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Characterization of biochar produced from Al Ghaf Tree for CO_2 Capture

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Abstract

Climate change, global warming, and rise in water levels are environmental problems caused by the high emissions of greenhouse gases, and the most harmed one is carbon dioxide. Biochar is a material produced by thermochemical conversions with oxygen-depleted conditions of organic materials, and this process calls pyrolysis. Recently, it has been evaluated as a carbon dioxide capture, and its porous structure, structural properties, and production methods are easy. Al Ghaf (Prosopis cineraria) tree is one of the United Arab Emirates' national trees with a wide range of intriguing properties, including high nutritional value, medicinal/pharmaceutical potential, and biosorption. This paper focuses on the biochar synthesized from three parts of the Al Ghaf tree: leaves, roots, and branches, to determine which part can achieve the maximum carbon dioxide capture. The ability of the produced biochar to capture carbon dioxide was tested through direct gas–solid interaction inside an integrated fluidized bed reactor. The carbon dioxide adsorption capacity was expressed by two methods related to (a) the loaded biochar mass and (b) the total amount of carbon dioxide fed to the reactor. The carbon dioxide adsorption capacity results concerning the loaded mass were 6.88%, 5.50%, and 3.63% for leaves, roots, and branches, respectively. At the same time, the results based on the total amount of carbon dioxide fed were 65.5%, 58.7%, and 37.7% for leaves, roots, and branches, respectively. Such results were confirmed by the physicochemical characteristics of the synthesized biochar using Scanning Electron Microscopy with Energy Dispersive X-ray Analysis, Thermogravimetric analysis (TGA), and X-ray diffraction analysis. Al Ghaf tree requires further study and inquiry to identify the most appropriate applications.

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Keywords: Biochar; UAE; Al Ghaf tree; Carbon dioxide capture; Carbon dioxide adsorption capacity

1. Introduction

Carbon dioxide is one of the greenhouse gases emitted by human activities. According to NASA's Jet Propulsion Laboratory, human activities have increased CO_2 concentration in the atmosphere by 48% since 1850 [1]. Currently,

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36 billion tonnes of carbon dioxide are released into the atmosphere yearly, but at a much lower rate than before [2]. This increased CO_2 emission is a projection of the earth's climate change or global warming [3]. People have started to step beyond this serious problem, and some CO_2 capture projects are being taken to decrease emissions [4]. Biochar is one of the carbon dioxide capture techniques with an adsorption capacity of carbon dioxide. In addition, it is a solid product of biomass from oxygen-absent or oxygen-limited pyrolysis, and its applications can significantly contribute to carbon sequestration [5]. It is a low-cost material due to its sources: plant waste, food waste, and other types of waste [6]. Many studies shall test all major factors affecting adsorption capacity [7,8]. Carbon dioxide adsorption capacity depends on the feedstock type [9,10], where each has its particular feature to host and let CO_2 molecules attach to the available active site on the biochar.

Al Ghaf is one evergreen tree that lives in arid regions [11] and lives above 120 years. It can be found in the desert in deserts in Asia, mainly in the Arabian Peninsula and semi-arid regions of the Indian sub-continent with *"Khejri"* and *"Janadi"* (local name in India), *"Jand"* (local name in Pakistan) [12,13]. Al Ghaf is classified as a leguminous tree, described as *"evergreen"*. After all, it appears green all seasons of the year and is *"drought-tolerant"* because it can survive in a difficult, harsh climate with scarce rainfall in the desert environment (Fig. 1a). The well-known example of Al Ghaf has been in Bahrain for 400 years, called their "Tree of Life", and it is still growing in the desert without apparent water sources [11,14]. Another feature of this distinguished tree is its extra tolerance to high salinity irrigation levels of up to 4500 ppm [15,16]. Their roots can grow as deep as 30 meters to access groundwater, and then its presence is an indicator of the presence of underground water [11,14,15].

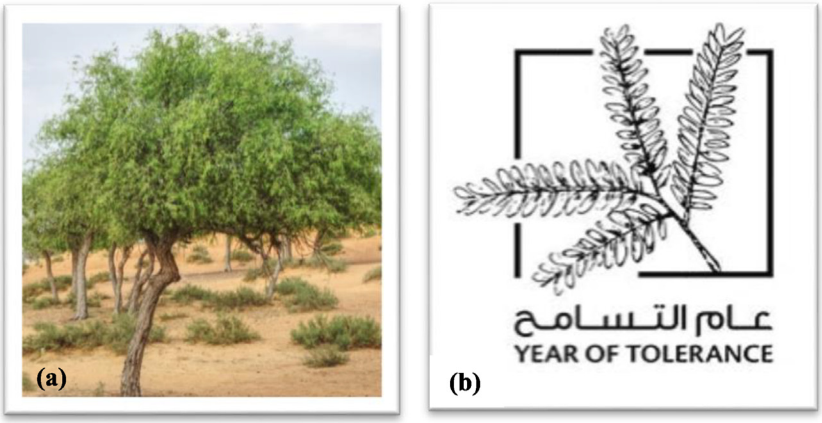

Fig. 1. (a) Al Ghaf tree growing in the UAE desert, (b) The symbol of "Year of Tolerance" in UAE.

In the United Arab Emirates (UAE) heritage, the Al Ghaf tree has a particular consideration in the lives of tribes. Officially, it was declared in 2008 as the national tree of the UAE [11,16,17], while in 2019, the Year of Tolerance, it was chosen to give a bright symbol for peace (Fig. 1b), steadfastness, and coexistence in the UAE [11,17,18].

There have been few studies on the Ghaf tree and its environmental benefits. This tree can be used to make biochar, and it may produce good results, reducing carbon dioxide emissions in the UAE. This research aims to assess the carbon dioxide adsorption capacity of Al Ghaf tree sections, specifically the leaves, roots, and branches, which store the most carbon. Biochar samples were also examined for their chemical, physical, and morphological properties to understand better Al Ghaf tree's features and major components.

2. Materials and methodology

The three parts of the Al Ghaf tree: leaves, roots, and branches Al Ghaf samples were obtained from a local house garden in Abu Dhabi, UAE. Around 500 g from each sample were separated, washed, and then left to dry under the sun for 48 h, as shown in Fig. 2. Dried samples lost their initial mass and became 400 g. These dried samples were grounded using a grinder, then sieved to get an average size of 300 μm. Then, the samples were placed in a furnace to proceed with the pyrolysis process at 300 °C with a retention time of 10 °C/min for a heating time of 120 min without oxygen.

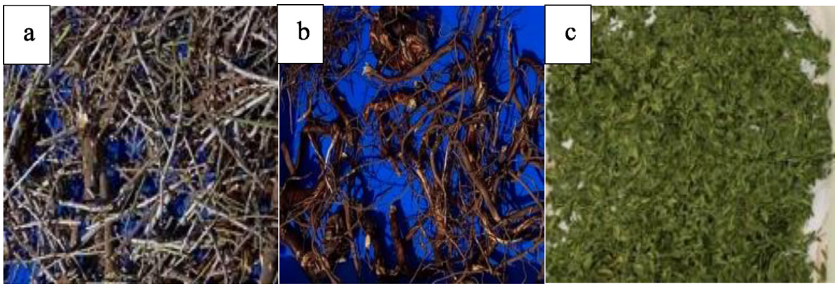

Fig. 2. Al Ghaf samples (a) branches, (b) roots, and (c) leaves while drying under the sunlight.

Pyrolysis parameters, i.e., temperature, heating, and retention times, are important because they determine the biochar yield and properties. With high-temperature organic matter, nitrogen, Ca, and Mg in biochar's decreased whereas the total carbon and phosphorus increased. Low retention times cause an increase in the biochar yield. Longer heating times (120 min) resulted high average biochar yield.

Different tests were done on these biochar samples to determine more properties of this tree and its parts by Scanning Electron Microscope (SEM), X-ray Diffraction (XRD), Energy Dispersive X-ray Analysis (EDX), Thermogravimetric Analysis (TGA), and the dissolution test. Furthermore, the same tests were applied to samples after exposure to CO_2 for comparison purposes.

CO_2 exposure to these samples occurred in a fluidized bed reactor (FBR). The outlet stream was attached with a CO_2 gas analyzer to determine CO_2 capture. FBR [10,19] has a cylindrical reactor with 8 cm diameter and 100 cm length. Each sample weight 80 g and was uploaded one at a time at room temperature (22–25 °C). The measured height of the uploaded solid particles inside the reactor was 4.8 cm. Due to technical operations, the flow rate was 2.8 L/min for the leaves sample but reduced to 1.5 L/min for the roots and 1.8 L/min for the branches samples. The supplied gas source was a 10% CO_2 and 90% air gas cylinder mixture. The use of this fluidization method to determine the capacity of CO_2 capture is restricted to carefully adjusting its affecting parameters such as the amount of uploaded solid particles, average particle size, and flow rate.

3. Results and discussion

The dissolving test, which measures pH, TDS, and conductivity of the resulting solution, was performed on these samples using a ratio of 1 g of biochar to 10 ml of deionized water for the first test. This test measures the acidity and alkalinity of the solution and its electrolyte content, as summarized in Table 1. Both branches and roots biochar have values close to each other with a neutral pH medium of approximately 7, while a little bit reduced to 6.3 pH value for leaves biochar. Such difference is due to the presence of mineral substances that causes around the doubled increase of TDS and conductivity with 1700 ppm and about 2300 μS, respectively.

Table 1. Results of dissolution test.

Sample	TDS [ppm]	Conductivity [μS]	pH
Leaves biochar	1700	2317	6.3
Roots biochar	800	1141	7.1
Branches biochar	908	1287	7.4

The biochar's thermal breakdown and devolatilization characteristics were studied using thermogravimetric (TGA) and derivative thermogravimetric (DTG) analysis. DTG test was adjusted to increase the temperature from 25 to 880 °C with a heating rate of 10 °C/min. Fig. 3a & b indicated that the thermal decomposition was approximately complete below 500 °C, and the major decomposition has the largest peak with a range (230–530 °C). The DTG curves revealed three degradation phases, as presented in Fig. 3b. The first phase has a weight loss classified by the volatilization of the water content and volatile organic compounds. The largest weight loss occurred between 300 °C and 530 °C, depending on the type of biochar. In this temperature range, the hemicelluloses and cellulose were decomposed. For each biochar, Hemicellulose decomposes between 160 and 360 °C, and cellulose decomposes

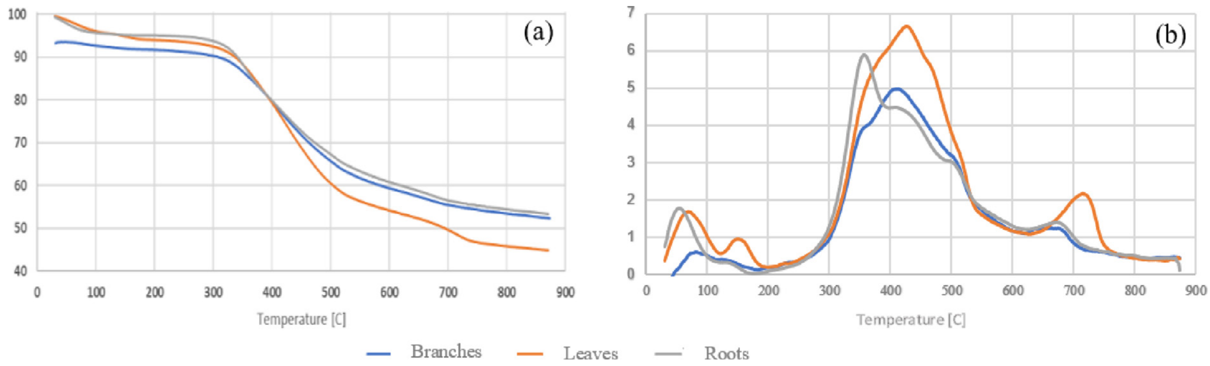

Fig. 3. (a) TGA and (b) DTG curves of the three biochar types.

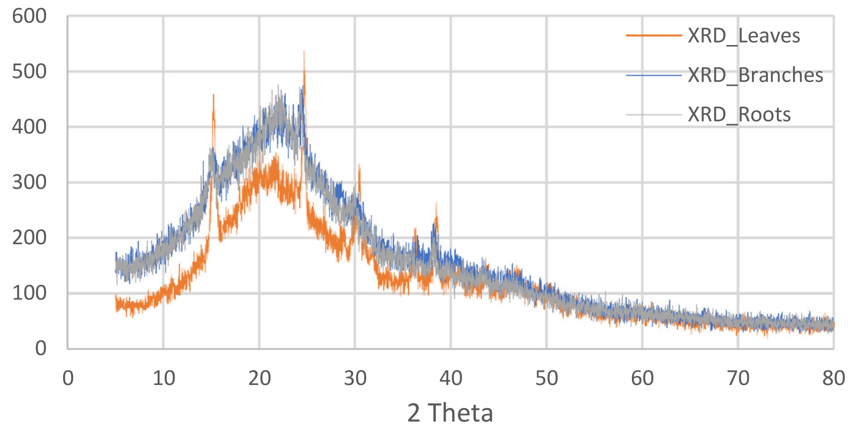

Fig. 4. XRD data of biochar synthesized from Al Ghaf leaves, branches, and roots.

between 240 and 390 °C. The decomposition temperature range of lignin is wider and higher, i.e., between 250 and 700 °C [20,21]. During the decomposition of the three components, they overlap and can therefore be considered pseudo-components. The third phase has additional weight loss, which the decomposition of complex lignin can explain. Again, TGA data showed that branches and roots biochar have very close properties while leaves biochar has a significant difference.

Compatible observations of TGA data can be noted by investigating the XRD data, shown in Fig. 4, where the lignin trend is noticed by the very similar trend of both branches and roots biochar. Sharp peaks are noted for the leaves' biochar trend line. Generally noting that the major substances in these samples are: lignin, cellulose, and hemicellulose, and they have their corresponding 2Θ angle. Nevertheless, sometimes these values shift when some fraction of these substances or different crystallinity exists. For example, amorphous cellulose at 18.5° can be shifted to 16.5° or 20.5° depending on the presence of other substances and their fraction [10,21–25]. Other sharpest peaks at 35.2° and 38.9° [21,25] recorded to the leaves biochar indicate that it has a richer amount of different cellulose crystallinity than the amount found in branches and roots biochar. Both branches and roots showed higher thermal stability in their TGA curves due to the higher amounts of amorphous lignin that degrade at relatively higher temperatures than cellulose and hemicellulose.

Exposure of CO_2 to these biochar types was achieved in the fluidized bed reactor (FBR), where the constant concentration of CO_2 gas source is supplied, and its pressure and flow rate are controlled. The measurements of CO_2 concentration at the output stream were recorded manually at each specific time. These measurements are the concentration of CO_2 that leaves the reactor unreacted. By subtracting these values from the initial constant concentration of the CO_2 gas mixture supply, which is 10% (v/v), the amount of the reacted (captured/consumed) CO_2 during the interaction with the biochar loaded in the (FBR) can be calculated. Fig. 5a, b & c show the trend of CO_2 consumed (calculated) for each biochar (blue color), which are obtained from the recorded data (red color).

Table 2. Obtained gas analyzer measurements results.

Sample	Exposure time to CO_2 [min]	CO_2 consumed [g]	Total amount of CO_2 fed to the reactor during the exposure time [g]	kg CO_2 consumed per kg uploaded biochar [%]	CO_2 consumed per total CO_2 fed to the biochar [%]
Leaves biochar	15	5.5	8.4	6.88	65.5
Roots biochar	25	4.4	7.5	5.50	58.7
Branches biochar	22	2.9	7.7	3.63	37.7

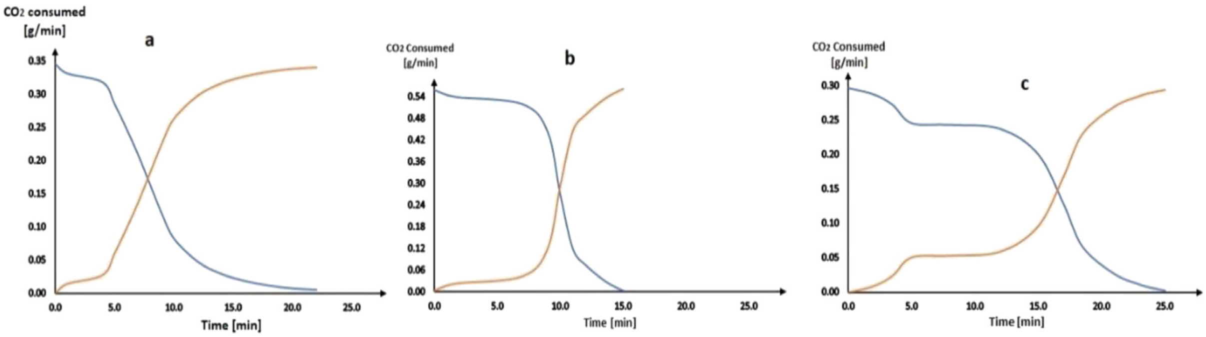

Fig. 5. Data of gas analyzer for CO_2 captured by (a) branches biochar (b) leaves biochar and (c) roots biochar. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

"Fast process" is the initial conclusion of these plots. It took 15–25 min, summarized in Table 2, for the gas analyzer readings to reach the value of the initial CO_2 supplied concentration, and then the end of the experiment, stopped CO_2 flowing. The simple unit conversion factor, including the flow rate and the density of CO_2, was done to get them into the unit [g of CO_2 consumed/min].

Consequently, the total CO_2 consumed can be easily calculated by calculating the area under the curve technique, done by "Graph" software. Table 2 summarizes the two methods of illustrating CO_2 capture. First, in various references to the unit, kg of CO_2 captured per kg of the biochar loaded in the reactor is commonly stated. Such values, 6.88% for leaves biochar, 5.5% for roots biochar, and 3.63% for branches biochar, are relatively low compared with reported values of another biochar, palm leaf biochar [10], which had a value of 9.0% at the same pyrolysis conditions. Furthermore, investigation in the published results of other biochar types found that the maximum capacity of CO_2 adsorbed by Al Ghaf was found for leaves biochar, 6.8% is within the range of biochar derived from P. nigra wood (4.9%), hickory wood (6.1%) and sugar cane bagasse (7.3%) [26].

Further comparison of CO_2 capture ability can be obtained by expressing the captured carbon dioxide as a percentage of total carbon dioxide fed to the experiment during the exposure time. This demonstrates the biochar's ability to adsorb CO_2 and allows a direct comparison of Al Ghaf biochar's types. As mentioned in Table 2, the values were 65.5% for leaves biochar, 58.7% for roots biochar, and 37.7% for branches biochar. It indicates that leaves biochar and roots biochar can adsorb more than half the amount of CO_2 entered into the reactor. In contrast, branches biochar can adsorb up to one-third of the total amount of CO_2 fed, confirmed by results of TGA, XRD, and images obtained by SEM.

Scanning Electron Microscope-Energy Dispersive X-ray spectroscopy (SEM-EDX) was applied to analyze biochars' chemical and structural properties. Fig. 6(a), (b), and (c) are images of branches, leaves, and roots biochar, respectively, before the exposure to CO2, while (d), (e), and (f) are for the same order after CO2 exposure. They show the structure of each biochar, including fibers and pores. The most interesting observation was the presence of some mineral carbonates and small white dots in (d), (e), and (f) images. This notice's expectation can be because of calcium and magnesium in the Al Ghaf tree, which is larger than that in spinach and lettuce [27]. Thus, expanding on that initial information is worthwhile by performing more experiments and tests on this intriguing tree.

The EDX analysis of the SEM was used for determining the elemental content of the C and O content as major elements of the produced biochar. Several dots and areas were analyzed for each biochar. Fig. 7 presents the obtained results showing a high consistency between the O/C Atomic ratio and the capacity of CO_2 adsorbed by

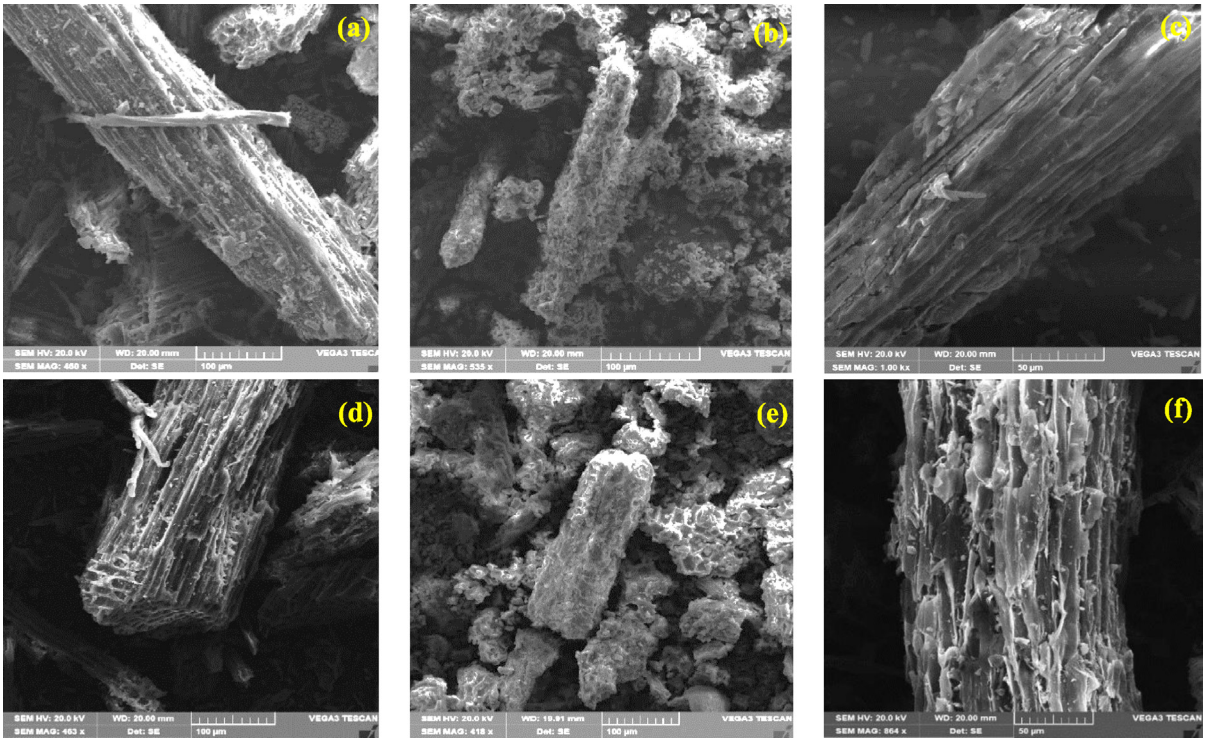

Fig. 6. SEM images of Al Ghaf (a) branches (b) leaves (c) roots biochar before exposure to CO_2, (d), (e), and (f) are of Al Ghaf branches, leaves, and roots biochar after exposure to CO_2.

the biochar of Al Ghaf leaves, roots, and branches. The O/C atomic ratio was 0.43, 0.40, and 0.35 for leaves, roots, and branches, respectively, which is proportionate with the carbon dioxide adsorption capacity of 6.88%, 5.50%, and 3.63% for leaves, roots, and branches, respectively.

Two expressions of CO_2 adsorption capacity were presented, showing the most commonly used by relating the amount of adsorbed CO_2 to the mass of the adsorbent biochar. It showed a significant capacity of Al Ghaf leaves biochar to CO2 adsorption capacity with the value of 6.8%, which exceeds the capacities of other plants' biochars. It is reported that the biochars of rice husk, Coconut shells, Carrot peels, wheat flour, and vine shoots showed adsorption capacities of 6.24, 6.04, 5.64, 5.7, 6.08%, respectively [28–31].

The second expression relates the amount of CO_2 captured to the total amount of CO_2 fed to the reactor during the exposure time. Its calculated results confirmed the advantage of Al Ghaf leaves biochar with a value of 65.5%. Some amendments can be done to improve carbon dioxide's future biochar adsorption capacity. Other pyrolysis conditions may affect carbon dioxide capture. Samples must be compared with the dried so the difference will be extra visible.

4. Conclusion and recommendations

Biochar deserves more attention to investigate and discover its precious features, mainly low expenses and naturally available. This paper focuses on the national tree in the United Arab Emirates (UAE), available in the Arabian Peninsula and semi-arid regions of the Indian subcontinent.

Three parts of Al Ghaf tree were chosen for the study: roots, branches, and leaves, and making biochar from these parts by pyrolysis at 300 °C for two hours in oxygen absence. To better understand the Al Ghaf tree's features and major components, TGA and XRD tests were performed. They showed approximately identical properties for branches and roots biochar but significantly different for leaves biochar. It has much amount of amorphous lignin and complex crystallinity of cellulose. SEM images discovered the morphological structure of the biochar, and it gave an interesting observation about the leaf's biochar where some calcium and magnesium carbonate were

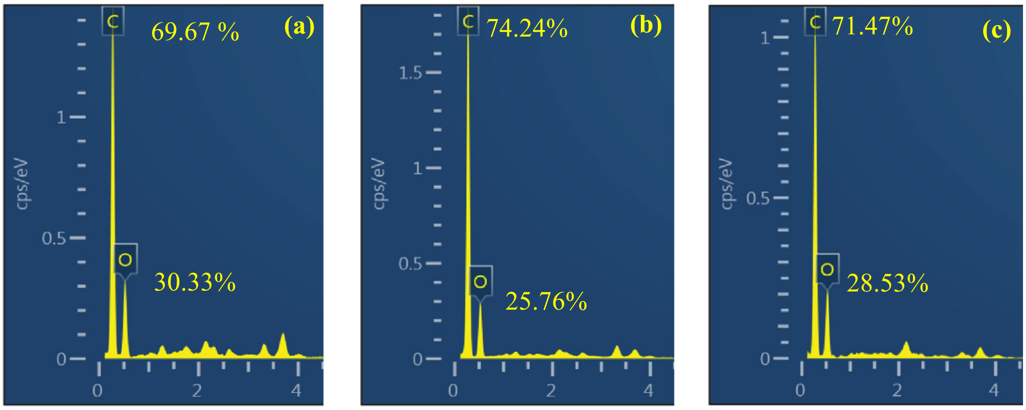

Fig. 7. EDX analysis of Al Ghaf biochar (a) branches (b) leaves, and (c) roots.

scanned. Compared with the previously obtained results of CO_2 adsorption for other materials, Al Ghaf biochar showed a significant superiority and higher efficiency.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

[1] NASA's Jet Propulsion Laboratory. Carbon dioxide concentration. NASA; 2021, Retrieved October 5, 2021.
[2] Ritchie H, Roser M, Rosado P. CO_2 and greenhouse gas emissions. In: Our world in data. 2020.
[3] O'Connor JP. Modeling of atmospheric carbon dioxide (CO2) concentrations as a function of fossil-fuel and land-use change CO2 emissions coupled with oceanic and terrestrial sequestration. Climate 2020;8(5):61.
[4] Letcher TM. Why do we have global warming? In: Managing global warming. Academic Press; 2019, p. 3–15.
[5] Li S, Chen G. Thermogravimetric, thermochemical, and infrared spectral characterization of feedstocks and biochar derived at different pyrolysis temperatures. Waste Manag 2018;78:198–207.
[6] Igalavithana AD, Choi SW, Shang J, Hanif A, Dissanayake PD, Tsang … DC, Ok YS. Carbon dioxide capture in biochar produced from pine sawdust and paper mill sludge: Effect of porous structure and surface chemistry. Sci Total Environ 2020;739:139845.
[7] Igalavithana AD, Yang X, Zahra HR, et al. Metal (loid) immobilization in soils with biochars pyrolyzed in N2 and CO2 environments. Sci Total Environ 2018.
[8] Creamer AE, Gao B, Zhang M. Carbon dioxide capture using biochar produced from sugarcane bagasse and hickory wood. Chem Eng J 2014.
[9] Jouiad M, Al-Nofeli N, Khalifa N, et al. Characteristics of slow pyrolysis biochars produced from rhodes grass and fronds of edible date palm. J Anal Appl Pyrolysis 2015.
[10] Salem IB, El Gamal M, Sharma M, et al. Utilization of the UAE date palm leaf biochar in carbon dioxide capture and sequestration processes. J Environ Manage 2021.
[11] EAD. Ghaf tree. 2021, https://www.ead.gov.ae/en/discover-our-biodiversity/plants/ghaf-tree (accessed December 14, 2021).
[12] Mahgoub O, Kadim IT, Al Ajmi DS, et al. Use of local range tree (Prosopis spp.) pods in feeding sheep and goats in the Sultanate of Oman. Zaragoza: CIHEAM; 2004, p. 191,
[13] Khatri A, Rathore A, Patil UK. Prosopis cineraria (L.) druce: a boon plant of desert—an overview. Int J Biomed Adv Res 2010.
[14] Oasis Palm Dubai Blog. Ghaf tree. 2021.

[15] Al Yamani W, Green S, Pangilinan R, et al. The impact of using treated sewage effluent to irrigate arid forests in the hyper-arid deserts of Abu Dhabi. 2017.
[16] Connect With Nature. Ghaf tree. 2021, https://connectwithnature.ae/knowledge-hub/ghaf-tree.
[17] Zibin A, Abdullah AD. The conceptualization of tolerance in the UAE press media: A case study of 'The Year of Tolerance'. Open Linguist 2019.
[18] Bhardwaj V. PODS of prosopis cineraria (GHAF): A gift of nature for nutraceutical. J Glob Ecol Environ 2021.
[19] Mohamed AO, El-Gamal MM, Hameedi S. System for carbon sequestration, stabilization of active alkaline solid waste, and a phenomenological approach to calculate carbonation effectiveness. 2021, Patent US20210146300A1, US.
[20] Abu-Jdayil B, Hittini W, Mourad A. Development of date pit–polystyrene thermoplastic heat insulator material: Physical and thermal properties. Int J Polym Sci 2019. http://dx.doi.org/10.1155/2019/1697627.
[21] Gea S, Siregar AH, Zaidar E, et al. Isolation and characterisation of cellulose nanofibre and lignin from oil palm empty fruit bunches. Materials 2020.
[22] Ju X, Bowden M, Brown EE, et al. An improved X-ray diffraction method for cellulose crystallinity measurement. Carbohydr Polym 2015.
[23] Nam S, French AD, Condon BD, et al. Segal crystallinity index revisited by the simulation of X-ray diffraction patterns of cotton cellulose Iβ and cellulose II. Carbohydr Polym 2016.
[24] Yan L, Pu Y, Bowden M, et al. Physiochemical characterization of lignocellulosic biomass dissolution by flowthrough pretreatment. ACS Sustain Chem Eng 2016.
[25] Trilokesh C, Uppuluri KB. Isolation and characterization of cellulose nanocrystals from jackfruit peel. Sci Rep 2019.
[26] Gargiulo V, Gomis-Berenguer A, Giudicianni P, et al. Assessing the potential of biochars prepared by steam-assisted slow pyrolysis for CO2 adsorption and separation. Energy Fuels 2018.
[27] Al Ghais S, Bhardwaj V, Kumbhar P. Prosopis cineraria (Ghaf): An unconventional desert protein rich. Am J Agric Res 2020.
[28] Khandaker T, Hossain MS, Dhar PK, et al. Efficacies of carbon-based adsorbents for carbon dioxide capture. Processes 2020.
[29] Li D, Ma T, Zhang R, Tian Y, Qiao Y. Preparation of porous carbons with high low-pressure CO2 uptake by KOH activation of rice husk char. Fuel 2015;139:68–70.
[30] Deng S, Wei H, Chen T, Wang B, Huang J, Yu G. Superior CO2 adsorption on pine nut shell-derived activated carbons and the effective micropores at different temperatures. Chem Eng J 2014;253:46–54.
[31] Hong SM, Jang E, Dysart AD, Pol VG, Lee KB. CO2 capture in the sustainable wheat-derived activated microporous carbon compartments. Sci Rep 2016;6(1):1–10.