Adsorption of Pb (II) Using Partially Deproteinated Water Hyacinth (Eichhornia crassipes) Roots

A.D. Nieva¹, M.D.D. Ang¹, H.G. Hipolito¹, E.J. Calderon¹, and K.R.S. Pamintuan¹,²

1 School of Chemical, Biological, and Materials Engineering and Sciences, Mapua University, Intramuros, Manila, Philippines 1002
2 Center for Renewable Bioenergy Research, Mapua University, Intramuros, Manila, Philippines 1002
E-mail: krspamintuan@mapua.edu.ph

Abstract. Water hyacinth (Eichhornia crassipes) is known to be an effective biosorbent capable of removing pollutants of industrial wastewater effluents, particularly heavy metals. This study determined and compared the effectiveness of removing Pb²⁺ in a lead-containing aqueous solution using untreated and treated water hyacinth roots. The treated biosorbent was the heavy organic matter that settled from the extraction of water-soluble portions of the water hyacinth roots upon centrifugation of the water hyacinth and deionized water mixture for 1 hour at ambient temperature. The treatment of the biosorbent resulted in less functional groups but more exposed fibers for which the Pb²⁺ ions can adhere to. At a 24-hour equilibrium time, it was determined that the untreated biosorbent gave higher adsorption capacity of 0.743 mg/g as compared to the 0.653 mg/g capacity of the treated biosorbent. However, it was observed that in a 2-hour equilibrium time, similar adsorption capacities were obtained at 0.75 mg/g for both biosorbents. The kinetic study reveals that saturation of the biosorbents was observed within a 2-hour contact time. At prolonged adsorption time, the decrease in adsorption capacity of the treated biosorbent was due to the adsorption-desorption process that occurred at the saturated sorbent surfaces, whereby the attached Pb²⁺ was released and re-attached interchangeably. The loss of functional groups in the treated biosorbent resulted in less strong bonds from chemical adsorption and thus in a higher contact time, the loosely binded Pb²⁺ ions return to the aqueous phase.

1. Introduction

Lead is one of the most toxic elements that can be found in nature yet it is an essential metal that supports our modern world. A survey on lead battery manufacturers shows that the concentration of Pb²⁺ in their wastewater effluent is in the range of 5-15 mg/L [1]. Even exposure at small concentrations of Pb²⁺ from the untreated wastewater would affect the central nervous system, liver, kidney, and gastrointestinal system leading to various diseases such as hepatitis, anemia, and encephalopathy. According to the Department of Environment and Natural Resources (DENR), the maximum allowable concentration for total Pb²⁺ in industrial wastewater effluents is 0.1 mg/L only. The high concentrations of Pb²⁺ in wastewater have prompted scientific investigations to develop efficient and effective methods and techniques for its removal in the contaminated wastewater. Some of the conventional ways to remove Pb²⁺ in an aqueous solution includes chemical precipitation, membrane separation, chemical oxidation, ion exchange, and electrodialysis but most of these methods are too expensive, have high energy requirements, ineffective for treating low metal ion
concentrations, and generates many waste products. Adsorption has been regarded as the most economical technique for removing Pb\(^{2+}\) from industrial wastewater as it is versatile, simple, low cost, flexible in design and operation, and can achieve a high removal capacity nearing 100% [2]. Nowadays, a variety of low-cost materials derived from plant wastes such as rapeseed (Brassica napus), Banyan leaves (Ficus benghalensis), and Rogers mushroom (Leptiot a hystrix) are being utilized as biosorbents and are significant for treating wastewaters that are contaminated with Pb\(^{2+}\) as they can achieve high adsorptive capacities of 88-95% [3][4][5]. Aquatic macrophytes, both living or dead, have been found out to be an effective heavy metal accumulator and thus they have been used in many wastewater treatments [6][7][8]. Water hyacinth (Eichhornia crassipes) is a free floating aquatic macrophyte that is highly abundant in tropical and sub-tropical countries such as the Philippines. The weed has been shown to exhibit extreme proliferation and has been reported that it can double its number every two weeks [9]. It has posed itself as a menace in bodies of water as it can cause blockage of water ways and suffocation of aquatic life. Thus, researchers have developed several possible uses for the invasive plant, one of which is to utilize the weed as a biosorbent. The biosorption capacity of finely ground water hyacinth roots against Pb\(^{2+}\) was found to reach up to 99.85% metal removal at optimum pH 5 [10]. Therefore, due to the high adsorption capacity of water hyacinth roots for Pb\(^{2+}\) ions, this was utilized in this study. This study aims to determine the effectiveness of partially deproteinated water hyacinth roots (DWHR) in the removal of lead (Pb\(^{2+}\)) in aqueous systems. The adsorbent in question is a by-product after obtaining water hyacinth cationic proteins (WHCP), which finds great use in immobilized disinfectant systems. Utilizing a processing by-product makes sure that the waste of a product still finds great use in heavy metal removal and maintaining water resources. Comparative studies of untreated and treated water hyacinth roots for the removal of Pb\(^{2+}\) were based only on the batch adsorption in a simulated lead-laden wastewater. The simulated lead-contaminated wastewater was based on the metal concentrations of water effluents in lead-battery manufacturing industries. Langmuir and Freundlich isotherms were used for equilibrium modelling, while pseudo-first and second order equations were used for kinetic modelling.

2. Materials and methods

2.1. Preparation of wastewater

Lead concentrations in lead-acid battery manufacturing industries were simulated by preparing a stock solution of 100 mg/L Pb\(^{2+}\) ion made by dissolving 0.16 grams of lead (II) nitrate salts distilled water enough to make 1 L solution. The high and low concentrations of the standards (5 mg/L and 15 mg/L) were prepared by dilution of the stock solution using distilled water. The pH of the solution was determined using a pH meter and was adjusted to the optimum pH of 5 by addition of 0.1 M HCl.

2.2. Preparation of biosorbent

Water hyacinth plants (Eichhornia crassipes) were collected randomly from the Marikina river, Philippines. The roots were separated from the shoots and were thoroughly washed using tap water to remove any dirt, dust, and other unnecessary substances. The roots were then digested by adding 10 mL of concentrated nitric acid per 1 gram of the roots and are boiled for 40 minutes. The solution was cooled down and 5 mL of perchloric acid was added and boiled again until fumes starts to appear. The mixture was cooled and 20 mL of water was added to reduce the fumes [10]. The digested roots were oven dried at a temperature of 65°C for 24 hours. A Wiley mill was used for the grinding of the dried roots and then passed through an 80 mesh screen (<0.18 mm) using a sieve shaker [11]. The roots were subjected to Fourier transform infrared spectroscopy (FTIR, Perkin-Elmer Spectrum 100) and scanning electron microscopy (SEM, Hitachi SU-8230) analysis to examine the functional groups present and to determine the surface morphology of the materials before and after the experiments. Approximately 250 mg of the powdered digested root was suspended in 10 mL of deionized water and placed in a micro test tube. The tubes were placed in a centrifuge for 1 hour to allow the proteins to dissolve in water while the excess organic matter settles to the bottom [12]. The heavy organic matters which contain the partially deproteinized water hyacinth were used as biosorbent.
2.3. Batch adsorption experiments
A set of 250 mL Erlenmeyer flasks were filled with 50 mL aliquot of the simulated lead-laden wastewater with different concentrations (5, 10, and 15 mg/L). Various sorbent dosages (1 g and 5 g) were added into the solution and the flasks were agitated in an isothermal shaker for 30 minutes and were left undisturbed for the next 24 hrs [10]. Traces of Pb\(^{2+}\) concentration in the solution were determined using an atomic absorption spectrophotometer (AAS). All measurements were done in triplicate.
All runs mentioned above were done for both treated and untreated adsorbents. The amount of Pb\(^{2+}\) adsorbed per gram of biosorbent \((q_e)\) was computed using Equation 1 and the adsorption efficiency \((E_a)\) was computed using Equation 2 as shown below.

\[
q_e = \frac{(C_i - C_e)V}{M} \quad (1)
\]

\[
E_a = \frac{(C_i - C_e)}{C_i} \times 100\% \quad (2)
\]

where \(C_i\) is the initial Pb\(^{2+}\) concentration, \(C_e\) is the equilibrium Pb\(^{2+}\) concentration, \(V\) is the volume of the solution and \(M\) is the mass of the biosorbent.

2.4. Adsorption isotherm and kinetic modelling
Langmuir and Freundlich adsorption isotherms were used to describe the biosorption of Pb\(^{2+}\) onto untreated and treated water hyacinth roots. Certain parameters can be obtained from the batch experiment which was used for both Langmuir and Freundlich isotherm models shown in Equations 3 and 4, respectively.

\[
q_e = \frac{q_{\text{max}}K_LC_e}{1 + K_LC_e} \quad (3)
\]

\[
q_e = K_FC_e^n \quad (4)
\]

where \(q_e\) is adsorptive capacity of the component, \(q_{\text{max}}\) is the maximum adsorptive capacity of the component, \(K_L\) is Langmuir equilibrium constant, \(C_e\) is the equilibrium concentration, \(n\) is the heterogeneity factor, and \(K_F\) is the Freundlich equilibrium constant.

Batch adsorption was conducted and analyzed at different contact times (i.e. 5, 10, 20, 30, 60, 90, 120 min.). This study utilized pseudo-first order (PFO, Equation 5) and pseudo-second order (PSO, Equation 6) to investigate the rate at which the biosorption occurs.

\[
\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (5)
\]

\[
\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (6)
\]

where, \(k_1\) is the pseudo-first-order rate constant, \(k_2\) is the pseudo-second-order rate constant, \(t\) is time, and \(q_e\) & \(q_t\) are the adsorption capacities at equilibrium and time \(t\), respectively.

3. Results and discussion

3.1. Adsorption capacity
Batch adsorption of Pb\(^{2+}\) for 24-hour equilibrium time utilizing the untreated water hyacinth roots resulted in >99% metal removal regardless of the initial Pb\(^{2+}\) concentration and biosorbent dosage with the highest being 99.53%. Presented on Figure 1 are the adsorption efficiencies of the untreated and treated water hyacinth roots at 24-hour equilibrium time.
Figure 1. Adsorption efficiency for 24-h equilibrium with adsorbent loading of 1 g (♦) and 5 g (■) for (a) untreated and (b) treated roots

The highest percent Pb$^{2+}$ removal when using treated water hyacinth roots was at 88.29% as observed in Figure 1b. However, in the 2-hour kinetic study, it was revealed that both biosorbents could reach >99% Pb$^{2+}$ removal at 15 mg/L initial Pb$^{2+}$ concentration and 1 g biosorbent dosage. The point of saturation was reached within the 2-hr equilibrium time and hence for prolonged contact time, there is a possibility for the desorption of the adsorbed Pb$^{2+}$ ions. Presented in Figure 2 are the adsorption capacities of the two biosorbents at varying initial Pb$^{2+}$ concentrations for 1 g and 5 g biosorbent dosage at a 24-hr equilibrium time.

The untreated water hyacinth roots always have the higher adsorption capacity reaching up to 0.743 mg/g while the treated biosorbent had a $q_a$ up to 0.653 mg/g. The adsorption capacities of both biosorbents were found to be proportional with the increase in initial Pb$^{2+}$ concentration. The increase in the initial metal concentration provided a greater driving force in the adsorption of metal ions from the aqueous phase onto the surface of the biosorbent and thus the possibility of interaction between the metal ions and the active binding sites increases, therefore its adsorption capacity also increases [4]. The adsorption capacities were also observed to be lowered when the biosorbent dosage was increased from 1g to 5g. The adsorption capacity of biosorbent was not fully utilized at a higher biosorbent dosage in comparison to lower dosage due to the limits provided by the constant initial Pb$^{2+}$ concentration.

Figure 2. Adsorption capacity of untreated (♦) and treated (■) water hyacinth roots at (a) 1-g dose and (b) 5-g dose
3.2. Biosorbent characterization

Figure 3 reveals the FTIR spectra and the frequencies obtained with untreated water hyacinth roots before and after the adsorption process.

![FTIR spectra](image)

**Figure 3.** FTIR spectra of (a) untreated and (b) treated water hyacinth roots taken before and after Pb$^{2+}$ adsorption

It can be observed that there is a broad absorbance at 3200-3600 cm$^{-1}$ which indicates the presence of OH or COOH groups. The frequency band at 2881.83 cm$^{-1}$ and 908.30 cm$^{-1}$ characterizes the C-H stretch vibrations for methyl groups. At 1637.16 cm$^{-1}$ and 1408.00, alkenes can be associated. Lastly, alkenes and aromatic rings was observed at 745.73 cm$^{-1}$. These functional groups can be attributed to the lignocellulosic nature of the biomass which are cellulose, lignin and hemicellulose. They are responsible for chemical bonding due to the polar functional groups present, specially the active carboxyl groups which readily bind with metal cations. Moreover, it can be observed in Figure 3a that the FTIR spectra of the biosorbent after the adsorption process retained the same functional groups present before adsorption though it exhibited lower values of percent transmittance which corresponds to higher population of bonds due to the interaction of the functional groups with Pb$^{2+}$ ion. The treated water hyacinth roots was also subjected to FTIR analysis before and after the adsorption process as shown in Figure 3b. The regions of high wave numbers, 3620.62 cm$^{-1}$ and 3346.94 cm$^{-1}$, can be attributed to the O-H stretching vibrations of hydrogen-bonded hydroxyl groups in polymeric association. The bands 2884.66 cm$^{-1}$ and 1432.96 cm$^{-1}$ are attributed within the bracket of C-H stretching and deformation, indicating the presence of methylene and methoxyl, respectively. In addition, wave numbers 1630.19 cm$^{-1}$ and 907.67 cm$^{-1}$ are associated with alkenes groups. Comparing the functional groups identified in the treated biosorbent to the untreated counterpart, there is a loss of the amine group since the extracted proteins are made up of amino acids. Amino acids are both comprised of an amine group and carboxyl group, the loss of the active carboxyl group would indicate less chemical adsorption with the Pb$^{2+}$ ions. Presence of more hydrocarbon groups was also observed because of protonation which serves as additional binding sites for Pb$^{2+}$.

The SEM micrograph of the untreated water hyacinth roots before and after adsorption is shown on Figure 4. Before adsorption, the untreated water hyacinth roots had a rough surface with a very thin epicuticular wax layer. After adsorption, the resulting biomass became more compacted as a consequence of the accumulated metal ions. The SEM micrograph of the treated water hyacinth roots before adsorption revealed a partially disintegrated surface version of the untreated counterpart as shown on Figure 5.

The observations on the treated water hyacinth roots before adsorption, as shown in Figure 5a, is notably due to the protein extraction which may have also led to the removal of part of hemicelluloses and lignin that interconnects the cellulose fibrils [13]. The loss of these parts signifies lower polar functional groups; this observation is in line with the results from the FTIR analysis. With similar observations as before, it can also be seen in Figure 5b that the treated biomass also became compact after the surface adsorption of Pb$^{2+}$. 


Figure 4. SEM micrograph of untreated water hyacinth roots (a) before and (b) after Pb\(^{2+}\) adsorption at x1000 magnification.

Figure 5. SEM micrograph of untreated water hyacinth roots (a) before and (b) after Pb\(^{2+}\) adsorption at x1000 magnification.

3.3. Equilibrium and Kinetic studies

Equilibrium adsorption isotherms are used to relate the concentration of the solute in the aqueous phase (C\(_e\)) to the equilibrium concentration of the solute on the surface of the biosorbent also known as adsorption capacity (q\(_a\)) [3]. The fitting of the experimental data of adsorption of Pb\(^{2+}\) using untreated water hyacinth roots at 1 g and 5 g dosage on Langmuir and Freundlich adsorption isotherms are presented in Figure 6.

![Isotherm plots for the biosorption of Pb\(^{2+}\) on 1 g (♦) and 5 g (■) dosage of untreated water hyacinth roots for (a) Langmuir and (b) Freundlich isotherm model](image)

It can be observed in Figure 6a that the values of y-axis (C\(_e\)/q\(_a\)) in the linearized Langmuir plot at 1 g biosorbent dosage are less than that at 5 g biosorbent dosage. The smaller the value of the ratio C\(_e\)/q\(_a\) would signify that most of the adsorbate concentration is at the surface of the biosorbent rather than in
the aqueous phase. In contrast, for the linearized Freundlich plot, the value of the y-axis (log $q_a$) at 1 g biosorbent dosage are greater than that at 5 g biosorbent dosage as shown on Figure 6b. The value of log $q_a$ is directly proportional to the adsorption capacity of the biosorbent. Both resulting plots are in agreement that the adsorption capacity at 1 g biosorbent dosage is higher than at 5 g biosorbent dosage, which is reflected in the earlier discussion on adsorption capacities. Summarized on Table 1 are the obtained parameters of the adsorption isotherms for the biosorption of Pb$^{2+}$ on untreated water hyacinth roots.

**Table 1. Adsorption Isotherm Parameters utilizing Untreated Water Hyacinth Roots**

| Biosorbent dosage, g | Langmuir | Freundlich |
|----------------------|----------|------------|
|                      | $q_{max}$, mg/g | $K_L$ | $R^2$ | $1/n$ | $K_F$, mg/g | $R^2$ |
| 1                    | 2.370    | 3.403  | 0.581  | 0.797  | 3.864  | 0.924 |
| 5                    | 0.323    | 0.122  | 0.910  | 0.670  | 0.700  | 0.975 |

The data presented on Table 1 indicates that the adsorption of Pb$^{2+}$ using untreated water hyacinth roots better fits the Freundlich isotherm model than the Langmuir adsorption isotherm. The Freundlich isotherm model assumes a heterogeneous surface that accounts for the unequal affinity between the adsorbate and the active sites of the biosorbent [9]. It can be observed that the $K_F$ value at 1 g biosorbent dosage (3.864 mg/g) is higher than that at 5 g biosorbent dosage (0.700 mg/g). The $K_F$ value is an indicator of the adsorption capacity, the higher its value, the higher the maximum capacity. In terms of the constant $1/n$, the value at 1 g biosorbent dosage (0.797) is also higher than that at 5 g biosorbent dosage (0.670). The constant $1/n$ is a measure of adsorption intensity, the higher its value signifies more favorability on adsorption. The magnitudes of both Freundlich isotherm constants are in agreement that 1 g biosorbent dosage would result to a better adsorption capacity and adsorption favorability than at 5 g dosage.

The fitting of the experimental data of adsorption of Pb$^{2+}$ using treated water hyacinth roots at 1 g and 5 g dosage on Langmuir and Freundlich adsorption isotherms are presented in Figure 7.

Like the observations made from using untreated water hyacinth roots, the treated water hyacinth roots also have lower $C_a/q_a$ in the linearized Langmuir plot and higher log $q_a$ in the linearized Freundlich plot at 1 g biosorbent dosage as seen on Figure 7. These signify that the adsorption capacity at 1 g biosorbent dosage was also better as compared to 5 g biosorbent dosage. Summarized on Table 2 are
the obtained parameters of the adsorption isotherms for the biosorption of Pb\(^{2+}\) on treated water hyacinth roots.

| Biosorbent dosage, g | q\(_{\text{max}}\), mg/g | K\(_{L}\) | R\(^2\) | l/n | K\(_{F}\) | R\(^2\) |
|----------------------|----------------------|--------|-----|-----|--------|-----|
| 1                    | 0.222                | 0.416  | 0.670 | 0.428 | 0.133  | 0.993 |
| 5                    | 0.031                | 0.477  | 0.741 | 0.296 | 0.022  | 0.924 |

The data presented on Table 2 indicates that the adsorption of Pb\(^{2+}\) using treated water hyacinth roots better fits the Freundlich isotherm model than the Langmuir adsorption isotherm. It can be observed that the K\(_{F}\) and l/n values at 1 g biosorbent dosage (0.133 mg/g & 0.428) are both higher than that at 5 g biosorbent dosage (0.022 mg/g & 0.296). The magnitudes of both Freundlich isotherm constants agree that 1 g biosorbent dosage would result to a better adsorption capacity and adsorption favorability than at 5 g dosage. Both untreated and treated water hyacinth roots best fit the Freundlich isotherm which indicates that both systems follow a heterogenous or multi-layer adsorption of Pb\(^{2+}\) [9]. Kinetics of adsorption provides useful information in determining the potential rate-controlling step which includes the mass transport and chemical reactions taking place within the adsorption process [3]. The adsorption kinetics study was performed utilizing 15 mg/L Pb\(^{2+}\) concentration and 1 g biosorbent dosage as these were proven to result to the highest adsorption efficiencies. The fitting of experimental data of adsorption of Pb\(^{2+}\) using untreated and treated water hyacinth roots on pseudo-first and pseudo-second order model are presented in Figure 8. The adsorption of Pb\(^{2+}\) on both untreated and treated water hyacinth roots corresponds better with the pseudo-second order model. It can also be seen that the plots for both biosorbents overlapped when fitted on the pseudo-second order model which signifies that both biosorbents have similar mechanism of adsorption. This coincides with the results that the data best fits the Freundlich isotherm showing that the adsorption was multilayer or heterogenous in nature [14]. Their rate of adsorption is proportional to the amount of Pb\(^{2+}\) determined and the square of the number of binding sites, which corresponds to the term (q\(_e\) - q\(_t\))^2 in the pseudo-second order model [11]. Summarized on Table 3 and Table 4 are the kinetic parameters obtained for untreated and treated water hyacinth roots, respectively.

![Figure 8](image-url)  
Figure 8. Kinetic plots for the biosorption of Pb\(^{2+}\) on 1 g dosage of untreated (●) and treated (■) water hyacinth roots for (a) pseudo-first and (b) pseudo-second order model

There is a high correlation coefficient value of >0.9999 for both biosorbents when fitted in the pseudo-second order model as seen on Table 3 and Table 4. In this model, it indicates that there is significance in the chemical reaction between the adsorbate and the biosorbent wherein the rate-limiting step is the
surface adsorption that involves chemisorptions [10]. As discussed in the biosorbent characterization earlier, water hyacinth roots contain polyfunctional groups (e.g. carboxyl, hydroxyl, amine) that act as metal-binding sites. This agrees with other studies, in which it was determined that the mechanism for adsorption was due to the carboxylate group found on the surface of the water hyacinth roots which was efficient at capturing Pb\(^{2+}\) [13]. The rate constant (k) and adsorption capacity at equilibrium (q\(_e\)) can be determined from the slope (1/q\(_e\)) and intercept (1/kq\(_e^2\)) of the linearized pseudo-second order kinetic model.

| Table 3. Kinetics Parameters for Adsorption of Pb\(^{2+}\) on Untreated Water Hyacinth Roots |
|-----------------------------------------------|
| Rate constant | q\(_e\) (cal), mg/g | R\(^2\) |
|----------------|-----------------|------|
| Pseudo-first Order Kinetics | 0.028 | 0.063 | 0.96901 |
| Pseudo-second Order Kinetics | 1.209 | 0.748 | 0.99998 |

| Table 4. Kinetics Parameters for Adsorption of Pb\(^{2+}\) on Treated Water Hyacinth Roots |
|-----------------------------------------------|
| Rate constant | q\(_e\) (cal), mg/g | R\(^2\) |
|----------------|-----------------|------|
| Pseudo-first Order Kinetics | 0.029 | 0.062 | 0.93673 |
| Pseudo-second Order Kinetics | 1.269 | 0.747 | 0.99999 |

For the 2-hour kinetic study, the calculated equilibrium capacities are 0.748 mg/g and 0.747 mg/g for untreated and treated water hyacinth roots, respectively. The calculated equilibrium capacity for the treated water hyacinth roots was higher as compared to the earlier experiment. As discussed before, the batch adsorption from the earlier experiment was done for a 24-hour equilibrium time and that due to the prolonged contact time, there was a decrease in the adsorption capacity of the treated biosorbent. This difference in equilibrium capacity was due to the adsorption-desorption process that occurred upon reaching the saturation point of the sorbent surface, whereby the adsorbed Pb\(^{2+}\) was released and re-attached interchangeably, causing the adsorption capacity to be reduced or stay constant [15]. In the case of the treated biosorbent, at prolonged contact time, the loosely bound Pb\(^{2+}\) ions were more likely to return to the aqueous phase and thus it resulted to lower adsorption capacity as compared to its untreated counterpart. As supported by the FTIR analysis, due to the loss of functional groups upon protein extraction treatment, less strong bonds from chemical adsorption would occur. Hence, there would be more physical adsorption which indicates weaker yet faster adsorption. This agrees with the higher rate constant observed for when using treated water hyacinth roots.

4. Conclusion

This study demonstrated the high adsorption capacity of untreated and treated water hyacinth roots in the removal of Pb\(^{2+}\) in a simulated wastewater. Protein extraction treatment of the water hyacinth roots resulted to less functional groups but more exposed fibers for which the Pb\(^{2+}\) ions can adhere to. The adsorption mechanism for both biosorbents follows the Freundlich adsorption isotherm, with a correlation coefficient value (R\(^2\)) >0.9, signifying a multilayer adsorption onto a heterogeneous surface. The adsorption kinetics of both biosorbents correspond greatly to the pseudo-second order model reaching a R\(^2\) value >0.99, which indicates that chemical adsorption mostly occurs between the Pb\(^{2+}\) ions and the functional groups present in the surface of the biosorbents. The untreated water hyacinth roots have been proven to be more efficient in the batch adsorption of Pb\(^{2+}\) for 24 hours as it can achieve an adsorption capacity of 0.743 mg/g as compared to the 0.653 mg/g capacity of its treated counterpart. However, the adsorption capacities calculated from the 2-hour kinetic study revealed similar adsorption capacity for both untreated and treated biosorbents. Hence, it is possible for the treated water hyacinth roots to match the adsorption efficiency of its untreated counterpart.

5. References
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