



Research Article

A biotechnological approach of Pb(II) sequestration from synthetic wastewater using floral wastes



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Abstract

This research is aimed at investigating the removal of lead from synthetic wastewater using floral wastes through biosorption. Lead reduction from synthetic wastewater using three distinct flower wastes—*Tagetes erecta*, *Polianthes tuberosa*, and *Crossandra infundibuliformis*, was investigated in this study. A batch experiment was conducted to assess and optimize different parameters—pH, bio-dosage, retention time, and initial lead ion concentration. Experimental data were examined by Langmuir, Freundlich, and Temkin isotherm models and pseudo-first-order and pseudo-second-order kinetic models. Biomass characteristics were analyzed by Fourier-transform infrared (FTIR) and field emission scanning electron microscopy (FESEM). Results showed that maximum absorption of lead using floral wastes (1% w/v) with an initial lead ion concentration of 750 mg L⁻¹ for 6 h of retention time at pH 6 with an agitation speed of 150 rpm was 98.63%, 95.42%, and 93.69% by *T. erecta*, *P. tuberosa*, and *C. infundibuliformis*. Freundlich isotherm showed multilayer sorption on the heterogeneous surface of biosorbents. Biosorption of Pb(II) followed a pseudo-first-order kinetic model instead of pseudo-second-order kinetic model. FTIR revealed significant modification in the functional group that followed the metal chelation process. FESEM analyses showed changes in surface morphology in all the biosorbents. The desorption experiment revealed the reusability potential of these floral waste biosorbents. The toxicity of untreated and treated lead stock solution was verified by the phytotoxic assessment using *Vigna radiata* seeds. Elevated growth of *V. radiata* was observed in treated lead synthetic wastewater using *T. erecta* floral waste biosorbent and tap water (control).

Keywords Lead pollution · Biosorption · Floral wastes · Eco-friendly approach

1 Introduction

Civilization and the global advancement of industrialization have resulted in different forms of water pollution. Toxic heavy metal contamination in the water system through industrial wastewater is now a major worldwide environmental concern. Increased industrial activity by mankind has caused intensified stress of the environment leading to deterioration of the ecosystem. Unlike organic

contaminants, heavy metals are not biologically degradable and it has the propensity to aggregate in living organisms [8]. The accumulation and exposure of heavy metals in living organisms beyond permissible levels may lead to disorders and diseases [19]. Lead is a growing concern due to its elevated human body toxicity [10]. Lead has been added into the ecosystem from a wide range of sources such as tetraethyl-lead production, ammunition, mining, storage batteries, plating, ceramics, paints, glass products

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sectors, cosmetics, car batteries, lead smelting, and radiators [1, 32]. It remains in the environment and negatively impacts human health and biodiversity [24].

Even at very low levels, lead is systemically toxic. It has also shown specific toxicity to kidneys, bones, heart, nervous tissue, intestine, and reproductive systems [22, 38]. Long-term exposure to lead at the very low concentration of 1.0 µg/g has been reported to induce anemia, and this leads to increased blood pressure, especially in middle aged and elderly people. Fatal brain and kidney damage have been associated with exposure to high lead concentrations in children and adults [37]. So, the concentration of lead in industrial wastewater must be reduced before it is released into the environment. The classical techniques to treat toxic lead heavy metal contamination include ion exchange, chemical precipitation, membrane separations techniques, and electrodialysis [35]. These techniques have different disadvantages, such as operating costs, incomplete eradication, high capital investment, high energy consumption, and low selectivity [31]. Microbial remediation of toxic wastewater is an attractive method but is not yet adequate for large-scale treatment [16].

It is therefore vital that alternative techniques be developed for the effective treatment of heavy metal contaminated wastewater which is cost effective and environmentally friendly. Biosorption techniques are regarded as a suitable method for removing heavy metals particularly when the adsorbent is cheap and easily accessible. The process of biosorption requires a solid phase (biosorbent) and a liquid phase (water or solvent) comprising a dissolved species to be sorbed (metal ions). Because of the higher affinity of the biosorbent to the metal ions, both are attracted and bounded by various mechanisms until the equilibrium achieved [2]. It is a consequence result of three distinct processes, namely physical adsorption or surface precipitation, ion exchange and metal complexation that is due to the interaction leading to functional group interactions, ion exchange, electron delocalization [27]. Mostly, biosorbents comprise of hydroxyl and carboxyl functional groups where proteins, polysaccharides, and cellulose are the key components. These functional groups associate with metal ions in covalent bonding, complexation, micro-precipitation, biosorption, electrostatic attraction, and van der Waals attraction resulting in metal biosorption on the biosorbents [6]. A variety of biosorbents have been used to extract Pb(II) ion from synthetic wastewater, including temperate and semiarid soil, rice husk ash, sandy loam soil, *Aspergillus tamarii*, mustard husks, and mandarin peel [17].

Flowers are considered as a disposable material in marriages, gardens, hotels, churches, Dargah, temples, and other cultural and religious celebrations [39]. About 1450 tonnes of floral waste is estimated to be produced every day from temples alone across India [29]. Floral wastes

have applications in the biosorption process that will assist in the wastewater treatment and other industrial effluents. It will solve the floral waste disposal problems and environmental pollution [34]. The majority of the people generally use the garlands of *T. erecta* (TE), in prayer, *C. infundibuliformis* (CI) to bow their heads, and *P. tuberosa* (PT) is usually used in temples and worship of ancestor during weddings or funerals. Therefore, a lot of floral waste is generated every day. In view of these aspects, *T. erecta*, *P. tuberosa*, and *C. infundibuliformis* are considered the cheapest and easily available flower wastes throughout the year. With this goal in mind, this research investigated the use of floral wastes as a biosorbent to test their efficiency and ability to remove lead from wastewater. Therefore, the aim of this work is (1) to examine the efficacy of floral waste biosorbents for Pb(II) sequestration in synthetic wastewater; (2) to optimize the effect of biosorption parameters—pH, bio-dosage, initial lead ion concentration, and retention time on biosorption process; (3) to evaluate the characteristics of biosorbents before and after biosorption process; (4) to understand the mechanism and nature of biosorption process using isotherm and kinetics models; (5) to study the desorption of metals from loaded floral waste biosorbents; (6) to investigate the phytotoxicity effect of treated synthetic wastewater; and (7) to investigate the biosorbent ability to treat textile wastewater.

2 Materials and methods

2.1 Preparation of biosorbents

Floral wastes were collected from temples, nurseries, gardens, and flower markets in Vellore district, Tamil Nadu, India. Samples were washed twice with tap water and three times using double distilled water to remove impurities. The washed floral wastes were sun-dried for 3–5 days, then ground to fine powder, sieved through 60 mesh sieve, and stored at room temperature in an airtight container.

2.2 Preparation of lead synthetic wastewater for analysis

Lead synthetic wastewater standard (1000 mg L⁻¹) was prepared using Pb(NO₃)₂ (Himedia, India) in milli-Q-water [3]. The 750 mg L⁻¹ experimental solution of required lead ion concentration was prepared from the stock solution.

2.3 Biosorption studies

Batch experiments were carried out to evaluate the floral biosorbent materials (PT, TE, CI). Experiments were conducted in 250 ml of Erlenmeyer flasks each containing

100 ml of lead (750 mg L^{-1}); 1 gm of biosorbent was added to each flask and agitated in a rotary shaker at 150 rpm with temperature of 37°C for 6 h. The pH of the solution was maintained at 6. The synthetic lead wastewater was filtered through Whatman No. 40 filter paper before and after treatment, and the filtrates were examined by atomic absorption spectrophotometer (AAS) (AAS 240 varian) to assess the concentration of a lead ion in the solution. Optimization of batch experiment for lead removal was also performed using initial lead ion concentration of 1000 to 100 mg L^{-1} , bio-dosage of 0.1, 0.5, 1, 1.5, 2 g/100 ml, retention time of 1–6 h, and at the pH of 2–10.

2.4 Calculation of metal uptake

The lead removal efficiency and biosorption capability of floral waste biosorbents were determined using Eqs. 1 and 2, respectively:

$$\% \text{ Removal efficiency} = \frac{(C_o - C_e)}{C_e} \times 100 \quad (1)$$

$$Q_e = \frac{(C_o - C_e)V}{M} \quad (2)$$

where

C_o —Lead ion concentration in the solution before biosorption process (mg/L)

C_e —Lead ion concentration in the solution after biosorption process (mg/L)

V —Volume of the solution (mg/L)

M —Mass of biosorbent (g/L)

Q_e —Amount of lead metal ions biosorbed (mg/g)

2.5 Characterization of the biosorbents

The raw (untreated) and lead-loaded (treated) biosorbents were characterized to ascertain the presence of different functional groups associated throughout the Pb(II) biosorption process which was evaluated by using an FTIR spectrophotometer (Spectrum Two FTIR/SP10 S/W). FESEM (Carl Zeiss, Sigma) was employed to compare surface morphology of untreated and treated biosorbents.

2.6 Desorption experiment

A desorption experiment was performed to assess biosorbents efficiency and reusability. This experiment was conducted with 0.1 mol L^{-1} of H_2SO_4 and NaOH (Himedia, India). The separated biosorbents from the biosorption process were dried and mixed with 50 ml of each of 0.1 mol L^{-1} H_2SO_4 and NaOH solution. The solution was kept in a rotary shaker for overnight incubation. The samples were

then filtered, and the filtrates were analyzed by AAS to determine lead ions desorbed in the aqueous solution.

2.7 Phytotoxicity studies

Phytotoxicity studies were conducted to assess the toxicity on *V. radiata* of the treated and untreated lead synthetic wastewater [4]. Five ml of tap water was used as a control. Seeds of *V. radiata* were sowed in Petri plates and sprinkled with a 5 ml untreated 750 mg L^{-1} of lead ion synthetic wastewater and treated synthetic wastewater. The seeds were grown at room temperature for 5 days, and the full length of the plant was measured (root and shoot).

2.8 Treatment of textile wastewater

To examine the applicability of the *T. erecta* floral waste biosorbent which was selected based on the biosorption process employed in textile wastewater treatment, the studies were conducted in Erlenmeyer flasks with 100 ml wastewater. The effluent was treated with the 1% (w/v) of floral wastes for 6 h of retention time at the pH 6 with an agitation speed of 150 rpm at 37°C . The physicochemical parameters were studied according to American Public Health Association (APHA).

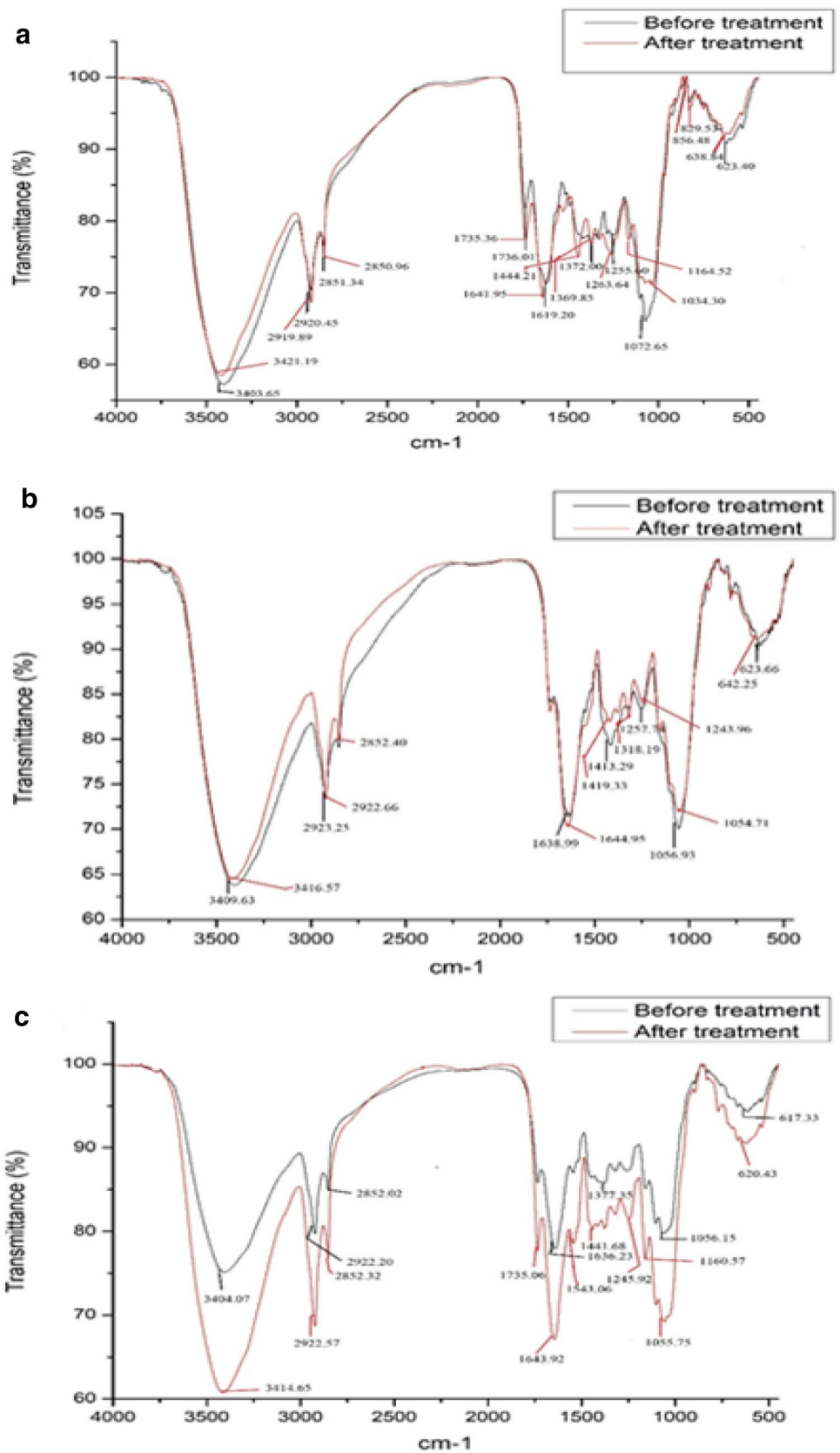
3 Results and discussion

3.1 Characterization of biosorbents

3.1.1 Fourier-transform infrared spectroscopy

FTIR has been used for detecting and recognizing adsorbent surface groups in metal ion binding [18]. FTIR of *T. erecta*, *P. tuberosa*, and *C. infundibuliformis* biosorbents before and after biosorption of lead was performed to identify the metal chelation of a functional group and various chemical groups called carboxyl, hydroxyl, amide, ether, etc. (Figure 1a, b). Functional groups responsible for removal of metal ions from biosorbent depend on different aspects such as chemical state, accessibility, sites quantity, affinity among surfaces in the biosorbents and metals [26]. The FTIR spectrum of untreated and treated *T. erecta* with a peak of $1736.01\text{--}1735.36 \text{ cm}^{-1}$ is the stretching vibration of C=O bond based on non-ionic carboxylic acid and can be attributed to carboxylic acids or their esters that are normally present in plants. The peak at $2851.34\text{--}2850.96 \text{ cm}^{-1}$ and $2920.45\text{--}2919.89 \text{ cm}^{-1}$ has alkanes, stretching vibration of C–H. The band noted at $3403.65\text{--}3421.19 \text{ cm}^{-1}$ is the stretching vibration of O–H of the carboxylic group. FTIR range of untreated and treated *P. tuberosa* of $1297.74\text{--}1243.96 \text{ cm}^{-1}$ and

Fig. 1 FTIR spectrum of untreated and treated floral waste biosorbents: **a** *T. erecta*, **b** *P. tuberosa*, **c** *C. infundibuliformis*



1056.93–1054.71 cm^{-1} is the C–N stretching vibration of aliphatic amines. Peak at 1413.29–1419.33 cm^{-1} is the stretching C–C vibration of the aromatic ring. The peak at 2923.25–2922.66 cm^{-1} is the C–H stretching vibration of alkanes. 3409.63–3416.57 cm^{-1} is the representing alcohol and phenol compound of O–H vibration. In the FTIR spectrum of native and lead-loaded *C. infundibuliformis*, 1056.15–1055.75 cm^{-1} can be assigned as stretching vibration of C–N aliphatic amines. The band at 1337–1441 cm^{-1} is the representing vibration as bending and rock vibration of C–H of alkanes group. The peak observed at 2852.02–2852.32 cm^{-1} is the stretching vibration of C–H of alkanes and alkyls. The peak at 3404.97–3414.65 cm^{-1} is the stretching vibration of N–H symmetric and asymmetric of amides. FTIR peaks may change to smaller or greater wave numbers after lead loading due to the interaction of functional groups in the floral waste biosorbents with lead ions. Changing bands into greater frequencies showed an improvement in the strength of the bond when changing into reduced frequencies indicated bond weakening [11]. In this research, the wide and acute band acquired in raw biomass before the biosorption process is changed to greater frequencies when lead is loaded that is after treatment indicating increased bond strength in the process of biosorption. Carboxyl, hydroxyl group, aliphatic amines, and carbonyl are functional groups involved in heavy metals bindings to plant biomass suggested by the FTIR spectrum. It reflects that the lead removal mechanism is primarily through chemical bonding.

3.1.2 Field emission scanning electron microscopy

Changes in morphology have been investigated using FESEM for all biosorbents before and after the lead biosorption process (Fig. 2a–h). In the case of *T. erecta*, many holes and spots were shown at the native phase in a form of the dark environment but after biosorption process clustered and irregular structure of surface morphology. Relatively smooth with clear observation of the surface was seen in the case of *P. tuberosa* biosorbent. However, FESEM showed layered and clustered particle form in biomass after exposure to lead. In *C. infundibuliformis*, an elevated porous matrix and a broad surface area were seen, after sorption treatment of lead responded for appearances of shiny particles in the biosorbent surface.

3.2 Optimization of biosorption parameters

3.2.1 Optimization of pH

pH is a significant controlling parameter in the biosorption experiment that significantly affects the surface charge of biosorbent, degree of ionization, and the process of metal

biosorption [30]. Also, it affects functional group activity in biomass, competition between metallic ion, and metals solution chemistry [12]. Lead biosorption was checked at distinct pH ranges of 2, 4, 6, 8, and 10 with 1 gm biosorbents dose in 100 ml [Fig. 3a]. It was noted from the research that the removal efficiency was excellent with varying pH with all three biosorbents, but optimum efficacy in removing lead was at pH of 6. The maximum lead sorption for TE was 98.54%, for PT 95.85%, for CI 93.67%, at a pH of 6. The reason for the better absorption noticed in pH 6 could be ascribed to the number of H^+ ions observed that neutralize the adsorbent surface which is negatively charged, thus lowering the diffusion of organics at higher pH promoting metal uptake [25]. It has been well understood that a low pH (high acidic) led to high H^+ concentration in the solution thereby protonating the functional group of the biosorbents surface [21, 30]. Furthermore, at high pH (high alkalinity) the absorption of the metal ions decreased and this can be attributed to the fact that the degree of protonation of the adsorbent functional group during absorption decreased progressively, consequently decreasing the removal of lead ions [14].

3.2.2 Optimization of bio-dosage

The optimization of bio-dosages was performed using five different grams of bio-dosage of the floral waste biosorbents (0.2%, 0.4%, 1%, 1.5%, 2% (w/v)) with 750 mg L^{-1} of lead synthetic wastewater. Lead removal percentage was noted for TE at 98.19%, for PI at 95.57%, for CI at 91.86%, as depicted in Fig. 3b. Biosorption of lead was found to increase when it reaches up to the dosage of 1%. As dosage of floral waste biosorbents increased, the number of active sites available for lead biosorption process also increased and subsequently much more biosorption of lead ion can occur [40]. It was observed that TE and PT had not shown much change in the biosorption process with an increase in dosage up to 2%. However, CI had demonstrated a reduction in the efficacy of evacuation of lead in synthetic wastewater. The result could be due to aggregation or overlapping of active sites at higher dosage leading to a decrease in the complete biosorbents area of the surface [9, 18].

3.2.3 Optimization of retention time

Retention time is an important parameter for industrial effluent treatment processes. The optimization of retention time was assessed with various time intervals in the range of 1–6 h. It was noted that in all the samples the maximum sorption process took place in 6 h and it was enough to achieve balance equilibrium. Lead removal was observed for TE at 99.16%, for PI at 96.66%, CI at 92.10%,

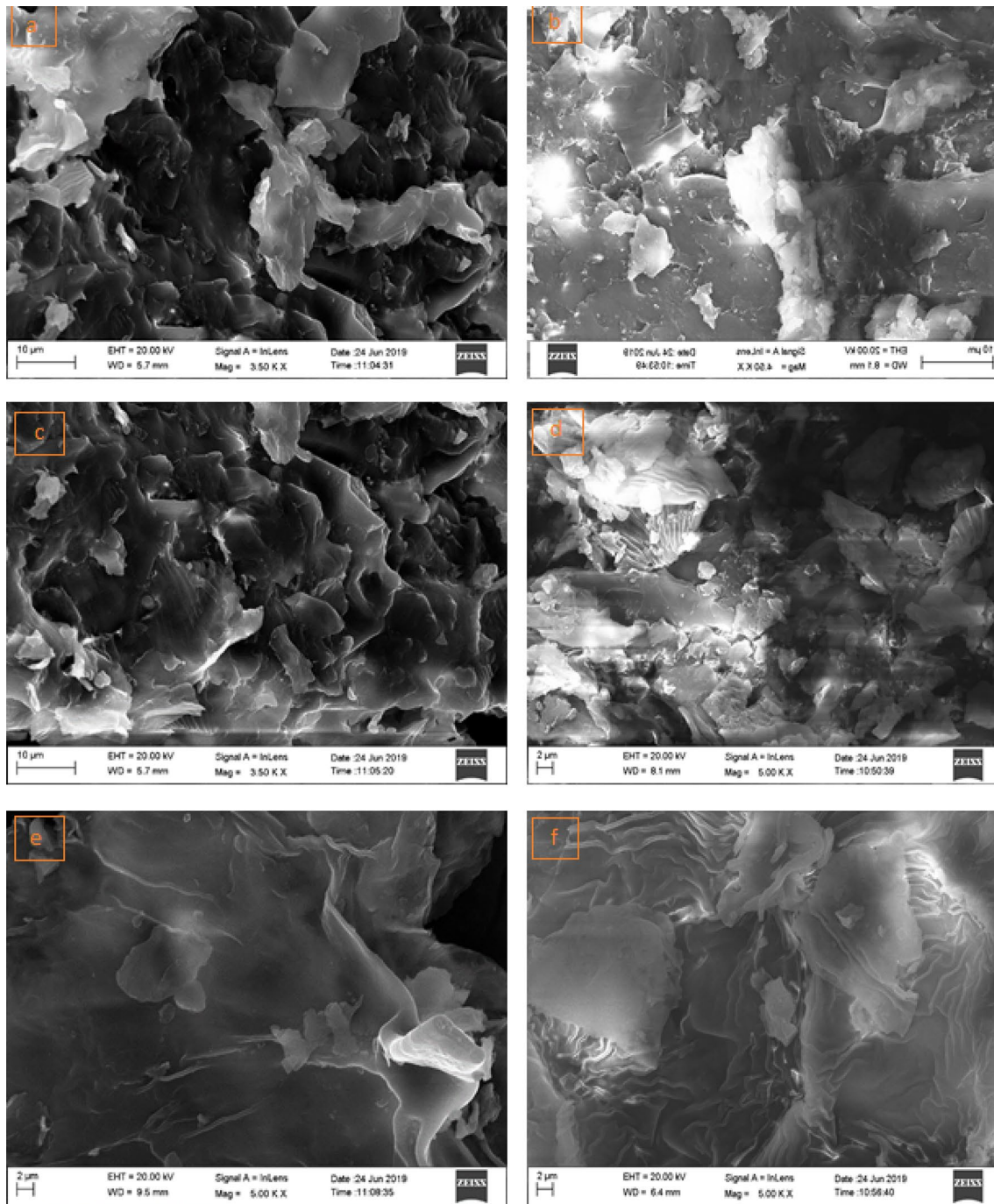


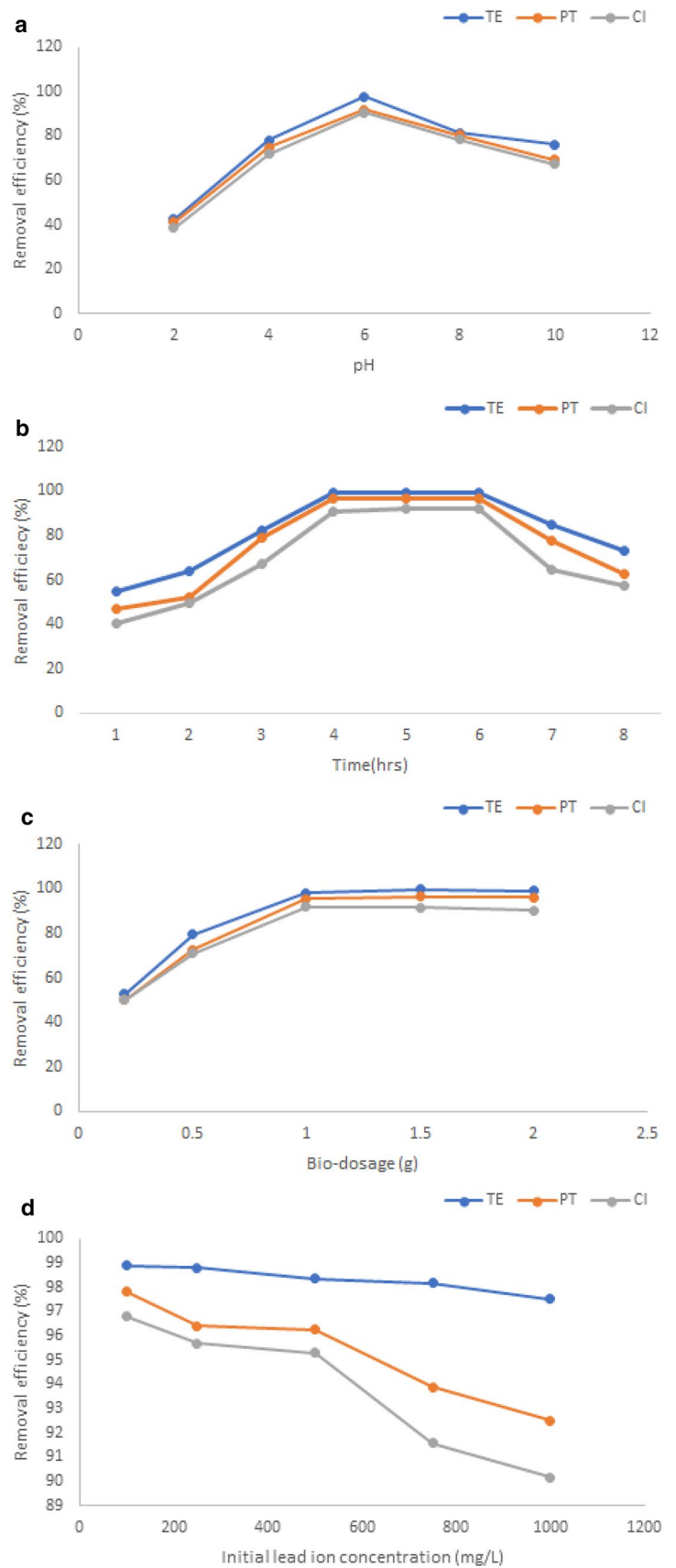
Fig. 2 Scanning electron micrograph of untreated (native) and lead-treated (exhausted) floral waste biosorbents (**a, b**–*T. erecta*, **c, d**–*P. tuberosa*, **e, f**–*C. infundibuliformis*)

as shown in Fig. 3c. Initially, the uptake of lead (II) ion was fast possibly due to the accessibility of vacant active sites on the surface of the biosorbents [7]. Later, the increase in time showed no improvement in biosorption process. It is well recognized that the speed of metal absorption is affected by different variables that affect the transfer of mass from synthetic wastewater to sites of binding [12].

3.2.4 Optimization of initial lead ions concentration

The initial concentration of lead ions in synthetic wastewater is a driving factor for the development of metal ions resistance to mass transfer between solid biosorbent and aqueous solution [20]. Removal of lead at the different metal concentrations (100, 250, 500, 750, 1000 mg L⁻¹)

Fig. 3 Effect of pH **a**, retention time **b**, bio-dosage **c**, initial lead ions concentration **d** on the removal of Pb(II) from synthetic wastewater by floral waste biosorbents (TE, PT, CI) under controlled condition (initial lead ions concentration: 750 mg L⁻¹; bio-dosage: 1 g L⁻¹; retention time: 6 h; pH: 6; temperature: 37 °C; agitation speed: 150 rpm)



was carried out by all three different biosorbents [Fig. 3d]. The result demonstrated that the lead sorption capability of all three biosorbents for TE at 98.9%, for PT at 97.8%, for CI at 96.78% showed maximum reduction in initial lead ions concentration of 100 mg L⁻¹. The characteristics of sorption have shown that biosorbents surface saturation depends on the concentration of the initial lead ions concentration. The proportion of the surface area of sorption to the total accessible of lead ions is large at low concentration, and absorption sites have absorbed the remaining lead ions rapidly. However, when compared to low concentration, high concentration removal efficiency may have been reduced owing to the absence of accessibility of active sites on the surface of the biosorbents [21].

3.3 Study of isotherm and kinetic models

3.3.1 Biosorption isotherms

Biosorption capacities and surface characteristics of the biosorbent can be studied by using the isotherm model. Isotherm biosorption—Langmuir, Freundlich, and Temkin, was carried out to find the ideal lead experimental data [21]. In this research, the Langmuir [Eq. (3)], Freundlich [Eq. (4)], and Temkin [Eq. (5)] models have been chosen for the evaluation of lead biosorption on floral waste biosorbents and equilibrium concentration in synthetic wastewater:

$$C_e/Q_e = C_e/Q_m + 1/bQ_m \tag{3}$$

$$\ln Q_e = \ln K_f + 1/n \times \ln C_e \tag{4}$$

$$q_e = B_T \ln k_t + B_T \ln C_e \tag{5}$$

where C_e is the equilibrium concentration of lead ion in the solution (mg L⁻¹), Q_e is the amount of lead ion sorbed per specific unit of biosorbent (mg g⁻¹), Q_m is the maximum sorption capacity calculated from equation (mg g⁻¹), b is the Langmuir constant which is related

to sorption capacity and energy of the sorption, K_f and $1/n$ are Freundlich constant which is related to sorption capacity (mg g⁻¹) and sorption intensity of the biosorbent, $B_T = RT/b$, B_T is Temkin constant, and K_t is the Temkin isotherm equilibrium binding constant (l/mg) equivalent to the maximum binding energy. The fittest model of the biosorption process was verified by coefficient determination (R^2). The R^2 value always ranges from 0 to 1, and the model is stronger and easier to estimate the response if the value of R^2 is close to 1. The most accurate estimate of lead biosorption using floral biosorbents in this study is the Freundlich model as it is generated with a greater R^2 value than Langmuir and the Temkin models. Lower correlation coefficients have been noted from the Freundlich and Temkin models, indicating that the model was not suitable. The data observed from this experiment fitted well to the Freundlich model with high correlation coefficients (R^2) for TE 0.991, PT 0.9793, CI 0.9779, respectively. The best-fitted Freundlich model indicated that multilayer lead sorption existed predominantly onto heterogeneous surfaces of floral wastes. According to the Bazargan-Lari [5] research, when the value of $1/n$ was between 0.1 and 1.0, the sorption process is favorable. It is observed that the $1/n$ values of floral waste biosorbents were less than 1.0 (Table 1), indicating the favorability of biosorption of lead ions on floral waste biosorbents.

3.3.2 Biosorption kinetics

To investigate the control mechanisms of the sorption processes, the pseudo-first-order (6) and pseudo-second-order (7) models were applied.

The kinetic model of pseudo-first order, also called as the Lagergren equation, is:

$$\text{Log}(q_e - q_t) = \text{log } q_e - K_1/2.303 \times t \tag{6}$$

$$t/q_t = 1/K_2q_e^2 + 1/q_e \times t \tag{7}$$

Table 1 Langmuir, Freundlich, and Temkin constants for Pb(II) biosorption onto various floral wastes

Parameters		<i>T. erecta</i>	<i>P. tuberosa</i>	<i>C. infundibuliformis</i>
Q_m (mg/g)	Langmuir isotherm	166.66	129.533	181.818
b (mg/L)		0.056	0.030	0.008
R^2		0.989	0.969	0.216
K_f (mg/g)	Freundlich isotherm	10.046	5.094	5.030
$1/n$ (mg/L)		0.739	0.695	0.690
R^2		0.991	0.979	0.977
B_T (KJ/mol)	Temkin isotherm	87.003	171.031	106.762
K_t (g/L)		0.001	0.352	1.360
R^2		0.953	0.290	0.682

Table 2 Kinetic parameters for the lead sorption onto different floral wastes biomass

Parameters		<i>T. erecta</i>	<i>P. tuberosa</i>	<i>C. infundibuliformis</i>
q_e (mg/g)	Pseudo-first-order kinetic model	286.747	140.184	201.976
K_1 (min^{-1})		3.5×10^{-2}	2.5×10^{-2}	3.3×10^{-2}
R^2		0.925	0.920	0.911
q_e (mg/g)	Pseudo-second-order kinetic model	108.695	105.263	108.695
K_2 ($\text{g mg}^{-1} \text{min}^{-1}$)		7.45×10^{-4}	7.83×10^{-4}	6.05×10^{-4}
R^2		0.635	0.735	0.633

where q_e and q_t (mg g^{-1}) are the amounts of lead ion adsorbed on the biosorbent at time and at equilibrium phase, respectively; K_1 and K_2 are the rate constants of pseudo-first order and pseudo-second order of biosorption models. The correlation coefficients (R^2) of pseudo-first-order and pseudo-second-order models for biosorption of lead using floral wastes biomass were found to be 0.9253, 0.9206, 0.9112 and 0.6359, 0.7352, 0.6338 (Table 2). The results indicated that the coefficient of correlation (R^2) for the pseudo-first-order was much higher compared with pseudo-second-order kinetic equation suggesting that the experimental data closely followed the pseudo-first-order kinetic model.

3.4 Desorption and application studies

3.4.1 Desorption studies

It is extremely important to expound biomass metal sorption and desorption activity to establish and standardize a technique of biosorption process for industrial use. An adequate eluent or desorbing solution allows to desorb the metal which is loaded in biomass. Therefore, biomass can also be used in different cycles of sorption–desorption. Also, the method of desorption is essential for evaluating the mechanism of adsorption. If a desorption of the metal ions (sorbate) from the surface of biosorbent can also be effectively acquired using potent desorbent such as acidic or alkaline, the mechanism of absorption will be ion exchange or chemical bonding. When it becomes a physical bonding, deionized water can desorb the sorbate [21]. Desorption experiment was conducted using $0.1 \text{ mol L}^{-1} \text{ H}_2\text{SO}_4$ and NaOH as a desorbent solution. During desorption process from floral biomass using H_2SO_4 , 83.76%, 81.7%, 78.59% of lead ions were recovered compared to 59.86%, 55.23%, 42.44% using NaOH as shown in Fig. 4. The findings show that the mechanism of ion exchange seems to be the main mechanism for the absorption of Pb(II) ions by floral biomass.

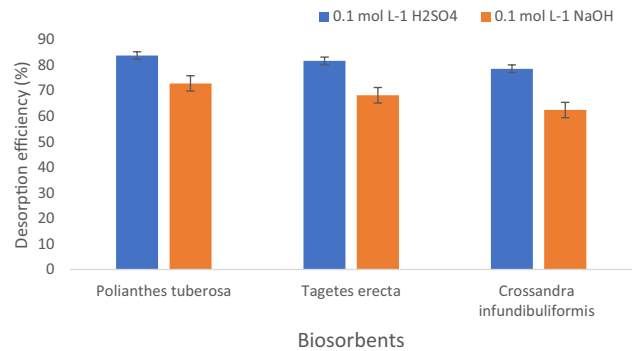


Fig. 4 Desorption efficiency of Pb(II) ions from floral waste biosorbents using $0.1 \text{ mol L}^{-1} \text{ H}_2\text{SO}_4$ and NaOH

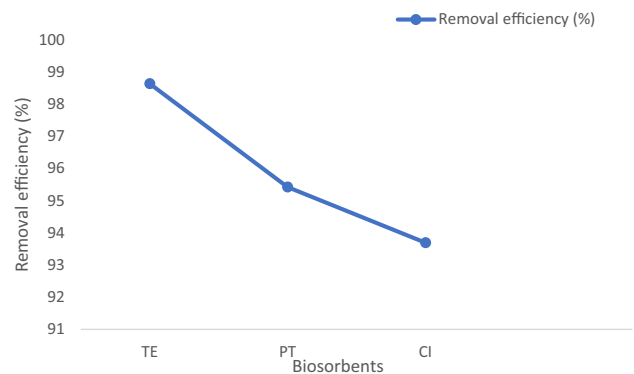


Fig. 5 Removal efficiency of floral waste biosorbents on lead synthetic wastewater

3.4.2 Comparison of biosorbents

The efficiency of *T. erecta*, *P. tuberosa*, and *C. infundibuliformis* biosorbents was examined based on the overall adsorption of lead with the standard condition (Fig. 5). These flower waste biosorbents contributed to the differences in metal uptake because of their functional groups, surface area, and varying structure. Moreover, the number of metal ions bound on the surface of the biomass will depend on the active sites present and also how quickly they can be assessed [13] and this property plays an important role in the removal efficiency of each

biosorbent. Carboxyl group, esters, amide, alkanes and alkyls, and alkyl halides are the major functional groups which are responsible for achieving the maximum removal efficiency range of 98.63% by *T. erecta* in biosorption process when compared to other floral wastes. Based on the properties and maximum removal efficiency, *T. erecta* was thus used for further application studies of phytotoxicity and real wastewater treatment. The floral waste biosorbents sorption abilities were also compared with other biosorbents (Table 3).

3.4.3 Phytotoxicity studies

Phytotoxicity was assessed using *V. radiata* for untreated, treated, control samples, and the results are shown in Fig. 6. The growth of *V. radiata* on lead-treated synthetic water is confirmed by evaluating the shoot length (Table 4); 1 cm of *V. radiata* growth was seen in the untreated lead stock solution on the fifth day. In treated lead synthetic wastewater, the *V. radiata* seed growth was 3.45 cm of length; in tap water, the growth was 3.66 cm. The seeds in the treated stock solution were observed to grow better than that of the untreated stock solution on the fifth day. For industrial and irrigation purposes, this treated solution is considered to be adequate and safe.

3.4.4 Treatment of textile effluent

Application experiments using real effluent were conducted to evaluate the suitability of floral waste as a biosorbent in optimal batch conditions. A kind of effective biosorbent is not just absorbed numerous heavy metals from aqueous solutions but also able to treat real wastewater. Therefore, our focus was toward the biosorbent sorption capacity to remove heavy metal from industrial wastewater. The physicochemical characteristics of textile wastewater before and after the biosorption process are illustrated in Table 5. 90.90% of lead, 78.53% of cadmium, 62.04% of copper, 80% of total suspended solids, and 87.35% of total hardness were removed from textile

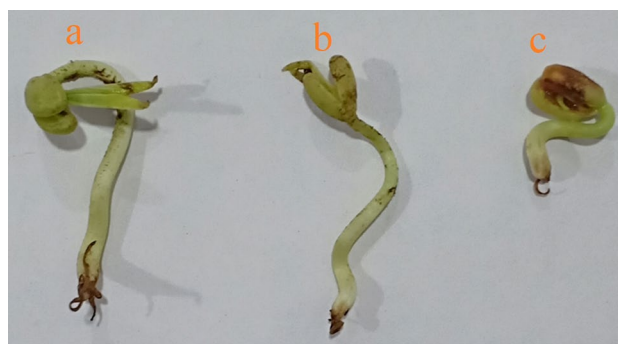


Fig. 6 Growth of *V. radiata* plants at fifth day on **a** tap water (control), **b** treated lead synthetic wastewater, **c** untreated synthetic wastewater

effluent after treatment by *T. erecta* biosorbent. So, this result indicated that *T. erecta* biosorbent sample is a suitable material for reducing heavy metal contamination from industrial wastewater.

4 Conclusion

In the present research, the effectiveness of the removal of Pb(II) was explored using floral wastes. Increasing costs and environmental considerations for the treatment of heavy metals present in the industrial effluent have led to the need for new low-cost or no-cost adsorbents from renewables. The current research showed that floral wastes may be used to remove Pb(II) as an efficient biosorbent. The FTIR spectra of floral waste biosorbents before and after treatment showed that aliphatic amines, carboxyl, hydroxyl group, and carbonyl groups may participate in binding of lead ions. This study showed a maximum of 98.63, 95.42, and 93.69% biosorption of lead ion from aqueous solution by *T. erecta*, *P. tuberosa*,

Table 3 Comparison of biosorption capacities of Pb(II) with various biosorbents

Biosorbents	Removal capacity (mg/g)	References
Egg shell	90.9	[28]
Raw agave bagasse	35.6	[33]
Palm nut shell	95.2	[15]
Fly ash	37	[36]
<i>Oryza sativa</i> L. husk	8.6	[41]
Apricot stone activated carbon	21.38	[23]

Table 4 Phytotoxicity studies of tap water, treated synthetic wastewater, and untreated synthetic wastewater using *V. radiata* plants by measuring the growth length of plants

S. no	Days	Tap water (cm)	Treated synthetic wastewater (cm)	Untreated synthetic wastewater (cm)
		Mean and std. dev	Mean and std. dev	Mean and std. dev
1	1st	1.40 ± 0.1	1.36 ± 0.15	0.56 ± 0.06
2	2nd	2.76 ± 0.15	1.71 ± 0.10	0.83 ± 0.11
3	3rd	2.3 ± 0.2	2.23 ± 0.11	1.33 ± 0.10
4	4th	2.83 ± 0.20	2.76 ± 1.2	1.36 ± 0.06
5	5th	3.66 ± 0.25	3.45 ± 0.21	1.49 ± 0.06

Table 5 Physicochemical parameters of textile wastewater before and after treatment

S. no	Test	Before treatment	After treatment	Permissible limit
1	pH	9.6	6.8	5.5–9
2	TS (mg/L)	51,500	32,850	–
3	TDS (mg/L)	43,850	30,430	500–2000
4	TSS (mg/L)	15,000	3000	800
5	Total hardness (mg/L)	870	110	250
6	Lead (mg/L)	6.82	0.62	0.1
7	Cadmium(mg/L)	5.45	1.17	0.1
8	Copper (mg/L)	4.69	1.78	0.1

C. infundibuliformis, respectively, with 1% (v/w) for 6-h retention time at pH 6. Studies showed that increased bio-dosage and retention time resulted in increased reduction efficiency and increased initial lead (II) concentration and pH resulted in decreased removal efficiency. The experimental biosorption data are well fitted with the Freundlich isotherm model and pseudo-first-order kinetic model. Phytotoxicity assay revealed elevated shoot growth and germination of *V. radiata* plants using treated lead synthetic wastewater. Floral wastes biomass also showed the good reusability and textile wastewater treatment capability. So, it can be concluded that the treated synthetic lead water is appropriate for industrial and irrigation use. Hence, the floral waste biosorbents are easily accessible, environmentally friendly, and efficient for removing lead ions from wastewater due to their high biosorption capacity when compared with other biosorbents.

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Compliance with ethical standards

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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