



Research Article

A Comparative Physicochemical and Adsorption Properties of Rice Husk, Cotton Stem, and Coconut Shell Biochar

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Abstract

As the world is moving towards ecofriendly solutions in every sector, crop residue management draws attention worldwide. This study investigates the transformation and characterization of abundant crop residues found largely in Gunupur, Rayagada locality like rice husk, cotton stem, and coconut shell into biochar adsorbents through pyrolysis. Biochar is not only a source of adsorption but also found to be a rich carbon source for soil rejuvenation. Comparative analysis divulges physiochemical properties as well as adsorption capacities of these adsorbents which will result in better environmental remediation. (SEM, BET, FTIR, XRD, and CHNS Analysis). The temperature for the results was 550 °C. The CHNS elemental analysis entails that the cotton stem biochar has the highest carbon content of 57.923% followed by Coconut shell and rice husk. Meanwhile cotton stems have the highest nitrogen content of 2.189%. The BET surface area analysis reveals the highest pore size 59.995 m²/g that is of rice husk. At the same temperature cotton stem biochar has pore size of 3.6156 m²/g. XRD patterns in RH-B-001 shows multiple peaks implying good crystallinity Higher pyrolysis temperatures typically increase crystallinity, showing sharper peaks for ordered carbon structures. FTIR was done to observe surface functional groups after pyrolysis. RH-B-001 has moderate aromaticity and shows defined peaks for silicates.

Keywords

Biochar, Rice Husk, Cotton Stem, XRD, FTIR, BET Surface Area, Comparative Analysis

1. Introduction

Agriculture plays a vital role in the socioeconomic growth of every country. A rapidly developing country like India who ranks second as a global agriculture powerhouse also generates agriculture wastes in vast amounts [1]. According to the Press Information Bureau of India, India is generating over 350 million tons of agricultural wastes per year which

has the potential of generating 18,000 MW of power (PIB, 2026). In rural households, a part of these wastes is used for animal feeding, roof development, as fuel for cooking, and other industrial purposes [2]. After the use also, there are millions of tons of residue remains unused from which 92 million tonnes are burned out in open fields [3]. This is an

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ancient practice of agriculture in which the land is prepared and cleaned for the next crop. As a result of this soil infertility increases and also it aids to contaminating air as particulate matter increases in air and thus causing global warming [4]. In India, burning crop residue adds 91 Tg of CO₂, 4.1 Tg of CO, 0.6 Tg of CH₄, 0.1 Tg of NO_x, and 1.2 Tg of PM to the country's annual emissions of greenhouse gases and pollutants. The temperature of the soil has increased to 33.8–44.2 °C up to 1 cm (about 0.39 in) depth due to the agriculture waste burning, which decreases the soil fertility by eliminating the beneficial microorganisms and thus degrading the organic matter of soil like carbon and nitrogen [5, 6]. Conversion of this vast amount of agricultural waste into a great source of carbon that is biochar seems to be achievable via slow pyrolysis. Biochar can be produced from various biomass via pyrolysis which not only acts as an excellent adsorbent but also have high content of organic carbon and high resistance to physical or chemical breakdown [7]. Biochar acts as a super adsorbent material used to treat heavy metals present in water bodies or effluents. It also enhances the carbon content of the soil and water with holding capacity by making the soil rich in organic matter and making it fertile. Chemical composition of the biomass like cellulose, hemicellulose, lignin, volatile compounds and carbon content affects the physiochemical and morphological properties of biochar [8]. Various crop residues such as rice husk, coconut shell, palm shell, sugarcane bagasse [9], almond shell, coffee husk, olive husk [10], Indian bael shell [11], rice straw, corn straw and wheat straw [12] were investigated for biochar production through pyrolysis. Recycling this abundant waste biomass to produce biochar is an environmentally friendly process [13]. Asian countries that are major rice producers include China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, Japan, Philippines, Republic of Korea and Pakistan (International Rice Research Institute, 2020). After harvesting the rice goes for milling where most of the residues like rice straw, rice husk and rice bran are generated [14]. The global rice husk production annually is about 120 tonnes [15]. Rice husk biochar (RHB) accounts for 20% of rice weight and it contains 50% cellulose, 25–30% lignin, 15–20% silica, and 10–15% moisture [16]. Converting the rice husk into functional adsorbent can reduce waste and its use on paddy fields can increase the carbon content of the soil [14]. Rayagada, located at the southern part of Odisha is one of the major cotton producing districts of India [17]. Post harvesting the cotton stems are mainly used as fuel by the rural people. Converting cotton stem biomass into biochar reduces agricultural waste while producing highly porous biochar [18]. The Food and Agriculture Organisation (FAO) reported that India is one of the major coconuts producing countries producing 14.7 million tons of coconut annually (FAO, 2019). Coconut shell is mostly composed of lignin, cellulose and hemicellulose [19]. When the rate of cellulose breakdown increases, the biochar improves porosity [20]. In-

crease in the breakdown of lignin content contributes to biochar with a high surface area, high FC content, and fine aromatic structure [21]. This study is a comparative analysis between the physiochemical and morphological characteristics of three biochar derived from Rice straw (RHB), Coconut Shell (CSB) and Cotton stem (COSB). This research will help to choose the biochar with higher surface area, high porosity and greater carbon content for future studies.

2. Materials and Method

2.1. Collection of Feedstocks

About 20 kg of rice husk is collected from Maa Tarini rice mill located in Gobariguda, Gunupur, Odisha, India. The cotton stems are collected from the agriculture field of the School of Agriculture, Gandhi Institute of Engineering and Technology, Gunupur, India. The coconut shell was collected from the market area of Gunupur. The long cotton stem sample was cut into smaller pieces of 5–7 cm to ensure efficient pyrolysis at low temperatures. The coconut shell was broken into smaller pieces for better pyrolysis. All three samples were washed thoroughly and completely dried in the oven at 70 °C for 14 hours [3].

2.2. Preparation of Biochar

The dried samples were collected and stored in a clean dry container. Slow pyrolysis is done at 550 °C with continuous nitrogen purging for high biochar yield. To maintain uniform pyrolysis temperature, the experiment was carried out at a heating rate of 12 °C/min for 1 kg of biomass, and the holding time was 1 hour. After pyrolysis the biomass was collected to allow it to cool to room temperature. After it cools down it is washed with distilled water several times followed by drying at 105 °C [22]. The biochar of rice husk, cotton stem, coconut shell is named as RHB, COSB and CSB respectively. Biochar yield is defined as the ratio of resulting biochar mass to the initial mass of the biomass feedstock used in the pyrolysis process [23].

2.3. Characterization of Biochar samples

The surface morphology and structural characteristics of the prepared biochar was analyzed by using scanning electron microscopy (SEM) at the Institute of Lifesciences, Bhubaneswar, India (Model: MAIA3 XMH). A small amount of dried biochar of three different samples was taken separately. The samples were examined under SEM at 300x to 500x magnification for particle shape, surface texture and aggregation behavior [24]. BET surface area analysis was done to characterize surface area, total pore volume, mean pore diameter with adsorption of nitrogen at 77 K using BET surface area and pore size analyzer (Make: Quanta chrome Instruments). The biochar samples

were first dried at 105 °C and then degassed at 300 °C for 6 hours prior to BET analysis [25]. The use of elemental analyser (CHNS) supplemented the energy content evaluation by determining the contents of carbon, hydrogen, nitrogen, and Sulphur [26]. FTIR analysis was carried out using Fourier transform infrared spectroscopy (Make: Nicolet IS50, Thermo fisher scientific, India) using KBr pellet technique, equipped with a ceramic source, KBr beam splitter and deuterated triglyceride sulphate (DTGS) detector over a spectral range of 4000-5000 cm^{-1} with 64 scans per minut.

3. Results and Discussions

3.1. SEM Analysis of Biochar Sample

The SEM micrographs are illustrated in Figures 1-6. Figure 1 shows the SEM image of rice husk biochar at 361X. A precise porous structure with ordered silica rich pattern is visible at higher magnification from Figure 2. Figure 3 and Figure 4 show a rough heterogenous surface with defined micropores and fractured structure which reflects enhanced porosity and surface area after pyrolysis [27]. Figure 5 and Figure 6 demonstrate highly porous structures of cotton stem biochar.

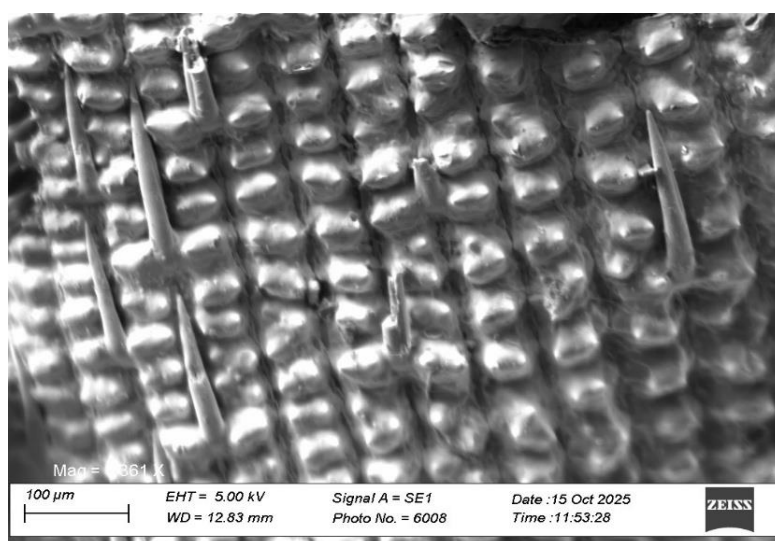


Figure 1. SEM image of rice husk biochar (361×).

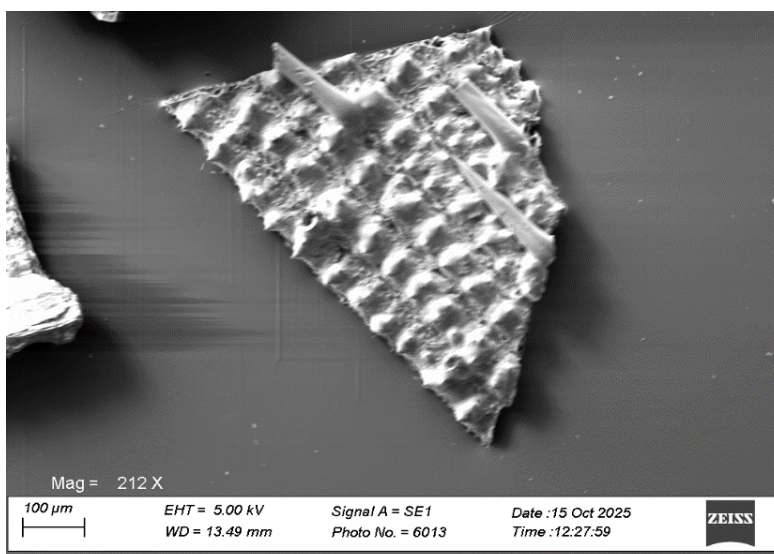


Figure 2. SEM image of rice husk biochar (212×).

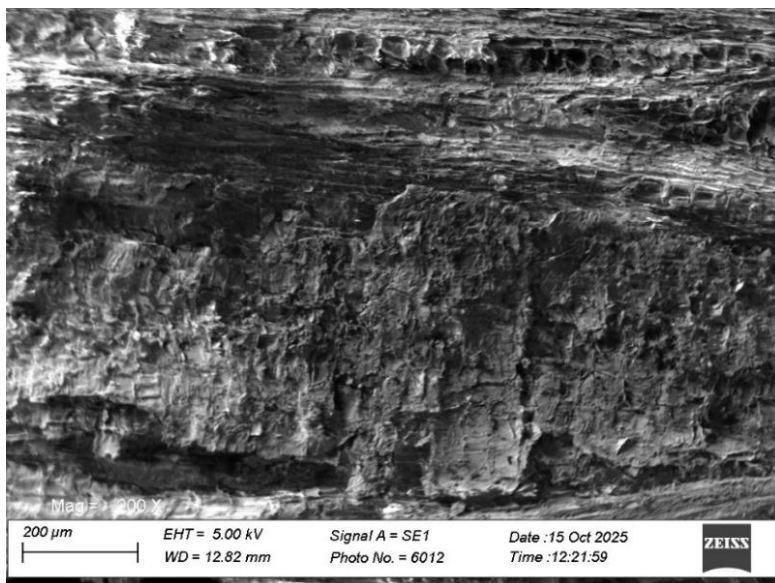


Figure 3. SEM image of coconut shell biochar (200×).

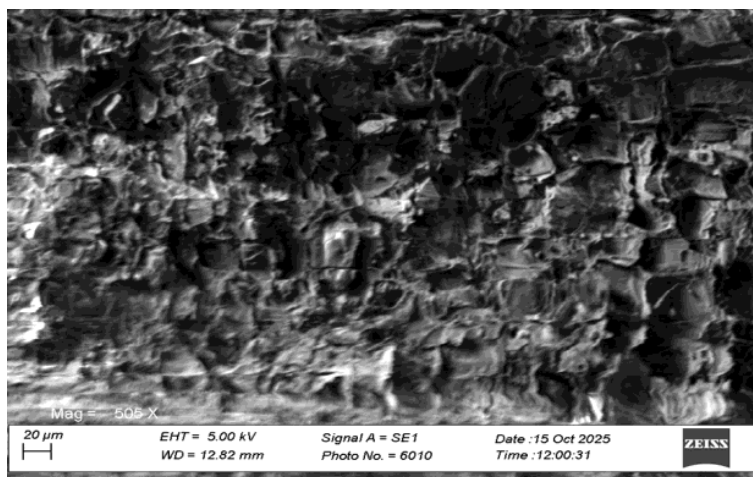


Figure 4. SEM image of coconut Cotton stem biochar (505×).

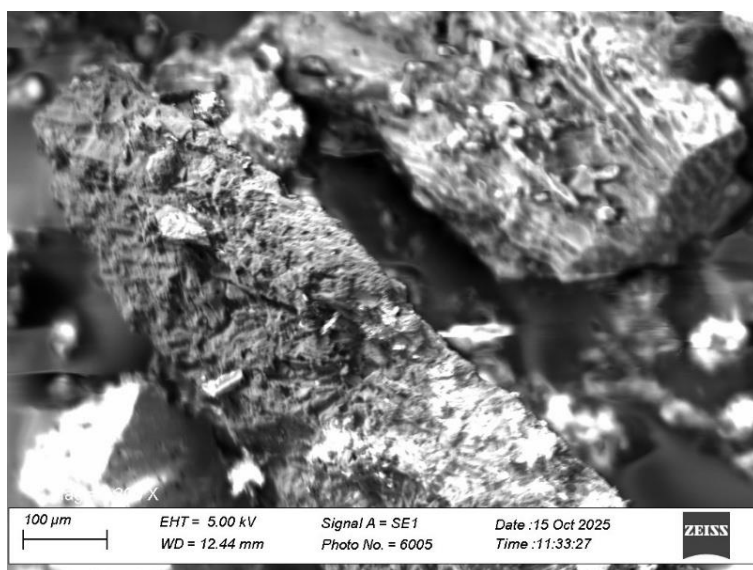


Figure 5. SEM image of coconut Cotton stem biochar (200×).

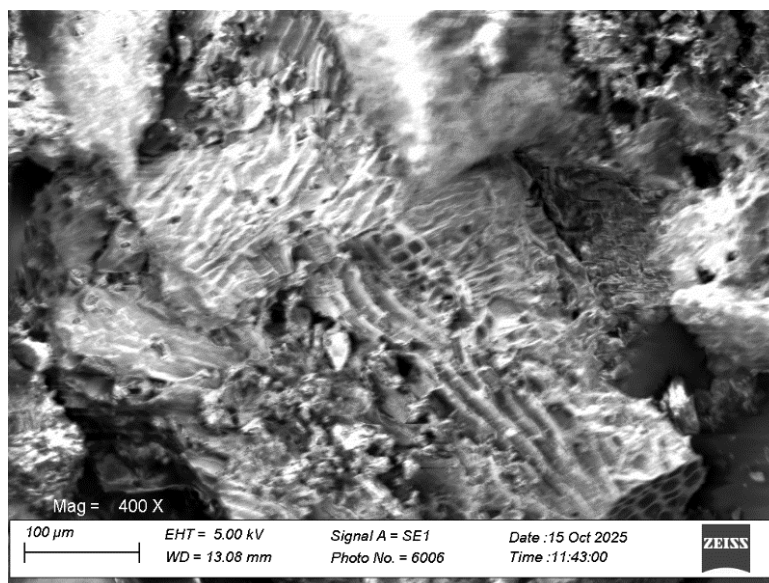


Figure 6. SEM image of coconut Cotton stem biochar (400×).

3.2. CHNS Elemental Analysis of Biochar Samples

Table 1 shows detailed elemental analysis of the three biochar. High lignin content indicates a greater proportion of carbon rich structures, suggesting a higher carbon content in material [27]. Cotton stem biochar contains highest amount of carbon that is of 57.923 percentage and 2.183 of nitrogen content which is highest among the other two.

Table 1. CHNS Elemental analysis of biochar samples.

Sample name	Carbon	Hydrogen	Nitrogen
Rice husk Biochar	45.233	1.625	1.495
Cotton stem Biochar	57.923	3.726	2.189
Coconut Shell Biochar	50.570	1.691	1.963

3.3. BET Surface Area Analysis

BET is the surface area analysis of biochar to define the pore size and pore diameter of the three biochar samples. Table 2 shows rice husk has the largest surface area that is 59.995 m²/g. Total pore volume of the biochar is 0.0386 which is highest among the three. This will help in the adsorption of any heavy metal and contaminants from the water [3].

Table 2. BET analysis of biochar samples.

Sample name	BET Surface Area (m ² /g)	Total Pore (cm ³ /g)	Average Volume Pore Diameter (nm)
Rice husk Biochar	59.995	0.0386	1.2879
Cotton stem Biochar	3.6156	0.0031	1.7091
Coconut shell Biochar	14.484	0.0125	-3.1553

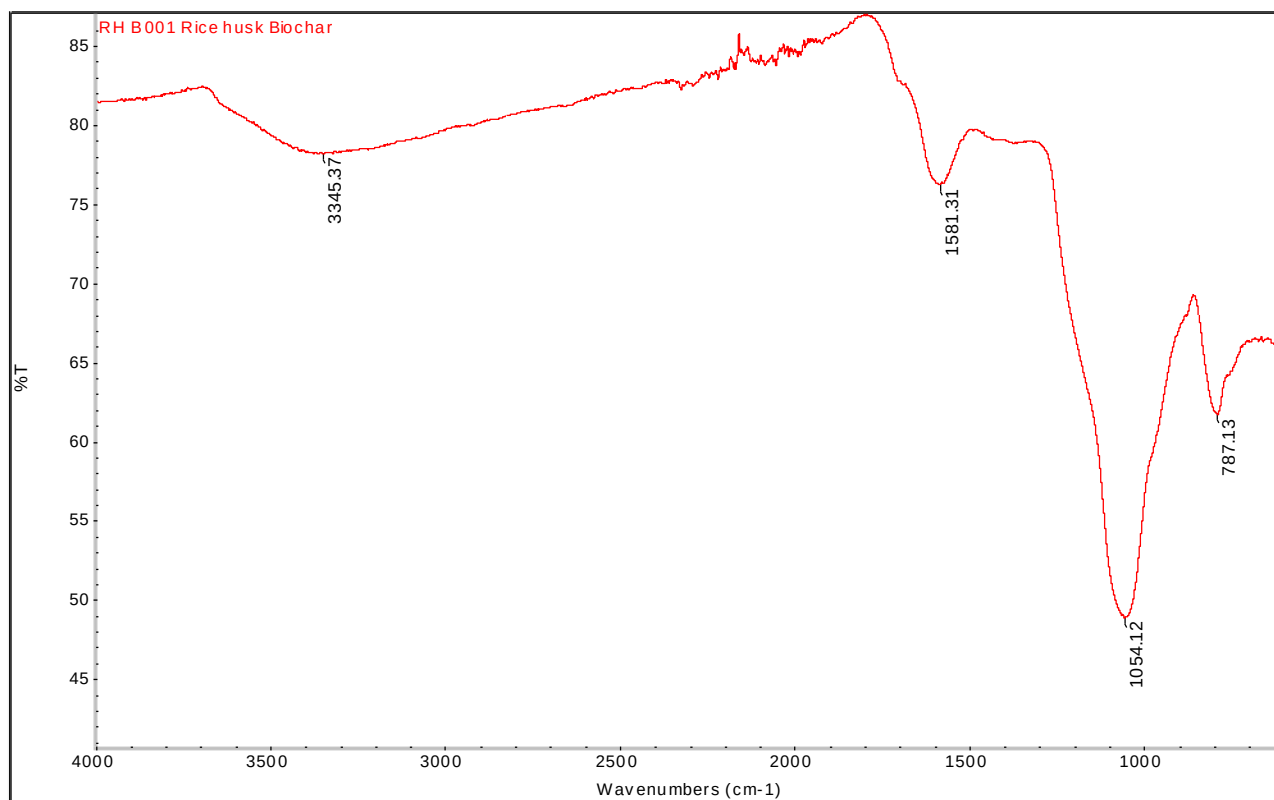


Figure 7. FTIR of rice husk biochar.

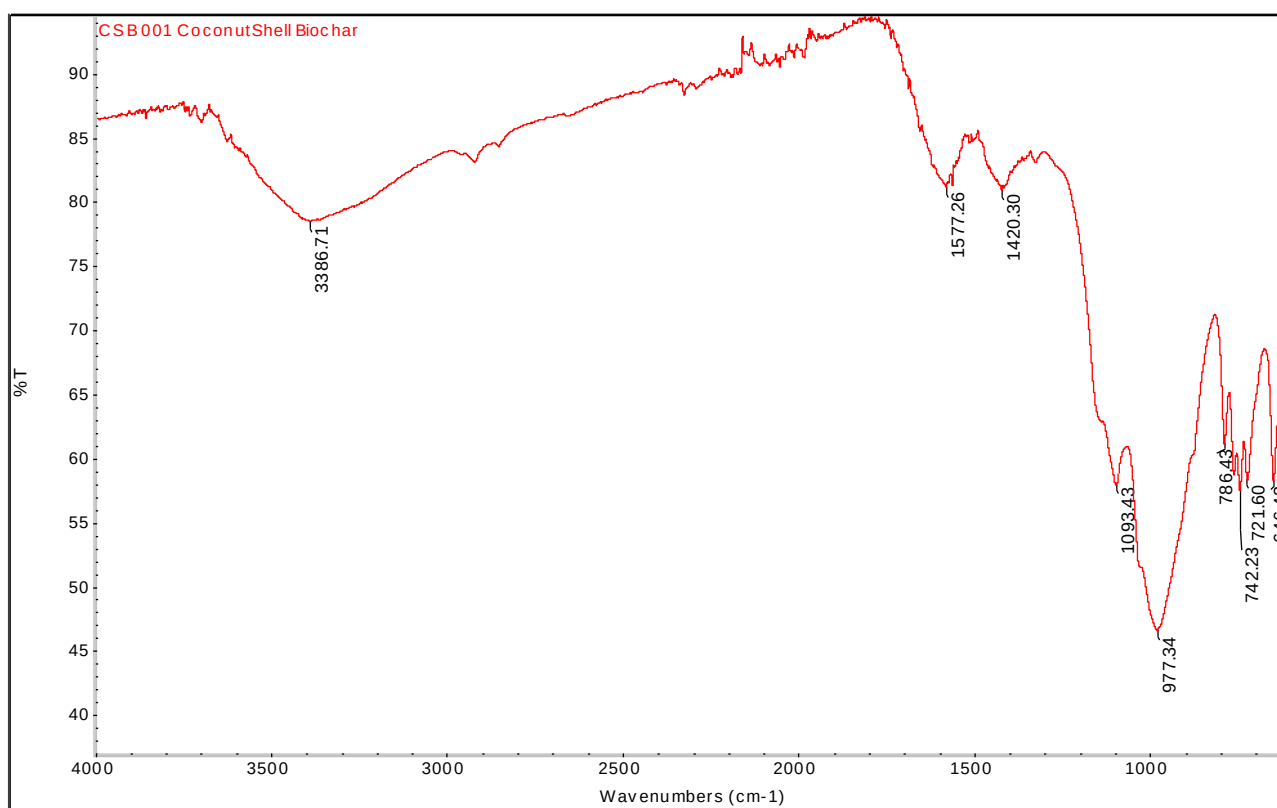


Figure 8. FTIR of cotton shell biochar.

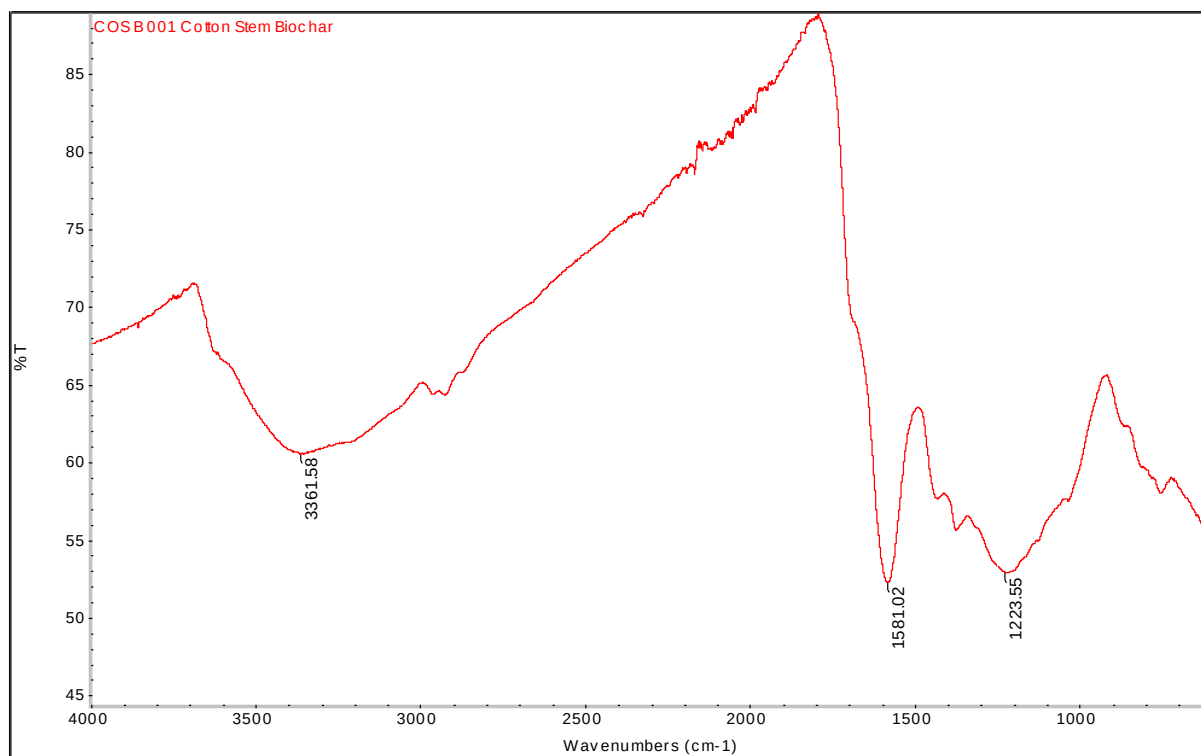


Figure 9. FTIR of cotton stem biochar.

3.4. Fourier Transform Infrared (FTIR) Spectroscopic Analysis of Biochar Samples

FTIR analysis of cotton stem, coconut shell and rice husk biochars show distinct functional group variations. All samples ex-

hibit a broad O-H band (3400 cm^{-1}), weaker in coconut shell biochar, indicating higher dehydration and aromatization. Aliphatic C-H bands (2900 cm^{-1}) are weak in all, nearly absent in coconut shell biochar. The C=O band ($1700\text{--}1740\text{ cm}^{-1}$) is strong in cotton stem, weak in rice husk and nearly absent in coconut shell biochar, showing reduced oxygenated groups. Rice husk biochar also shows silicate related peaks due to mineral content [27].

3.5. XRD Analysis of Biochar

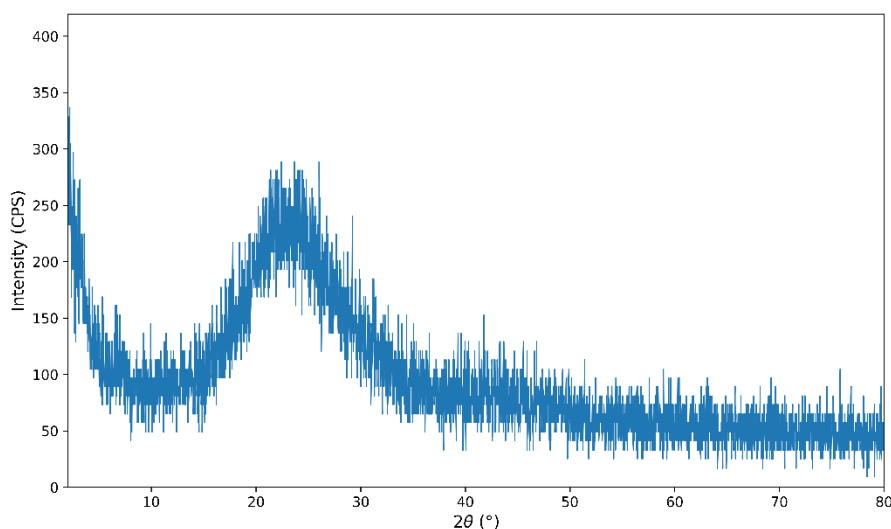


Figure 10. XRD analysis of rice husk biochar.

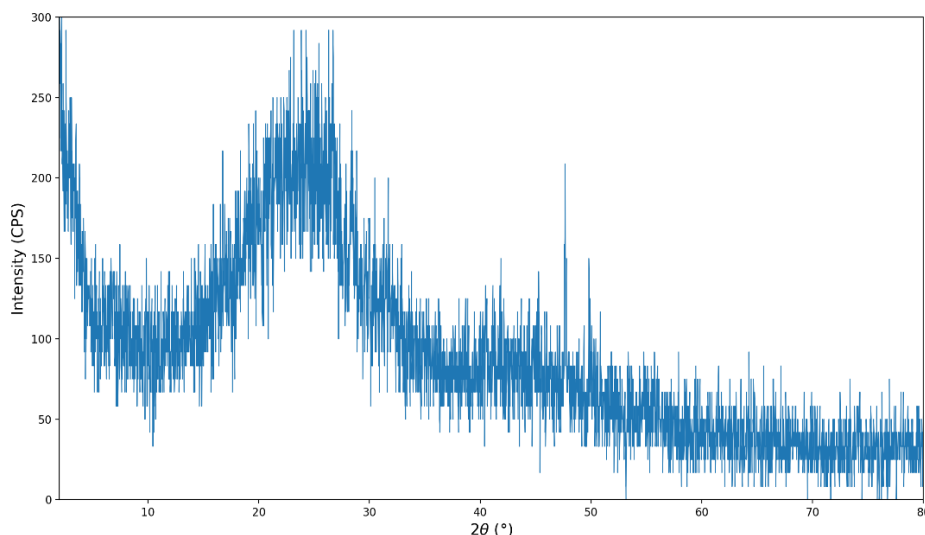


Figure 11. XRD analysis of coconut shell biochar.

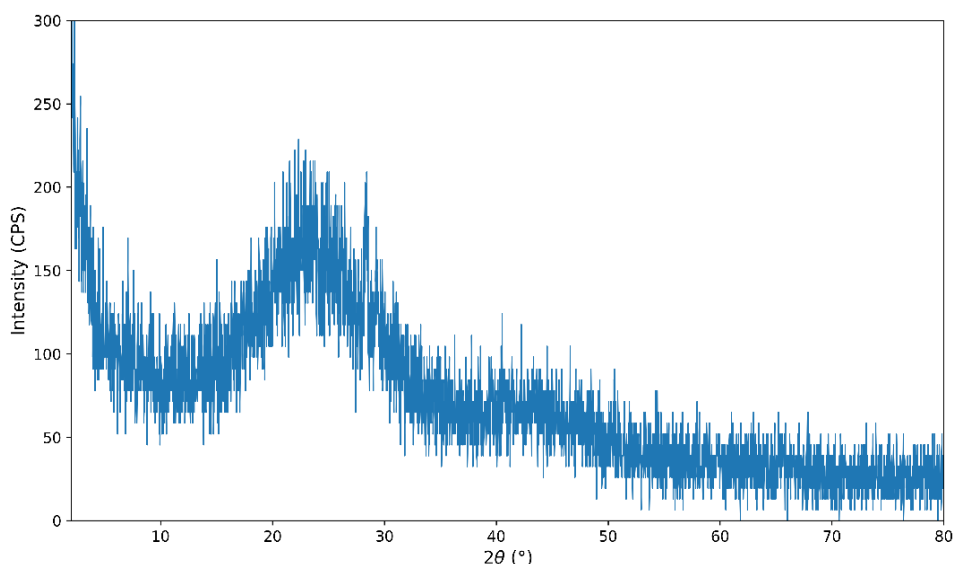


Figure 12. XRD analysis of cotton stem biochar.

Comparative XRD analysis of rice husk biochar, coconut shell biochar, and cotton stem biochar showed significant variation in structural characteristics. RHB exhibited broad peaks around 21-24°, indicating an amorphous structure with high silica content. CSB showed strong peaks at 24.330 and 26.620, suggesting higher crystallinity and better graphitic carbon ordering due to the compact lignocellulosic composition of coconut shell. COSB displayed a major peak at 28.410 along with several mineral associated peaks, indicating moderate crystallinity and mineral presence.

Overall, Coconut shell biochar demonstrated the highest structural stability; Rice husk biochar showed maximum amorphous nature and cotton stem biochar exhibited intermediate structural properties.

4. Conclusions

The present comparative study demonstrated that biochars produced from rice husk, coconut shell and cotton stem through slow pyrolysis at 550°C possess distinct physiochemical and structural characteristics suitable for environmental applications. Among the three samples, cotton stem content, indicating enhanced carbonization and nutrient retention potential. Rice husk biochar showed the largest BET surface area pore volume, making it a promising adsorbent for heavy pollutant removal. Coconut shell biochar displayed comparatively higher crystallinity and graphitic ordering in XRD analysis, suggesting superior structural stability. SEM analysis confirmed the development of porous and hetero-

genous surfaces in all biochars, while FTIR spectra revealed the presence of important oxygen containing functional groups. Overall, the study highlights that the selection of feedstock significantly influences biochar properties, and each biochar possesses unique advantages for adsorption, soil amendment, and sustainable environmental remediation applications.

Abbreviations

XRD	X-ray Diffraction
SEM	Scanning Electron Microscope
FTIR	Fourier Transform Infrared Spectroscopy
BET	Brunauer Emmett Teller
DTGS	Deuterated Triglycine Sulphate

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Author Contributions

Anjali Panigrahi: Conceptualization, Resources, Methodology, Writing – Original draft

Sudipta Maity: Data curation, Supervision, Validation

Rinki Maharana: Formal Analysis, Investigation

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Reddy, K. S., P., Mishra, A. Agricultural Waste generation and Management Strategies in India. *Journal of Environmental Management*. 2025, 318(2), 115-126. <https://doi.org/10.1016/j.jenvman.2025.115126>
- [2] Jain, N., Bhatia, A., Pathak, H. Emission of Air Pollutants from Crop Residue Burning in India. *Aerosol and Air Quality Research*. 2014, 14(1), 422-430. <https://doi.org/10.4209/aaqr.2013.01.0031>
- [3] Sahoo, D., Roy, P., Das, M. Agricultural Waste Burning and Biochar Production for Environmental Remediation. *Environmental Technology and Innovation*. 2021, 21(4), 101318-101330. <https://doi.org/10.1016/j.eti.2020.101318>
- [4] Lohan, S. K., Jat, H. S., Yadav, A. K. Burning Issues of Paddy Residue Management in India. *Renewable and Sustainable Energy Reviews*. 2018, 81(2), 693-706. <https://doi.org/10.1016/j.rser.2017.08.057>
- [5] Gupta, P. K., Sahai, S., Singh, N. Residue Burning in Rice-Wheat Cropping Systems: Causes and Implications. *Current Science*. 2004, 87(12), 1713-1717.
- [6] Kumar, P., Kumar, S., Joshi, L. Impacts of Crop Residue Burning on Environment and Human Health. *Environmental Development*. 2015, 15(3), 1-9. <https://doi.org/10.1016/j.envdev.2015.05.001>
- [7] Skouteris, G., Saroj, D., Melidis, P. Biochar for Water and Soil Remediation Applications: a Review. *Journal of Environmental Management*. 2015, 146(1), 90-101. <https://doi.org/10.1016/j.jenvmen.2014.07.023>
- [8] Ghysels, S., Ronsse, F., Pieters, J. Influence of Biomass Composition on Biochar Characteristics. *Biomass and Bioenergy*. 2020, 138(5), 105607-105615. <https://doi.org/10.1016/j.biombioe.2020.105607>
- [9] Windeatt, J. H., Ross, A. B., Williams, P. T. Characteristics of Biochars produced from Different Biomass Feedstocks. *Fuel*. 2014, 117(2), 338-347. <https://doi.org/10.1016/j.fuel.2013.08.090>
- [10] Kammoun-Rigane, M., Cheikh-Rouhou, S., Casabianca, H. Production and Characterization of Biochar from Agricultural Residues. *Waste and Biomass Valorization*. 2018, 9(6), 1009-1018. <https://doi.org/10.1007/s12649-017-9870-5>
- [11] Roy, P., Dias, Saha, A. Preparation and Characterization of Indian Bael Shell Biochar. *Bioresource Technology Reports*. 2018, 4(1), 202-208. <https://doi.org/10.1016/j.biteb.2018.10.003>
- [12] Zhang, X., Wang, H., L. Characterization of Biochar Derived from Rice Straw, Corn Straw and Wheat Straw. *Journal of Analytical and Applied Pyrolysis*. 2017, 127(4), 246-253. <https://doi.org/10.1016/j.jaap.2017.09.012>
- [13] Mahanim, S. M. A., Asmawati, D., Rafidah, J. Production and Characterization of Biochar from Agricultural Biomass Waste. *International Journal of Engineering and Technology*. 2011, 11(1), 34-37.
- [14] Karam, D., Nagabovanalli, P., Kumari, S. Rice Husk Biochar and Its Environmental Significance: A Review. *Biomass Conversion and Biorefinery*. 2022, 12(7), 2391-2408. <https://doi.org/10.1007/s13399-020-01110-y>
- [15] Bodie, A. R., Micciche, A. C., Atungulu, G. G. Global Rice Husk Production and Utilization Potential. *Journal of Agricultural Engineering*. 2019, 56(3), 45-53.
- [16] Singh, B. Rice Husk Biochar. Production, Characterization and Applications. *Renewable Energy Reviews*. 2018, 81(1), 222-234. <https://doi.org/10.1016/j.rser.2017.07.009>

- [17] Dalei, B. B., Mishra, S., Patnaik, H. Cotton Production Scenario in Rayagada District of Odisha. *Journal of Agricultural Sciences*. 2015, 85(6), 812-816.
- [18] Dong, X., Li, G., Lin, Q. Production of Porous Biochar from cotton Stem Biomass and Its Environmental Applications. *Chemosphere*. 2022, 287(2), 132263-132272. <https://doi.org/10.1016/j.chemosphere.2021.132263>
- [19] Borel, L. D. M. S. Ribeiro, N. J., Almeida, R. Characterization of Coconut Shell Biomass for Production. *Biomass Conversion and Biorefinery*. 2021, 11(5), 1721-1730. <https://doi.org/10.1007/s13399-019-00572>
- [20] Lie, J., Chen, D., Zhou, Y. Effect of Cellulose Degradation on Biochar Porosity Development. *Fuel Processing Technology*. 2020, 199(3), 106267-106275. <https://doi.org/10.1016/j.fuproc.2019.106267>
- [21] Jiang, J., Xu, R., Jiang, T. Influence of Lignin Decomposition on Biochar Aromaticity and Surface Area. *Bioresour. Technology*. 2020, 314(1), 123729-123737. Li, Y., Shao, J., Wang, X. Preparation and Characterization of Biochar through Slow Pyrolysis. *Journal of Cleaner Production*. 2020, 248(4), 119266-119235. <https://doi.org/10.1016/j.jclepro.2019.119226>
- [22] Qin, L., Chen, M., Yi, H. Biochar Yield and Physico-chemical Properties Under Different Pyrolysis Conditions. *Journal of Environmental Chemical Engineering*. 2020, 8(6), 104289-104298. <https://doi.org/10.1016/j.jece.2020.104289>
- [23] Ma, Z., Chen, D., Gu, J. SEM Analysis of Biomass Derived Biochar and Pore Structure Evaluation. *Microscopy Research and Technique*. 2016, 79(10), 941-948. <https://doi.org/10.1005/jemt.22734>
- [24] Parthasarathy, P., Narayanan, K. S., Ahmed, A. BET Surface Area and Pore Characterization of Biochar Derived from Agricultural Residues. *Material Today Proceedings*. 2020, 33(7), 2560-2565. <https://doi.org/10.1016/j.matpr.2020.02.863>
- [25] Ahmad, M., Lee, S. S., Rajapaksha, A. U. Biochar as a Sorbent for Contaminant Management in Soil and Water: A Review. *Chemosphere*. 2019, 99(2), 19-33. <https://doi.org/10.1016/j.chemosphere.2013.10.071>
- [26] Castilla-Caballero, D., Herrera-Barros, A., Albis-Arrieta, A. Morphological Characteristics of Biochar Produced from Lignocellulosic Biomass. *Biomass Conversion and Biorefinery*. 2020, 10(4), 1021-1030. <https://doi.org/10.1007/s13399-019-00484>
- [27] Armynah, B., Tahir, D., Marsongko, P. Structural Characterization of Biomass Derived Biochar Using FTIR and Elemental Analysis. *Journal of Physics: Conference Series*. 2018, 979(1), 012038-012045. <https://doi.org/10.1088/1742-6596/979/1/012038>

Biography



Anjali Panigrahi is currently working as a project Assistant in the Department of Biotechnology at Gandhi Institute of Engineering and Technology University. She previously served as a postmaster Innovation Fellow at the BIRAC E-Yuva Center. She has a strong research background in material chemistry, analytical chemistry, and microbiology, with interests in sustainable technologies and applied biotechnology. She has actively participated in research projects, laboratory experimentation, scientific writing, and data analysis. Her research work mainly focuses on innovative and eco-friendly approaches for biotechnological and environmental applications. She is dedicated to advancing scientific research through interdisciplinary collaboration and innovation.



Sudipta Maity is driving as the EYC Coordinator at the DBT-BIRAC E-Yuva Center. He is an accomplished researcher in biotechnology and environmental microbiology with expertise in bioenergy, biocomposites, biomaterials, drug delivery, and environmental re-mediation. His research primarily focuses on polyhydroxyalkanoates (PHAs), sustainable biopolymers, microbial biotechnology, and waste valorization. He has authored numerous high impact research publications with significant citations in reputed international journals. He has actively contributed to innovative research on biofertilizers, microbial fermentation, and sustainable agricultural applications, promoting eco-friendly technologies and interdisciplinary scientific advancement.



Rinki Maharana is an M. Tech. Biotechnology student at GIET University with research interests in microbial biotechnology, bioplastics, and nanotechnology. She completed her B. Tech. in biotechnology Engineering from the same institution in 2024 and currently works as a lab assistant in the Department of Biotechnology. Her technical expertise includes microbial analysis, molecular biology, and nanotechnology. Done internship training at Rapture Biotech Pvt. Ltd., Hyderabad, in Biotechnology research and industrial application.

Research Field

Anjali Panigrahi: Surface Chemistry, Analytical Chemistry, environmental

Sudipta Maity: Microbiology, Material Science, Analytical chemistry

Rinki Maharana: Nanotechnology, Environmental biotechnology