

ANIMAL AND PLANT-BASED MAGNETIZED BIOCHARS IN LEAD-CONTAMINATED SOIL REMEDIATION: A LITERATURE REVIEW

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ABSTRACT

This research was carried out to evaluate f. Animal and plant-based magnetized biochar efficiency in the remediation of soils contaminated with Pb. The PRISMA 2020 method was developed for the literature review, using scientific metasearch engines such as Web of Science, Scopus, and ScienceDirect; then, the Boolean formula was determined for analysis; Finally, relevant articles were synthesized. The results yielded 35 articles on biomass origin, biochar preparation, and obtained remediation efficiency. The result is the following: The most commonly used type of precursor material has been plant (90%); the most frequently used biochar production method was pyrolysis at 500C° (35%) and the FeCl₃ (18%) was the magnetizing agent; the maximum lead removal efficiency was 99.50% using an oriental banana as a precursor material in 120 days, in addition to a FeCl₃ magnetizing agent with a 99.50% removal percentage; Finally, a general result obtained was that the remediation efficiency will depend on two important factors: the magnetizing agent and precursor material porosity.

Keywords: Lead, soil contamination, biomass, agricultural soil remediation.

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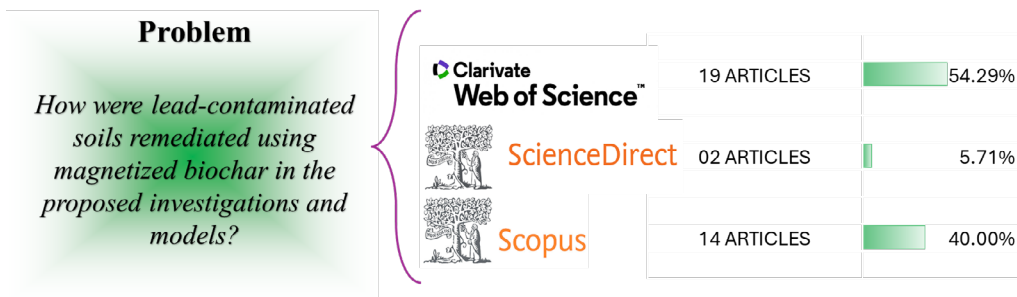
BIOCARBÓN MAGNETIZADO DE ORIGEN ANIMAL Y VEGETAL EN LA REMEDIACIÓN DE SUELOS CONTAMINADOS CON PLOMO: REVISIÓN DE LA LITERATURA

RESUMEN

Esta investigación se llevó a cabo para evaluar la eficiencia del biocarbón magnetizado de origen animal y vegetal en la remediación de suelos contaminados con Pb. Se desarrolló el método PRISMA 2020 para la revisión de la literatura, utilizando metabuscadores científicos como Web of Science, Scopus y ScienceDirect; luego, se determinó la fórmula booleana para el análisis; finalmente, se sintetizaron los artículos relevantes. Los resultados arrojaron 35 artículos sobre el origen de la biomasa, la preparación del biocarbón y la eficiencia de remediación obtenida. El resultado es el siguiente: el tipo de material precursor más utilizado ha sido vegetal (90 %); el método de producción de biocarbón más utilizado fue la pirólisis a 500 °C (35 %) y el FeCl₃ (18 %) fue el agente magnetizante; La máxima eficiencia de remoción de plomo fue del 99,50 % utilizando un banano oriental como material precursor en 120 días, además de un agente magnetizante FeCl₃ con un porcentaje de remoción del 99,50 %. Finalmente, un resultado general obtenido fue que la eficiencia de la remediación dependerá de dos factores importantes: el agente magnetizante y la porosidad del material precursor.

Palabras clave: plomo, contaminación del suelo, biomasa, remediación de suelos agrícolas.

ABSTRACT GRAPHIC



INTRODUCTION

Currently, economic activities such as mining, metallurgy, electronics, energy, and agrochemical uses have generated a drastic increase in lead concentrations in the environment that exceed the maximum permissible levels in agricultural soils [1]. Lead is a toxic metal harmful to all living organisms [2]; From these stems the importance of the analysis of research that allows remediation of this contamination in agricultural soils. It is known that contact with humans, after absorption into the body, alters the cardiovascular, renal, skeletal, reproductive, and neurological systems [3]. Likewise, when absorbed by plants, it alters their growth functions, metabolism, and photosynthetic activity, reducing an average of forty-two percent in roots [4].

Biochar is a product obtained after organic waste pyrolysis under restricted oxygen conditions oscillating at a temperature of 300°C – 700°C. Unlike coal, which is used to generate fuel, biochar is intended for agricultural use, remaining in the soil as a long-lasting carbon reservoir [5], thus making it an ecological solution since it retains nutrients, water, and generates greater crop productivity. The physical and chemical properties of biochar are due to different aspects such as pyrolysis mode, the degrees of temperature, the speed at which it is heated, and execution time. Its increase in the degrees of heating would significantly affect its structure, the composition of the functional groups, and a pH increase [6].

The adsorption of biochar is improved by making modifications that affect the surface through physical or chemical activation, yet they can cause a decrease in its surface. A treatment of acid or alkaline solutions and the use of oxidizing agents can increase biochar surface groups however, the use of reagents, in addition to being toxic, are expensive and the generation of waste is not friendly to the environment. Modified biochar cannot be extracted from the soil. Metals present in biochar could be released into the environment as the years go by [7]. The Fe magnetization of biochar is a chemical modification that is used to enlarge surfaces and porosities, for

a better performance of the immobilization of metals, since its magnetic charge has a strong electron transfer capacity. Likewise, its application is usually in fine powder, which in an aqueous medium makes its recovery difficult. Therefore, it is necessary to immobilize them within a structure to guarantee their recovery [8].

Materials such as vegetal straw, rice husks, and animal manure with oxygen limited to a temperature below 700°C can be used for biochar production, vegetal, with ferrite [MFe_2O_4] as a magnetizing material, due to its high magnetic property, stability and easy to modify, adsorbing a maximum of 268.86 mg/g [9]. Biochars from cow, chicken, fish, and camel bones produced at 500°C are more effective than those at 800°C to reduce the bioavailability of heavy metals. These biochars at high temperatures lose their metal-holding capacity, decreasing functional groups [10].

In the research background, this study found that Mendoza [11] collected information on biochar for soil remediation with metals from the mining industry. The pyrolysis process was conducted at 300°C using straw rice, wood, leaves, fruit peels, and kitchen waste., There was an adsorption percentage of 51.86% of metal Zinc, 73.96% of metal Lead and 49.10% metal cadmium, generating a positive impact for the soil increasing pH and its physicochemical properties. In addition, Qu et al., [12], reported that biochar can be magnetized with Fe_2O_3 , Fe, and Fe_3O_4 using thermochemical methods, reductive deposition, coprecipitation, and mechanical grinding. Biomass can come from food residues, fruit skins, and animal bones, evidencing that modified biochar has applications to remove heavy metals in soil and water with great effectiveness due to adsorption because adsorbates enter an adsorbent. This magnetized biochar also has characteristics that allow its recovery, avoiding secondary environmental contamination. Azeem et al. [13] provided information showing that bone-based biochar has micropores in its structure with calcium and potassium concentrations. These micropores benefit heavy metal retention, because it has a smaller surface area than activated carbon, so it provides great capacity to treat lead, copper, zinc and cadmium. On the other hand, Dong et al. [14], used 3 types of biochar, based on bamboo, fir wood and rice straw. They were magnetized to have greater lead adsorption, obtaining good results in lead adsorption with magnetized biochar since it increased pH and improved biochar characteristics. Biochars from firewood and shrubs were more effective. Finally, biochar from coffee husks and corn cobs according to Cruz et al. [15] are highly efficient in As and Pb immobilization. In their study they published that agro-industrial residues from Piura and Tumbes, Provinces in Peru, pyrolyzed at 600°C for 2 hours and impregnated with ZnO nanoparticles optimize the structures of the biochar to immobilize metals in terms of the Balance and kinetics Magnetized biochar based on corn cob stands out. Thus, it is considered a promising material to remediate water.

In lead-contaminated soil treatments using magnetized biochar, several mechanisms have been analyzed, such as sorption, complexation, precipitation, and ion exchange [16]. The properties of magnetized biochar must have undergone adequate pyrolysis, characterized by strong ionic bonds, and resilient biomass [17]. Studies have been conducted on to remediate soils that propose the use of biochar, due to its specific surface area and porosity with a high capacity for heavy metal ion fixation and adsorption, which, also facilitates the adsorption of nutrients in plants, improving soil fertility [17].

This research has been aligned with SDGs (sustainable development goals), meeting the objective related to No. 15. Life of Terrestrial Ecosystems because it has investigated treatments in soils with lead and guarantee the ecosystem's health and life. In addition, the objective related to climate action was met, since the study identified the measures applied to counteract the consequences of human pollution. Finally, it is in line with the objective related to terrestrial ecosystem life, since the study has identified research that proposes methods that reverse soil degradation and prevent health impacts on ecosystems [18].

Regarding the general problem in this review, it asked How soils contaminated with lead were remediated using magnetized biochar in proposed studies and models. To this end, the following questions were established for specific problems. What were the types of animals and plant-based magnetized biochar used to remediate soils with Pb? Which methods were implemented to elaborate magnetized biochar to remediate soils with Pb and what was the efficiency of Pb removal in contaminated soils applying magnetized biochar?

This is environmentally justified, since the treatments were identified and described to minimize and decontaminate soils with Pb, safeguarding ecosystems. Socially, it contributed to meeting SDGs (Sustainable Development Goals), since it contributes by showing applied knowledge in ecosystem care and improvement s; Finally, it is theoretically justified, since it contributed to the identification of experimental research that will allow the remediation of environmental impacts in soils with lead in future applications.

Understanding the troublesome reality exposed, researchers decided to establish a general objective which is to evaluate the remediation of soils contaminated with lead after using magnetized biochar in proposed studies, and models. Likewise, the following specific objectives were established including analyzing the types of Animals and plant-based magnetized biochar used to remediate soils with Pb, to analyze the methods to process magnetized biochar to remediate soils with Pb, and analyze the efficiency of Pb removal in contaminated soils by applying magnetized biochar.

1. MATERIALS AND METHODS

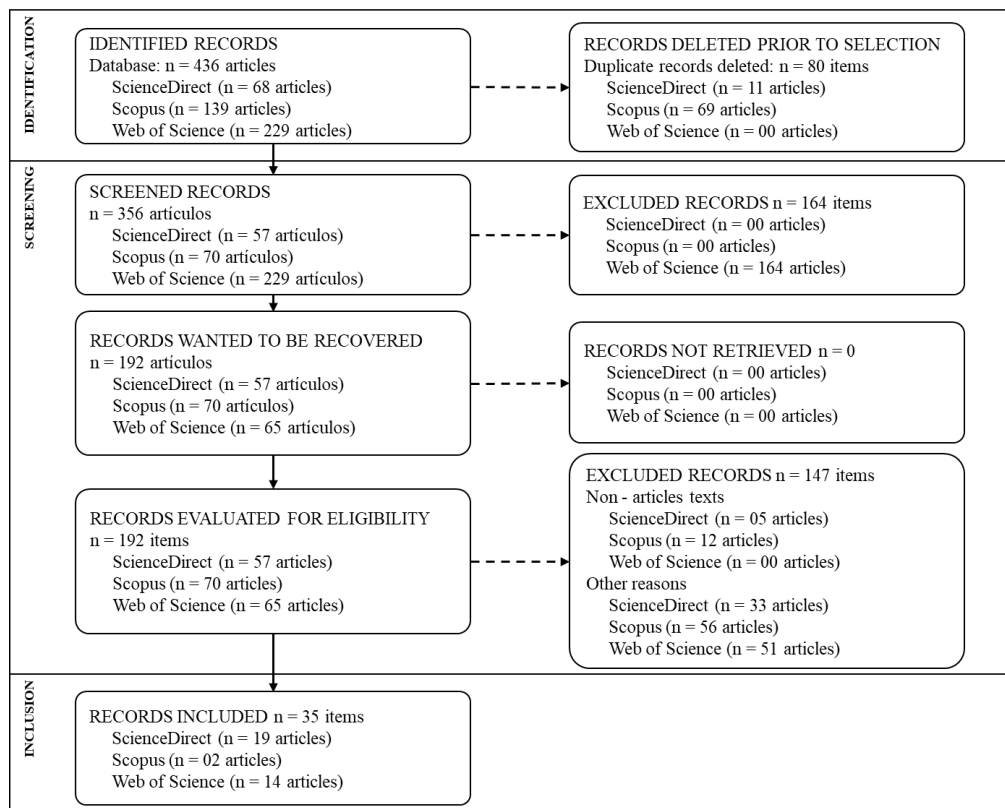
The focus of this literature research was qualitative, because literary sources and the analysis of experimental articles [19] have been explored with the objective of obtaining and understanding the results of animal and plant origin magnetized biochar in the remediation of soils with lead. In addition, PRISMA 2020 model was followed as the literature review method, because it defines a guide for literature reviews, [20].

Selection of sources and database: Scopus, Web of Science and ScienceDirect, which contain knowledge from various fields such as environmental engineering, allowed researchers to access peer-reviewed scientific publications worldwide, ensuring validity, reviewing and analyzing Animal and plant-based magnetized biochar studies to remediate lead-contaminated soil.

The research methodology was continued using Boolean functions to identify only scientific research related to the research problem. For Web of Science , the following was formulated: ((all=((“magnetic biochar*” or “magnetized biochar*” or “remediation with magnetized biochar*” or “remediation with magnetic biochar*” or “remediation with modified biochar*” or “modified biochar”))) and all=((“soil*”))) and all=((“lead*” or “pb”)); for Scopus , the following was formulated: title-abs-key (“magnetic biochar*” or “magnetized biochar*” or “remediation with magnetized biochar*” or “remediation with magnetic biochar*” or “remediation with modified biochar” or “modified biochar”) and title-abs-key (“soil*”) and title-abs-key (“lead*” or “pb*”); for ScienceDirect search engine, it was formulated: (“magnetic biochar” or “magnetized biochar” or “remediation with magnetized biochar” or “remediation with magnetic biochar” or “remediation with modified biochar” or “modified biochar”) and (“soil”) and (“lead” or “Pb”).

Volume of publications: The study analyzed a total of 192 articles and identified 35 experimental studies aimed at solving the research problem. Next, data was collected, defining Author, year, country, title, origin of biomass, biomass, pyrolysis, magnetizing agent, percentage, and time of lead results. In Web of Science, the study identified 14 articles, and in Scopus, 02. Finally, the study identified 19 in ScienceDirect. To this end, the diagram of the 2020 PRISMA method was made for monitoring, see Figure 1.

Figure 1. 2020 PRISMA diagram



Source: own elaboration.

Ethical and scientific integrity considerations. A Literature review, like any scientific activity, has been based on strict ethical principles to ensure rigor, honesty, and accountability. These principles have ranged from information handling integrity to respect for participants' autonomy and rights. In essence, ethics has sought to guarantee result reliability and positive impact on society, presenting accurate truthful results, free of manipulation or bias. It was also carried out with equity, without discrimination, considering transparency in all aspects. Other authors' intellectual property was respected to avoid plagiarism, ensure that the work adheres to ethical standards and allow researchers to contribute to the construction of solid reliable knowledge that benefits society.

2. RESULTS

Types of Animals and Plant Origin Magnetized Biochar Used for Pb Soil Remediation

Table 1 shows the biomass precursor material used to produce BM (magnetized biochar) found in the articles searched in ScienceDirect.

Table 1. Types of Magnetized Biochar – ScienceDirect

Author	Year	Country	Origin of biomass	Biomass
Yang et al. [16]	2021	China	Animal	Eggshell
Nazari et al. [21]	2019	Iran	Vegetal	Chickpea straw
Gao et al. [22]	2020	China	Vegetal	Rapeseed straw
Wan et al. [23]	2020	U.S.A.	Vegetal	Red cedar sawdust
Wu et al. [24]	2020	China	Vegetal	Rice husk
Cui et al. [25]	2022	China	Vegetal	Reed straw
Cui et al. [25]	2022	China	Vegetal	Reed straw
Li et al. [26]	2022	China	Vegetal	Corn stalk
Qi et al. [27]	2022	China	Animal	Fish scales
Wang et al. [28]	2022	China	Vegetal	<i>Eichhornia crassipes long-rooted powder</i>
Wang et al. [29]	2022	China	Vegetal	<i>Eichhornia crassipes long-rooted</i>
Wang et al. [29]	2022	China	Vegetal	<i>Eichhornia crassipes long-rooted</i>
Ke et al. [30]	2023	China	Vegetal	Rice husk
Liu et al. [31]	2023	China	Vegetal	Rice straw
Ma et al. [32]	2023	China	Vegetal	Tender corn
Peng et al. [33]	2023	China	Vegetal	Dried corn stalk
Feng et al. [34]	2024	China	Vegetal	Reed straw
Lahori et al. [35]	2024	Pakistan	Vegetal	Vegetal residues
Saleem et al. [36]	2024	Pakistan	Vegetal	Watermelon peel
Su et al. [37]	2024	China	Vegetal	Bamboo
Yang et al. [38]	2024	China	Vegetal	Bean straw

Source: own elaboration.

Table 2 shows the biomass precursor material used in the production of the BM (magnetized biochar) of the articles searched in the Scopus metasearch engine.

Table 2. Types of magnetized biochar – Scopus

Author	Year	Country	Origin of biomass	Biomass
Yang et al. [39]	2021	China	Vegetal	Banana branches
Han et al. [40]	2023	China	Vegetal	Wheat straw powder

Source: own elaboration.

Table 3 shows the biomass precursor material used to produce BM (magnetized biochar) in the articles searched in Web of Science.

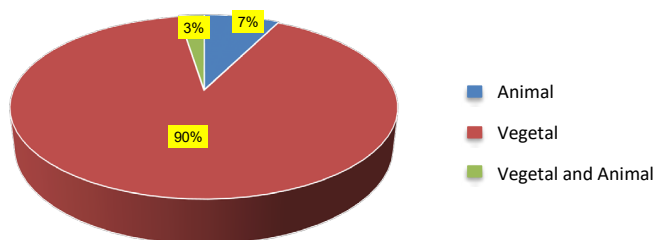
Table 3. Types of Magnetized Biochar - Web of Science

Author	Year	Country	Origin of biomass	Biomass
Rodriguez et al. [41]	2019	Colombia	Vegetal	Corn on the cob
Diao et al. [17]	2022	China	Vegetal	Rice straw
Fan et al. [42]	2020	China	Vegetal	Rice straw
Gong et al. [43]	2020	China	Vegetal	Wheat straw
Gong et al. [43]	2020	China	Vegetal	Wheat straw
Mandal et al. [44]	2020	China	Vegetal	Green tea
Rizwan et al. [45]	2020	China	Vegetal	Rapeseed straw
Rizwan et al. [45]	2020	China	Vegetal	Rapeseed straw
Pan et al. [46]	2021	China	Animal	Pork skin
Pan et al. [46]	2021	China	Vegetal	<i>Platanus orientalis</i> Linn branches
Wen et al. [47]	2021	China	Vegetal	Oriental Banana
Zhou et al. [48]	2021	China	Vegetal	Mango leaves
Ning et al. [49]	2022	China	Vegetal and Animal	Kitchen waste [rice, Vegetals, fruits, meat, and bones)
Yin et al. [50]	2022	China	Vegetal	Bamboo Shavings
Yang et al. [51]	2023	China	Vegetal	Rice straw
Ghandali et al. [52]	2024	Iran	Vegetal	Wheat straw
Zhang et al. [53]	2024	China	Vegetal	Bamboo Parts

Source: own elaboration.

After identifying the various origin types of biomass analyzed, the review observed that 90% used plant biomasses, 7% animal, and 3% both, as shown in Figure 2.

Figure 2. Precursor material



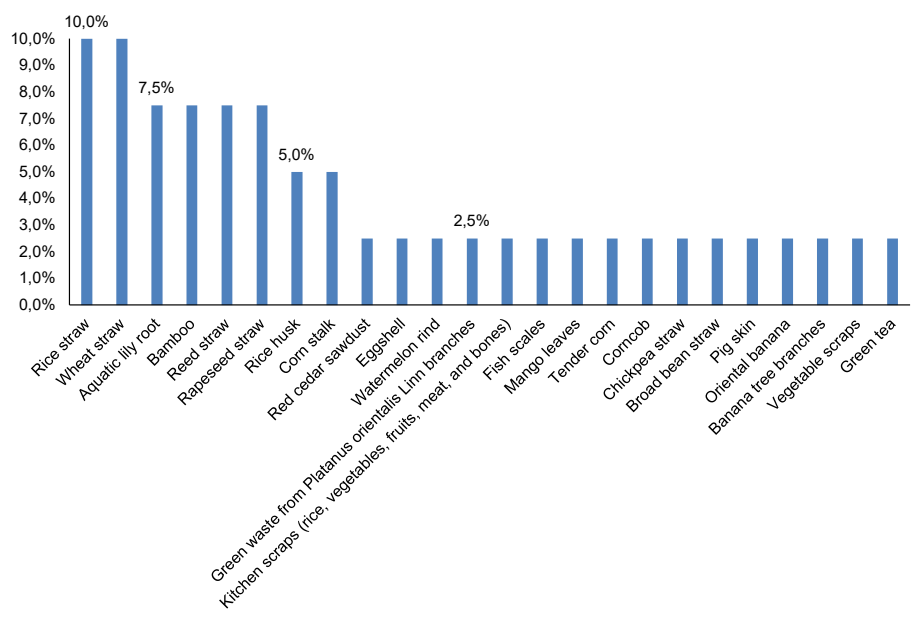
Source: own elaboration.

The study identified precursor materials used to remediate soils with lead, as evidenced in Figure 3, where they used rice straw biomasses, representing 10% of the total of the most used biomasses and 10% of wheat straw biomass. On the other hand,

7.5% of the total biomass used to produce magnetic biochar included 4 types like long water lily root , bamboo biomass, cane straw, and rapeseed straw. On the other hand, 5% of the total biomass analyzed were rice husks and corn stalks. Finally, 2.5

% of each of the biomasses was red cedar sawdust, eggshell, watermelon shell, green waste from *Platanus orientalis* Linn branches kitchen waste (rice, vegetables, fruits, meat and bones), fish scales, mango leaves, tender corn, corn cob, chickpea straw, bean straw, pigskin, oriental banana, banana branches, vegetable residues, and green tea.

Figure 3. Types of biomasses



Source: own elaboration.

Methods of processing magnetized biochar for soil with Pb remediation

Table 4 shows the methods of processing magnetized biochar for lead-contaminated soil remediation in ScienceDirect.

Table 4. Method to make magnetized biochar - ScienceDirect

Author	Biomass	Pyrolysis Method	Magnetizing Agent
Yang et al. [16]	Eggshell	Pyrolysis before magnetization at 800 °C for 2 hours in an N ₂ atmosphere.	KH ₂ PO ₄
Nazari et al. [21]	Chickpea straw	Pyrolysis before magnetization at 800 °C for 2 hours in an N ₂ atmosphere.	Citric acid
Gao et al. [22]	Rapeseed straw	Pyrolysis before magnetization at 500 °C for 2 hours.	KH ₂ PO ₄
Wan et al. [23]	Red cedar sawdust	Pyrolysis before and after magnetization at 300°C for 2 h at a rate of 3 °C/min in N ₂ atmosphere.	FeCl ₃ and FeSO ₄
Wu et al. [24]	Rice husks	Pyrolysis before magnetization at 500 °C for 2 hours at a rate of 5 °C/min.	MnO ₂
Cui et al. [25]	Reed straw	Pyrolysis before magnetization at 400 °C for 2 hours.	Potassium Dihydrogen Phosphate (PDP)
Cui et al. [25]	Reed straw	Pyrolysis before magnetization at 400 °C for 2 hours.	hydroxyapatite (HAP)
Li et al. [26]	Corn stalk	Pyrolysis after magnetization at 500 °C for 2 hours at a rate of 10 °C/min in N ₂ atmosphere.	MgCl ₂ and AlCl ₃
Qi et al. [27]	Fish scales	Pyrolysis before magnetization at 300 °C for 1 hour and after magnetization at 400 °C for 2 hours.	MgCl ₂
Wang et al. [28]	<i>Eichhornia crassipes</i> long-rooted powder	Pyrolysis before magnetization at 700 °C for 2 hours in an N ₂ atmosphere.	Fe(NO ₃) ₃ and FeSO ₄
Wang et al. [29]	<i>Eichhornia crassipes</i> long-rooted	Pyrolysis before magnetization at 700 degrees Celsius for 2 hours.	Fe(NO ₃) ₃
Wang et al. [29]	<i>Eichhornia crassipes</i> long-rooted	Pyrolysis before magnetization at 700 °C for 2 hours.	FeSO ₄
Ke et al. [30]	Rice husk	Pyrolysis before magnetization at 500 °C for 2 hours at 10 °C/min in an N ₂ atmosphere.	Siderite (Fe ₂ O ₃ 60.22% by weight)
Liu et al. [31]	Rice straw	Pyrolysis before magnetization at 500 °C for 2 hours at a rate of 5 °C/min.	Chitosan (C ₆ H ₁₁ NO ₄)
Ma et al. [32]	Tender corn	Pyrolysis before magnetization at 550 °C speed of 15 °C min for 2 hours, after magnetization, 4h in an atmosphere of N ₂ .	Elemental Sulphur S°
Peng et al. [33]	Dried corn stalk	Pyrolysis after magnetization at 500 °C for 2 hours in an N ₂ atmosphere.	MgCl ₂ and AlCl ₃
Feng et al. [34]	Reed straw	Pyrolysis before magnetization at 500 °C for 2h at a rate of 0 °C/min in N ₂ atmosphere.	Goethite (Gt) synthesized with KOH to Fe(NO ₃) ₃
Lahori et al. [35]	Vegetable residues	Pyrolysis before magnetization at 450 °C for 1.5 hours in an N ₂ atmosphere.	Thiourea
Saleem et al. [36]	Watermelon peel	Pyrolysis after magnetization at 500 °C for 2 hours.	Thiourea
Su et al. [37]	Bamboo	Pyrolysis before magnetization at 700 °C for 4.5 h and then at 500 °C for 30 minutes in an N ₂ atmosphere.	MnCl ₂
Yang et al. [38]	Bean straw	Pyrolysis before magnetization at 500 °C for 2 hours at a rate of 20 °C/min in N ₂ atmosphere.	FeCl ₃ and KMnO ₄

Source: own elaboration.

Table 5 shows the methods to process magnetized biochar for lead-contaminated soil remediation s in Scopus.

Table 5. Method of making magnetized biochar - Scopus

Author	Biomass	Pyrolysis Method	Magnetizing Agent
Yang et al. [39]	Banana branches	Pyrolysis before and after magnetization at 650 °C for 2 and 1 hours.	FeCl ₃
Han et al. [40]	Wheat straw powder	Pyrolysis before magnetization at 600 °C for 2 hours.	Sulfoaluminate cement

Source: own elaboration.

Table 6 shows the methods to process magnetized biochar for lead-contaminated soil remediation in Web of Science.

Table 6. Method to make magnetized biochar – Web of Science

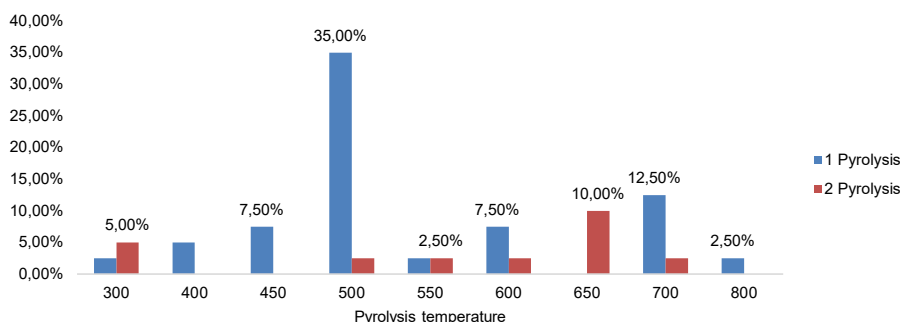
Author	Biomass	Pyrolysis Method	Magnetizing Agent
Rodriguez et al. [41]	Corn on the cob	Pyrolysis before magnetization at 600 °C (2 h) in an N ₂ atmosphere.	Hydrogen peroxide
Diao et al. [17]	Rice straw	Pyrolysis before magnetization at 500 °C in 2h at a rate of 10 °C/min in N ₂ atmosphere.	FeSO ₄ and Fe ₂ (SO ₄) ₃
Fan et al. [42]	Rice straw	Pyrolysis before magnetization 500 °C for 5 h at a rate of 0 °C/min in N ₂ atmosphere.	Thiol
Gong et al. [43]	Wheat straw	Pyrolysis before magnetization at 300°C for 4 h at a rate of 20°C/min in N ₂ atmosphere.	FeCl ₃ and FeCl ₂
Gong et al. [43]	Wheat straw	Pyrolysis at 700°C for 4 h at a rate of 20°C/min in N ₂ atmosphere.	FeCl ₃ and FeCl ₂
Mandal et al. [44]	Green tea	Pyrolysis after magnetization at 450°C for 2 h at a rate of 3 °C/min in N ₂ atmosphere.	Nanovalent iron and FeCl ₂
Rizwan et al. [45]	Rapeseed straw	Pyrolysis before magnetization at 500 °C for 2 hours at a rate of 10 °C/min in N ₂ atmosphere.	KMnO ₄
Rizwan et al. [45]	Rapeseed straw	Pyrolysis before magnetization at 500 °C for 2 hours at a rate of 10 °C/min in N ₂ atmosphere.	Nano hydroxyapatite
Pan et al. [46]	Pork skin	Pyrolysis before magnetization at 650 °C for 2 hours and after magnetization 1 hour in an atmosphere of N ₂ .	FeCl ₃
Pan et al. [46]	<i>Platanus orientalis</i> Linn branches	Pyrolysis before magnetization at 650 °C for 2 hours and after magnetization 1 hour in an atmosphere of N ₂ .	FeCl ₃
Wen et al. [47]	Oriental Banana	Pyrolysis before magnetization at 650 °C for 2 h and after magnetization at 650 °C for 1 h in an N ₂ atmosphere.	FeCl ₃
Zhou et al. [48]	Mango leaves	Pyrolysis before and after magnetization at 600 °C for 2 hours at speed (10 °C/min) in N ₂ atmosphere.	Iron and Urea
Ning et al. [49]	Kitchen waste [rice, vegetables, fruits, meat, and bones)	Pyrolysis before magnetization at 500 °C for 2 hours in an N ₂ atmosphere.	HPO ₄
Yin et al. [50]	Bamboo Shavings	Pyrolysis after magnetization at 700°C for 2 h at a rate of 10 °C/min in N ₂ atmosphere.	KH ₂ PO ₄

Author	Biomass	Pyrolysis Method	Magnetizing Agent
Yang et al. [51]	Rice straw	Pyrolysis before magnetization at 550 °C for 2 h at a rate of 5 °C/min in N ₂ atmosphere.	MnCl ₂ and FeCl ₃
Ghandali et al. [52]	Wheat straw	Pyrolysis before magnetization at 500 °C for 3 hours in an N ₂ atmosphere.	MnO ₂ nanoparticles
Zhang et al. [53]	Bamboo Parts	Pyrolysis before magnetization at 600 °C for 5 hours at a rate of 10 °C/min in N ₂ atmosphere.	K ₂ FeO ₄

Source: own elaboration.

After analyzing the methods to make magnetized biochar, different degrees of temperature were observed in pyrolysis processes, where 35% of the biochar preparations were pyrolyzed at 500 °C, 12.5% were pyrolyzed at 700 °C, 10% were pyrolyzed at 650 °C and 7.5% at 600 °C, 7.5% were pyrolyzed at 450 °C and 5% at 400 °C. 2% were pyrolyzed at 300 °C, 550 °C and 800 °C. In addition, 10 of these biomasses have been pyrolyzed 2 times, and 30 were pyrolyzed only 1 time, as shown in Figure 4.

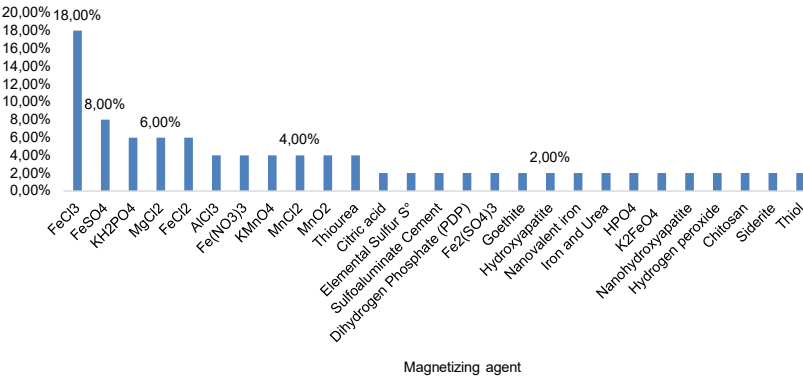
Figure 4. Pyrolysis temperatures and amount



Source: own elaboration.

Figure 5 shows the magnetizing agents involved in a biochar production method, where FeCl₃ was used in 18% of the total articles; an FeSO₄ magnetizing agent was used in 8%; an FeCl₂ magnetizing agent was used in 6%; a KH₂PO₄ magnetizing agent was used in 6%; a MgCl₂ magnetizing agent was used in 6%; KMnO₄, MnO₂, MnCl₂, Fe(NO₃)₃, AlCl₃ and thiourea magnetizing agents were used 4% each; Finally, Siderite, Thiol, Nanovalent Iron, Nanohydroxyapatite, Chitosan, Elemental Sulfur S⁰, K₂FeO₄, Sulfoaluminate Cement, Potassium Dihydrogen Phosphate (PDP), Citric Acid, Iron and Urea, Hydrogen Peroxide, HPO₄, Goethite, Fe₂(SO₄)₃ and Hydroxyapatite magnetizing agents had only 2%.

Figure 5. Biochar Magnetizing Agent



Source: own elaboration.

Pb removal efficiency in contaminated soils by applying magnetized biochar

Table 7 shows efficiency, time, and type of Lead-Contaminated Soil remediation from each magnetized biochar biomass source in the ScienceDirect.

Table 7. Lead-Contaminated Soil Remediation Efficiency – ScienceDirect

Author	Biomass	Pb Remediation Percentage	Pb Immobilization Time
Yang et al. [16]	Eggshell	99.00%	30 days
Nazari et al. [21]	Chickpea straw	1.21%	60 days
Gao et al. [22]	Rapeseed straw	81.70%	90 days
Wan et al. [23]	Red cedar sawdust	32.00%	1 day
Wu et al. [24]	Rice husks	8.88%	3 days
Cui et al. [25]	Reed straw	5.93%	60 days
Cui et al. [25]	Reed straw	5.88%	60 days
Li et al. [26]	Corn stalk	97.90%	28 days
Qi et al. [27]	Fish scales	66.12%	60 days
Wang et al. [28]	<i>Eichhornia crassipes</i> long-rooted powder	82.14%	14 days
Wang et al. [29]	<i>Eichhornia crassipes</i> long-rooted	48.08%	30 days
Wang et al. [29]	<i>Eichhornia crassipes</i> long-rooted	64.21%	30 days
Ke et al. [30]	Rice husk	81.03%	28 days
Liu et al. [31]	Rice straw	55.20%	15 days
Ma et al. [32]	Tender corn	37,5%	30 days
Peng et al. [33]	Dried corn stalk	20.00%	1.17 days
Feng et al. [34]	Reed straw	83.92%	12.5 days
Lahori et al. [35]	Vegetable residues	71.15%	15 days
Saleem et al. [36]	Watermelon peel	82.13%	60 days
Su et al. [37]	Bamboo	58.65%	30 days
Yang et al. [38]	Bean straw	69.87%	90 days

Source: own elaboration.

Table 8 shows Lead-Contaminated Soil remediation efficiency, time and type of each magnetized biochar biomass origin in Scopus.

Table 8. Lead-Contaminated Soil Remediation Efficiency – Scopus

Author	Biomass	Pb Remediation Percentage	Pb Immobilization Time
Yang et al. [39]	Banana branches	78.60%	30 days
Han et al. [40]	Wheat straw powder	64.84%	15 days

Source: own elaboration.

Table 9 shows Lead-Contaminated Soil Remediation efficiency, time, and type of each magnetized biochar biomass origin in Web of Science.

Table 9. Lead-Contaminated Soil Remediation Efficiency – Web of Science

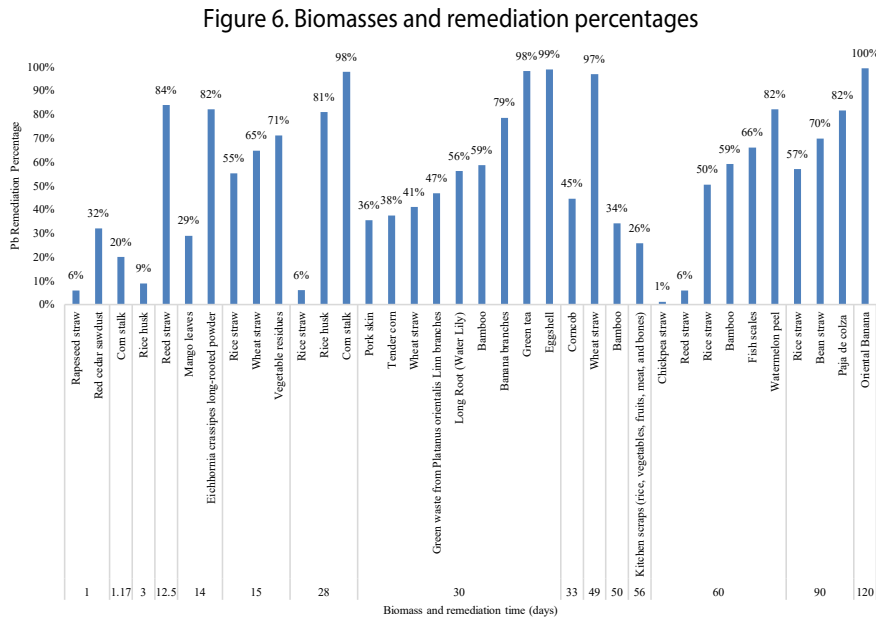
Author	Biomass	Pb Remediation Percentage	Pb Immobilization Time
Rodriguez et al. [41]	Corn on the cob	44.53%	33 days
Diao et al. [17]	Rice straw	50.47%	60 days
Fan et al. [42]	Rice straw	6.14%	28 days
Gong et al. [43]	Wheat straw	40.10%	30 days
Gong et al. [43]	Wheat straw	42.10%	30 days
Mandal et al. [44]	Green tea	98.33%	30 days
Rizwan et al. [45]	Rapeseed straw	7.09%	1 day
Rizwan et al. [45]	Rapeseed straw	4.95%	1 day
Pan et al. [46]	Pork skin	35.50%	30 days
Pan et al. [46]	<i>Platanus orientalis</i> Linn branches	46.80%	30 days
Wen et al. [47]	Oriental Banana	99.50%	120 days
Zhou et al. [48]	Mango leaves	29.00%	14 days
Ning et al. [49]	Kitchen waste [rice, vegetables, fruits, meat, and bones]	25.80%	56 days
Yin et al. [50]	Bamboo Shavings	34.20%	50 days
Yang et al. [51]	Rice straw	57.00%	90 days
Ghandali et al. [52]	Wheat straw	96.98%	49 days
Zhang et al. [53]	Bamboo Parts	59.20%	60 days

Source: own elaboration.

3. DISCUSSION AND/OR ANALYSIS OF THE RESULTS

Biomass remediation efficiency, and remediation time were analyzed, see Figure 6. The highest lead remediation efficiencies were obtained by Wen et al. [47], whose precursor material was an oriental banana with a 28-day remediation time and its remediation efficiency was 99.5%. This biomass was selected because of high P concentration

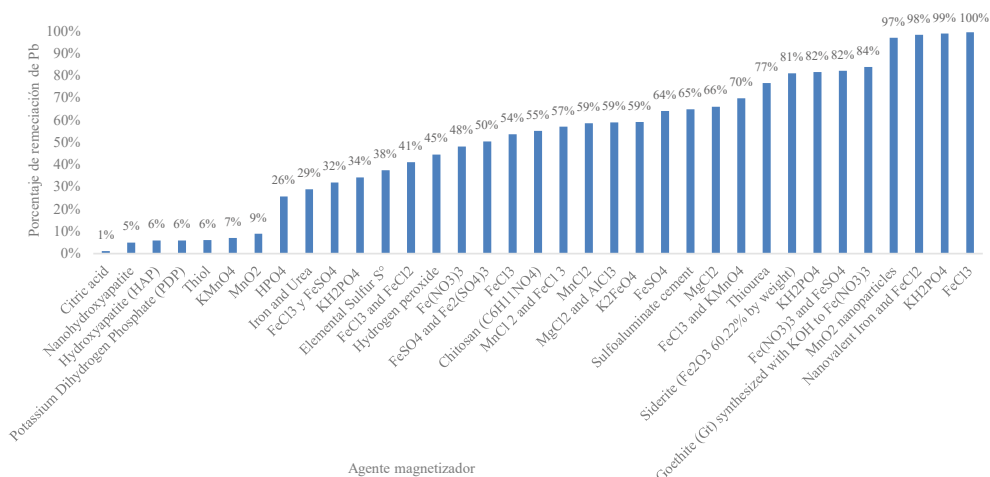
of, which forms a precipitate of little soluble character; in addition, it has functional groups with efficient sorption points that allowed the chelation of lead and formation of functional groups expressly such as “C-O-Pb-O-C”. Following this, Yang et al. [16] developed eggshell-based magnetic biochar with a 30-day-remediation time with a 99.0% remediation efficiency. The biomass was selected because of its abundant functional groups and adequate surface load, in addition to containing high amounts of calcium in its structure. It facilitated the adhesion to its magnetizer and the immobilization of lead in its functional groups and its porosity. With respect to Mandal et al., [44], green tea was used in a 30-day remediation time, achieving a yield of 98.3%; this biomass was selected for having an adequate pore structure that positively affects remediation, since green tea has a wide particle size distribution that allows the addition of its magnetizers (nanovalent iron and FeCl₂); moreover, they demonstrated that the material has high acidity allowing the existence of polyphenols in the material acted as reducing agents and coating. Such polyphenols aid in the formation of magnetizing biochar particle and particle size by binding to zero-valence iron; thus, providing an opportunity for lead immobilization. Finally, Li et al., [26], whose precursor material was corn stalk with a 28-day remediation time, achieved 97.9% remediation. This material has significant characteristics, such as its porous structure with an orderly honeycomb shape that improves the introduction of magnesium and aluminum hydroxide groups. It should be noted that the pyrolysis temperature at 500 °C, allowed the surface area to be expanded and more functional groups to adhere to the biochar molecule.



Source: own elaboration.

The magnetizing agent is another important factor in increasing the remediation performance of lead in agricultural soils. All this is evidenced in Figure 7. The most significant results were identified to obtain the highest lead remediation yield in agricultural soils. Wen et al. [47] used an oriental banana biomass, and ferric chloride (FeCl_3), which has a characteristic of being charged with iron ions. This allows biochar molecule lead adsorption. For Yang et al. [16], used monopotassium phosphate (KH_2PO_4) in their eggshell biochar as a magnetizing agent. This magnetizing agent gave a special chemical property to the biochar, loaded with P, which will allow optimal biochar structure. Following this, Mandal et al. [44], with their application of green tea to make biochar, used nanovalent iron and ferrous chloride (FeCl_2), obtaining a porous biochar, reagent thanks to its functional groups, redox and hydroxide potential, a uniform particle size, and a wide surface area. Finally, Li et al. [26], after elaborating biochar based on corn stalk, used magnesium chloride (MgCl_2) and aluminum chloride (AlCl_3) as magnetizing agents, due to the high porosity and roughness, which was achieved by increasing pyrolysis temperature. The application was carried out in acidic conditions, with high amounts of H^+ , improving the electrostatic repulsion of lead adsorbents with adequate precipitation and co-precipitation and surface area complexation.

Figure 7. Magnetizing agent and remediation percentage



Source: own elaboration.

CONCLUSIONS

To analyze the types of Animals and plant-based magnetized biochar that are used for the remediation of soils with Pb, precursor materials to produce magnetized biochar were identified, finding that 3% was animal and vegetal origin. 7% used only of animal origin, and finally, 90% was vegetal, concluding that the most used biochar was plant

precursor material. The preference is based on the abundance of biochar production materials, which entails low cost and diversity of functional groups in plant biomass to improve heavy metal adsorption capacity. The choice of plant biomass favors the efficiency and scalability option of magnetized biochar production [54]. Moreover, biochar has greater advantages in nutrients and metal retention due to a microporous structure [55]; In addition, magnetic modification will allow an increase of the functionality and selectivity of biochar to lead in agricultural environments [56]. That is why biochar has greater versatility compared to animal biochar in environmental applications.

To analyze the methods to elaborate magnetized biochar for the remediation of soils with Pb. Pyrolysis temperatures of 300 to 800 °C were observed, where the most commonly used was 500 °C, which allowed the surface area to expand and more functional groups to adhere to the biochar molecule, generating less ash. In addition, the most commonly used magnetizing agents by researchers were identified, and FeCl₃ was the most commonly used. Magnetic modification improves performance by increasing the surface area and active functional groups after employing a 500 °C pyrolysis and an FeCl₃ magnetizing agent and consequently effective heavy metal immobilization [57]. Moreover, in some cases, it was demonstrated that at a high temperature, between 500 and 900 Celsius, physical activation occurs in the presence of magnetizers, guaranteeing an active phase and lead mobility reduction [58]. Therefore, a combined biochar and magnetization process is important to define final efficiency.

To analyze the efficiency of Pb removal in contaminated soils by applying magnetized biochar. The highest percentage of oriental banana biomass was identified in 120 days. In addition, the efficiency of each magnetizer used was analyzed, and FeCl₃ was the most efficient. The most outstanding results demonstrated 99%-lead removal efficiencies or more after applying biochar with FeCl₃. However, it should be emphasized that different combinations with catalytic processes such as Fenton addition can enhance the degradation of contaminants and improve the immobilization of heavy metals [59]. Furthermore, it should be considered that adsorption results may differ due to the presence of other contaminants and soil pH, so more contextualized studies are required [60]. Therefore, the presence of functional groups and the appropriate magnetizing agent that will be responsible for high retention percentages must be analyzed a priori; however, a physical biochar recovery technique in the remediated site must be optimized [56].

To evaluate the efficiency of, animal and plant-based magnetized biochar in Pb-contaminated soil remediation, researchers have reached the general conclusion that biomass efficiency is given to its concentrations of phosphorus and calcium, abundance of functional groups, and wide surface areas. On the part of the magnetizing agent that

lends the biochar ion exchange capacity, in this study, the iron ions increased particle size distribution and thus surface area amplitude even though they can be separated from the treatment medium. Finally, the study observed that remediation will depend on magnetizing agents, since there is more than 90% in 120 days, and the same percentage of remediation in 30 days.

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