

Removal of lead from aqueous solutions using different coffee by-products (*Coffea arabica* L.)

Remoción de plomo de soluciones acuosas utilizando diferentes subproductos del café (*Coffea arabica* L.)

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RESUMEN

La contaminación con metales pesados se ha incrementado como resultado de la industrialización. Existen diversas técnicas para su tratamiento; sin embargo, estas representan diferentes desventajas, por lo que es necesario desarrollar investigación e innovar en tecnologías de remoción limpias y sostenibles en el tiempo. La investigación está orientada a revisar la literatura publicada acerca de la eliminación de plomo (II) de soluciones acuosas por medio de diferentes subproductos del café, como la cascarilla (*Coffea arabica* L.), y otros subproductos orgánicos, que contienen biosorbente de bajo costo con alto rendimiento de biosorción de plomo (II). Se ha registrado un mayor rendimiento de biosorción de plomo (II) en los granos y la cascarilla de café, superiores al 90 % y 230 mg/g, respectivamente. Por lo tanto, es necesario profundizar en la búsqueda de nuevos biosorbentes que sean sostenibles en el tiempo. A medida que se incrementa el valor del pH, disminuye el proceso de sorción, lo que hace de este un parámetro importante a evaluar en estudios posteriores.

Palabras clave: biosorbentes, biosorción, residuos agrícolas, cascarilla de café, metales pesados.

ABSTRACT

Both the production of, and contamination by, heavy metals have increased as a result of industrialization, thereby endangering biodiversity and human health. Several heavy metal removal techniques are available, but with a range of disadvantages, meaning that further research and innovation are required. The aim of this research is to summarize the literature on the removal of lead (II) from aqueous solutions using different coffee by-products such as coffee husk (*Coffea arabica* L.) and other organic waste products containing potential low-cost biosorbent materials with a high lead biosorption (II) yield. A higher lead (II) biosorption yield has been found in grounds and coffee husk, greater than 90 % and 230 mg/g, respectively, and further research will be required in the search for new biosorbents that are sustainable over time. Also, it has been shown that as pH value increases the sorption process decreases, making this an important parameter for the evaluation of subsequent studies.

Keywords: Biosorbents, biosorption, agricultural waste, coffee husk, heavy metals



Introduction

Heavy metal (HM) contamination is a global hazard that began with the industrial revolution (Jacob *et al.*, 2018), resulting principally from mining activities, foundries and the organic compounds used in agriculture (Carolin *et al.*, 2017). It is a problem affecting the stability of soil and water (Kobielska *et al.*, 2018), thereby generating environmental (Bello *et al.*, 2018) and public health problems (Reyes *et al.*, 2016). One of the first elements identified as toxic to humans was lead (Pb) and, over time, it has continued to have significant relevance (Thompson, 2018). Approximately half of the Pb extracted globally in 2017 came from China (USGS, 2017), totaling around four million metric tons (ILZSG, 2018), while in 2016 Peru produced a total of 310 metric tons (USGS, 2017).

The underlying dynamics of the global production of Pb (1805-2000) exhibit variations in countries such as Spain and Canada, while other countries, such as Peru and the United States, have maintained significant growth (Mudd *et al.*, 2017). In today's world, Pb production is focused mainly on the manufacturing of batteries and electrical products (Skerfving and Bergdahl, 2015). The final disposal of these products occurs in hazardous waste containers and landfills (US EPA, 2018), and most of the waste is not managed correctly (Vargas-Camareno and Romero-Esquivel, 2006), leading to adverse effects on the environment (Acurio *et al.*, 1997), such as accumulation and biomagnification in ecosystems (Yllanes *et al.*, 2014), reduction in plant size (Ghani *et al.*, 2010), decrease in biodiversity (Bello *et al.*, 2018), soil degradation (Guerrero and Pineda, 2016), the acidification of water (Ramírez and Castillo, 2008) and respiratory diseases (Tello, 2014).

Peru experiences significant problems with Pb in hydrographic basins: its concentration exceeds the EQS (Environmental Quality Standard) in water, affecting the fauna in aquatic ecosystems. Typical cases include the Mantaro River, in which the concentration of Pb in the slag deposit area of Huachán between 2013–2015 exceeded the corresponding EQS by 4000 % (Arce and Calderón, 2017). In the Ramis River, the Pb concentration surpassed the corresponding EQS by 10,000 % in 2003 (Pérez *et al.*, 2014), and in the Ventanilla Wetlands, the Pb concentration was found to be 700 % higher than the corresponding EQS (Vidal *et al.*, 2017). Furthermore, in the soils of urban parks, such as the Campo de Marte, El Olivar, the Pentagonito, Huachipa Zoo and Parque de las Leyendas, concentrations of Pb in the soil have been found to be almost double the EQS limit (Tello *et al.*, 2018). Between 2013 and 2015, the soils of La Oroya exceeded by ten-fold the acceptable EQS levels in soils for industrial use (Arce and Calderón, 2017).

In the context of these problems, studies are being conducted in the search for low-cost adsorbents such as organic by-products and natural compounds to remove heavy metals (Gunatilake, 2015; Jeguirim *et al.*, 2017). Agricultural activity generates significant amounts of

plant waste to which no added value is given (Pedreño *et al.*, 1995). In the case of bananas, only 25 % of any given bunch is usable, while 75 % is considered waste (Chávez and Rodríguez, 2016). This waste is eventually incinerated, or simply deposited in landfills due to the cost of disposal (Solé and Flotats, 2004), leading to air and water pollution (Flores, 2009) as the accumulated waste decomposes (Kolmans and Vásquez, 1999).

In Peru, the leading agricultural export is coffee: 425,416 hectares are dedicated to its cultivation, representing 6 % of the country's farmed land. Coffee production occurs in 17 departments, 67 provinces and 338 districts of Peru (Minagri, 2018). Global coffee production totals approximately 10 million tons, with Peru contributing almost 3 % of this total (USDA, 2018).

The aim of this article is to provide an overview of the literature on the removal of Pb from aqueous solutions using different coffee by-products such as coffee husk (*Coffea arabica* L.) and other organic waste products, addressing their importance as a low cost biosorbent material sustainable over time. This practice adds value to agricultural waste, employing it as an efficient alternative in the decontamination of the finite resource that is fresh water.

Theoretical framework

Heavy metals

Heavy metals (HM) are those whose density exceeds 5 g/cm³ (Gunatilake, 2015). Currently, HM contamination constitutes a severe hazard at both local and global levels (Reyes *et al.*, 2016; He and Chen, 2014; Fu and Wang, 2011), because HM are not biodegradable and travel through water, soil and air (Reyes *et al.*, 2016; Fu and Wang, 2011). Furthermore, their presence in the environment may be either natural or anthropic (Reyes *et al.*, 2016), constituting a risk to humans and the environment in general (Bello *et al.*, 2018; Carolin *et al.*, 2017).

The paper, mining and pesticide industries, among others, discharge effluents with HM (Carolin *et al.*, 2017; Kobielska *et al.*, 2018; Anastopoulos *et al.*, 2017), causing soil and water contamination, algae proliferation (Carolin *et al.*, 2017), acid drainage (Kobielska *et al.*, 2018), the deterioration of soil structure (Guerrero and Pineda, 2016), the destruction of ecological landscapes, and decreased biodiversity (Bello *et al.*, 2018). Bioaccumulation of HM in the food chain (He and Chen, 2014) and their presence in the air can lead to respiratory diseases (Tello, 2014). Among the most predominant HM in industrial effluents are copper (Cu), silver (Ag), cadmium (Cd), arsenic (As), mercury (Hg), and lead (Pb) (He and Chen, 2014; Fu and Wang, 2011). These are considered highly toxic (Carolin *et al.*, 2017). Pb is a toxic element that (Thompson, 2018) generates environmental imbalances at different concentrations (Bello *et al.*, 2018).

Lead

Pb is one of the most harmful HM (Gómez-Yepes and Cremades, 2013; Skerfving and Bergdahl 2015) and is considered an environmental pollutant (Ghani *et al.*, 2010; García-Rosales and Colin-Cruz, 2010). It is found in combination with other elements (Finkelstein *et al.*, 2014), in the form of sulfur, cerussite and galena (Acharya *et al.*, 2009; Shukla *et al.*, 2018; Flora *et al.*, 2006), and is bluish-white to gray in color (Thompson, 2018). Pb is present in effluents produced by the metal, electrical and motor vehicle industries (Carolin *et al.*, 2017; Ghani *et al.*, 2010) and is widely used because of its corrosion resistant, ductility and malleability properties (Reyes *et al.*, 2016; Bellinger, 2018; Flora *et al.*, 2006) in its metallic form and alloys (Gómez-Yepes and Cremades, 2013). Lead has been used since the Roman period (Mudd *et al.*, 2017), when it was used to make water pipes, window frames and utensils (Shukla *et al.*, 2018; Bellinger, 2018). Today, Pb is used in batteries, inks, alloys and fuels (Thompson, 2018; Flora *et al.*, 2006).

Effects of lead

Through mining, smelting and recycling (Flora *et al.*, 2006), Pb can cause a range of adverse effects on the ecosystem, contaminating water, air and soil, and affecting human health (Table 1). Such activities had their origin in the industrial revolution (Jacob *et al.*, 2018), with the presence of Pb increasing significantly worldwide, resulting in dispersion into the environment (Bellinger, 2018). Industrial activity remains a major source of environmental HM contamination, and in terms of Pb ecosystem contamination Peru is no exception (Table 2).

Removal of Pb from water is an ongoing concern (García-Rosales and Colin-Cruz, 2010; Fu and Wang, 2011; Carolin *et al.*, 2017). Different methods for removing Pb from water have been developed, including flotation, chemical precipitation, coagulation/flocculation,

membrane filtration, ion exchange and adsorption (Carolin *et al.*, 2017; Fu and Wang, 2011; Bello *et al.*, 2018; He and Chen, 2014, Kobielska *et al.*, 2018).

Heavy metal removal techniques

Flotation

Flotation is a solid-liquid separation technology in which metals in suspension are recovered by their attachment to gas bubbles (usually air) (Carolin *et al.*, 2017; Bilal *et al.*, 2013). This highly efficient technique, in which the size and speed of bubbles are the most important parameters, forms a low-lying sludge (Patil *et al.*, 2016). Dissolved air, ionic and precipitation flotation are the main processes employed in this technique to remove metal ions present in water (Fu and Wang, 2011; Bilal *et al.*, 2013).

Chemical precipitation

Chemical precipitation is the most widely used physicochemical treatment for separating metal ions from a solution (Gunatilake, 2015; Ku and Jung, 2001; Bila *et al.*, 2013). To achieve precipitation, chemicals are added that alter the pH, so that the precipitate does not dissolve in the solution (Hashim *et al.*, 2011; Fu and Wang, 2011; Bilal *et al.*, 2013). This technique is usually applied to remove metals at high concentrations from effluents (Carolin *et al.*, 2017).

Coagulation/flocculation

Coagulation consists of increasing the density of suspended particles in order to destabilize them (Carolin *et al.*, 2017; Bilal *et al.*, 2013). Flocculation consists of the action of polymers to bond large, suspended particles together to form agglomerates. Once the particles flocculate, they tend to precipitate (Fu and Wang, 2011). The effectiveness of this method is dependent upon the

Table 1. Adverse effects of lead (Pb) on ecosystem components and human health as a result of anthropogenic activities.

Metal ion	Effects	References
Pb ²⁺	Accumulation in ecosystems	Yllanes <i>et al.</i> , 2014; He and Chen, 2014
Pb ²⁺	Decrease in biodiversity	Bello <i>et al.</i> , 2018
Pb ²⁺	Soil degradation	Guerreo and Pineda, 2016, Tello <i>et al.</i> , 2018
Pb ²⁺	Plant physiology	Ghani <i>et al.</i> , 2010; Carolin <i>et al.</i> , 2017
Pb ²⁺	Acidification of surface waters	Ramírez y Castillo, 2008; Kobielska <i>et al.</i> , 2018
Pb ²⁺	Respiratory diseases	Tello, 2014; Reyes <i>et al.</i> , 2016; Shukla <i>et al.</i> , 2018

Table 2. Lead (Pb) contamination in Peruvian ecosystems and comparison with current legislation (EQS).

Lead contamination (Pb)	Found value	EQS value	EQS for water and soil	References
Mantaro River	0.1 mg/L	0.0025 mg/L	Category 4	Arce and Calderón, 2017
Ramis River	0.26 mg/L	0.0025 mg/L	Category 4	Peréz <i>et al.</i> , 2014
Ventanilla Wetlands	0.02 mg/L	0.0025 mg/L	Category 4	Vidal <i>et al.</i> , 2017
Lima city parks	266 mg/kg PS	140 mg/kg PS	Parks soil	Tello <i>et al.</i> , 2018
Soils in the city of La Oroya	9000 mg/kg PS	800 mg/kg PS	Extractive soil	Arce and Calderón, 2017



type of coagulant, dose, pH, temperature (Carolin *et al.*, 2017) and the type of flocculant, the most frequently used being aluminum sulfate (Fu and Wang, 2011; Carolin *et al.*, 2017; Bilal *et al.*, 2013).

Membrane filtration

Membrane filtration consists of the physical separation of solutes by passing a single stream through a membrane system (Gunatilake, 2015). This technique separates particles according to their size, concentration in solution, pH and pressure (Carolin *et al.*, 2017), employing a specific porous material to remove the HM in effluents (Patil *et al.*, 2016). Membrane processes include ultrafiltration, reverse osmosis and electrodialysis (Fu and Wang, 2011; Bila *et al.*, 2013; Gunatilake, 2015).

Ion exchange

Ion exchange consists of substituting ions on the surface of a solid for others that are in solution and have the same charge (Hamdaoui, 2009; Carolin *et al.*, 2017; Patil *et al.*, 2016). Ion exchange resin is a synthetic or natural material used to recover or eliminate metals (Carolin *et al.*, 2017; Fu and Wang, 2011; Bilal *et al.*, 2013). This technology is highly efficient in the removal of metals (Kang *et al.*, 2004), but it is very expensive and cannot be employed on a large scale (Bilal *et al.*, 2013).

Adsorption

Adsorption is considered an efficient, profitable and environmentally sustainable method (Carolin *et al.*, 2017; Fu and Wang, 2011). It produces high-quality treated effluent. Adsorption consists of removal of metals through the adhesion of the dissolved solid to a surface. Thus, it can be defined as the accumulation of heavy metal on the surface of a biosorbent (Patil *et al.*, 2016). Moreover, it is a reversible technique and does not produce toxic contaminants (Demirbas, 2008; Fu and Wang, 2011), and several bioabsorbents are available (Bilal *et al.*, 2013).

However, the techniques mentioned in this review have various advantages and disadvantages (Table 3), depending on the contaminated site and the degree of contamination, among other factors (Bello *et al.*, 2018; He and Chen, 2014; Carolin *et al.*, 2017), mostly related to cost, the generation of by-products, and the use of additional compounds (Fu and Wang, 2011; Rangabhashiyam and Balasubramanian, 2018).

While the search must continue for new technologies that are more environmentally friendly, affordable and sustainable over time (He and Chen, 2014; Gunatilake 2015), the biosorption technique meets several requirements (Sari *et al.*, 2011; Kobielska *et al.*, 2018).

Biosorption technology is a recent innovation that has shown promise for the removal of HM in aqueous

solutions (He and Chen, 2014; Bilal *et al.*, 2013; Fu and Wang, 2011; Carolin *et al.*, 2017).

Biosorption

HM biosorption is a sorption process (Rangabhashiyam and Balasubramanian, 2018; He and Chen, 2014). It transfers ions from the liquid phase to the solid phase (Gunatilake, 2015), facilitating a mass exchange of substances bound by physical and chemical interactions to the solid surface (Sörme and Lagerkvist, 2002). Compared to conventional methods, this technique exhibits advantages, such as

Table 3: Comparison of advantages and disadvantages of heavy metal effluent removal techniques.

Techniques	Advantages	Disadvantages	References
Flotation	Low sludge formation, high separation efficiency, uses bubble junctions	High operational and maintenance cost	Carolin <i>et al.</i> , 2017; Patil <i>et al.</i> , 2016; Fu and Wang, 2011; Bilal <i>et al.</i> , 2013
Chemical precipitation	Conventional and cheap, high concentration of metal	Chemical requirement, high amount of sludge, does not apply to low metal concentrations	Carolin <i>et al.</i> , 2017; Hashim <i>et al.</i> , 2011; Fu and Wang, 2011; Bilal <i>et al.</i> , 2013
Coagulation/ Flocculation	High efficiency, applicable to large industrial scale	Production of sludge in large quantities, produces by-products, high operating cost	Carolin <i>et al.</i> , 2017; Fu and Wang, 2011; Bilal <i>et al.</i> , 2013; Gunatilake, 2015
Membrane filtration	High metal removal, less space, selective membrane	High capital cost, complex process, backwash, uses other compounds, membrane fouling	Carolin <i>et al.</i> , 2017; Gunatilake, 2015; Rangabhashiyam and Balasubramanian, 2018; Fu and Wang, 2011; Bilal <i>et al.</i> , 2013
Ion exchange	High efficiency, fast kinetics, selective heavy metal removal Low sludge formation, uses low-cost adsorbent, high efficiency	Removes limited metal ions, high capital cost, low concentration of metal, use of reagents for regeneration	Hamdaoui, 2009; Bilal <i>et al.</i> , 2013; Carolin <i>et al.</i> , 2017; Kang <i>et al.</i> , 2004
Adsorption	Reversible technique, sustainable over time, does not produce pollutants	Loss of desorption capacity, in case of activated carbon it involves a high cost	Carolin <i>et al.</i> , 2017; Demirbas, 2008; Fu and Wang, 2011; Bilal <i>et al.</i> , 2013

low operating cost and high metal removal performance, and the absence of the production of contaminating by-products (He and Chen, 2014; Fu and Wang, 2011; Hashim *et al.*, 2011). The critical functional biosorbent groups are carboxyl, hydroxyl, sulfate, phosphate and amine (He and Chen, 2014; Hashim *et al.*, 2011), increasing adsorption activity for metal removal (Demirbas, 2008). The phenomena that influence the biosorption technique are adsorption, ion exchange and surface precipitation (Carolin *et al.*, 2017; Bilal *et al.*, 2013; Gunatilake, 2015).

Biosorption employs different biosorbents that generally include algae (He and Chen, 2014; Carolin *et al.*, 2017), fungi (Wang and Chen, 2009; Wang and Chen, 2006), bacteria (Jacob *et al.*, 2018; Sahmoune, 2018) and organic by-products (García-Rosales and Colin-Cruz, 2010; Bilal *et al.*, 2013; Fu and Wang, 2011). Currently, the search for low-cost adsorbents is being studied, with solid wastes having great importance as natural substances with great adsorbent capacity for use in the removal of HM (Fu and Wang, 2011; García-Rosales and Colin-Cruz, 2010; Bilal *et al.*, 2013; Bansode *et al.*, 2003; Gunatilake, 2015; Jeguirim *et al.*, 2017).

Organic by-products

Known as solid, urban, commercial or industrial waste, they are efficient components for the removal of HM present in effluents (Carolin *et al.*, 2017). The hydroxyl groups present in the cellulose, hemicellulose and lignin of the biomass and functional groups such as amide, amino, carboxyl, among others, have an affinity for metal ions (Yan *et al.*, 2010). Currently, there is a trend towards the use of plant material as a biosorbent, due to its low cost and efficiency in the removal of HM (Table 4), particularly lead (Pb).

Coffee

Coffee is one of the major products traded globally (Van Dam and Harmsen, 2010). The plant belongs to the

Rubiaceae family and its species include *Coffea arabica* and *Coffea canephora* (Anastopoulos *et al.*, 2017; Janissen and Huynh, 2018; Murthy and Naidu, 2012a). Several authors are studying coffee by-products as biosorbent material for the removal of HM (Table 5).

Coffee husk

At 57.8 %, carbohydrates make up the most significant proportion of the chemical composition of the coffee husk (Table 6). The coffee husk is a by-product of coffee, considered a potential biosorbent of HM (Jeguirim *et al.*, 2017; Anastopoulos *et al.*, 2017). It is composed of the dry outer skin, pulp and parchment (Oliveira *et al.*, 2008). Coffee cultivation generates considerable quantities of husk (Anastopoulos *et al.*, 2017): for each ton of coffee beans, an average of about one ton of husks is produced (Saenger *et al.*, 2001).

Table 5. Removal of heavy metals from water using different coffee by-products.

Metal ions	Coffee by-products	Removal (%) or (mg/g)	References
Pb 2+	Coffee grounds	96%	Seniūnaitė <i>et al.</i> , 2014
	Coffee husk	230 mg/g	Alemayehu <i>et al.</i> , 2014
	Coffee husk	50.8 mg/g	Berhe <i>et al.</i> , 2015
Cu 2+	Coffee grounds	97 %	Seniūnaitė <i>et al.</i> , 2014
	Coffee residue	70 mg/g	Kyzas, 2012
Cr 6+	Coffee husk	220 mg/g	Alemayehu <i>et al.</i> , 2014
	Coffee husk	59.5 mg/g	Ede, 2014
Ni 2+	Raw exhausted coffee	24.3 mg/g	Liu <i>et al.</i> , 2015
Zn 2+	Coffee residue	4.4 mg/g	Wu <i>et al.</i> , 2015

Table 6. Chemical composition of coffee husk.

Coffee components	Composition of coffee husk (%)	References
Carbohydrates	57.8	Murthy and Naidu, 2012b; Janissen and Huynh, 2018; Shemekite <i>et al.</i> , 2014
Cellulose	43	
Hemicellulose	7	
Moisture	12	
Lipids	1.5-2.0	
Total fiber	31.9	
Ash	6	
Protein	9.2	
Nitrogen	1.8	
Caffeine	1.2	
Tannins	4.5-9.3	
Chlorogenic acid	12.59	

Table 4. Removal of Pb (II) from water using different biosorbents from agricultural residues, and their biosorption efficiency.

Metal ion	Agricultural residues	Removal (%)	pH	References
Pb 2+	Rapeseed biomass	94.47	5	Morosanu <i>et al.</i> (2017)
Pb 2+	Orange peel	99.2	6	Tejada <i>et al.</i> (2016)
Pb 2+	Corn cob	67.5	6	Tejada <i>et al.</i> (2016)
Pb 2+	Orange peel	99.5	5	Cardona <i>et al.</i> (2013)
Pb 2+	Pseudostem banana	55	-	Ramírez and Enríquez (2015)
Pb 2+	Coir fiber	97	2.5	Conrad and Bruun (2007)



Different analytical techniques are used to identify the ion exchange capacity of the coffee husk: Fourier transform infrared spectroscopy (FTIR), N₂ adsorption-desorption (BRT, zero-load point, scanning electron microscopy (SEM) analysis (Anastopoulos *et al.*, 2017; Fiol and Villaescusa, 2009; Dulman and Cucu-Man, 2009). The amount of adsorbed metal ions is directly proportional to the surface area (Tan, 2010; Anastopoulos *et al.*, 2017; Oliveira *et al.*, 2008; Demirbas, 2008; Anastopoulos *et al.*, 2017; Jeguirim *et al.*, 2017; Wang and Chen, 2006).

Factors influencing biosorption

pH is an essential parameter of the biosorption process and is related to the solubility of metal ions (Cirik *et al.*, 2012; Abdel-Aty *et al.*, 2013; Wang and Chen, 2006; Farooq *et al.*, 2010). Hydrogen ions are formed in a competitive adsorbate (Tejada *et al.*, 2015); as pH increases, the repulsive forces between H⁺ and metal ions decrease and sorption is facilitated (Morosanu *et al.*, 2017); however, a pH value that is too high can cause analyte precipitation (Wang and Chen, 2006). Biosorbent concentration is the amount of biosorbent that is bonded to the metal ion binding sites in the biomass (Monteiro *et al.*, 2012; Zaib *et al.*, 2016). As the amount of biosorbent increases, the availability of active sites means that there will be a more significant removal of HM (Rangabhashiyam and Balasubramanian, 2018; Wang and Chen, 2006).

Biosorption contact time is an important parameter because it defines biosorption optimization (Montazer-Rahmati *et al.*, 2011; Wang and Chen, 2006). When a low concentration of Pb is removed, the contact time reaches biosorption equilibrium (Albis *et al.*, 2016). The initial concentration of the metal is another parameter that provides a vital driving force to overcome the mass transfer resistance of the metal between the aqueous and liquid phases (Sahmoune, 2018): the higher the initial concentration of the metal, the better the biosorption process (Wang and Chen, 2006).

One variable that affects the biosorption process is temperature (Morosanu *et al.*, 2017; Wang and Chen, 2006). It increases the biosorption of metals, since it increases the active sites of the biosorbent (Park *et al.*, 2010). However, a significant increase in temperature reduces biosorption capacity and leads to biosorbent problems (Krim *et al.*, 2006; Tejada *et al.*, 2015; Farooq *et al.*, 2010).

Conclusions

The galvanic, electrical, pesticide and mining industries are the primary sources of environmental lead contamination, generating imbalances in the components of environmental matrices, such as plant size reduction, decrease in biodiversity, soil degradation, water acidification and, as a consequence, the emergence of diseases which significantly affect public health.

In Peru, lead contamination exceeds the EQS values for water and soil by more than 100-fold in hydrographic basins and 10-fold in parks. In this context, biosorption constitutes an efficient and sustainable alternative for the removal of the lead (II) present in bodies of water.

The technique of biosorption uses organic by-products as biosorbent material for heavy metals. Coffee grounds and coffee husk are agricultural waste products with a high potential for lead (II) removal because coffee is one of the major globally traded products. Also, compared to other organic waste products, coffee growing generates considerable quantities of husk, which means less land is required for its production. pH is an essential parameter in the heavy metal biosorption process: as pH increases, the repulsive forces between the H⁺ ions and metal ions decrease, and sorption is facilitated; however, when the pH value is too high, precipitation can occur.

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Authors' contributions

JP-P: Principal investigator, study design, reviewing of secondary information, preparation and approval of the final manuscript. EV: Study design, reviewing and methodological support for the conducting of research, and approval of the final version. AV-A: Principal advisor, study design, ongoing reviewing throughout the process and approval of the final manuscript.

Competing interests

The authors declare no conflict of interest.

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