Applied Science Innovation (ASI)
Published by College of Physical and Applied Sciences, MOUAU

- *Received:* 30 July 2026
- *Revised*: 15 August 2026
- *Accepted:* 25 August 2026
- *Published:* 14 Sept. 2026

PREPARATION, CHARACTERIZATION OF UNMODIFIED AND MERCAPTOACETIC ACID-FUNCTIONALIZED MELON (*MELOTHRIA SPHAEROCARPA*) SEED HUSK BIOCHAR AS POTENTIAL ADSORBENTS FOR EMERGING ORGANIC POLLUTANTS

Julian Nwogu[1*], Ahmed Umar[2], and C. V. Ofomata[3]

[13]Department of Chemistry, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.
[2]Department of Chemistry, University of Abuja, FCT, Nigeria

***Corresponding author:** nwogujulian2@gmail.com

ABSTRACT

Melon seed husk is an abundant lignocellulosic agricultural residue with considerable potential as a low-cost precursor for the production of biochar-based adsorbents. This study investigated the structural and surface modification of melon seed husk through mercapto-acetic acid functionalization for enhanced surface area. The melon seed husk was carbonized at 450 °C for 1 hour in a muffle furnace to produce unmodified melon seed husk biochar (UMSH), which was subsequently functionalized with mercapto-acetic acid to obtain modified melon seed husk biochar (MMSH). The adsorbents were characterized using Brunauer–Emmett–Teller (BET) surface area analysis, X-ray diffraction (XRD), scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM–EDX), and Fourier-transform infrared spectroscopy (FTIR). BET analysis showed that functionalization increased the specific surface area from 318.34 to 362.32 m^2/g and the total pore volume from 0.286 to 0.328 cm^3/g, indicating enhanced pore development and accessibility of adsorption sites. The average pore diameter was within the mesoporous range, providing suitable diffusion pathways for relatively large pollutant molecules. XRD analysis demonstrated a marked transformation from a relatively crystalline structure containing distinct mineral phases to a predominantly amorphous carbon structure following modification. SEM analysis revealed that mercapto-acetic acid treatment produced a rougher and more heterogeneous surface characterized by pronounced grooves, ridges, and interconnected pore channels. EDX analysis confirmed the appearance of sulfur in the modified biochar, providing evidence for the successful incorporation of sulfur-containing functionalities. FTIR analysis further revealed changes in hydroxyl, aromatic, carbonyl, and C–O functional groups following modification, together with spectral features attributable to sulfur-containing functionalities. The study therefore provides a systematic physicochemical basis for the development of sulfur-functionalized melon seed husk biochar as a value-added modified biomass material for subsequent environmental and other advanced material applications.

Keywords: Mercaptoacetic acid, functionalization, melon seed husk, biochar, characterization

1. Introduction

The increasing generation of agricultural waste has intensified the need for sustainable strategies for biomass valorization and waste management. Lignocellulosic waste materials are considered attractive as precursors for carbonaceous materials because of its cellulose, hemicellulose and lignin contents which can be transformed into stable carbon-rich structures through thermochemical conversion (Ioannidou and Zabaniotou, 2007; Keiluweit *et al*., 2010; Crini, G., Lichtfouse *et al.*, 2019). Among these agricultural residues, melon seed husk represents an underutilized biomass resource with potential for conversion into value-added biochar. Converting this residue into useful carbon materials provides an opportunity to reduce biomass waste while producing materials with tunable physicochemical properties.

Biochar properties are strongly governed by the nature of the biomass precursor and carbonization conditions, including temperature, residence time and heating environment (Tripathi *et al.*, 2016; Kang, *et al.*, 2022). Carbonization promotes the decomposition of lignocellulosic constituents and the formation of an aromatic carbon framework, while volatile matter removal can generate a porous structure. Nevertheless, biochars produced directly from biomass may exhibit heterogeneous pore structures, residual mineral phases, limited surface functionality and relatively low structural uniformity (Kloss, *et al.*, 2012; Noor and Khan, 2023). Therefore, post-carbonization modification has become an important strategy for tailoring the textural and chemical properties of biomass-derived carbon materials (Ahmad *et al*., 2014; Tan *et al.*, 2015).

Mercaptoacetic acid functionalization provides a potential strategy for tailoring the surface chemistry of biomass-derived carbonaceous materials by introducing carboxyl (-COOH) and sulfur-containing functional groups that may alter surface polarity and provide additional interaction sites for contaminants (Kim e*t al.*, 2025). The resulting changes in surface chemistry can influence adsorption through mechanisms such as hydrogen bonding, electrostatic interactions, π–π interactions, and specific surface interactions, depending on the physicochemical characteristics of the adsorbent and target contaminant.

The present study focuses on the preparation and characterization of unmodified and Mercaptoacetic acid functionalized melon seed husk adsorbents. It specifically examines the extent to which mercaptoacetic acid functionalization alters the textural properties, structural ordering, surface morphology, elemental composition and surface functional groups of melon seed husk biochar. By integrating these complementary characterization techniques, this work provides a comprehensive assessment of the structural and surface transformation of an underutilized agricultural residue into a functionalized carbonaceous material.

2. Materials and Methods

2.1 Material Sample

The adsorbent material used in this present study was prepared from melon seed husk (figure 1) which was obtained from a local market in Umuahia City. The chemicals used in this study included Hydrochloric acid (Merck, purity 99%), Sodium hydroxide pellets, (Merck 98% purity), Mecapto-acetic acid, (Sigma-Aldrich, 99% purity), Dimethylsulfoxide, (Sigma-Aldrich, 99.5% purity), and deionized water.



Figure 1. Image of raw melon seed husk

2.2 Preparation and modification of biochar

In the present study, Melon (*Melothria sphaerocarpa*) seed husk was procured from a local market in Umuahia, Abia State, Nigeria. The raw husk was properly washed with deionized water to remove any adhering impurities, then air-dried at room temperature for 72 hours. The dried material was crushed into a fine powder and pyrolyzed at 450 °C for 1 hour in a muffle furnace (Advatec-KL-420 Japan) with limited oxygen. The resulting biochar was allowed to cool to ambient temperature and labeled as unmodified biochar. A fraction of the biochar was treated with mercaptoacetic acid (analytical grade) to improve its surface functionality. 0.3 M mercapto-acetic acid solution was added to the biochar, and the mixture was allowed to react under static conditions for 24 hours. The modified biochar was filtered and repeatedly washed with deionized water until the pH of the filtrate was neutral. After drying for 4 hours at 100°C, the sample was ground into a fine powder and stored in a hermetic bottle for further use.

2.3 Characterization of the activated carbon

The morphological properties of the obtained biochar was evaluated by Scanning Electron Microscopy (SEM, JSM-7600F, JEOL, Japan) and Energy Dispersive X-ray spectroscopy (EDS, SU1510, Hitachi, Japan) in line with Davies, *et al.*, (2022) and Hodoroaba, (2020). Textural parameters, such as the Brunauer-Emmett-Teller surface area (SBET), total pore volume (Vtot), and pore size distribution, were obtained using nitrogen adsorption isotherms at 77 K using an Autosorb-1 analyzer while the Barrett-Joyner-Halenda (BJH) analysis was used to provide additional insights into the pore structure (Naderi, 2015). The surface functional groups of the adsorbents were identified using Fourier Transform Infrared Spectroscopy (FT-IR, Cary 630, Agilent Technologies, USA) with KBr as a reference in the 400-4000 cm-1 wavenumber range in accordance to Smith, (2011) and the X-ray diffraction (XRD) analysis was used evaluate structural changes following carbonization and mercaptoacetic acid modification using an EDX-3600B X-ray diffractometer in accordance to Epp, (2016).

3. Results and Discussions

3.1 Scanning Electron Microscopy (SEM_EDX) Analysis

SEM analysis was used to examine the surface morphology, while EDX determined the elemental composition of the adsorbents.

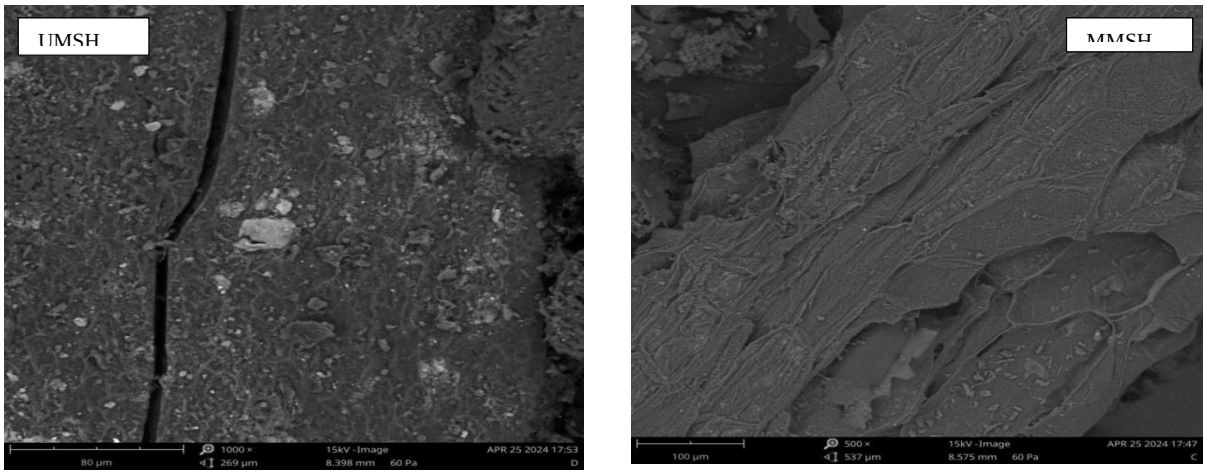
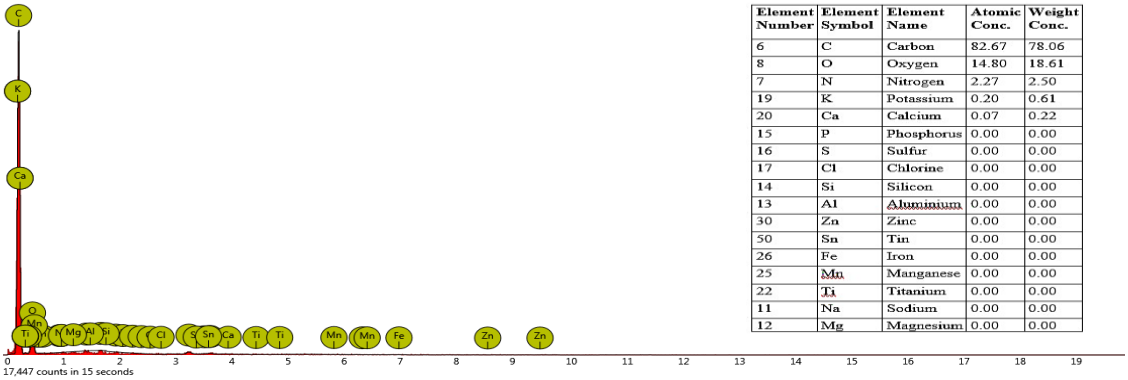
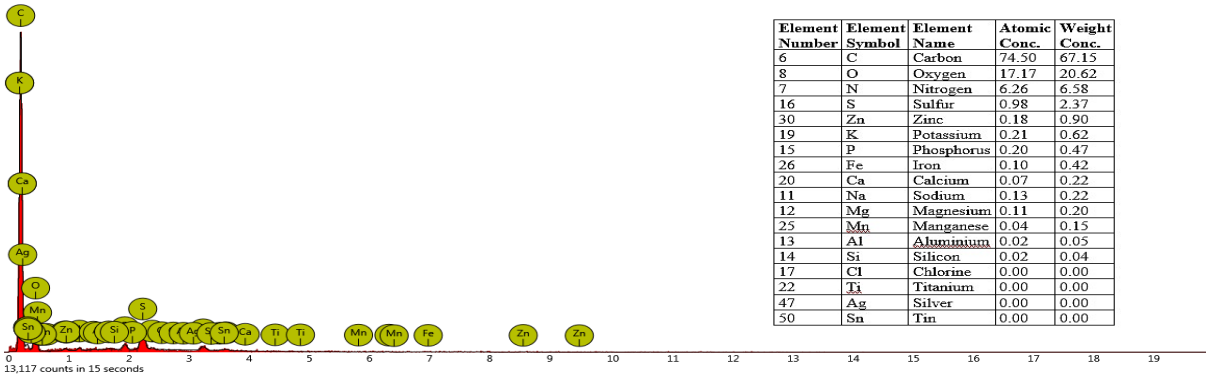


Figure 2. SEM image for unmodified melon seed husk (UMSH) and modified melon seed husks (MMSH) biochar



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	82.67	78.06
8	O	Oxygen	14.80	18.61
7	N	Nitrogen	2.27	2.50
19	K	Potassium	0.20	0.61
20	Ca	Calcium	0.07	0.22
15	P	Phosphorus	0.00	0.00
16	S	Sulfur	0.00	0.00
17	Cl	Chlorine	0.00	0.00
14	Si	Silicon	0.00	0.00
13	Al	Aluminium	0.00	0.00
30	Zn	Zinc	0.00	0.00
50	Sn	Tin	0.00	0.00
26	Fe	Iron	0.00	0.00
25	Mn	Manganese	0.00	0.00
22	Ti	Titanium	0.00	0.00
11	Na	Sodium	0.00	0.00
12	Mg	Magnesium	0.00	0.00

Figure 3. EDX spectra for unmodified melon seed husk (UMSH) biochar



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	74.50	67.15
8	O	Oxygen	17.17	20.62
7	N	Nitrogen	6.26	6.58
16	S	Sulfur	0.98	2.37
30	Zn	Zinc	0.18	0.90
19	K	Potassium	0.21	0.62
15	P	Phosphorus	0.20	0.47
26	Fe	Iron	0.10	0.42
20	Ca	Calcium	0.07	0.22
11	Na	Sodium	0.13	0.22
12	Mg	Magnesium	0.11	0.20
25	Mn	Manganese	0.04	0.15
13	Al	Aluminium	0.02	0.05
14	Si	Silicon	0.02	0.04
17	Cl	Chlorine	0.00	0.00
22	Ti	Titanium	0.00	0.00
47	Ag	Silver	0.00	0.00
50	Sn	Tin	0.00	0.00

Figure 4. EDX spectra for modified melon seed husk (MMSH) biochar

As shown in Figure 2, the unmodified melon seed husk (UMSH) biochar exhibits an irregular, rough surface with macro- and micropores, cracks, and cavities formed during pyrolysis. These features are typical of agricultural-waste biochars and can enhance adsorption by increasing surface area and pore accessibility (Sun *et al*., 2018; Chen *et al.*, 2017). The modified melon seed husk (MMSH) retains its fibrous structure but shows increased surface roughness, grooves, ridges, and irregular pores. These changes suggest surface etching caused by mercaptoacetic acid modification without significant structural degradation. The resulting microchannels and pores may improve mass transfer and adsorption capacity, consistent with previous studies on chemically modified biochars (Ahmed *et a*l., 2016; Lyu *et al.*, 2020; Cheng *et al.*, 2018). The EDX spectral in Figure 3 and figure 4 shows carbon as the dominant element within the biochars, reflecting the carbon-rich nature of biochar after pyrolysis. Oxygen is also present, indicating oxygen-containing functional groups that can contribute to pollutant adsorption (Dia *et al.*, 2021). In MMSH (Figure 4), the prominent sulfur peak confirms the incorporation of sulfur-containing groups from mercaptoacetic acid, which can enhance adsorption performance (Gomez-Marroquín *et al.*, 2024).

3.2 Brunanuer-Emmett-Teller (BET) Analysis

As shown in figure 5, the UMSH exhibited a BET surface area of 318.163 m²/g, which increased to 362.102 m²/g after mercaptoacetic acid modification (MMSH). This increase indicates the development of a more porous structure and a greater number of accessible adsorption sites following chemical treatment. The improvement is attributed to the removal of non-structural components such as hemicellulose and lignin, as well as the creation of additional micropores during modification (Rouquerol *et al.*, 2014). A BET surface area of below 100 m²/g can provide a substantial surface for adsorption; however, adsorption performance also depends on pore structure and the nature of surface functional groups (El-Azazy *et al.*, 2021; Nworie *et al.*, 2019).

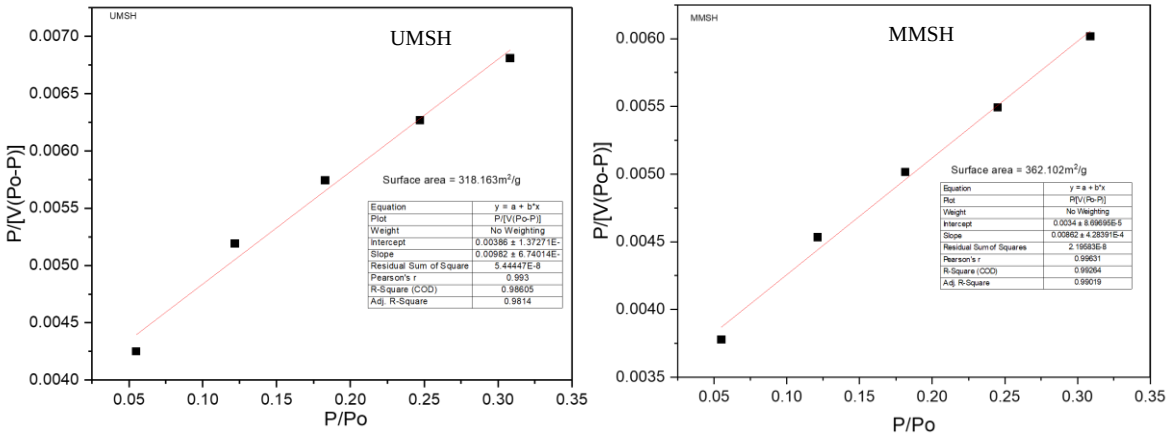


Figure 5. BET surface area plot for unmodified melon seed husk (UMSH) and modified melon seed husk (MMSH) biochar

Similarly, the total pore volume increased from 0.286 cm³/g in UMSH to 0.328 cm³/g in MMSH, demonstrating the formation of a more open internal pore network. Chemical modification is known to remove impurities and amorphous biomass constituents, thereby opening blocked pores and generating new ones within the carbon matrix (Tan *et al*., 2015). The pore size distribution further confirmed that melon seed husk biochar is predominantly mesoporous. The average pore diameter of UMSH was 6.190 nm, which

increased slightly after modification while remaining within the IUPAC mesoporous range of 2–50 nm (Thommes *et a*l., 2015). The enlargement of pore channels is attributed to acid-induced dissolution of lignin, hemicellulose, and surface impurities, resulting in improved pore accessibility and connectivity (Foo & Hameed, 2012; Ioannidou & Zabaniotou, 2007).

Table 1. BET summary of specific surface areas and pore characteristics UMSH and MMSH biochar

Biochar	**Surface Area (m^2/g)**	**Micropore Volume (cm^3/g)**	**Pore diameter (nm)**	**Av. Pore width(nm)**
UMSH	318.335	0.286	2.920	6.19
MMSH	362.315	0.328	2.920	6.214

3.3 Fourier Transform Infrared Spectroscopy (FTIR).

The Fourier Transform Infrared Spectroscopy (FTIR) spectral presented in Figures 6 were used to identify the surface functional groups present on the unmodified melon seed husks (UMSH) and modified melon seed husks (MMSH) biochar. The UMSH biochar spectrum exhibited a broad absorption band around 3200–3600 cm^{-1}, which is attributed to the stretching vibration of hydroxyl (-OH) groups associated with alcohols and phenolic compounds. The presence of hydroxyl groups contributes significantly to hydrophilicity and adsorption potential of biochar materials (Ahmad *et al.*, 2014). The FTIR spectra of MMSH biochar when compared to the UMSH biochar exhibited more pronounced peaks, and slight shifts in functional group positions, confirming successful surface modification. The enhanced intensity of peaks around 1700 cm^{-1} and 1100–1200 cm^{-1} suggests an increase in oxygen-containing functional groups after modification. In addition, the appearance or enhancement of bands associated with sulfur-containing groups may be linked to mercaptoacetic acid modification, introducing thiol (-SH) functionalities onto the biochar surface. Thiol-functionalized biochars have been reported to possess enhanced adsorption affinity due to the strong binding ability of sulfur-containing groups toward pollutants (Lyu *et al*., 2020).

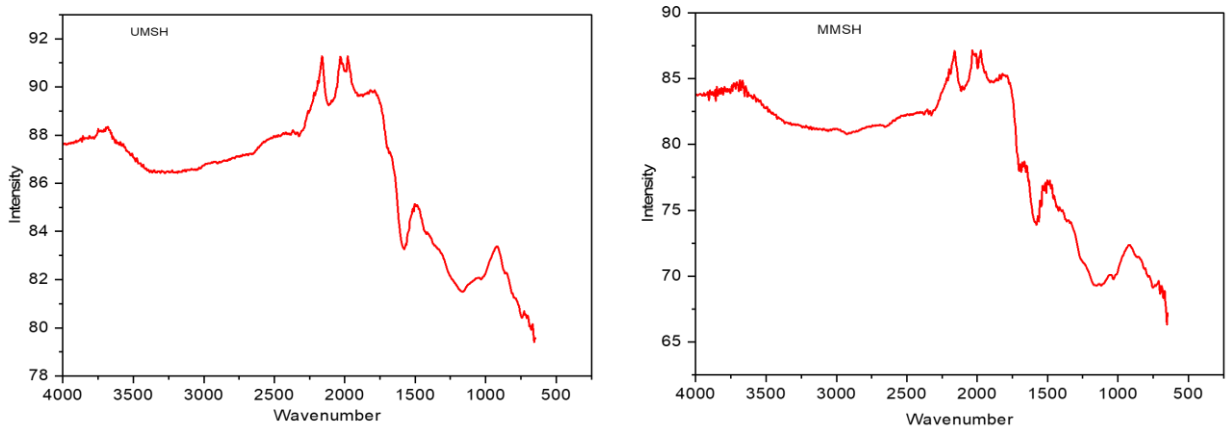


Figure 6. FTIR spectral of unmodified melon seed husk (UMSH) and modified melon seed husk (MMSH) biochar

3.4. X-Ray Diffraction (XRD)

The unmodified melon seed husk (UMSH) in Figure 7 exhibited well-defined diffraction peaks with the most intense reflection at 37.911° and a relatively narrow FWHM of 0.189°, indicating a comparatively high degree of crystallinity. Biomass-derived biochars commonly retain mineral phases because thermally stable inorganic constituents, such as silica, aluminosilicates, and iron oxides, become concentrated within the ash fraction during pyrolysis while the organic fraction undergoes thermal decomposition (Keiluweit *et al.*, 2010; Jiang *et al*., 2019). The retention of these crystalline mineral phases indicates that the unmodified melon seed husk biochar possessed a comparatively high degree of crystallinity prior to chemical modification. Following mercaptoacetic acid modification as shown in figure 8, the modified melon seed husk (MMSH) exhibited a single broad diffraction peak centred at 2θ = 23.334° with a substantially larger FWHM of 13.23°, accompanied by the disappearance of the sharp crystalline reflections observed in the unmodified sample.

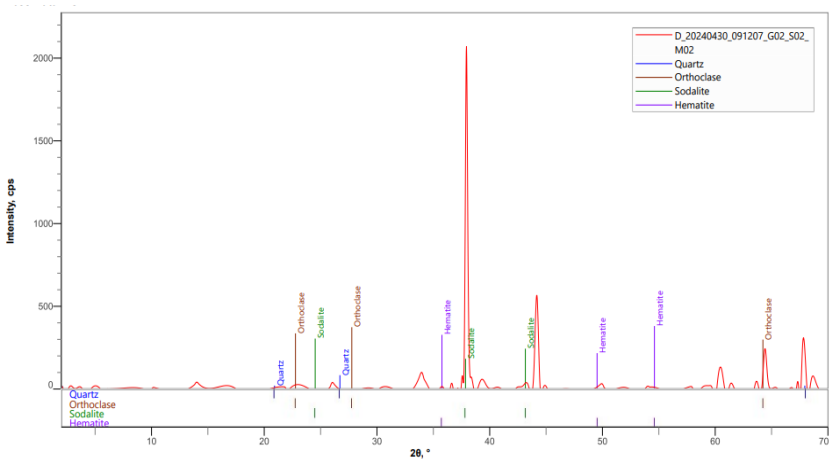


Figure 7. X-ray diffraction pattern of unmodified melon seed husk (UMSH) biochar

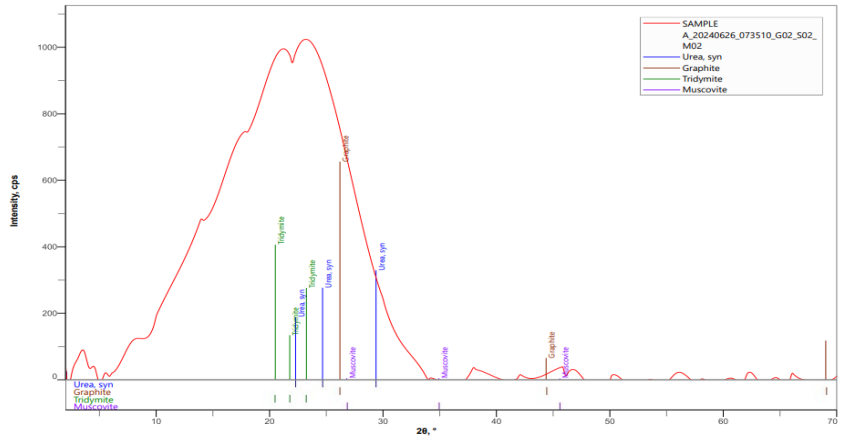


Figure 8. X-ray diffraction pattern of modified melon seed husk (MMSH) biochar

The broad diffraction peak is characteristic of a predominantly amorphous carbon structure, indicating that chemical modification disrupted the crystalline domains and promoted structural disorder within the biochar. Such broadening of XRD reflections following chemical treatment has been attributed to the partial dissolution of crystalline mineral phases, disruption of the carbon framework, and development of new pore structures (Huang *et al.*, 2017; Mashoene *et al.*, 2023). Acid modification can also remove mineral impurities and expose previously inaccessible pores, thereby reducing the intensity of crystalline reflections while increasing the proportion of amorphous carbon (Li *et al.*, 2021).

4. Conclusion

The findings of this study highlight the potential of mecaptoacetic acid-functionalized *melothria sphaerocarpa* seed husk biochar as an efficient, sustainable, and low-cost adsorbent for the remediation of contaminated water. The valorization of agricultural waste into functional adsorbent materials also supports environmental sustainability and circular economy principles. Therefore, MMSH biochar presents a promising alternative material for future wastewater treatment applications involving emerging organic pollutants.

Acknowledgement

The authors sincerely appreciate the support and assistance received during the course of this research work. We acknowledge the laboratory staff and technical personnel who provided assistance with the characterization of the adsorbent materials. We also appreciate the support of our colleagues and research collaborators for their various contributions to the success of this work. Finally, we are grateful to our institution for providing the facilities and resources necessary to carry out this study.

References

Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D., & Ok, Y. S. (2014). Biochar as a sorbent for contaminant management in soil and water: a review. *Chemosphere*, *99*, 19-33.

Ahmed, M. B., Zhou, J. L., Ngo, H. H., Guo, W., & Chen, M. (2016). Progress in the preparation and application of modified biochar for improved contaminant removal from water and wastewater. *Bioresource technology*, *214*, 836-851.

Chen, D., Xie, S., Chen, C., Quan, H., Hua, L., Luo, X., & Guo, L. (2017). Activated biochar derived from pomelo peel as a high-capacity sorbent for removal of carbamazepine from aqueous solution. *RSC advances*, *7*(87), 54969-54979.

Cheng DeYi, C. D., Du Chao, D. C., Huang ZhaoQin, H. Z., Dai JingYu, D. J., Du QiWen, D. Q., & Shao AiYun, S. A. (2018). Adsorption of Zn (II) from wastewater by sulfhydryl rice husk carbon.

Crini, G., Lichtfouse, E., Wilson, L. D., & Morin-Crini, N. (2019). Conventional and non-conventional adsorbents for wastewater treatment. *Environmental Chemistry Letters*, *17*(1), 195-213.

Dai, L., Lu, Q., Zhou, H., Shen, F., Liu, Z., Zhu, W., & Huang, H. (2021). Tuning oxygenated functional groups on biochar for water pollution control: A critical review. *Journal of Hazardous Materials*, *420*, 126547.

Davies, T. E., Li, H., Bessette, S., Gauvin, R., Patience, G. S., & Dummer, N. F. (2022). Experimental methods in chemical engineering: Scanning electron microscopy and X-ray ultra-microscopy—SEM and XuM. *The Canadian Journal of Chemical Engineering*, *100*(11), 3145-3159.

Dungani, R., Munawar, S. S., Karliati, T., Malik, J., & Aditiawati, P. (2022). Study of characterization of activated carbon from coconut shells on various particle scales as filler agent in composite materials. *Journal of the Korean Wood Science and Technology*, *50*(4), 256-271.

El-Azazy, M., Nabil, I., Hassan, S. S., & El-Shafie, A. S. (2021). Adsorption characteristics of pristine and magnetic olive stones biochar with respect to clofazimine. *Nanomaterials*, *11*(4), 963

Epp, J. (2016). X-ray diffraction (XRD) techniques for materials characterization. In *Materials characterization using nondestructive evaluation (NDE) methods* (pp. 81-124). Woodhead Publishing.

Foo, K. Y., & Hameed, B. H. (2012). Preparation, characterization and evaluation of adsorbents from agricultural waste biomass**.** *Bioresource Technology*, *111*, 425–432.

Gomez-Marroquín, M. C., Carbonel, D., Esquivel, S., & Colorado, H. (2024). Thiol-modified olive-stone biochar preparation for Hg (II) removal from aqueous solutions. *Journal of Environmental Engineering and Science*, *19*(3), 177-188.

Hodoroaba, V. D. (2020). Energy-dispersive X-ray spectroscopy (EDS). In *Characterization of nanoparticles* (pp. 397-417). Elsevier.

Huang, H., Tang, J., Gao, K., He, R., Zhao, H., & Werner, D. (2017). Characterization of KOH modified biochars from different pyrolysis temperatures and enhanced adsorption of antibiotics. *RSC advances*, *7*(24), 14640-14648.

Ioannidou, O., & Zabaniotou, A. (2007). Agricultural residues as precursors for activated carbon production—A review. *Renewable and sustainable energy reviews*, *11*(9), 1966-2005.

Jiang, Y., Ren, C., Guo, H., Guo, M., & Li, W. (2019). Speciation Transformation of Phosphorus in Poultry Litter during Pyrolysis: Insights from X-ray Diffraction, Fourier Transform Infrared, and Solid-State NMR Spectroscopy. *Environmental science & technology*, *53*(23), 13841-13849.

Kang, Z., Jia, X., Zhang, Y., Kang, X., Ge, M., Liu, D., & He, Z. (2022). A review on application of biochar in the removal of pharmaceutical pollutants through adsorption and persulfate-based AOPs. *Sustainability*, *14*(16), 10128.

Keiluweit, M., Nico, P. S., Johnson, M. G., & Kleber, M. (2010). Dynamic molecular structure of plant biomass-derived black carbon (biochar). *Environmental science & technology*, *44*(4), 1247-1253.

Kim, E. B., Ameen, S., & Li, H. (2025). Chitosan-mercaptoacetic acid functionalized pepper stem derived biochar for enhanced adsorption of Pb heavy metal ions. *Desalination*, 119570.

Kloss, S., Zehetner, F., Dellantonio, A., Hamid, R., Ottner, F., Liedtke, V., & Soja, G. (2012). Characterization of slow pyrolysis biochars: effects of feedstocks and pyrolysis temperature on biochar properties. *Journal of environmental quality*, *41*(4), 990-1000.

Li, C., Huang, Q., Zhang, H., Wang, Q., Xue, R., Guo, G., & Hu, S. (2021). Characterization of biochars produced by co-pyrolysis of hami melon (Cantaloupes) straw mixed with polypropylene and their adsorption properties of cadmium. *International Journal of Environmental Research and Public Health*, *18*(21), 11413.

Lyu, H., Xia, S., Tang, J., Zhang, Y., Gao, B., and Shen, B. (2020). Thiol-modified biochar synthesized by a facile ball-milling method for enhanced sorption of inorganic Hg^{2+} and organic CH_3Hg^+. *Journal of Hazardous Materials*, 384, 121357.

Mashoene, T. N., Leudjo Taka, A., Akpotu, S. O., Lawal, I. A., & Klink, M. J. (2023). Surface Modification of tea-waste-based biochar adsorbent: Synthesis, characterization, and batch adsorption for the removal of zidovudine ARV drug and phenol. *Applied Sciences*, *13*(13), 7493.

Naderi, M. (2015). Surface area: brunauer–emmett–teller (BET). In *Progress in filtration and separation* (pp. 585-608). Academic Press.

Noor, A., & Khan, S. A. (2023). Agricultural wastes as renewable biomass to remediate water pollution. *Sustainability*, *15*(5), 4246.

Nworie, F. S., Nwabue, F. I., Oti, W., Mbam, E. 1., & Nwali, B. U. (2019). Removal of methylene blue from aqueous solution using activated rice husk biochar: Adsorption isotherms, kinetics and error analysis. *Journal of the Chilean chemical society*, *64*(1), 4365-4376.

Rouquerol, F., Rouquerol, J., Sing, K. S. W., Llewellyn, P., & Maurin, G. (2014). *Adsorption by Powders and Porous Solids: Principles, Methodology and Applications* (2nd ed.). Academic Press.

Smith, B. C. (2011). *Fundamentals of Fourier transform infrared spectroscopy*. CRC press.

Stuart, B. (2004). *Infrared Spectroscopy: Fundamentals and Applications*. John Wiley and Sons.

Sun, L., Chen, D., Wan, S., & Yu, Z. (2018). Adsorption studies of dimetridazole and metronidazole onto biochar derived from sugarcane bagasse: kinetic, equilibrium, and mechanisms. *Journal of Polymers and the Environment*, *26*(2), 765-777.

Tan, X., Liu, Y., Zeng, G., Wang, X., Hu, X., Gu, Y., & Yang, Z. (2015). Application of biochar for the removal of pollutants from aqueous solutions. *Chemosphere*, *125*, 70-85.

Thommes, M., Kaneko, K., Neimark, A. V., Olivier, J. P., Rodriguez-Reinoso, F., Rouquerol, J., & Sing, K. S. W. (2015). Physisorption of gases, with special reference to the evaluation of surface area and pore size distribution (IUPAC Technical Report). *Pure and Applied Chemistry*, *87*(9–10), 1051–1069.

Tripathi, M., Sahu, J. N., & Ganesan, P. (2016). Effect of process parameters on production of biochar from biomass waste through pyrolysis: A review. *Renewable and sustainable energy reviews*, *55*, 467-481