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Lead Ion Removal from Water Using Fava Beans Pod-Derived Phytoadsorbents: A Green Approach

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Abstract

The contamination of natural ecosystems—particularly water bodies—with harmful chemical substances poses a serious environmental threat on a global scale. Among these contaminants, toxic heavy metals such as lead, arsenic, cadmium, and mercury are especially concerning due to their non-biodegradable nature and ability to accumulate in living organisms. These metals can enter the human body through the food chain, even at trace levels, leading to various severe health issues, including neurological, developmental, and organ-related disorders. Therefore, the development of eco-friendly, cost-effective, and sustainable technologies for removing such contaminants from aquatic systems is of high importance. In this study, we explored the potential of a phytoadsorption-based approach for lead ion removal using an agricultural waste material—empty fava bean pods. Dried pods were ground to particles ranging in size from 350 to 1000 µm and used as bioadsorbents under ambient conditions and neutral pH. A series of batch adsorption experiments were conducted to evaluate the removal efficiency. The results showed a considerable removal rate of lead ions, reaching up to 58.2%. Furthermore, the adsorption capacity of the biomass was determined to be as high as 50.0 mg/g, especially when low amounts of dry biomass were applied. These findings suggest that fava bean pods are a promising, low-cost bioadsorbent for treating heavy metal-contaminated water.

Keywords: Lead Ions, Phytoadsorption, Fava Beans Pods, Bioadsorbent, Heavy Metal Contamination

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INTRODUCTION

Contamination of aquatic systems by heavy metals is a global issue. The removal of these contaminants can be achieved using natural materials. Phytoremediation is a green and powerful technique that has been used in recent decades to remove pollutants from water using dead biomass of plants [1]. The phytoadsorption process has emerged as a potential process for the uptake of both essential heavy metals (iron; Fe, zinc; Zn, copper; Cu, cobalt; Co, manganese; Mn) and non-essential heavy metals (arsenic; As, lead; Pb, cadmium; Cd, chromium; Cr, mercury; Hg, and nickel; Ni) from aquatic systems [2–4]. Anthropogenic activities and natural sources are the main contributors to heavy metal pollution in environment [5, 6]. Toxicity of certain heavy metals is linked to their ability to accumulate in soft tissues of human and animals leading to a wide range of disorders or diseases [7–11]. Removing of these toxic metals from aquatic systems can be performed by phytoadsorption method using different types of plants and agricultural wastes [12–21]. Recently, we reported the efficiency of phytoadsorption in removing lead ions from aqueous solutions using dry fava beans (*Vicia faba* L.), dry empty fava beans pods, and dry pomegranate peels as potential bioadsorbents [22–25]. In this report, we investigated the phytoadsorption of lead ions from their aqueous solutions using dry empty fava bean pods for a prolonged time period.

MATERIAL AND METHODS

Sample Preparation

Lead Ions (Pb^{2+})

A 100-ppm solution of lead ions was prepared by dissolving lead nitrate, $Pb(NO_3)_2$, in distilled water. This concentration was used in all subsequent experiments.

Biomass of Empty Fava Beans Pods

Fresh fava beans were collected from the local market, Benghazi city, Libya. The fava beans pods were emptied from seeds, washed with water, and dried in dark place for 2 months. Next, they were ground and an amount of 350–1000-µm particles were sieved with two sieves. The dry particles were then stored in dark and dry place for next steps [24].

Phytoadsorption Experiments and Analysis of Samples

All experiment procedures and sample analysis were conducted according to standard methods [22–25]. Dry empty fava beans pods particles (2.0, 1.0, 0.50, or 0.10 g) were separately added to 100 mL of the lead nitrate solution (100-ppm) for each sample in a 500-mL polyethylene bottle. Each bottle was shaken using instrumental shaker (Flask Shaker SF1) at different rates (200, 400, 600, and 800 OSC/min) for 90 minutes at room temperature without altering the pH of the solution. Next, all bottles were left for 24 hours to allow the biomass to precipitate. Afterward, the settled solutions were filtered using Whatman filter papers No 1. The resulting filtrates were then diluted to 1 ppm and acidified with 0.5 mL of 60% nitric acid to maintain the pH at around 3, and stored in a refrigerator for the next steps. Then, the lead ion concentration in each filtrate was determined using a flame atomic absorption spectroscopic (FAAS) instrument (Model: Perkin Elemer 500) at room temperature of 24 °C and a *p*H range of 2.5–3.6. Finally, the removal percentage (%) of lead ions and the adsorption capacity q_e (mg/g) were calculated. The adsorption capacity of each sample after equilibrium was determined by mass balance relationship equation as follows:

$$q_e = (C_i - C_d)\, V/W$$

Where C_i is the initial concentration of lead ion solution (mg/L), C_d is the detected concentration of filtrate solutions (mg/L), V is the volume of the solution (L) and W is the mass of adsorbate (g) [9, 20].

RESULTS AND DISCUSSION

Shaking Rate (200 OSC/min)

Shaking of different amounts of biomass (2.0, 1.0, 0.5, and 0.1 g) for 90 minutes were achieved. In general, a decrease in the fluctuation of the removal percentage of lead ions was observed in entries 1–4 (Table 1 and Figure 1).

Shaking Rate (400 OSC/min)

The removal percentage of lead ions from their aquation solutions by fava bean pod particles (2.0, 1.0, 0.5, and 0.1 g) showed a similar pattern from 58 to 34.1% (entries 5–8, Table 1 and Figure 1) after 90 minutes of shaking. These results were slightly better than those from the previous four experiments.

Shaking Rate (600 OSC/min)

At the same period of time (90 minutes) using the same amounts of biomass particles (2.0, 1.0, 0.5, and 0.1 g), the removal percentage of lead ions from their solutions showed the same efficiency of the shaking rate of 400 except for the ninth experiment, which exhibited a higher percentage (entry 9, Table 1).

Table 1. The removal percentage of Pb^{2+} (%) and adsorption capacity, q_e, (mg/g) after shaking using dry empty fava beans pods.

Entry	Biomass (g)	Shaking rate (OSC/min)	Pb removal (%)	Adsorption capacity (mg/g)
1	2.0	200	58.0	2.90
2	1.0	200	27.3	2.73
3	0.5	200	47.9	9.58
4	0.1	200	20.7	20.7
5	2.0	400	58.0	2.90
6	1.0	400	42.4	4.24
7	0.5	400	49.7	9.94
8	0.1	400	34.1	34.1
9	2.0	600	58.2	2.91
10	1.0	600	42.0	4.20
11	0.5	600	42.4	8.48
12	0.1	600	31.5	31.5
13	2.0	800	55.8	2.79
14	1.0	800	29.8	2.98
15	0.5	800	26.9	5.38
16	0.1	800	50.0	50.0

Conditions: Pb^{2+} concentration = 100 ppm. Particle size of dry empty fava beans pods: 350–1000 µm. Contact time: 90 min. Bottle volume: 500 mL. Sample volume: 100 mL.

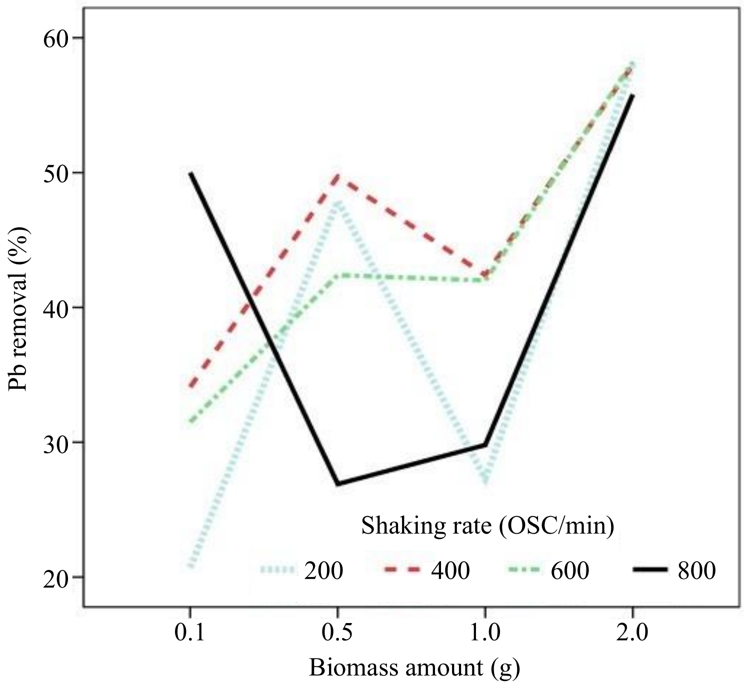

Figure 1. Removal percentage of Pb^{2+} after shaking using dry empty fava beans pods.

Shaking Rate (800 OSC/min)

The removal percentage of lead ions by fava bean particles was moderate, with the highest percentage reaching 55.8% (entries 13–15) after the same consumed time and the same biomass loading. Interestingly, the lowest loading of biomass (0.1 g) has showed a removal percentage of 50% which represents unusual result compared with the other experiments.

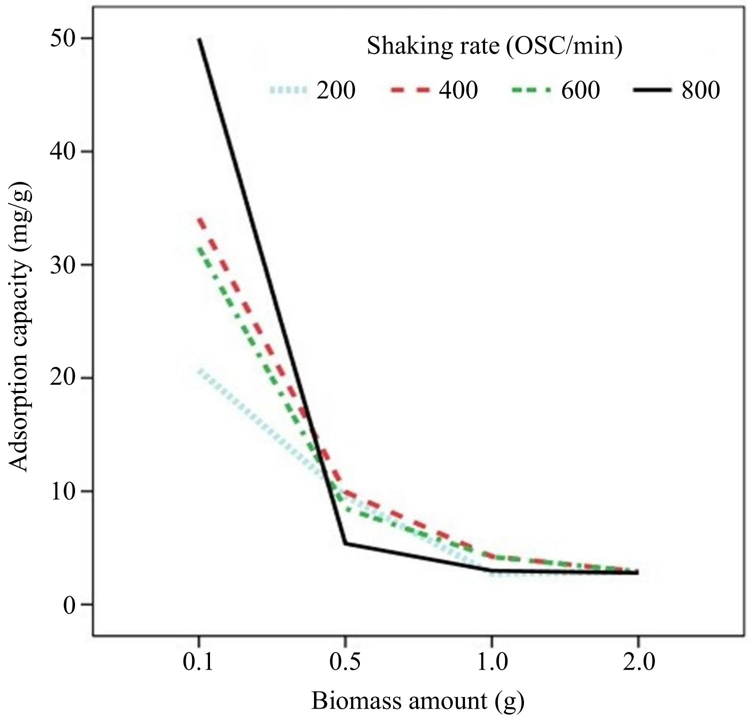

Figure 2. Adsorption capacity, q_e, of dry empty fava beans pods for removal of Pb^{2+}.

Based on the observed data, the efficiency of phytoadsorbent particles of dry empty fava beans pods (size of 350–1000 μm) for the removal of lead ions form their aqueous solutions in the designed experiments was good. Generally, the removal percentage of lead ions increased gradually by increasing the biomass loading with some exceptions. On the other hand, it was observed that conducting the designed experiments with a moderate shaking rate showed high removal of lead the aqueous media. These results are consistent with the findings from our previous report [24].

ADSORPTION CAPACITY OF DRY EMPTY FAVA BEANS PODS

Generally, the adsorption capacity (q_e) of the dry particles of fava beans pods for removing lead ions from their aqueous solutions was moderate in most experiments under the conditions used (Table 1 and Figure 2). In all rates of shaking, it was observed that the adsorption capacity was gradually decreased due to the increasing amounts of the loaded biomass. This efficiency was in agreement with our previous work for taking up lead ions from their aqueous solution using the same biomaterial at the same shaking rates [24].

CONCLUSION

Phytoadsorption is an efficient approach for removing heavy metals from their solutions using biowaste materials. Consequently, the 350–1000 μm sized-particles of dry empty fava beans pods were able to uptake lead ions from their 100 ppm-aqueous solutions at different shaking rates during the same duration (90 min). In addition, the observed adsorption capacity increased as the biomass loading decreased.

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Conflict of Interest

None.

Authors' Contributions

All authors contributed to data analysis, drafting, and revising the paper and agreed to be responsible for all aspects of this work.

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