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CO_2 CAPTURE INNOVATION THROUGH DEVELOPMENT OF BIOCHAR BASED BIOMATERIAL

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ABSTRACT

The field of sustainable technologies has shown great importance in redefining agro-industrial waste, especially in the study of biomass as an interest. In this context, Brazil stands out in the global production of crops such as sugar cane and especially coffee, which can be collected and reused, as well as converted into biochar thought carbonization. This material, as a solid species from the biomass carbonization process, is resistant to degradation and has a high surface area that can be used for adsorption of substances. In addition, it is possible to improve the structure of biochar by incorporating activators, giving it the ability to adsorb carbon dioxide (CO_2), a major contributor to the greenhouse effect. The addition of activators to biochar for CO2 capture is an innovative approach that combines environmental remediation with ease of use. This combination has the potential to improve the effectiveness and efficiency of CO_2 capture, thereby contributing to climate change mitigation efforts. It is hoped that this innovation will create a synergy between sustainability and the development of new biomaterials as a promising solution for reducing CO_2 in the atmosphere.

Keywords: Biomaterials. Carbon Sequestration. Greenhouse Gas Reduction. Adsorption.

1 INTRODUCTION

The advent of new technologies in the agro-industrial and environmental sectors has led to a surge of interest in the development of sustainable solutions. Biomass, a renewable resource consisting of lignocellulosic materials, has emerged as a prominent area of focus. These materials are readily available and cost less to extract and process than natural fibers[1]. Considering the national scenario, as outlined by the National Supply Company (CONAB), the expected harvest for food crops such as sugar cane and coffee in the 2024/25 season is expected to reach a total of 685.86 million tons and 58.81 million bags, respectively[2]. Given the potential for overconsumption in both domestic and industrial applications, it is critical to explore ways to recycle materials. This could involve the collection and reuse of by-products in low energy, low complexity processes, thereby restoring their value and utility. It has been demonstrated in the scientific literature that highly adsorbent carbonaceous materials can be derived from biomass through processes such as pyrolysis, resulting in biochar, a high surface area carbonaceous material[3]. Biochar has been extensively used as a vector for soil fertility, sustainable energy production and, most importantly, to aid in the capture of greenhouse gases due to its high adsorptive character, bioavailability, resistance to degradation and importance in the prevention of global warming[3]. It is worth noting its low process cost compared to activated carbon, as the process of activating carbon makes the final product more expensive[4]. This implies the possibility of attaching oxides and other compounds to the biochar structure with the aim of modifying its properties and increasing its adsorption capacity and surface area. Magnetic particles such as ferric oxide are incorporated into this biomaterial, resulting in a composite that facilitates the recovery and reuse of the adsorbent[5] in addition, the ability to increase porosity and surface area is an essential property for CO_2 adsorption[6,7]. There is a current interest in improving the adsorption of gaseous compounds that are harmful to the environment, with the goal of exploring more sustainable resources with simpler and more economical processes. The objective of this evaluation is to assess the effects of each raw material used in the production of biochar and to examine the relevant factors that affect the adsorptive capacity associated with the synthesis of the biocomposite.

2 MATERIAL & METHODS

In this study, articles on the production of biochar and magnetic biochar were reviewed in scientific databases such as Scopus and Google Scholar over the last decade. Data was extracted from the articles to facilitate comparisons between them. Among the analyses of the results, the first necessary step is to examine the growing publication of papers combining the terms "biochar", "CO2 capture" and "magnetite" from 2014 to 2024. In the first instance, when analyzing the relationship between the material and the removal of greenhouse gases, there is a concern about replacing conventional adsorbents, such as graphene[8] and activated carbon[4] which represent consolidated but expensive and highly complex processes. Furthermore, there are results on the characterization, production, prospects, and functionalization of biochar to adsorb carbon dioxide[6,7], with data growing especially in the last five years, as can be seen in Figure 1 (on the left). Figure 1 on the right shows the results of the relationship between biochar and magnetite. Figure 1 illustrates that synthesis challenges arise when comparing the pure material to its consolidated counterparts, such as surface area and pore volume. These issues are particularly pronounced when it comes to carbon dioxide (CO_2) capture and its active site bonds[4] Consequently, the synthesis of a composite allows for the correction of these adverse properties that have been observed over time. In addition, the results can be significantly modified by varying the biomass and the proportion of oxide in the mixture[9].

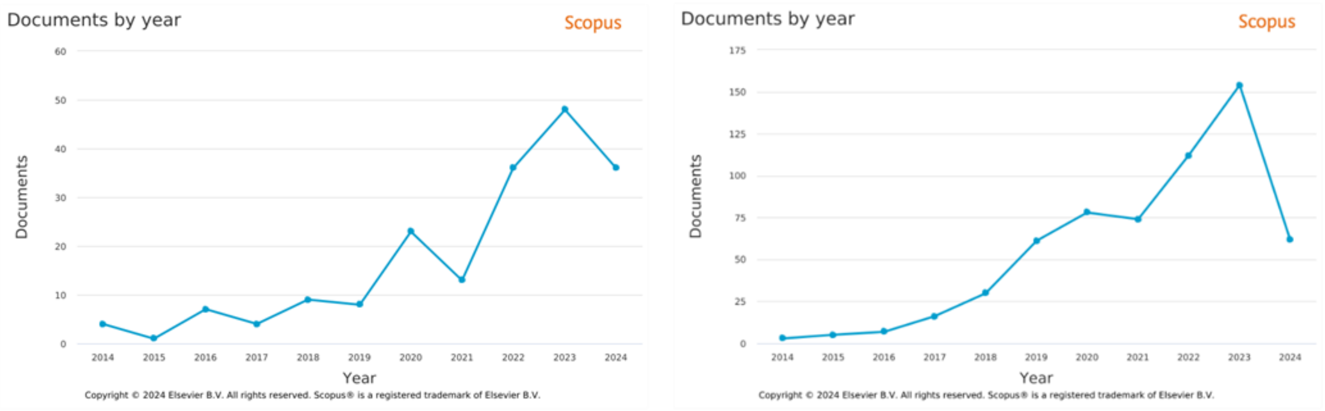

Figure 1 An overview of published articles relating to the topics of biochar and CO_2 (on the left) and biochar and magnetite (on the right) (Scopus).

3 RESULTS & DISCUSSION

Pyrolysis

The carbonization of biochar is characterized by low cost and high performance, and the process of obtaining it can be carried out in experimental and industrial phases. The treatment is based on physicochemical transformations by heating, inducing pyrolysis and structural rearrangement. The process is consistent regardless of the raw materials used, resulting in the production of volatile gases and the transformation of the initial biomass into a carbonaceous product[6] and, in some cases, into bio-oil[3]. In general, the release of volatile compounds from the biomass structure allows carbonization processes to reorganize the structure of the material, resulting in biochar[10]. In this process, several variables affect the quality of the resulting products: the temperature at which the reaction takes place, the composition and type of equipment used, the length of time the reaction is allowed to proceed, and whether activators have been added. These factors can affect the amount of decomposition that occurs and consequently the quality of the final biochar produced[11].

Biochar

Biochar has received considerable attention due to its applications in bioenergy and environmental remediation. In addition, the adsorption characteristics of biochar produced from different feedstocks and production conditions vary considerably, resulting in different adsorption structures, including the size of active sites and surface area, and the amount of CO_2 that can be adsorbed. Table 1 illustrates these differences as a function of the biomass used.

Table 1 Research status on CO_2 capture using food waste-derived engineered biochar.

Feedstock	**Method**	**BET surface area (m^2 g^{-1})***	**CO_2 uptake (mmol g^{-1})**	**Ref.**
Bamboo sawdust	Pyrolysis 600 °C, 2 h	374,42 – 540,31	3.38	12
Chicken manure	Pyrolysis 450 °C, 1 h	34,6 – 328.6	2.2 - 10.2	13
Coffee ground	Pyrolysis 400 °C, 1 h	34 - 1684	0.14 - 2.67	6
Microalgae	Pyrolysis 800 °C, 20 min	5.0 - 422.6	1.82 – 4.09	14
Oak branches	Pyrolysis 700 °C – 900 °C, 1 h	324.21 – 788.81	1.46 - 1.64	15
Pine wood (70%) and sewage sludge (30%)	Pyrolysis 600 - 800 °C	731 - 2623	3.00 – 3.88	7
Rambutan	Pyrolysis 500 °C – 900 °C, 90 min	7.80 – 569.64	1.56 – 1.75	16
Sugarcane bagasse	Pyrolysis 350 °C	5.47	1.22	17
Vine shoots	Pyrolysis 600 °C, 1h	538 – 1671	2.16 – 2.42	18
Walnut shell	Pyrolysis 500 °C – 900 °C, 90 min	397	2.0	19

*Brunauer-Emmett-Teller (BET) tests performed in nitrogen (N_2).

In addition, CO_2 adsorption tests can be used as a means of assessing the quality of the biochar produced, as the adsorption and desorption performance allows the material to be analyzed as an adsorbent, which can vary depending on the raw material[7]. In most cases, an increase in temperature can be taken as an indication that there will be greater adsorption of contaminants by the material. However, there are cases where this increase is not linear, such as that observed for biochar produced from oak shoots[15]. In this material, the highest CO_2 adsorption capacity was observed when the production temperature was 700°C (muffle furnace) and 800°C (rotary kiln) and the maximum adsorption capacity was 1.46 and 1.64 mmol.g^{-1}, respectively[15].

To improve the performance of their products, some biomasses require activation or structural modification treatments that can improve the definition of pores and functional groups on the surface, improving adsorption and reactivity processes. Therefore, the synthesis of an activated biochar can help to increase the specific surface area and mechanical resistance values[19]. This process can occur mainly with the use of KOH as an activating agent[6,7,12,14,17,18], as it allows for an increase in the development of regularly shaped micropores, thus increasing the surface area of the material[7]. CO_2 sequestration is also a factor influenced by this activator. With respect to coffee beans[6], KOH activated biochar allows for an increase in relative microporosity and the formation[6] and exposure[7] of active sites capable of adsorbing the contaminant, as well as good durability and selectivity for carbon dioxide binding[6]. Other methods of activating carbonaceous biomaterials include the addition of doping gases such as N_2[13], the addition of molten salts[15] and most notably the addition of metal oxides[16,19]. The first process produces compounds with high selectivity for CO_2 that can be recovered after capture, and with a larger surface area compared to pure biochar. This effect is because activated biochar has a greater number of active amine sites due to the addition of N_2 to the sample[13]. The next process is characterized as catalytic pyrolysis, the advantages of which are increased pyrolysis efficiency and improved product quality, since the molten salts are responsible for heat and mass transfer between biomass particles in the process, as well as producing biochar with stable adsorption capacities[15]. Among the methods mentioned, the addition of metal oxides provides chemosorption processes, since special functional groups are formed on the surface of the biochar during the heat treatment of the metal incorporated in the process[19]. Chemosorption can occur with different types of metal oxides, among which those with magnesium ions (Mg^{2+}), which form $MgCO_3$ when exposed to CO_2 adsorption, have given the best results[16]. In aqueous media, magnetite (Fe_3O_4) is increasingly used as a metal oxide incorporated into biochar for the adsorption of contaminants, such as the removal of arsenic from water[5]. The adsorption process involves the formation of complexes between magnetite and arsenic (III) through their adsorption in the octahedral and tetrahedral interstices, resulting in the formation of layers of chemisorbed arsenic within the structure[5]. It is well documented in the literature that CO_2 adsorption is possible on the surface of magnetite, with the same interstitial interactions that can occur under arsenic-containing conditions[19]. This occurs through the formation of a bond between CO_2 and Fe^{2+} related defects in the oxide structure, which then form coordinated structures with well-defined kinetic behavior and intermolecular interactions[20]. The most notable aspect of this process is the formation of multiple layers of CO_2 on the magnetic molecules, which serves to confirm the physical adsorption of the material in its crystalline structure[20].

4 CONCLUSION

The objective of this review was to provide a comprehensive overview of the advances made in the production of biochar over the past decade, with a particular focus on its adsorptive capacity. It examines the use of these adsorbents, activated or not, for the purpose of CO_2 capture as a means of mitigating the impact of human activities on climate change. The implications of this research are significant, as it highlights the potential of biochar not only as an effective adsorbent for environmental remediation, but also as a critical tool in the fight against climate change. By enhancing CO_2 capture, biochar can play a significant role in reducing greenhouse gas emissions, promoting sustainable practices, and supporting global efforts to meet climate goals. This dual functionality underscores the importance of continued innovation and application of biochar technology in environmental sustainability and climate change mitigation strategies.

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