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Use of Activated Carbon from *Prunus persica* and *Persea americana* for the Removal of Arsenic and Lead in Contaminated Water

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Water contamination by heavy metals is caused by various anthropogenic activities that alter ecosystems and health. Thus, this research determined the efficiency of activated carbon from *Prunus persica* and *Persea americana* for the removal of arsenic and lead in contaminated water. The activated carbons were physically and chemically characterized. For the removal of metals, tests were carried out using different doses (3, 5 and 7 g) of activated carbon and different contact times (1, 15 and 30 min). The results indicated that, with respect to the characteristics of granulometry, porosity, humidity and organic matter, the activated carbon from *Persea americana* presented 0.85 mm, 0.51%, 74% and 92%, respectively. Whereas, the activated carbon from *Prunus persica* showed 0.85 mm, 0.48 %, 68% and 87%, respectively. In addition, activated from *Prunus persica* achieved arsenic and lead removals of 96.94% and 97.19%, respectively. Whereas, the activated carbon from *Persea americana* achieved removals of 95.37% and 95.52%, respectively. On the other hand, physico-chemical parameters such as electrical conductivity, turbidity, BOD5, COD, suspended solids and oils and greases also showed significant reductions. In conclusion, both activated carbons have great potential in the removal of arsenic and lead, and can be applied in the treatment of water contaminated with these metals.

1. Introduction

Heavy metals are inorganic pollutants whose accumulation, distribution and permanence in rivers are potentially dangerous due to their toxicity (Salas-Mercado et al., 2020; Ayme Estacio et al., 2022). Arsenic and lead are the metals with the highest toxicity, and their chronic exposure can damage various organs and promote the development of diseases (Moreno-Rivas & Ramos-Clamont Montfort 2018). In Peru, according to environmental quality standards, surface water intended for human consumption with disinfection treatment must have a maximum concentration of arsenic and lead of 0.01 mg/L (Ministerio del Ambiente - MINAM, 2017).

Lead is the heavy metal found in the greatest quantity and availability in the atmosphere, hydrosphere and edaphosphere, mostly available at a pH of less than 5, i.e., in acidic conditions (Reyes et al., 2016). For its part, arsenic is an element totally distributed throughout the atmosphere and is found in different variations, being a very soluble compound in water and its availability varies according to the pH level (Reyes et al., 2016).

In that sense, various researches such as membrane filtration, electrochemical treatments, photocatalytic reactions, coagulation, etc. have been employed for the removal of heavy metals, but some of these methods cause secondary pollution or low efficiency and high energy consumption, limiting their future applications (He et al. 2023). Compared to previous methods, adsorption technology is considered a potentially efficient and energy-saving strategy (He et al. 2023), highlighting activated carbon as one of the most widely used adsorbent materials within contaminated effluent treatment systems (Ortuño Sánchez 2019). Activated carbon has the capacity to remove a higher percentage of heavy metals compared to zeolite and sand as filtration media, achieving removal values higher than 50 % (Vera Puerto et al. 2016). Likewise, this material has good filtration capacity for physicochemical and microbiological contaminants (Rodríguez Meza et al. 2018). In addition, the

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use of activated carbon is an eco-friendly technique (Cabello-Torres et al., 2021; Loyola S. et al., 2022), without employing mechanized treatments that involve the use of other resources that can produce the alteration of the physical and chemical composition of water. On the economic side, it is a low-cost methodology due to the reuse of easily acquired waste from supply markets.

Research that used activated carbon derived from seeds, achieved good adsorption capacity of heavy metals, achieving removal values higher than 97 % for lead and higher than 70 % for arsenic (Aguirre Achaquihui 2017; Rosales Fernández & Quevedo Sanchez 2019). Therefore, this research evaluated the efficiency of activated carbon based on *Prunus Pérsica* and *Persea Americano* for the removal of heavy metals such as arsenic and lead from contaminated water, respecting environmental quality standards for water for human consumption and crop irrigation. *Prunus pérsica* is a species that grows mainly in temperate zones, and this product is the most consumed worldwide, which makes it easy to acquire (Nava Vega 2005). *Persea americana* is a species that grows in warm climates, where 40 % of the fruit is the seed located in the center of the fruit (Nava Vega 2005).

2. Materials and methods

2.1 Raw material and production of activated carbon

Two kg of peach (*Prunus persica*) [Figure 1a] and avocado (*Persea american*o) [Figure 1b] residues were collected from supply markets and were subjected to washing, fragmentation, drying at 40 °C and weighing. Subsequently, the residues were carbonized in a muffle at 800 °C for 30 minutes in an inert atmosphere. Then, they were pulverized and sieved (800 µm) to achieve particle homegenization.

For the chemical activation of the charcoal, 1 mL of phosphoric acid (activating agent) was added for each gram of *Prunus persica* and *Persea americano* endocarp powder, in order to break the bonds that bind the cellulose chains together at a temperature lower than 500 °C. Finally, the activated carbon was washed with distilled water to eliminate the remains of the reagents and other agents that were impregnated.

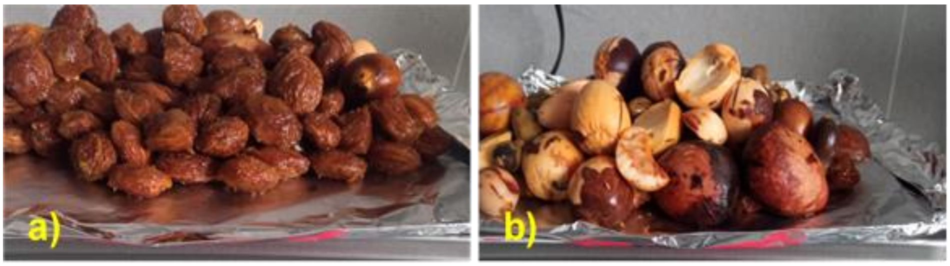

Figure 1: Organic wastes: (a) Endocarp of Prunus persica and (b) Endocarp of Persea americana

2.2 Characterization of activated carbon

The characterization of the activated carbon was subject to the "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates" (ASTM C136-01). In the characterization of both activated carbons, the granulometry, porosity, moisture percentage and organic matter content were evaluated.

2.3 Treatment of arsenic contaminated water

For the treatment of water contaminated with arsenic and lead, 1000 mL of contaminated water at pH 5.9 were used, with dosages of activated carbon from *Prunus persica* and *Persea americano* that were composed of 3, 5 and 7 g. The removal of the contaminants was evaluated by the jar test which contains four or six stirring paddles that mix the contents of the containers, at the same mixing speed for all containers which is controlled by a revolutions meter in RPM, and the operating conditions for each test are shown in Table 1.

Table 1: Operating conditions in the jar test for contaminant removal

Activated carbon	Dose	Contact time	Agitation speed	Sedimentation time
Activated carbon from *Prunus persica* and Activated carbon from *Persea americana*	3 g	30 minutes	40 rpm	60 minutes
	5 g	30 minutes	40 rpm	
	7 g	1 minutes	280 rpm	
		15 minutes	80 rpm	
		30 minutes	40 rpm	

2.4 Evaluation of physico-chemical parameters

The evaluation of physicochemical parameters such as electrical conductivity, turbidity, BOD5, COD, suspended solids and oils and fats was carried out with doses of 3, 5 and 7 g of activated carbon. For this purpose, beakers containing 1000 mL of contaminated water at pH 5.9 were used, which were subjected to the jar test at 40 rpm for 30 minutes.

3. Results and discussion

3.1 Characteristics of activated carbon

Table 2 shows the physicochemical properties of activated carbon, including porosity, particle size, humidity and organic matter content.

Table 2: Characteristics of organic waste activated carbon

Activated carbon	Porosity (%)	Particle size (mm)	Humidity (%)	Organic matter (%)
Prunus persica	0.48	0.85	68	87
Persea americano	0.51	0.85	74	92

From Table 1 it was observed that the activated carbon from *Prunus persica* and *Persea americano* had a particle size of 0.85 mm and porosity of 0.48% and 0.51%, respectively. Regarding moisture, activated carbon from *Prunus persica* and *Persea americano* had moisture contents of 68% and 74%, and organic matter percentages of 87% and 92%, respectively. Similarly, Mamani Navarro et al. (Mamani Navarro et al. 2019) elaborated activated carbon from Duckwed (*Lemna gibba L.*) by chemical activation with phosphoric acid at a temperature of 500 to 600 °C, presenting a diameter between 150.5 µm and 2.094 mm with a degree of porosity between 10.48 and 125.3 µm longitudinal pore diameter. Therefore, it can be concluded that the most important factors influencing the adsorption process are the particle size and the pore structure of the activated carbon.

3.2 Arsenic removal

Arsenic removal was performed at pH 5.9 for each dose of activated charcoal. In 30 min of contact, the 3 g dose of activated carbon from *Prunus persica* and *Persea americana* achieved removals of 94.93 % and 93.60 %, respectively. While, the 5 g dose of activated carbon from *Prunus persica* and *Persea americana* achieved 96.44 % and 95.10 % removals, respectively. Table 3 shows the arsenic removal values for dose 7 of activated carbon from *Prunus persica* and *Persea Americano*.

Table 3: Arsenic removal with respect to contact time

Contact time	Dose of activated carbon	Arsenic concentration before treatment (mg/L)	Arsenic concentration after treatment (mg/L)	Removal (%)	Average removal (%)
1 minute	7 g of *Prunus persica*	0.533	0.115 0.123 0.119	78.42 76.92 77.67	77.67
	7 g of *Persea americana*	0.533	0.156 0.164 0.160	70.73 69.23 69.98	69.98
15 minutes	7 g of *Prunus persica*	0.533	0.032 0.029 0.034	94.00 94.56 93.62	94.06
	7 g of *Persea americana*	0.533	0.066 0.059 0.054	87.62 88.93 89.87	88.81
30 minutes	7 g of *Prunus persica*	0.533	0.018 0.015 0.016	96.62 97.19 97.00	96.94
	7 g of *Persea americana*	0.533	0.028 0.021 0.025	94.75 96.06 95.31	95.37

From Table 3 it was determined that the appropriate dose of both *Prunus Persica* activated carbon and *Persea americano* activated carbon was 7 g in 30 min contact, achieving arsenic removal values of 96.94 % and 95.37 %, respectively. Chen et al. (Chen et al. 2023) removed As(III) between 91.91 % to 97.15 % in the pH range of 4.0-6.0 using iron-sulfur codoped biochar (Fe/S-BC). On the other hand, Niazi et al. (Niazi et al. 2018) achieved maximum As(III) removal between 88 % and 90 % at pH between 7.2 and 9.1, using perilla leaf biochar. Also, Kim et al. (Kim et al. 2019) used iron-modified biochar to remove arsenite, achieving removals of more than 72.3% at As(III) concentrations between 1 and 30 mg/L.

3.3 Lead removal

Lead removal was performed at pH 5.9 for each dose of activated charcoal. In 30 min of contact, the 3 g dose of activated carbon from *Prunus persica* and *Persea americana* achieved removals of 95.16 % and 93.85 %, respectively. While, the 5 g dose of activated charcoal from *Prunus persica* and *Persea americana* achieved 96.12 % and 94.26 % removals, respectively. Table 4 shows the lead removal values for dose 7 of activated carbon from *Prunus persica* and *Persea americana*.

Table 4: Lead removal with respect to contact time

Contact time	Dose of activated carbon	Lead concentration before treatment (mg/L)	Lead concentration after treatment (mg/L)	Removal (%)	Average removal (%)
1 minute	7 g of *Prunus persica*	0.558	0.205	63.26	63.98
			0.197	64.70	
			0.201	63.98	
	7 g of *Persea americana*	0.558	0.197	64.70	65.35
			0.189	66.13	
			0.194	65.23	
15 minutes	7 g of *Prunus persica*	0.558	0.122	78.14	78.61
			0.119	78.67	
			0.117	79.03	
	7 g of *Persea americana*	0.558	0.106	81.00	82.20
			0.099	82.26	
			0.093	83.33	
30 minutes	7 g of *Prunus persica*	0.558	0.016	97.13	97.19
			0.014	97.49	
			0.017	96.95	
	7 g of *Persea americana*	0.558	0.023	95.88	95.52
			0.025	95.52	
			0.027	95.16	

Table 4 shows that the 7 g doses of both *Prunus Persica* and *Persea Americano* activated carbon achieved higher lead removal rates of 97.19 % and 95.52 %, respectively. In the research by Chen et al. (Chen et al. 2023), they achieved Pb(II) removals of 97.15 % using iron-sulfur codoped biochar (Fe/S-BC), indicating that the increase of hydroxyl ions and the formation of precipitates play a vital role in the immobilisation of the pollutant. On the other hand, Marín Castro & Vásquez Frieri (Marín Castro & Vásquez Frieri, 2019) were able to remove 99.75 % of lead with modified mineral carbon (impregnated with carbon disulphide and sodium hydroxide). In turn, Aguirre Achaquihui (Aguirre Achaquihui 2017) with a dose of 20 g of activated carbon from eucalyptus seeds achieved the removal of 98.7 % of Pb(II) and 70.3 % of As(V). Meanwhile, Ruiz Menendez (Ruiz Menendez 2018) with a dose of 100 g of activated carbon from orange peel (*Citrus sinensis* L. Osbeck) achieved 98.85 % lead removal. Dorregaray De La Cruz (Dorregaray De La Cruz 2018) used a concentration of 200mg/L of activated carbon from pineapple (*Ananas comosus*) peel, achieving a removal of 87.64 % of lead.

3.4 Physico-chemical parameters

Table 5 and Table 6 show the reduction values of physicochemical parameters such as electrical conductivity, turbidity, BOD5, COD, suspended solids and oils and greases.

Table 5: Reduction values of physico-chemical parameters of polluted water after activated carbon treatment of Prunus persica

Physico-chemical parameters	Activated carbon from *Prunus persica*			
	Before treatment	After treatment		
		3 g	5 g	7 g
Electrical conductivity (µs/cm)	1788	960.3±2.7	921.7±3.3	879.3±5.3
Turbidity (NTU)	183	177.67±0.01	178.75±0.01	180.46±0.01
BOD5 (mg/L)	824	577.7±3.3	587.3±2.7	628.0±2.0
COD (mg/L)	1014	525.3±4.3	576.7±4.3	641.0±4.0
Suspended solids (mg/L)	257	233.5±0.6	231.2±0.1	238.6±0.3
Oils and Greases (mg/L)	23	21.2±0.1	21.6±0.1	21.8±0.1

Table 6: Reduction values of physico-chemical parameters of polluted water after activated carbon treatment of Persea Americano

Physico-chemical parameters	Activated carbon from *Persea americano*			
	Before treatment	After treatment		
		3 g	5 g	7 g
Electrical conductivity (µs/cm)	1788	1146.0±6.0	969.3±5.3	907.7±9.3
Turbidity (NTU)	183	177.03±0.03	168.21±0.67	178.82±0.03
BOD5 (mg/L)	824	503.0±4.0	440.3±5.3	514.0±2.0
COD (mg/L)	1014	396.7±1.7	343.0±6.0	531.7±4.7
Suspended solids (mg/L)	257	222.5±0.6	219.6±0.4	227.8±0.6
Oils and Greases (mg/L)	23	21.0±0.8	21.0±0.9	21.6±0.1

From Table 5 and Table 6 it was observed that all physicochemical parameters were reduced with the application of different doses of activated carbon, having better results with the 5 g dose of activated carbon from both *Prunus persica* and *Persea americana*. The activated carbon from *Persea americana* had better results compared to the activated carbon from *Prunus persica*, and this is due to the fact that the higher amount of organic matter present in the precursor gives rise to activated carbons with better yields (Rojas-Morales, Gutiérrez-González & Colina-Andrade 2016). This shows that both activated carbons are an environmentally friendly and low-cost treatment technique due to the reuse of waste from food markets, which are easily available.

4. Conclusions

Activated carbons from *Prunus Persica* and *Persea Americano* with doses of 7 g and a contact time of 30 minutes achieved maximum arsenic removal values of 96.94% and 95.37%, and lead removal values of 97.19% and 95.52%, respectively. The activated carbon from *Prunus persica* had higher removal compared to the *Persea americana* carbon due to its higher porosity and amount of organic matter. On the other hand, the physico-chemical parameters of the contaminated water were also considerably reduced. This shows that both activated carbons have great potential in the removal of arsenic and lead, and can be applied in the treatment of water contaminated with these metals.

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