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Biosorption of heavy metals from wastewater using agricultural waste biomass.

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Abstract

About 70% of the surface of the earth is covered with water. Astoundingly, only 3% is fresh water, which is because of the global problem of water pollution (Ivanova et al., 2016). Water pollution occurs when harmful substances, usually chemicals and microorganisms, invade a water body. A significant group of chemical pollutants is toxic heavy metals. Heavy metal ions threaten flora and fauna, and several methods have been devised to eliminate them. Several accustomed methods are currently being employed to remove heavy metal ions from wastewater. For instance, ion exchange, chemical precipitation, membrane filtration, and adsorption using activated carbon (Gunatilake, 2015). However, these techniques have certain drawbacks, such as cost inefficiency, high energy consumption, and they are not reliable when the heavy metal ion concentration is low. Biosorption is an alternative method and is environmentally friendly compared to conventional methods (Ivanova et al., 2016). In simple terms, biosorption is the removal or binding of substances from a solution using bio-derived materials termed biosorbents (Yu et al., 2020). Although several biosorbents can remove heavy metals from wastewater, this review pays particular attention to agricultural waste biomass. Biomass is the mass of living organisms that constitute microorganisms, plants, animals, fats, sugars, proteins, and cellulose from a biochemical standpoint (Houghton, 2008). This review aims to understand the latest developments and the future outlook in applying biosorption to remove heavy metal ions using agricultural waste biomass.

Keywords: Biosorption; biomass; heavy metals; agricultural waste; biosorbent

Introduction

Many developing countries still dispose of about 90% of the wastewater into freshwater bodies without being treated, causing it to be unsuited to human consumption and aquatic life (UN-Water). Toxic heavy metals are approaching dangerous levels when contrasted with other chemical pollutants. Heavy metals occur naturally, and they have high atomic weight and a density not less than five times the density of water (Tchounwou et al., 2012). Chromium (Cr), lead (Pb), cadmium (Cd), arsenic (As), manganese (Mn), zinc (Zn), copper (Cu), and mercury (Hg) are toxic heavy metals of great concern. Massive industrialization worldwide to a greater extent is one of the chief reasons for the increased accumulation of heavy metals in water bodies (Ivanova et al., 2016). Mining, metallurgy, fertilizer and pesticide, energy and fuel production, and the pharmaceutical industry are specific industries contributing to amassing toxic heavy metal ions in water bodies. Heavy metals are not biodegradable. Once they get into water bodies, they accumulate in living organisms and result in various diseases and disorders to humans and animals. Biosorption has emerged as an eco-friendly and cost-effective method in removing and recovering heavy metal ions from industrial effluents. This review paper discusses the significant advances, current status and research, and future outlook of the application of biosorption in removing heavy metals using agricultural waste biomass.

1. Why removing heavy metals from wastewater

1. a) Heavy metals and their route to wastewater

Heavy metals occur naturally in the earth's crust (Tchounwou et al., 2012) Releasing industrial effluents without proper treatment into the water bodies is the primary source of surface water pollution. Their exploitation in various industries like metallurgy, petroleum refinery, battery manufacturing, fertilizer production, and dye production has led to their wide environmental distribution (Ali et al., 2019). Products containing heavy metals release heavy metals into the atmosphere during processing and disposal, contaminating water bodies. (M & Khan M, 2016) Nuclear power stations, microelectronics, textiles, plastics, metal processing in refineries, mining operations, and wood preservation and paper processing. (Tchounwou et al., 2012) Other sources of heavy metals include domestic effluents and agricultural run-off due to the application of metal-based pesticides (M & Khan M, 2016).

Table 1.1: Industrial sources of heavy metals

Heavy metal	Sources	References
Mercury	Mining, paint industry.	(Jyothi, 2020)
Cadmium	Fertilizers, pesticides, fossil fuel burning.	(Jyothi, 2020)
Lead	Paint industry, batteries, mining	(Jyothi, 2020)
Arsenic	Mining, petroleum refining, pesticides, wood preservatives.	(Jyothi, 2020) (Li et al., 2019)
Chromium	Steel fabrication, electroplating	(Jyothi, 2020)

1. b) **Toxicity of heavy metals.**

The toxicity of heavy metal ions refers to the capacity of heavy metal to induce detrimental consequences on human beings and animals. It is contingent on the bioavailability of heavy metal together with the dosage (Igiri et al., 2018). Heavy metals are non-biodegradable. When they cumulate in living organisms, they give rise to several diseases and disorders that eventually put human life at risk. However, some heavy metals like iron, zinc, copper, and cobalt are essential as nutrients for humans in small quantities but are toxic in larger quantities. Few heavy metals such as mercury, cadmium, lead, and arsenic are lethal even at low concentrations (Jyothi, 2020). Heavy metal contamination is an environmental concern that has affected millions of people worldwide. Heavy metals are systemic toxicants that can induce multiple organ damage, even in trace concentrations Tchounwou et al.). The toxicity and severity of health effects are influenced by several factors, for instance, genetics, dose, route of exposure, gender, age, and chemical species (Tchounwou et al., 2012). Exposure to toxic heavy metals of human beings occurs in several ways or routes, including ingestion through food and drink, inhalation as dust or fumes, or absorption when they contact the skin. Generally, the toxicity of heavy metals to human beings is due to the chemical reactivity of the heavy metal ions with cellular structured proteins, enzymes, and the membrane system (Mahurpawar, 2015). Heavy metals interrupt cellular processes like growth, proliferation, differentiation, damage-repairing, and apoptosis (Balali-Mood et al., 2021). Mercury, cadmium, arsenic, and lead, are regarded as prime concern metals of public health significance due to their high toxicity. Heavy metals' dire and chronic toxic effects target different biological processes and body organs.

The table below lists the target organs and clinical effects of chronic exposures to heavy metals.

Table 1.2: Clinical effects of heavy metal exposure

Heavy	Target organs	Clinical targets	References
Mercury	The nervous system, brain, developing fetus	memory loss, neuromuscular effects, Minamata disease	(Zhang et al., 2020) (Fernandes Azevedo et al., 2012)
Cadmium	kidneys, lungs	renal and hepatic dysfunction, lung damage, lung cancer, Itai-Itai disease	(Genchi et al., 2020) (Chen et al., 2019) (Jyothi, 2020) (Balali-Mood et al., 2021)
Lead	The nervous system, brain	urinary disorders, hypertension, stillbirths, alteration in brain and nervous system development in kids, anemia	(Boskabady et al., 2018)
Arsenic	liver, skin	damage to blood vessels, decreased production of red blood cells, infertility, skin changes like hyperkeratosis	(Briffa et al., 2020) (Mahurpawar, 2015)

1. c) **Methods for removing heavy metals from wastewater**

To remove heavy metals from wastewater, several practical approaches can be used. Many conventional treatment methods have been employed to remove heavy metals from industrial effluents (Ivanova et al., 2016). The commonly used techniques are chemical precipitation, ultrafiltration, ion exchange, and reverse osmosis.

i) Chemical Precipitation

Chemical precipitation is the most commonly employed method in removing heavy metal ions from industrial effluents. It is economical and easy to operate (Bolisetty et al., 2019) A chemical reagent known as precipitant is added to the contaminated water. The precipitant reacts with the heavy metal ions to produce insoluble precipitates like hydroxide and sulfide precipitation, which then can be separated from the pure water by filtering the water (Yu et al., 2020). The mechanism of the precipitation process is based on the production of insoluble heavy metal precipitation by mixing dissolved metals in the solution and the precipitant (Gunatilake, 2015). Chemical precipitation is not reliable in removing heavy metals in trace concentrations; therefore, the heavy metal concentration does not reach the ranges acceptable for discharge (Bolisetty et al., 2019). The addition of treatment chemicals, especially lime, increases the release of waste sludge by up to 50 %. (Da'na).

ii) Ion Exchange

Ion exchange is another widely utilized approach in removing heavy metals from wastewater. In this technique, an ion exchange resin with a specified uptake capacity to exchange its cations with heavy metal ions in a solution is used (Zhao et al., 2016). The positively charged ions in cationic resins such as hydrogen and sodium are exchanged with positively charged heavy metal ions (Gunatilake, 2015). Either synthetic or natural solid resins can be used, but, in most cases, the former is used because of their effectiveness and thorough removal potential of heavy metal ions from wastewater. The most common ion exchange resins available in the market are zeolites, sodium silicates, and polystyrene sulfonic acid (Bolisetty et al., 2019).

iii) Reverse Osmosis

Reverse osmosis is a water treatment technique that uses applied pressure. The applied pressure forces contaminated water to pass through a membrane that retains heavy metals ions. The heavy metal ions are retained from one side, and pure water can pass from the other side of the semi-permeable membrane. High energy consumption substantial initial investments are the major drawbacks of reverse osmosis (Bolisetty et al., 2019).

iv) Electrodialysis

Electrodialysis is another membrane-based separation technique. It is based on electric potential differences. The potential difference drives metal ions to migrate towards oppositely charged electrodes (Ivanova et al., 2016). The membranes used can be split into two categories: cation-exchange and anion-exchange. Electrodialysis is modeled based on electrochemistry principles (Zhao et al., 2016). Removing heavy metals from underground water in Korea was attained by an electrodialysis system to remove arsenic, lead with 73.9 and 89.9%, respectively (Ivanova et al., 2016).

2. Why Opting for Biosorption

A fundamental question that comes into play is why opting for biosorption is an alternative method to remove heavy metal ions from wastewater. Albeit the above outlined conventional methods have higher removal capacities in removing heavy metals, their utilization may demand several pre-treatments alongside additional treatments, thereby incurring high installation and operational costs. Given the drawbacks accompanying using conventional methods, economic and sustainable technologies should be put in place and implemented. Biosorption has been reckoned as a new, cost-effective, and effective alternative technology for removing heavy metals from industrial effluents (Ivanova et al., 2016). Biosorption presents several advantages as compared to the widely employed traditional methods. Biosorption has a low operational cost because of low or no energy requirements and chemicals. The process is also efficient, and there is an insufficient quantity of sludge generated, making it an environmentally friendly approach. Many conventional methods prove ineffective, especially at dilute concentrations (1-100mg/L) (Mathew et al., 2016). Biosorption has a high eradication rate, and it is capable of decreasing the concentration of heavy metals from ppm to ppb level (D. S. M. C. K. Jain & Yadav, 2017).

3. Why use agricultural waste biomass

The utilization of agricultural waste to eliminate heavy metal ions has been broadly explored and evaluated by scientists worldwide (Joseph et al., 2019). The use of agricultural waste biomass to eliminate heavy metal ions from industrial effluents has gained much recognition because of its economic benefits and exceptional removal efficiency accredited to various functional groups (Alalwan et al., 2020). There are three kinds of biosorbents based on their sources; non-living biomass like barks and fruits peels, algal biomass, and microbial biomass, for instance, algae, bacteria, fungi, and yeast (Burakov et al., 2018). Agricultural waste biomass has several advantages; for example, it is easily accessible and inexpensive, less sludge generation, the possibility of heavy metal recovery, and regeneration ability (Burakov et al., 2018). Generally, agricultural waste biomass, specifically cellulose, manifests appreciative biosorption efficiency (Noor et al., 2017). The high biosorption capacity is ascribed to different functional groups, for instance, amino, acetamido, carbonyl, sulfonyl, alcoholic, phenolic, and amido groups (Renu et al., 2017). These functional groups have an affinity for heavy metal ions to form metal complexes or chelates (Renu et al., 2017).

4. Agricultural waste materials that can be utilized as biosorbents

The use of agricultural wastes as biosorbents to eliminate heavy metals from industrial effluents has increased recently. Most studies have focused on plant waste like rice husk, sugarcane bagasse, citrus fruits peels, potato peels, and maize corn cob. Some other biosorbents like sunflower stalk, wheat straw, sunflower stalk, coconut waste, and coffee husk have also been widely studied as potential biosorbents (C. K. Jain & Malik, 2016). These agricultural waste materials have demonstrated good removal capabilities for numerous heavy metal ions, particularly wastewater. They can be used in their natural form or physically or chemically modified to enhance efficiency (De Gisi et al., 2016).

Rice husk

Rice husk is derived from the milling process of paddy (Gautam et al., 2019). Nearly 22 % of the weight of paddy is rice husk (Gautam et al., 2019). Various experiments have expressed the capability of rice husk to eliminate heavy metal ions from wastewater. An analysis of the removal efficiency of different heavy metal ions using rice husk showed removal efficiencies between 5.5 and 58.1 mg/g (Joseph et al., 2019).

Figure 4.1 Rice husk (Anjitha & Goerge, 2016)

Rice husk comprises cellulose, hemicellulose, lignin, and a high silica percentage. Due to its high silica content, risk husk has high mechanical strength and structural strength (Duraisamy et al., 2015). In 2016 (Al-Baidhani & Al-Salihy, 2016) performed experiments to evaluate the efficiency of rice husk for the removal of cadmium, lead, and chromium from aqueous solutions. The results obtained showed 97.6% for Cd, 90% for Pb, and 84% for Cr.

Table 4.1.0 Rice husk biosorption capacity for heavy metal ions removal.

Biosorbent type	Heavy metal ions	Biosorption capacity (mg/g)	Reference
Rice husk (raw)	Cr^{3+}	23	(Sobhanardakani et al., 2013)
Rice husk (raw)	Cu^{2+}	30	(Sobhanardakani et al., 2013)
Rice husk (modified)	Cd^{2+}	73.8	(Akhtar et al., 2010)

Rice husk can also be modified to increase the adsorption efficiency. In a study investigating the removal of selected divalent metal ions from aqueous solutions using activated rice husk (Akhtar et al., 2010), pre-treated rice husk with 0.1M nitric acid and 1M potassium carbonate at a temperature of 473K. The pre-treatment notably increased the biosorption capacity of rice husk (Akhtar et al., 2010). Another study to examine the removal of Cd^{2+} from aqueous media using rice husk was conducted. It was revealed that the chemical (HCl and NaOH) and thermal treatments (573K for three hours) on rice husk quadruple biosorption capacity of Cd^{2+} (Hoyos-Sánchez et al., 2017).

Orange Peel

Some recent studies have investigated the capacity of orange peels as an economical and eco-friendly biosorbent for heavy metal removal. (Akinhanmi et al., 2020) found out that orange peel can be a valuable biosorbent for removing cadmium from wastewater; its adsorption efficiency was 128 mg/g at a temperature of 45 degrees Celsius. Orange peels also showed good potential for regeneration (Akinhanmi et al., 2020). In another study, (Guo et al., 2011) investigated the removal of copper, cadmium, nickel, zinc, and lead from an aqueous solution using orange peel treated with potassium chloride. The maximum adsorption capacities for Cu^{2+}, Cd^{2+}, Pb^{2+}, $Zn^{2+,}$ and Ni^{2+} were 59.77, 125.63, 141.84, 45.29, and 49.14 mg/g, respectively (Guo et al., 2011). Additionally, recycle and reuse experiments indicated that KCl treated orange peels could be used for more than ten cycles (Guo et al., 2011).

Table 4.1.1 Orange peel biosorption capacity for heavy metal ion removal

Type of Biosorbent	Heavy metal ion	Biosorption capacity (mg/g)	Reference
Orange peel (modified)	Cd (II)	128.23	(Akinhanmi et al., 2020)
Orange peel (sulfur pre-treated)	Pb (II)	164	(Liang et al., 2011)
Orange peel (sulfur pre-treated)	Zn (II)	80	(Liang et al., 2011)
Orange peel (KCl modified)	Cd (II)	125.63	(Guo et al., 2011)

Sugarcane Bagasse

Sugarcane bagasse is the fraction of biomass resulting from the cleaning, preparation, and extraction of sugarcane juice (Rabelo et al., 2015). Sugarcane bagasse comprises three major components, cellulose, hemicellulose, and lignin. It also contains carboxylic and hydroxyl groups, which exhibit favorable capability for removing heavy metals ions over a broad range of pH (Noor et al., 2017).

Figure 4.2 Sugarcane Bagasse (Adopted from IndiaMart)

In some studies, attempts have been executed to survey the use of sugarcane bagasse as an effective biosorbent for Cr^{3+} removal. (Garg et al., 2007) observed the removal efficiency of sugarcane bagasse to be 92 % for the removal of Cr^{3+}. Another study investigating nickel removal using activated charcoal derived from sugarcane bagasse pith (Anoop Krishnan et al., 2011) reported a maximum adsorption capacity of 140.55mg/g. In 2015 (Gupta et al., 2015) carried out experiments to investigate the removal efficiency of As(III) and As (IV) using thiol functionalized sugarcane bagasse. (Gupta et al., 2015) The adsorption efficiency was 25.57 and 34.48 mg/g for As (III) and As (IV), respectively.

Table 4.1.2 Sugarcane bagasse biosorption capacity for heavy metal ions removal

Biosorbent type	**Heavy metal ion**	**Biosorption capacity (mg/g)**	**Reference**
Activated carbon from sugarcane bagasse.	Ni^{3+}	140.55	(Anoop Krishnan et al., 2011)
Thiol functionalized sugarcane bagasse.	As^{3+}	26	(Gupta et al., 2015)
Thiol functionalized sugarcane bagasse.	As^{4+}	35	(Gupta et al., 2015)
ZnCI activated sugarcane bagasse.	Cr^{6+}	77.5	(Cronje et al., 2011)
Sunnic anhydride modified sugarcane bagasse.	Cu^{2+}	133	(Karnitz et al., 2007)

Wheat Straw

Wheat straw is the stalk left over after wheat grains are harvested. Commonly, it is regarded as waste, and in some parts of the world, farmers burn it, leading to air pollution and creating a public health threat. Nevertheless, these stalks still serve a great purpose, they can be utilized to eliminate heavy metals from industrial effluents. Wheat straw is as well lignocellulosic material that comprises cellulose, hemicelluloses, lignin and sugars, and some other chemical compounds (D. S. M. C. K. Jain & Yadav, 2017).

Figure 4.3 Wheat straw, Adopted from IndiaMart online store

Wheat straw has several organic functional groups, such as carbonyl, sulfonyl hydroxyl, and phenolic, responsible for binding heavy metals. A study to examine the biosorption of cadmium ions on modified wheat straw was carried out by (Farooq Umar et al., 2011). The straw was modified with urea under the effect of microwave radiation. (Farooq Umar et al., 2011) found out the biosorption capacity to be 39.22 mg/g at pH 6. Another study (Dang et al., 2009) investigated the biosorption equilibrium and kinetics of Cd^{2+} and Cu^{2+} ions on wheat straw in an aqueous system. He observed the adsorption capacity of Cd^{2+} and Cu^{2+} to be 14.5 and 8.9 mg/g, respectively. (Dang et al., 2009) also found out that it was possible to reuse the metal-loaded wheat straw after desorption.

Table 4.1.3 Wheat straw biosorption capacity for heavy metal ion removal

Biosorbent type	**Heavy metal ion**	**Biosorption capacity (mg/g)**	**Reference**
Unmodified wheat straw	Pb^{2+}	10.38	(Athar et al., 2013)
Wheat straw modified with urea	Cd^{2+}	39.22	(Farooq Umar et al., 2011)
Black carbon from burned wheat straw	Cr^{6+}	21.34	(Wang et al., 2010)
Nitric acid-treated wheat straw	Cu^{2+}	8.85	(Dang et al., 2009)

5. Factors affecting biosorption

a) **Mechanisms of biosorption process**

The biosorption mechanism is an intricate process involving sorbate binding onto the biosorbent (Kanamarlapudi et al., 2018). The mechanism for biosorption of heavy metal ions can consist of various steps. The steps may include chemisorption, adsorption, complexation, chelation, and ion exchange (Alalwan et al., 2020). Biosorbents comprise different functional groups such as phenolic, amino, carboxyl, amide, and sulfonyl, attracting and sequestering heavy metal ions (Park et al., 2010). The critical process parameters affecting the biosorption process are pH, temperature, biosorbent dosage, and contact time (Kanamarlapudi et al., 2018).

b) **pH**

Since various functional groups are involved, pH affects the charge of these functional groups and, therefore, the number of heavy metal ions that get adsorbed. Most heavy metals are cationic species; the more negative charge the biosorbent has, the greater the sorbed metal ions (Torres, 2020). Hydrogen ions and heavy metal ions compete for the binding sites at lower pH values. Precipitation of heavy metal ions occurs in the form of hydroxides in an alkaline medium, reducing the amount of sorbed metal ions (Torres, 2020). A study by (Karnitz et al., 2007) to determine the effect of pH on the Biosorption of Cd^{2+} and Pb^{2+} using sugarcane bagasse indicated a maximum biosorption capacity at pH 6.0 and pH 6.5, respectively. However, this behavior is different for the case of heavy metals whose predominant forms are anionic, like arsenic and chromium. In such a scenario, acidic pH values (2.0-4.0) are conducive to attaining higher biosorption capacity. In lower pH values, the biomass has a more significant number of positive charges, which allows the attraction of anions (Torres, 2020). (Garg et al., 2007) conducted a study to investigate the removal of chromium hexavalent ions from aqueous solutions using jatropha oil cake, maize corn cobs, and sugarcane bagasse. The highest biosorption efficiency was observed at pH 2.0 and considered the ideal pH (Garg et al., 2007).

c) **Temperature**

Temperature is a crucial factor in the biosorption of heavy metals. Temperature is responsible for the thermodynamics of the biosorption process (Farooq Umar et al., 2011). A decrease or increase in temperature should be followed by altering the number of heavy metal ions sorbed by the biomass. Generally, the biosorption capacity increases at elevated temperatures because of a reduction in Gibb's free energy and bond breaking, amongst other reasons (Joseph et al., 2019). It causes an increase in the frequency of collision between the biomass and the heavy metal ions and enhances the active sorbent sites, resulting in higher affinity (Qasem et al., 2021). In an experiment, (Malkoc & Nuhoglu, 2005) observed an increase of approximately 20 % in the removal efficiency of Ni^{2+} using tea waste when the temperature was increased from 25 to 60 degrees Celsius. This increase was attributed to the increased mobility of Ni^{2+} ions and the increased number of sorption sites due to the breaking of chemical bonds (Malkoc & Nuhoglu, 2005).

d) Biosorbent Dosage

Biosorbent dosage is directly proportional to the heavy metal uptake. (Gupta et al., 2015) conducted a study to investigate the removal of As^{3+} and As^{5+} using sugarcane bagasse. The dose rate was increased from 0.5 to 2.5g/L, and the initial concentration of As^{3+} and As^{5+} was maintained at 500ppb. (Gupta et al., 2015) observed a removal efficiency of 98% for both As^{3+} and As^{5+}using 0.3g sugarcane bagasse. The increase in the percentage removal As^{3+} and As^{5+} with dosage rate was ascribed to the rise in the number of active sites (Gupta et al., 2015). (Akinhanmi et al., 2020) also discovered that the percentage removal of Cd^{2+} using orange peels appreciably increased by increasing the orange peel dose from 0.01 to 0.04g.

e) Contact time

Contact time studies are imperative. They provide the minimum time required to eliminate the maximum amount of heavy metal ions from the wastewater and, therefore, help scale up the biosorption process. (Sobhanardakani et al., 2013) performed experiments to investigate the removal of Cu^{2+} and Cr^{3+} from wastewater using organic solid waste rice husk. (Sobhanardakani et al., 2013) studied the removal of Cu^{2+} and Cr^{3+} at varying contacting times of 10, 20, 30, 60, 90, and 120 minutes. Removal efficiency increased with the lapse of contact time. The biosorption rate was speedy initially because of the many binding sites available. About 45% and 55% of Cu^{2+} and Cr^{3+} were removed within 10 minutes and equilibrium removal after 30 minutes. So (Sobhanardakani et al., 2013) accepted 30 minutes as the optimum contact time and was used for the subsequent experiments. It should be noted that optimum contact time varies from experiment to experiment.

6. Challenges and Future Perspective

Biosorption has emerged as a sustainable and reliable method for removing toxic heavy metal ions from wastewater compared to traditional methods applied for the same purpose. Developing countries can embrace and leverage this technique because it is easy cheap to operate. One of the significant advantages of biosorption is its capability to remove toxic heavy metals even in minute concentrations. This review reveals the potential of different agricultural waste materials as biosorbents for heavy metal removal. The prospect of biosorption has been explored and indicated at both laboratory and pilot levels. A great deal of research work has been done on the biosorption of heavy metals. However, the implementation of biosorption to authentic wastewater at an industrial scale is still narrow. Therefore, the future perspective is to explore the application of biosorption at an industrial scale. Up to date, a few commercial enterprises have been established. The currently available knowledge about biosorption can make it possible to develop large-scale procedures and extend the application of biosorption beyond laboratory studies. Since biosorbents are selective, a set of potential biosorbents might need to be standardized for wastewater coming from different sources. If a particular kind of biosorbent is efficient in removing chromium ions from steel industry effluent, it does not imply that the same type of biosorbent is efficient in removing lead ions from effluent originating from the battery industry. Another future perspective is the recovery of heavy metal ions. With biosorption, the chances of recovering the heavy metal ions are higher than in traditional methods.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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