groups (Basu et al., 2017). The reallocation of 1409.74 cm^{-1} could be attributed to involvement of carboxyl groups ($-COO^-$). The difference between the spectra of lead treated banana pulp in stomach medium and in aqueous medium do not differ widely. The observation of the FTIR spectra of Chromium treated banana pulp in aqueous and stomach medium shows that peak reallocations, change in transmittance occurs similar to lead.

So, the functional groups such as aromatic rings, carbonyl, carboxyl, and amide groups are involved as well (Figure 2). However, in the case of sample treated with chromium in stomach medium, reallocation of the peak 3275 cm^{-1} is greater than other samples. Similarly, the disappearance of the 1409.74 cm^{-1} and 1248.8 cm^{-1} peaks might also indicate more involvement of carboxyl and O-H groups in case of chromium in stomach medium. It has been reported that Cr(III) has affinity to bind to -OH, NH, C=O, and C-O (Azam et al., 2021). So, the above findings are consistent.

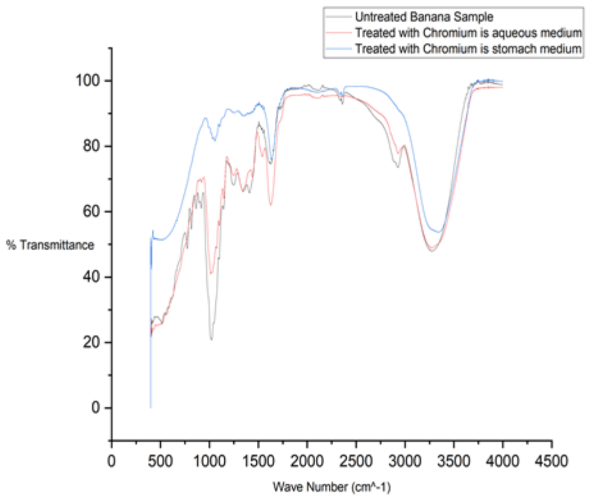
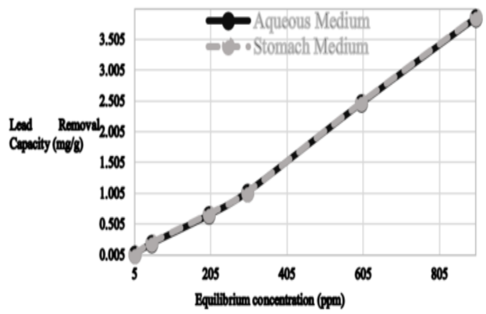


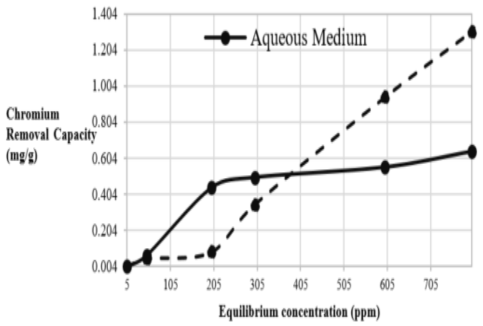
Figure 2. FTIR results for untreated banana pulp and treated with chromium in aqueous and stomach medium.

3.2 Analysis of experimental data

Figure 3 depicts stomach condition's impact on banana pulp's removal capacity for both lead and chromium at the equilibrium concentrations. For lead, the equilibrium concentrations for the solutions were 5 ppm, 50 ppm, 200 ppm, 300 ppm, 600 ppm and 900 ppm while for chromium, the equilibrium conditions were 5 ppm, 50 ppm, 200 ppm, 300 ppm, 600 ppm and 800 ppm. With minimal difference between them, removal capacity rises incrementally with equilibrium concentration for both aqueous and stomach mediums. In the stomach condition i.e.at lower pH, metals compete with H^+ for the exchange sites in the system causing partial release of the latter. (Annadurai et al., 2003). However, there was only a slight difference in the removal efficiency of lead (Pb^{+2}) in aqueous and stomach medium. So, the change in pH to acidic condition presented little effect to the removal efficiency. Similar results were found in literature where banana peel derived carbon foam (BPCF) was used as adsorbent to remove lead (Pb^{+2}) and chromium (Cr^{6+}) for varying pH from 2.0 to 7.0 (Y. Li et al., 2016). It was suggested that although BPCF contained pH-susceptible functional groups such as carboxyl and hydroxyl, pH alteration resistant ion exchange elements such as “K, Ca, Mg” were also present. Banana pulp contains these ion exchange elements as well (Pareek, 2016) which might explain the indifference between the aqueous and stomach medium. As discussed in the section of FTIR spectroscopy, the effect of functional groups such as hydroxyl groups, carboxylate ion, carbonyl groups have similar effect on both lead in aqueous and stomach medium which might have also contributed to the similarity of results in aqueous and acidic media.



(i)



(ii)

Figure 3. Isotherm plot of (i) lead and (ii) chromium in aqueous medium(25°C) and stomach medium (37°C).

In Figure 3(ii), the isotherm for chromium in aqueous and stomach mediums depicts removal capacity's incremental connection with equilibrium concentration. Initially, the capacity in stomach medium is lower than aqueous, but it surpasses it beyond ~230 ppm. The contribution of pH, temperature and functional groups might need to be considered in this case. The study on BPCF also mentioned that the adsorption of Cr^{6+} was significantly influenced by pH unlike Pb^{2+}. The minimum removal efficiency was found to be at pH 2.0 for Cr^{6+}. One reason suggested for this phenomenon was that the size of Cr^{6+} hydrates (CrO_4^{-2}, $Cr_2O_7^{2-}$, and $HCrO^{4-}$) at pH 2 is larger than that of free metal ions making it difficult for them to get through the pores and spread to the interior. The speciation diagram for Cr^{+3} complexes shows that at pH 2 Chromium complexes are in the form Cr^{3+} and $Cr(OH)^{+2}$ (Leyva-Ramos et al., 1995). Cr^{3+} in aqueous solutions coordinate six water molecules. Thus, the size of the hydrates of the Cr^{+3} at pH 2 might explain the low removal capacity at lower concentrations. In a study of the adsorption of Cr^{3+} from an aqueous solution onto activated carbon, the effect of temperature was studied at 25 and 40°C (Broadbent et al., 1992).

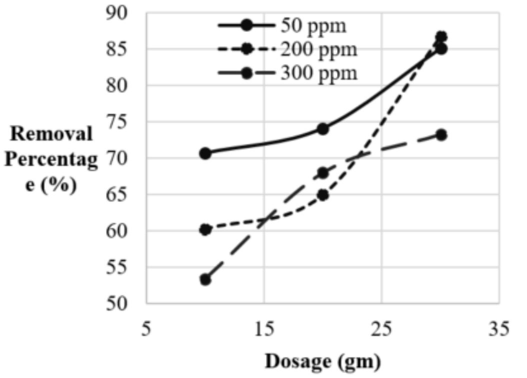


Figure 4. Effect of variation in dosage (10, 20, and 30g) for 50,200, and 300 ppm lead concentration.

From figure 3, it can also be observed that the removal capacity of lead is higher than that of chromium for a fixed concentration in case of both aqueous and stomach medium. In figure 4, the impact of banana pulp dosage on varying concentrations is depicted. As dosage increases for a given concentration, percentage removal rises, likely due to higher availability of binding sites (H. Peli Thanthri et al., 2020).

4. Conclusions

Banana was targeted as one of the alternatives to identify the heavy metal remediation capability. The study explored the capability of banana to remove heavy metals from both aqueous and stomach simulated medium. FTIR analysis showed that different functional groups such as -OH, amine, amide, carboxyl, carbonyl might be involved in the removal process of lead and chromium. For the lead solution, removal capacity was comparable to the aqueous medium. However, for the chromium solution, removal capacity was initially lower than the aqueous medium. As the concentration increased, removal capacity gradually surpassed that of the aqueous medium. Additionally, it was found that the percentage removal of chromium was significantly lower than that of lead both in aqueous and stomach medium. The investigation thus successfully demonstrated the heavy metal reduction capability of the banana pulp in both aqueous and stomach simulated medium suggesting the potential of developing a natural chelating agent from banana fruit.

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