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Utilization of *Ziziphus lotus* Fruit as a Potential Biosorbent for Lead(II) and Cadmium(II) Ion Removal from Aqueous Solution

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ABSTRACT

The removal of cadmium (II) and lead (II) ions from aqueous solutions by the *Ziziphus lotus* fruits powder, as inexpensive and eco-friendly biosorbent, was studied in batch mode. Fruits powder (FP) revealed the highest uptake rate at pH=8 and pH=7 for Cd(II) and Pb(II) consecutively. The best metal adsorption rate is obtained with a temperature ranging from 25 to 30 °C, a contact time of 90 min, an initial ionic concentration of 100 mg/L, and a biosorbent dosage ranging from 3.5 to 5 g/L.The experimental kinetic data of the biosorption process for both heavy metal ions were fitted by the pseudo second order model. The equilibrium data fitted very well to the Langmuir model. The maximum monolayer biosorption capacities were 33.94 mg/g and 69.06 mg/g for Cd(II) and Pb(II) respectively. The main chemical groups which are involved in the trapping of Cd(II) and Pb(II) and which have been revealed by FTIR spectral analysis are: N–C, O=C, H-O, H-C, and O–C. The present research confirms that *Z. lotus* fruits could be exploited as a low-cost and an effective biosorbent for the elimination of Cd(II) and Pb(II) ions from aqueous solution.

Keywords: heavy metals biosorption, *Ziziphus lotus*, wastewater treatment, kinetic isotherms.

INTRODUCTION

An expanding environmental problem linked mostly to industrial expansion is water pollution. Industries need a lot of water for their activities, which results in contaminated effluents (Lu 2022). Environmental pollution with heavy metals is now one of the major problems in the globe. It is considered that industrial activities is one ofthe contributing factorsof heavy metal pollutionin the world (Alengebawy et al., 2021). A major portion of wastewaters are produced by various industrial sectors, including fertilizer synthesis, mining, metallurgy, etc. (Lutzu et al., 2021). These wastewaters contain a significant amount of heavy metal ions, and their release into the environment without early treatment is potentially dangerous (Saini et al., 2020). Heavy metals that can be present in industrial effluent, can accumulate in a variety of plant and animal organisms until spreading through the biomagnification process to all trophic levels, posing a serious threat to the ecosystem's health (H. Zhang et al., 2021).

The utilization of treated effluents for industrial processes is progressively spreading throughout the world due to the scarcity of freshwater resources. Reusing wastewater after applying a variety of treatment techniques contributes to reduce water shortages, protect resources for solely potable use, reduce water pollution and to preserve ecosystem life (Ungureanu et al., 2020). A multitude of wastewater treatment technologies are presently required like coagulation-flocculation (Zhao et al., 2021), adsorption (Chai et al., 2021), flotation (Kyzas and Matis 2018), reverse osmosis (Arolaet al. 2019), membrane filtration (Hube et al., 2020), electrochemical treatment (Tang et al., 2019), and chemical precipitation (Peng and Guo 2020).

Adsorption is a process relies on the utilization of an adsorbent, which is a material with a large surface area, important porosity, and that guarantee rapid sorption equilibrium kinetics. Among the several heavy metal removal processes, adsorption has proven to be the simplest and most effective, allowing users to avoid the often expensive and harmful conventional techniques (Febrianto et al., 2009).

In the search for low-cost and readily available adsorbents, biological materials have been investigated frequently as potential metal sorbents. Biosorption, has been recommended as a simple, economic, efficient, and environmentally friendly technique (Keshri et al., 2017). A multitude of biosorbents have been investigated utilizing orange peel (Dey et al., 2021), banana peel (Akpomie and Conradie 2020), apple pomace (Gryko et al., 2021), palm fruit bunch (Rambabu et al., 2020), wheat straw (Wu et al., 2019), coir pith (Parab and Sudersanan 2010), aquatic plants (Ali et al., 2020), and other materials.

Various biomolecules' surface functional chemical groups, such as carboxylgroups, hydroxyl groups, amino groups, sulfonate groups, and phosphate groups, are largely responsible for metal binding via complexation, ion exchange, and electrostatic interactions (Kikuchi and Tanaka 2012). Several molecules with aromatic rings, particularly from plants, can chelate heavy metals via reactive chemical groups: lignin, flavonoids, coumarins, and phenolcarboxylic acids (Ashish Singh 2017). Aside from aromatic compounds, polysaccharides, which are polymers of monosaccharides (sugars), offer excellent adsorption properties, which can be attributed to the diversity of functional chemical groups, especially the hydroxyl entities of glucose monomers showing high chemical reactivity (Tran et al., 2019).

The jujube tree, *Z. lotus*, is a thorny plant, with a distribution that stretches across the entire north of the Maghreb. The jujubes, which are locally known as ''Nbeg'', are little fruits produced by the plant called sedra (El Maaiden et al., 2020). The fruits are dried and reduced to a flour in certain regions where the species is abundant, and then transformed into ''Zemmita'' a culinary preparation with a pleasant and succulent taste that is typical of some Maghreb regions (Ghedira 2013).

Numerous academic research on the nutritional and health potential of the bioactive substances of *Z. lotus* has recently been published (El Maaiden et al., 2019). *Z. lotus* contain protein, lipids, fibers, polysaccharides, organic acides,aromatic compounds, and macro elements (calcium, potassium, magnesium and sodium) (Letaief et al., 2021).

Z. lotus materials (leaves, fruit seeds, and fruits shell) have been used to produce efficient adsorbents. As they are constituted of aromatic compounds, polysaccharides, and other organic and mineral molecules, biomaterials from *Z. lotusare* an excellent inexpensive alternative to use as a biosorbent (Asmaa et al., 2018). Several studies have recently evaluated the ability of biomaterials derived from *Z. lotus* to remove synthetic dyes and heavy metals (El Messaoudi et al., 2016; El Messaoudi et al., 2017).

The main aim of this research is to explorethe potentiel of *Z. lotus* fruitspowder as a ecofriendly biosorbents to eliminate Cd(II) and Pb(II) ions from an aqueous solution. Parameters including biosorbent dosage, particle size, pH,initial ion concentration, contact time, and temperature were investigated. The equilibrium of biosorption and kinetic data were studied using two isotherm models (Langmuir isotherm and Freundlich isotherm), and two kinetic models (the pseudofirstorder and the pseudosecond order).

MATERIALS AND METHODS

Biosorbent preparation

In September 2021, *Z. lotus*fruits were taken from fruiting bushes in the west of Al Hoceima (Morocco).The samples were cleaned several times with distilled water to remove debris, and then dried in the sun before being dried at 60 °C for 24 hoursusing an electric oven. Samples were reduced to powder using an electric mixer. Then and without any prior treatment, the fruit powder (FP) was placed in a glass beaker for later use.

Ionicstock solutions

An initial concentration of 1 g/L was prepared for both Cd(II) and Pb(II), after dissolving in distilled water an appropriate quantitie of $Cd(NO_3)_2 \cdot 4H_2O$ and an appropriate quantitie of $Pb(NO_3)_2$ respectively.

The different concentrations are obtained through a series of dilutions of the ionic stock solution.

Batch biosorption studies

In a batch system, the biosorption experiments of Cd(II) and Pb(II) on the FP sample were evaluated. The biosorption process was studied in relation to pH, temperature, dosage of biosorbent, initial metal concentration, contact time, and size of biosorbent particles. In 300 mL Erlenmeyer flasks with continuous agitation, the biosorption tests were conducted. Using a HANNA instruments (pH 209) pH meter, the pH values were adjusted to preferred values with 0.1 mol/L HCl or 0.1 mol/L NaOH solution. For each experiment, freshly diluted solutions were applied. The chemicals used were all of the highest quality. Under the optimized condition, for the two ions, the pH was varied from 2 to 10.

The influence of temperature, in the range of 15 to 60 °C, was studied under optimal conditions. An isothermal shaker was used to regulate the temperature.The optimum biosorbent dose was identified using a range of biosorbent dosages from 0.5 to 9 g/L.The range of metal ion concentrations was from 0.25 to 100 mg/L.The adsorbate-adsorbent contact time ranged from 10 to 90 minutes.

Changing the size of the biosorbent particles from less than 100 µm to more than 500 µm was utilized to study how particle size impacted biosorption process.The pH was 8 for Cd(II) and 7 for Pb(II), the temperature was 25 °C, the initial metal concentration was 100 mg/L, and the biosorbent dosage was 4 g/L. At 3000 rpm for 10 minutes, the samples were centrifuged to separate the liquid phase from the solid phase at the end of each batch adsorption test.

The adsorption capacity q_e (mg/g) and removal percentages (%R) of Cd(II) and Pb(II) from their aqueous solutions by the FP were calculated by Equation (1) and (2) consecutively, based on the quantification of the metal ions in the ionic solution before and after the adsorption process employing an atomic absorption spectrophotometry (GBC 932 plus).

$$q_e = \frac{C_i - C_e}{m} \tag{1}$$

$$(\%R) = \frac{C_i - C_e}{C_i} * 100 \tag{2}$$

where: C_i – is the initial ions concentration (mg/L);
C_e – is the equilibrium cations concentration after adsorption (mg/L);
m –represents the mass of the biosorbent per litre of ionic solution (g/L).

Characterization of samples

The specific surface area (SSA) of FP was calculated by the adsorption isotherms of N_2at -196 °C (77 K), using the BET (Brunauer–Emmett–Teller) method (ASAP 2020, Micromeritics, USA). The samples of our study were degassed at 160 °C for 12 hours before each test.The FTIR spectroscopy (FTIR, Bruker Alpha) was used to identify different functional groups in each sample. KBr discs were prepared with each containing 1 mg of the sample and 100 mg of KBr. In the range 400 to 4000 cm^{-1} that FTIR spectra were generated with detector at 2 cm^{-1} resolution.

Kinetic study of biosorption

Two kinetic models, a pseudo first order kinetic (PFOK) model and a pseudo second order kinetic (PSOK) model, were used to analyze the biosorption kinetics results. The PFOK model is expressed in equation (3), while the PSOK model is given as shown in equation (4):

$$q_t = q_e(1 - e^{-K_1 * t}) \tag{3}$$

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e} \tag{4}$$

where: q_e and q_t (mg/g) – are respectively the quantities of heavy metal ions adsorbed at equilibrium and at any time t (min);
K_1 and K_2 – are the rate constants for the PFOK and PSOK models, respectively.

Biosorption isotherm

The obtained biosorption measurements were examinedusing the Langmuir model and Freundlich model. Thus, the Langmuir model is based on the assumptions of a homogeneous adsorption surface containing similar adsorption sites, and a single monolayer is formed when adsorption is maximal. The following equation (5) is a description of this model:

$$q_e = q_m \frac{1 + K_L C_e}{K_L C_e} \quad (5)$$

where: q_e (mg/g) – the biosorbed quantity at equilibrium state;
C_e – the equilibrium concentration of the metal cation (mg/L);
K_L – the Langmuir equilibrium constant (L/mg);
q_m – the maximum adsorption capacity (mg/g).

The Freundlich isotherm model assumes that the adsorption surface is heterogeneous. It is a model which can be used to describe the multilayer adsorption, and for which the following equation provides a description (6):

$$q_e = K_F C_e^{\frac{1}{n}} \quad (6)$$

where: K_F ($mg^{1-1/n}$ g^{-1} $L^{1/n}$) represents the Freundlich constant and n represents a heterogeneity factor.

While the K_F constant is associated to adsorption capacity, the 1/n value is associated to the intensity of biosorption. Based on the correlation coefficients (r^2) values obtained, the best model that fits with experimental data was chosen.

RESULTS AND DISCUSSION

Biosorption studies

The pH effect on ions adsorption

The efficacy of the adsorption during the wastewater treatment process is influenced by pH solution. The distinctive adsorption sites of the biosorbent could be impacted by any change affecting the pH of the solution (Beni et Esmaeili 2020). The influence of pH on the biosorption ofCd (II) and Pb (II) by FP was evaluated over a pH range of 2 to 10 as shown in Figure 1. Thus, the elimination of both Cd(II) and Pb(II) from ionic solution has proved to be strongly linked to the variation of the pH solution.In highly acid medium, the capacity to trap metal ions was limited, and gradually increases with the increase in the pH value before starting to decrease when the pH of the medium exceeds certain values for both Cd (II) and Pb (II). Over the pH range from 2 to 8, the adsorption capacity increases from 2 to 27 mg/g and from 8.4 to 60.8 mg/g for Cd (II) and Pb (II) respectively. From pH=8, this same capacity of FP to adsorb metal ions progressively decreases to reach 22.2 mg/g and 50.9 mg/g for Cd (II) and Pb (II) respectively, in pH=10.

When the pH is low, the environment contains a lot of H^+ protons, which interact with the negative charges of the biosorbent, and thus could explain the low capacity of the FP to adsorb the two metal cations in an acidic medium.When the pH gradually increases, the surface of the biomaterialbecomes more and more negative which

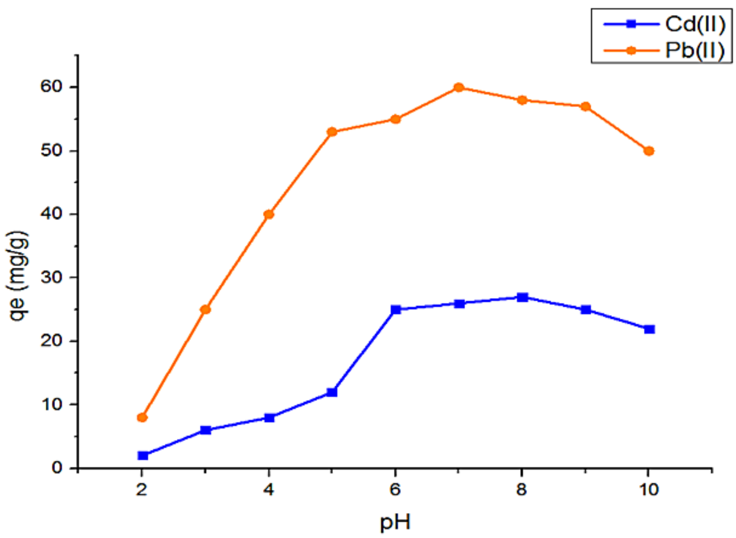

Figure 1. pH effect on Cd(II) and Pb(II) biosorption by FP: C_i = 100 mg/L, size of particles <100 µm, m = 1 g/L, T (°C)= 25 °C, and contact time = 90 min

increasesgradually,through the electrostatic interactions, the adsorbed quantity of the two metallic species charged positively (Quyen et al., 2021). For pH values higher than 8, the reaction medium is enriched with OH^- ions that can form complexes with the Cd(II)and Pb (II) cations, which could explain the progressive decrease in the adsorption capacity beyond pH=8 (Bhattacharjee et al., 2020).

Temperature effect

Theinfluence of temperatureon the biosorption of Cd(II) and Pb (II) onto FPwas studied in the temperature range of 15–60 °C as shown in Figure 2. For both Cd(II) and Pb (II), the adsorption capacity increases with the increase in the temperature of the medium. This capacity reaches its optimum value at 25 °C, and beyond which it gradually decreases. For both Cd(II) and Pb(II), the adsorption capacity increases with increasing medium temperature. This capacity reaches its optimum value at 25 °C, before gradually decreasing when the temperature exceeds its optimum. when the temperature of the medium increases the molecular agitation increases, which explains the increase in the biosorption capacity. The decrease in this capacity beyond 25 °C would be due to the weakening of the interactions between the ionic species and the adsorbent.

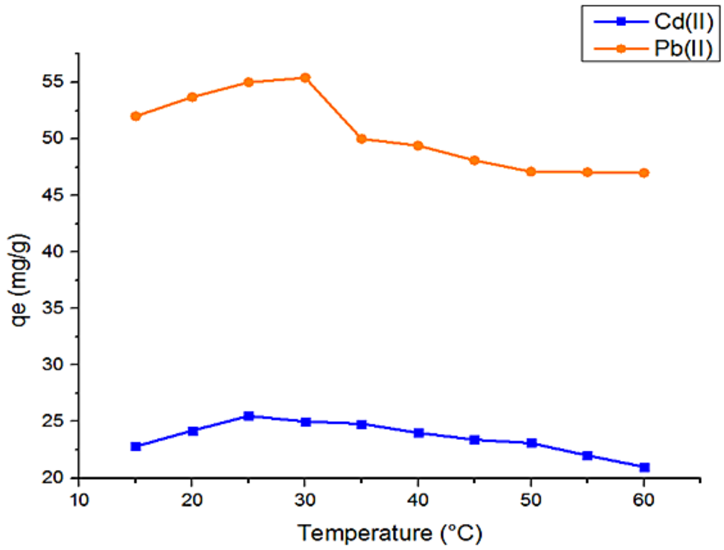

Figure 2. Temperature effect on Cd(II) and Pb(II) biosorption by FP: C_i = 100 mg/L, size of particles <100 µm, m = 1 g/L, pH = 8 for Cd(II) /pH=7 for Pb(II), and contact time = 90 min

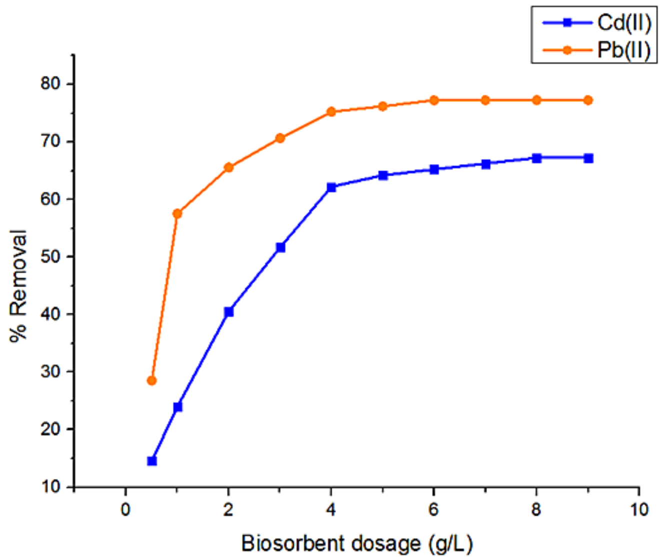

Figure 3. Biosorbent dosage effect on Cd(II) and Pb(II) biosorption by FP : C_i = 100 mg/L, size of particles <100 µm, T (°C) = 25 °C, pH = 8 for Cd(II) /pH= 7 for Pb(II), and contact time = 90 min

Biosorbent dosage effect

The efficiency of both Cd(II) and Pb(II) removal as a function of FP dosage was evaluated. The results are illustrated in Figure 3. The dosage of biosorbent was adjusted from 0.5 to 9 g/L, while the other study parameters (temperature, pH, initialion concentration, contact time, and particle size) were kept constant. The FP eliminationefficiency increased from 14.56 to 67.28% and from 28.56 to 77.28%, when the dosage of biosorbent was increased from 0.5 to 9 g/L, respectively for Cd(II) and Pb(II). The results obtained show that, as the dosage of the biosorbent increases the efficiency of the elimination also increases. This trend could be explained by the increase in the number of metal ion adsorption sites on the surface of the biosorbent when its dosage increases (Kumar et al., 2018; Abdel-Raouf et al., 2022).

Effects of biomaterial particle size/contact time

The adsorption kinetics of Cd(II) and Pb(II) were studied for different sizes of FP particles ranging from less than 100 µm to more than 500 µm, and as a function of contact time. The results are illustrated in Figure 4. The data obtained indicate that the biosorption kinetic depends on both the contact time and particle size of the biosorbent. The best rate of Cd (II) and Pb (II) adsorption by FP, is obtained by particles smaller than 100 µm. Generally, with increasing contact time, the biosorption process slows down before stagnating beyond 80 min.With a particle size less than 100 µm, the amounts adsorbed at equilibrium are 25.54 and 58.32 mg/g respectively for Cd(II) and Pb(II). It was clear that the biosorption efficiency increases with the decrease of the biosorbent particle size. This result could be explained by the increase in the specific surface area (SSA) of

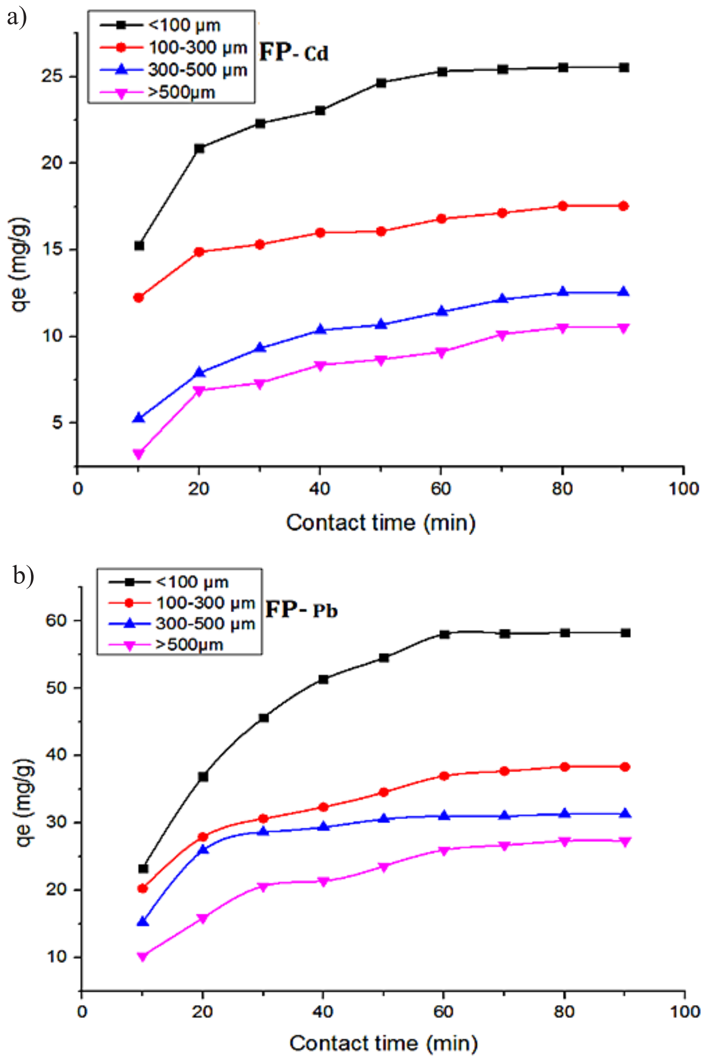

Figure 4. Effect of biomaterial particle size/contact time on Cd(II) (a) and Pb(II) (b) biosorption by FP : C_i = 100 mg/L, m = 1 g/L, T (°C) = 25 °C, and pH = 8 for Cd(II) /pH= 7 for Pb(II)

Table 1. Particle size groups (PSG) and specific surface area (SSA) of FP

Particle size groups (PSG) (μm)	Specific surface area (SSA) (m^2/g)
<100	2.022
100–300	1.657
300–500	1.325
>500	0.953

the biosorbent particles when they decrease in size (Mishra et al., 2010), as indicated in Table 1. Thus, in order to examine the impact of various parameters on the biosorption process, particles smaller than 100 μm were utilized because they are the most efficient at removing metal ions.

Preferential cation trapping

The intrinsic properties of metal ions affect the ability of their adsorption on the biosorbent surface. Thus, Cd(II) is a soft Lewis acid with a lower electronegativity (1.69), whereas Pb(II) is a hard Lewis acid with a higher electronegativity (2.33). Furthermore, the hydrated radius of Cd^{2+} (0.426 nm) is greater than that of lead Pb^{2+} (0.401 nm) (Cheng et al., 2021). All these factors could explain the preferential adsorption of lead compared to that of cadmium on the biosorbent surface (Dias et al., 2021).

Characterization of samples: FTIR analysis

To determine the main biochemical groups contained in the biosorbent, and which have been involved in the process of cationic trapping highlighted, the FTIR spectra was utilized as a qualitative analysis. Figure 5 shows the infrared spectra (400–4000 cm^{-1}) of FP. The appearance of any FTIR spectra is intimately linked to the phytochemical composition of the biosorbent biomass (Marmouzi et al., 2019; Lazzari et al. 2018). The broad and intense absorption peak at 3430 cm^{-1} for FP indicates the presence of O–H groups (phenols, alcohols, and carboxylic acids) characteristic of pectins, lignin, and cellulose (Chen et al. 2018). The observed peaks at 2928 cm^{-1}, would have been generated by the C-H stretching vibrations of aliphatic acids. A stretching vibration of the C=O bond would be due to the carboxylic groups and their esters, which had probably given the peak at 1732 cm^{-1}. The peak at 1163 cm^{-1} would result from stretching of the C-O antisymmetric bridge of FP biomass's cellulosic components. An absorption band, at around 1056 cm^{-1}, due to $–O\text{-}CH_3$ group, indicates the presence of lignin in the FP samples. An intense band at 614 cm^{-1} would be generated by the bending modes of the aromatic compounds. Additionally, the same Figure 5 shows that for FP loaded with heavy metals (Cd and Pb), the intensities of the peaks corresponding especially to the hydroxyl and carboxyl groups decreaseor slightly shifted after the ionic adsorption process. The FTIR spectra reveal that the hydroxyl and carboxyl groups, abundantly present in FP biomass, contribute significantly in the adsorption of Cd(II) and Pb(II) by involving electrostatic interactions.

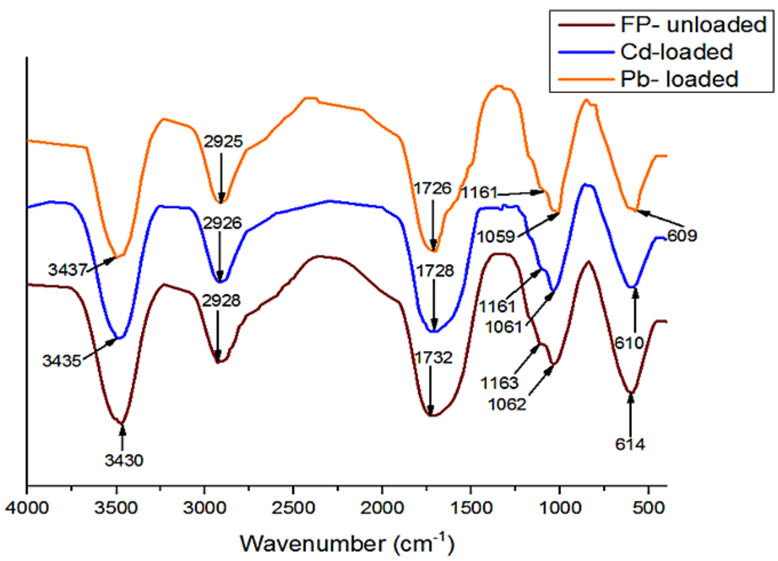

Figure 5. FTIR analysis of fruits powder (FP): spectra of FP-unloaded, spectra of Cd-loaded, and spectra of Pb-loaded

Kinetic study of biosorption

The pseudo second order kinetic model and the pseudo first order kinetic model were used to interpret the experimental data in order to understand the mechanism that controls the adsorption process. Nonlinear regression was used to estimate the parameters of both models. Table 2 presents the obtained data and correlation coefficients (r^2). The kinetic parameters of Cd(II) and Pb(II) adsorption onto *Z. lotus* fruits powder (FP), given by the two models indicate that the correlation coefficients (r^2) are closer to 1 for the PSOK model compared to the correlation coefficients given by the PFOK model.Moreover, the calculated values ($q_{e,cal}$) which were predicted by the PSOK model are nearer to the experimental values ($q_{e,exp}$), contrary tothe values predicted by the PFOK model, which are different and far from the values obtained experimentally.

We can conclude that Cd(II) and Pb (II) adsorption onto FP of *Z. lotus* appears to be more pseudo second order kinetic, suggesting a predominant chemisorption process. Similar results were reported on Cd(II) and Pb (II) biosorption by *Leucaena leucocephala* (Cimá-Mukul et al., 2019a), *Caragana korshinskii* (Wang et al., 2021), and *Lactarius scrobiculatus* (Anayurt et al., 2009).

Biosorption isotherm

The biosorption capacities of FP for cadmiumCd (II) and lead Pb (II) were investigated for different initial metal concentrations as shown in Figures 6–7. According to the experimental data,the biosorption capacity increases with the increase in the ionic concentration in the reaction medium. Strong driving forces for mass flow could explain the tendency of an increase in adsorption capacity with the increasing of metal ions concentration (Feisther et al., 2019).

A high concentration of dissolved ions in solution implies a high quantity of these ions will be adsorbed on the surface of the biosorbent. Therefore, the initial metal concentration determines the biosorption capacity. According to Giles categorization, the isotherms form was type L (Bernal-Romero et al., 2019). Generally this type of isotherm is characteristic of adsorption with little competition between the adsorbate and the molecules composing the solvent (Ramadoss and Subramaniam 2019). The experimental biosorption isotherms obtained were compared with the biosorption isotherm models. The Langmuir and Freundlich sorption parameters obtained from the isotherms as well as the correlation coefficients are indicated in Table 3. The table shows

Table 2. The kinetic parameters of Cd(II) and Pb(II) uptake by FP

Metals	Pseudo first order			Pseudo second order		
	q_e (mg/g)	K_1 (min^{-1})	r^2	q_e (mg/g)	K_2 (g/mg.min)	r^2
Cd	20.82256	0.07278	0.98764	24.45464	0.00311	**0.99102**
Pb	48.39676	0.07112	0.98906	57.67035	0.00127	**0.9967**

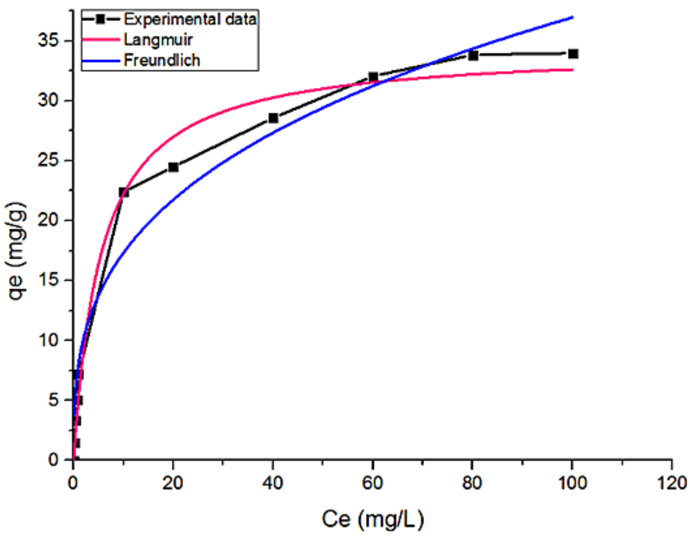

Figure 6. Langmuir and Freundlich isotherms of Cd(II) biosorption on FP : biosorbent dosage = 1 g/L, size of particles <100 µm, pH = 8, T (°C) = 25 °C and contact time = 90 min

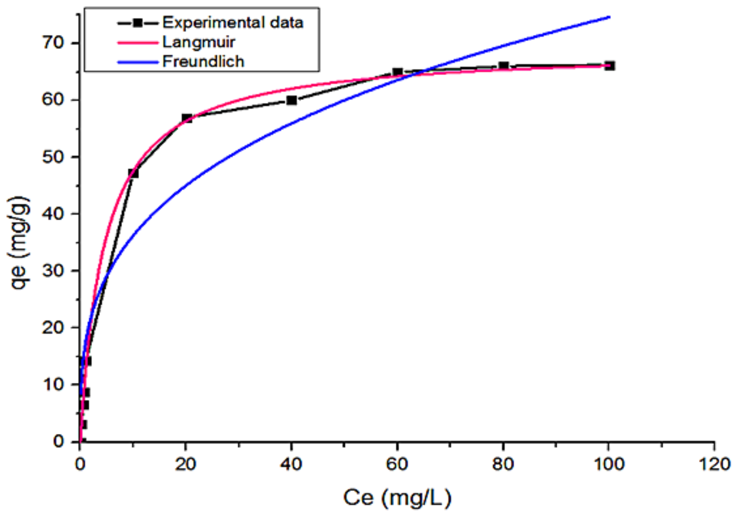

Figure 7. Langmuir and Freundlich isotherms of Pb(II) biosorption on FP : biosorbent dosage =1 g/L, size of particles <100 µm, pH = 7, T (°C) = 25 °C and contact time = 90 min

that the Langmuir model, with a r^2 value close to 1, generated the best fit of experimental data.This result suggests that Cd(II) and Pb(II) are homogeneously adsorbed on a monolayer surface of the biosorbent. The maximum monolayer adsorption capacities are higher for Pb(II) than for Cd(II) and this with the following order:

$$q_m \begin{cases} FP \\ Pb \end{cases} \left(= 69.06\,\frac{\text{mg}}{\text{g}}\right) >$$

$$> q_m \begin{cases} FP \\ Cd \end{cases} (= 33.94\ \text{mg/g})$$

The obtained biosorption capacities of FP were compared with the results obtained from previous studies on the sequestration of Pb(II) and Cd(II) by plant biomass. The biosorbent potentiel of *Z. lotus* fruits powder (FP) has been revealed by the present study to be clearly superior to that of several biosorbents cited in the literature, as shown in Table 4.

Table 3. Isotherms constants (Langmuir and Freundlich) that describe the sorption of Cd(II) and Pb(II) onto FP

Metals	Langmuir parameters			Freundlich parameters		
	q_m (mg/g)	K_L (L/mg)	r^2	K_F ($mg^{1-1/n}\,g^{-1}\,L^{1/n}$)	n	r^2
Cd	33.94	0.1895	**0.9896**	8.09	3.0519	0.9461
Pb	69.06	0.2218	**0.9986**	17.61	3.1896	0.9084

Table 4. Comparison of maximum biosorption capacity of *Ziziphus lotus* fruits powder (FP) for Cd(II) and Pb(II) with other environmentally friendly biosorbents

Biosorbents	q_m (mg/g) Cd (II)	q_m (mg/g) Pb (II)	References
Phragmites biomass	6.40	5.46	(Amro et al. 2019)
Curry leaf	37.03	60.9	(Mukherjee et al. 2020)
Sunflower achene	11.40	22.64	(Mahmood-ul-Hassan et al. 2015)
Banana stalk	3.66	29.17	
Corn cob	13.58	29.17	
Cladophora biomass	12.07	20.65	(Amro et Abhary 2019)
Grape bagasse	23.20	14.40	(De Gisi et al. 2016)
Leucaena leucocephala residues	14.79	25.51	(Cimá-Mukul et al. 2019b)
Litchi chinensis peels	15.27	-	(Ansari et al. 2020)
Citrus limetta leaves	-	69.82	(Aboli, Jafari, and Esmaeili 2020)
Ziziphus lotus (fruits)	33.94	69.06	Present study

CONCLUSIONS

Conventional methods for sequestering Cd(II) and Pb(II) cations from wastewater are known to be expensive. Using fruits of *Z.lotus*, this research investigated the removal of Cd(II) and Pb(II) ions from an ionic media. The biosorption capacity was strongly dependent on biosorbent dosage, Temperature, pH, contact time, initial metal concentration, and particle size. The characterization of the material by the BET method revealed that particles whose size is less than 100 µm have the highest specific surface area and can be selected for better metal ions adsorption. The kinetic and isotherm modeling of the obtained results show that all the biosorption processes are well described by the PSOK model and Langmuir isotherm model. Thus, the values of the maximum biosorption capacity, obtained from the Langmuir model, follow the order:

$$q_m \begin{cases} FP \\ Pb \end{cases} \left(= 69.06\,\frac{\text{mg}}{\text{g}}\right) >$$

$$> q_m \begin{cases} FP \\ Cd \end{cases} (= 33.94\ \text{mg/g})$$

All these considerations reflect that the biosorption method using *Ziziphus lotus* fruits, an inexpensive and environmentally friendly biosorbent, could be used in industrial treatment processes for the elimintion of Cd(II) and Pb(II), and also offering an alternative to conventional processes.

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