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Pomegranates peel as a bioadsorbent for removing lead ion from aqueous solution: A phytoadsorption study.

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Abstract: Removing toxic heavy metals from ecosystems remains a significant challenge, necessitating the exploration of environmentally friendly solutions. Phytoremediation stands out as one of the most effective, sustainable, and eco-conscious methods. In recent decades, phytoadsorption has emerged as a promising, cost-effective, and benign approach for detoxifying contaminated aquatic environments from heavy metals.

In our study, we investigated the use of dry pomegranate peels as a biosorbent to extract lead (Pb^{2+}) ions from aqueous solutions through the phytoadsorption process. Various amounts of dried biomass (5.0, 2.0, and 0.5 grams) were tested under different shaking speeds (400, 600, and 800 oscillations per minute) and contact times. The results demonstrated that dried pomegranate

peels could remove up to 83.2% of lead ions from 250 ppm aqueous solutions at room temperature and neutral *pH*. Additionally, the bioadsorption capacity of the pomegranate peels reached up to 28.8 mg/g.
These findings suggest that pomegranate peels have the potential to serve as effective bioadsorbents for the removal of lead heavy metals from polluted aquatic systems.

Keywords: Lead, Heavy metals, Phytoremediation, Pomegranate peels, Bioadsorbent

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Introduction

Environmental pollution is caused by both natural and anthropogenic sources. The main pollutants of ecosystems—land, water, and air are heavy metals. While some heavy metals, like iron (Fe), copper (Cu), zinc (Zn), nickel (Ni), and manganese (Mn), are necessary for human life, non-essential heavy metals, such as arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), chromium (Cr), and cobalt (Co), are extremely toxic and can lead to a variety of illnesses. Depending on the dosage, duration, and type of exposure, as well as the metal's bioaccumulation and speciation, lead heavy metal, which is ranked second in toxicity after arsenic metal, can harm a variety of soft tissues [1-5]. One of the intriguing methods for eliminating harmful heavy metals and other contaminants from contaminated ecosystems is the bioremediation process. It falls into three primary categories microbial remediation (bioremediation based on microorganisms), zooremediation (bioremediation based on animals), and phytoremediation (bioremediation based on plants). One effective, affordable, environmentally friendly, and sustainable method of removing harmful heavy metals from soil and aquatic systems is phytoremediation [6-10]. Various mechanisms, depending on the type of plant biomass, are used to describe this technology [11-16]. The phytoremediation process for dead cell biomass is known as the phytosorption process, and it is divided into two primary mechanisms phytoadsorption and phytoabsorption. Through physical or chemical adsorption, pollutants are removed from contaminated environments by the phytoadsorption process, which is a biological physico-chemical interaction between the dead cell material of plants and the pollutants. The process by which metal ions adhere to the surface of plant particles allows for the phytoadsorption of heavy metals from their solutions [17-22]. The effectiveness of phytoadsorption of heavy metals using plants as biosorbents can be influenced by a variety of factors. Initial metal concentration, dosage of plant material, temperature, contact time, pH, presence of additional cations, and chemical changes of biosorbents are some of these variables [21]. The phytoremediation techniques for the removal of heavy metals from contaminated systems can be applied to a wide range of plant families [6,19,23-32]. Nonetheless, the phytoremediation of certain heavy metals, including lead, copper, chromium, nickel, zinc, and cadmium, from aqueous solutions was studied using pomegranate peels. They demonstrated a remarkable adsorption capacity and were able to remove high percentages of these metals [32-36]. The removal of lead ions from their aqueous solutions using a straightforward, inexpensive, environmentally friendly, and effective phytoadsorption technique was recently reported by our group [37-41]. In this report, we will use the phytoadsorption methodology to examine pomegranate peel as an absorbent for the removal of lead ions from an aquatic system.

Results and discussion

Following a shake with a quantity of powdered pomegranate peels, the lead ion concentrations in all samples decreased. These findings were brought about by the biomaterials' adsorption effect on the lead metal cations through their surface negative charges. The amount of pomegranate peel powder loaded, the initial metal concentration, and the contact time all had an impact on the amounts of lead ions that were removed.

Biomass Amount: 5.0 g

Using 5.0 g of loading pomegranate peels, contact time (min) and shaking speed (OSC/min) were investigated under the 250-ppm concentration of Pb^{2+} ions.

Effect of Contact Time at Different Shaking Speeds

The resulting observations showed that there was a fluctuation pattern of the removal amounts of lead ions by pomegranate peels under the mentioned conditions of contact times and shaking (Table 1, Figure 1). At a shaking rate of 400 OSC/min, generally, there was a fluctuation in the observed removal percentages of lead ions from 53.4% (with adsorption capacity of 2.7 mg/g) after 30 minutes of shaking into 51.6% (with adsorption capacity of 2.6 mg/g) for the 60-minutes case followed by a sharp increase of removal to 79.2% (with adsorption capacity of 4.0 mg/g) after 120 min (entries 1–3). At shaking speed of 600 OSC/min, the removal percentage was increased gradually from 57.7% (with adsorption capacity of 2.9 mg/g) in the first experiment (entry 4). to reach the optimum reading at 83.2% (with adsorption capacity of 4.2 mg/g) after 60 min (entry 5). followed by an increase of the removal percentage at 78.4% (with adsorption capacity of 3.9 mg/g) during a contact time of 120 minutes (entry 6). In contrast, the removal percentages of lead ions at a shaking speed of 800 OSC/min were in gradual decreasing pattern. For instance, the removal percentage was 67.8% (with adsorption capacity of 3.4 mg/g) in the first 30 minutes (entry 7). Then, the adsorption decreased in the next two experiments to register 59.8% and 51.2 (with adsorption capacities of 3.0 and 2.6 mg/g) at 60 and 120 min, respectively, (entries 8 and 9). The removal percentage of 51.2% represents the lowest value of this studied group under the used conditions.

Table 1. Removal percentage of Pb^{2+} (%) from a 250-ppm of lead solution and adsorption capacity (qe) using 5.0 g of dry pomegranate peels.

Entry	Shaking Speed (OSC)	Contact Time (min)	Detected Pb Conc. (ppm)	Remained Pb Percentage (%)	Removed Pb Percentage (%)	Adsorption Capacity (mg/g)
1	400	30	116.5	46.6	53.4	2.7
2	400	60	121	48.4	51.6	2.6
3	400	120	52	20.8	79.2	4.0
4	600	30	105.7	42.3	57.7	2.9
5	600	60	42	16.8	83.2	4.2
6	600	120	54.1	21.6	78.4	3.9
7	800	30	80.6	32.2	67.8	3.4
8	800	60	100.6	40.2	59.8	3.0
9	800	120	122.1	48.8	51.2	2.6

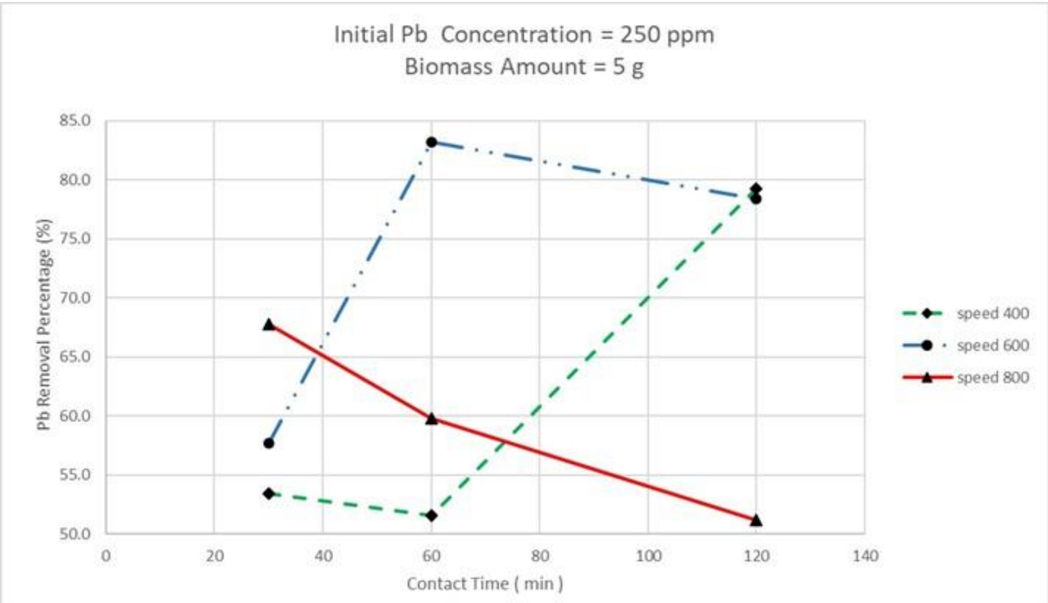

Figure 1. Effect of contact time and shaking rate on the adsorption of 250-ppm lead metal ions onto 5.0 g of pomegranate peels as phytoadsorbent.

Biomass Amount: 2.0 g

Using 2.0 g of loading pomegranate peels, contact time (min) and shaking speed (OSC/min) were investigated under the 250-ppm concentration of Pb2+ ions.

Effect of Contact Time at Different Shaking Speeds

The observed results showed a similar pattern of the removal of lead metal using the dead biomass of pomegranate peels under applied conditions (Table 2, Figure 2). Figure 2 showed high adsorptions, followed by significant decreases and then the removal percentages increased remarkably.

For the shaking speed at 400 OSC/min, generally, there was a higher removal at 61.6% (with adsorption capacity of 7.7 mg/g) after 30 minutes of shaking (entry 10). Next, the two trials showed 42.6% and 43.9% (with adsorption capacity of 6.6 and 6.7 mg/g) during contact times of 60 and 120 min (entries 11 and 12). At a shaking speed of 600 OSC/min, there was a similar pattern of adsorption of lead ions. The removal percentages were 60.8%, 49.6% and 53.8% (with adsorption capacities of 7.6, 6.2 and 6.7 mg/g) at the mentioned periods of time 30, 60, and 120 minutes of shaking (entries 13 –15). At a shaking rate of 800 OSC/min, although the removal percentages were better, the pattern of adsorption was similar. For instance, the first 30 minutes of shaking lead to 62.9% (with adsorption capacity of 7.7 mg/g) of removal (entry 16) followed by a decrease in removal at 53.7% (with adsorption capacity of 6.7 mg/g) at a contact time of 60 min (entry 17). The best removal percentage of lead ions using the pomegranate peels appeared at 72.5% (with adsorption capacity of 9.1 mg/g) by shaking for 120 minutes under the mentioned conditions (entries 18).

Table 2. Removal percentage of Pb^{2+} (%) from a 250-ppm of lead solution and adsorption capacity (qe) using 2.0 g of dry pomegranate peels.

Entry	Shaking Speed (OSC)	Contact Time (min)	Detected Pb Conc. (ppm)	Remained Pb Percentage (%)	Removed Pb Percentage (%)	Adsorption Capacity (mg/g)
10	400	30	95.9	38.4	61.6	7.7
11	400	60	118.6	47.4	42.6	6.6
12	400	120	115.2	46.1	43.9	6.7
13	600	30	97.9	39.2	60.8	7.6
14	600	60	126	50.4	49.6	6.2
15	600	120	115.4	46.2	53.8	6.7
16	800	30	95.3	38.1	62.9	7.7
17	800	60	115.7	46.3	53.7	6.7
18	800	120	68.7	27.5	72.5	9.1

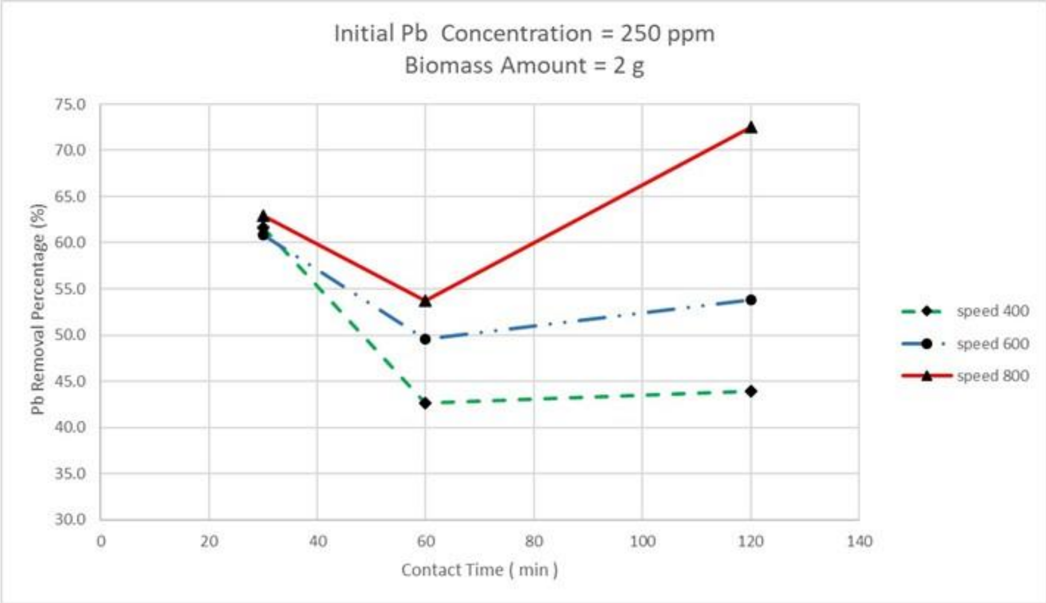

Figure 2. Effect of contact time and shaking rate on the adsorption of 250-ppm lead metal ions onto 2.0 g of pomegranate peels as phytoadsorbent.

Biomass Amount: 0.5 g

Using 0.5 g of loading pomegranate peels, contact time (min) and shaking speed (OSC/min) were investigated under the 250-ppm concentration of Pb2+ ions.

Effect of Contact Time at Different Shaking Speeds

The resulting observations showed a contrast pattern of the Pb removal percentages (%) within the contact time of shaking. (Table 3, Figure 3). For the shaking rate of 400 OSC/min, the removal percentage was 53.2% (with adsorption capacity of 26.6 mg/g) in the first 30 minutes of shaking (entry 19). Then, the adsorption of pomegranate peels jumped to the optimum value at 57.6% (with adsorption capacity of 28.8 mg/g) at a contact time of 60 min (entry 20). The next experiment showed a decrease of removal percentage at 41.5% (with adsorption capacity of 20.7 mg/g) after 120 minutes (entry 21). In the next two rates of shaking; 600 and 800 OSC/min, the pattern of removal was similar even though the amounts of removal of lead ions were lower than the lower shaking rate. For example, after 30 minutes of shaking, the removal percentages of lead metal were 39.1 and 41.1 (with adsorption capacity of 19.6 and 20.6 mg/g) at a speed of 600 and 800 OSC/min, respectively (entries 22 and 25). After slight decrease in the removal percentages for both shaking rates after 60 minutes, the last two experiments showed an increase in the percentages at 39.8 and 43.4% (with adsorption capacity of 19.9 and 21.7 mg/g) at contact times of 120 min (entries 24 and 27).

Table 3. The removal percentage of Pb2+ ions (%) and adsorption capacity (qe) from a 250-ppm concentration of lead solutions after shaking using 0.5 g of pomegranate peels.

Entry	Shaking Speed (OSC)	Contact Time (min)	Detected Pb Conc. (ppm)	Remained Pb Percentage (%)	Removed Pb Percentage (%)	Adsorption Capacity (mg/g)
19	400	30	117.1	46.8	53.2	26.6
20	400	60	106.1	42.4	57.6	28.8
21	400	120	146.3	58.5	41.5	20.7
22	600	30	152.2	60.9	39.1	19.6
23	600	60	158.4	63.4	36.6	18.3
24	600	120	150.5	60.2	39.8	19.9
25	800	30	147.2	58.9	41.1	20.6
26	800	60	151.9	60.8	39.2	19.6
27	800	120	141.6	56.6	43.4	21.7

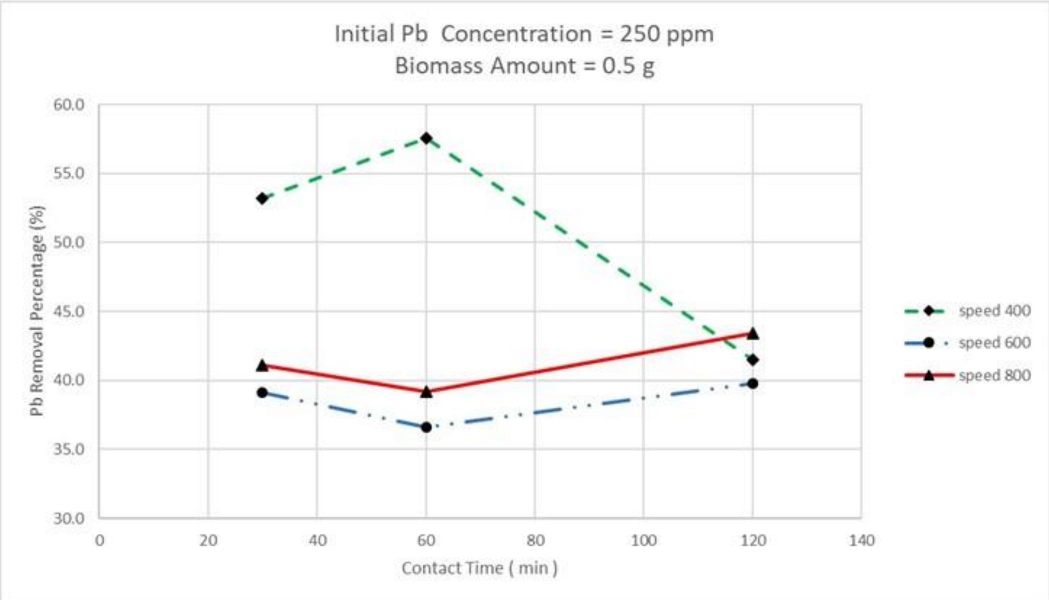

Figure 3. Effect of contact time and shaking rate on the adsorption of 250-ppm lead metal ions onto 0.5 g of pomegranate peels as phytoadsorbent.

Effect of Biomass Amount on Adsorption Capacity

The adsorption capacity (qe) of dried pomegranate peels for removing lead ions from aqueous solutions increased significantly as the amount of biomass used decreased, across all tested shaking rates (Table 4, Figure 4). In general, the highest adsorption capacities were achieved when the lowest biomass quantities were combined with slower shaking rates, given the same contact time. For instance, using 0.5 g of dried pomegranate peels resulted in a maximum adsorption capacity of 26 mg/g after 30 minutes of shaking at 400 oscillations per minute (OSC/min) (entry 3). In contrast, the lowest adsorption capacity 2.7

mg/g was observed when 5 g of biomass was used under the same shaking rate and contact time (entry 1).

Table 4. Adsorption capacity (mg/g) of dry pomegranate peels (g) after shaking rate (OSC/min) at contact time (30 min).

Entry	Shaking Speed (OSC)	Biomass amount (g)	Detected Pb Conc. (ppm)	Remained Pb Percentage (%)	Removed Pb Percentage (%)	Adsorption Capacity (mg/g)
1	400	5.0	116.5	46.6	53.4	2.7
2	400	2.0	95.9	38.4	61.6	7.7
3	400	0.5	117.1	46.8	53.2	26.6
4	600	5.0	105.7	42.3	57.7	2.9
5	600	2.0	97.9	39.2	60.8	7.6
6	600	0.5	152.2	60.9	39.1	19.6
7	800	5.0	80.6	32.2	67.8	3.4
8	800	2.0	95.3	38.1	62.9	7.7
9	800	0.5	147.2	58.9	41.1	20.6

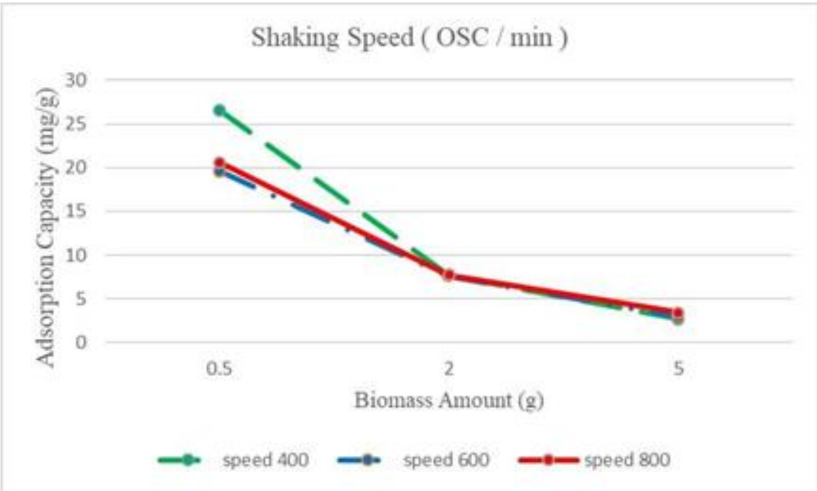

Figure 4. Effect of biomass amount on adsorption capacity of Pb^{2+}.

Material and methods

Sample Preparation

Lead Metal (Pb^{2+})

Lead metal ion solution (250 ppm) was prepared by dissolving of lead nitrate, $Pb(NO_3)_2$, in distilled water which was utilised later for the designed experiments.

Biomass

Fresh pomegranates were obtained from a local market in Benghazi city, Libya. The peels were separated, thoroughly washed with water, and then dried in a dark area for three months. After drying, the peels were ground into a powder and stored in a cool, dark, and dry place until further use.

Phytoadsorption Experiments and Analysis of Samples

The standard procedures were followed for all experiment procedures and sample analysis [17, 38-41]. Separately, 5.0, 2.0, or 0.50 g of dead plant biomass were added to 100 mL of lead solution in a 500 mL polyethylene bottle container. After that, they were thoroughly shaken for three different durations (30, 60, and 120 minutes) at different rates of 400, 600, and 800 OSC/min using an Instrumental Shaker (Flask Shaker SF1). Every experiment was conducted with a pH of neutral (by checked the PH used PH meter) and at room temperature. To allow the solid matter to precipitate, all bottles containing the mixture of lead and pomegranate peels were left for a full day. Whatman filter papers No. 1 were then used to filter the precipitated mixtures that were produced. After being diluted to 1–10 ppm, the filtrates were acidified with nitric acid (0.5 mL of 60% HNO_3) to a pH of about 3 for the analysis step, and they were then placed in a freezer. A flame atomic absorption spectroscopic (FAAS) device (Model: Perkin Elemer 500) was used to measure the concentrations of the remaining lead metal ions in each filtrate at room temperature (24 °C) and solution pH (2.4–3.8). Lastly, the adsorption capacity (mg/g) and lead ion removal percentage (%) were computed. Using the mass balance relationship equation, the adsorption capacity qe (mg/g) of each sample following equilibrium was determined as follows:

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

Where C_i represents the initial concentration of lead ions in the solution (mg/L), C_d is the concentration of lead ions detected in the filtrate (mg/L), V the volume of the solution (L), and W is the mass of the adsorbent (g).

Conclusions

Phytoremediation techniques especially the phytoadsorption process are among the most environmentally friendly and effective methods for removing heavy metals from the environment. Experimental results demonstrated that dried pomegranate peel biomass serves as an excellent biosorbent for extracting lead from highly concentrated aqueous solutions, exhibiting a notable adsorption capacity. Consequently, this approach offers a promising solution for the remediation of heavy metal-contaminated aquatic environments.

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