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Agricultural waste valorisation via activated carbon synthesis: A comprehensive study of material properties and environmental applications

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Abstract
This study presents a comprehensive characterization of activated carbons derived from five agricultural waste materials: corn cob, coconut shell, rice husk, sugarcane waste, and groundnut shell. A systematic investigation was conducted to evaluate their physical, chemical, and adsorptive properties for potential application in water treatment. The activated carbons were characterized using multiple analytical techniques, including proximate analysis, bulk density measurement, scanning electron microscopy (SEM), iodine number determination, and methylene blue adsorption studies. Results revealed that coconut shell-derived activated carbon exhibited superior characteristics with the highest BET surface area (1000.15 m^2/g), optimal fixed carbon content (88.92 %), and maximum methylene blue removal efficiency (96%). SEM analysis confirmed well-developed porous structures across all samples, with distinct morphological variations based on precursor materials. Bulk density varied significantly among samples, ranging from 0.121 g/cc (rice husk) to 1.562 g/cc (groundnut shell). Notably, sugarcane waste-derived activated carbon showed the highest iodine number (1593 mg/g), indicating excellent microporosity. The methylene blue adsorption capacity followed the order: coconut shell (80 mg/g-Lt) > groundnut shell (76.5 mg/g-Lt) > sugarcane waste (69.17 mg/g-Lt) > corn cob (64.7 mg/g-Lt) > rice husk (51.67 mg/g-Lt). This study demonstrates that agricultural waste materials can be effectively converted into high-performance activated carbons for water treatment applications, with coconut shell emerging as the most promising precursor among the studied materials.

Keywords: Bio-char, activated carbon, coconut shell, husk, energy & agricultural

1. Introduction
The global surge in agricultural production generates vast quantities of biomass waste, presenting both environmental challenges and untapped opportunities for sustainable material development. Annually, billions of tons of agricultural residues, including coconut shells, rice husks, corn cobs, sugarcane bagasse, and groundnut shells, are either discarded or burned, contributing to environmental degradation and greenhouse gas emissions (Ukanwa *et al*., 2019). Converting these abundant waste materials into value-added products, particularly activated carbon, represents a promising strategy for waste valorisation while addressing critical environmental challenges (Wu *et al*., 2020) [30]. Activated carbon, with its exceptional surface properties and versatile applications, has emerged as a crucial material in environmental remediation, particularly in water treatment applications (Kosheleva *et al*., 2019) [8].

The rapid industrialization accompanying population growth has led to increased discharge of pollutants into aquatic ecosystems (Sosa *et al*., 2023) [25]. Industries such as textile, food, cosmetics, and paper manufacturing are significant contributors to dye-containing effluents, presenting an urgent environmental challenge (Lotfy & Roubik, 2023) [11]. These organic dyes not only alter water colour but also impede sunlight penetration, severely impacting aquatic ecosystems and endangering both flora and fauna through toxic chemical exposure (Sosa *et al*., 2023) [25].

Researchers have explored various treatment methodologies, including sedimentation with clarification, coagulation-flocculation, chemical oxidation, membrane filtration, adsorption, and biodegradation.

Among these, adsorption technology has emerged as a particularly effective approach for dye removal. While methylene blue, a commonly used industrial dye, poses significant environmental concerns, earlier studies have investigated cost-effective adsorbents including coir pith, sawdust, fruit shells, banana pith, peanut hulls, and wheat bran (Rao & Rathod, 2019) [22]. However, activated carbon has garnered significant attention due to its superior adsorption capabilities.

Activated carbon's effectiveness stems from its unique carbonaceous structure, characterized by a highly crystalline form and extensively developed internal pore network. The activation process creates sophisticated pore structures with specific surface chemistries, resulting in enhanced surface area, porosity, and mechanical strength (Karic *et al*., 2022) [7]. The material's adsorption efficiency is determined by the relationship between the target molecule size and the adsorbent's pore dimensions (Jaria *et al*., 2022) [6]. Agricultural byproducts rich in carbon content serve as economical precursors for activated carbon synthesis. Available materials include wheat husk, straw, palm fiber, rubber wood sawdust, bamboo dust, date pits, coconut shell, groundnut shell, sugarcane waste, oil cake, and corn cob. These derived activated carbons find applications in hazardous contaminant removal, municipal and industrial wastewater treatment, catalysis, medical applications, and valuable metal recovery (Blasi *et al*., 2023; Ufitikirezi *et al*., 2024) [3, 27]

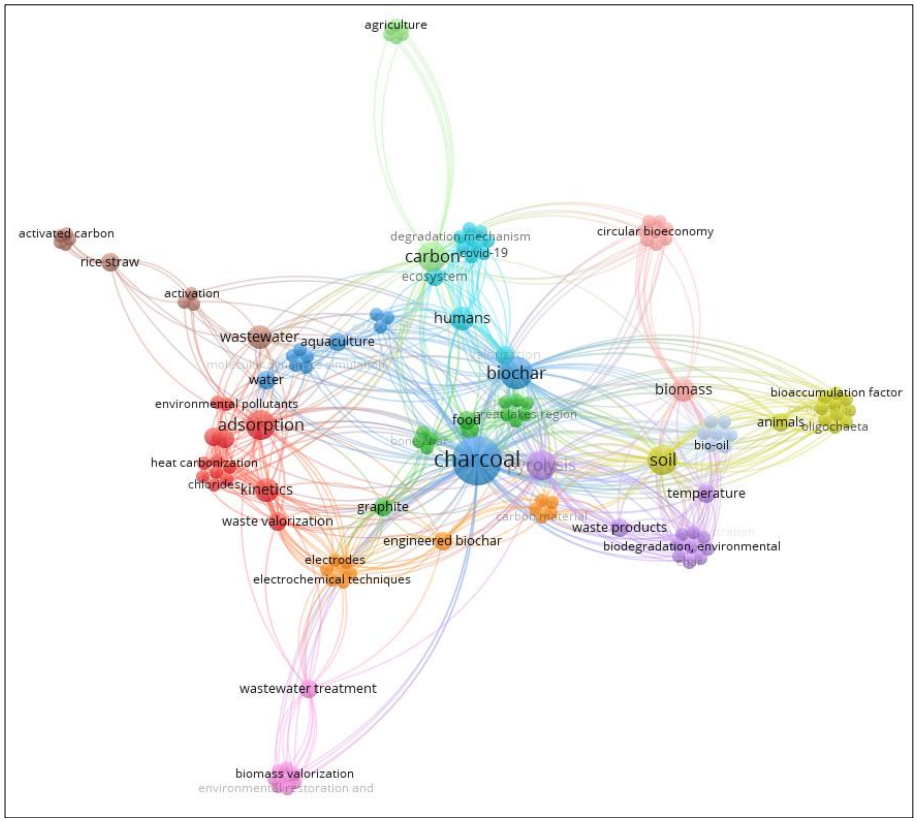

Fig 1: Network Visualization of Author Keywords

This comprehensive study investigates the transformation of five distinct agricultural wastes into high-performance activated carbons, examining their material properties and effectiveness in environmental applications, specifically focusing on dye removal from industrial effluents. Fig. 1.1 illustrates the author keywords collected for the respective research work in the form of network visualization. This approach not only provides a sustainable solution for agricultural waste management but also contributes to the circular economy by creating valuable materials for environmental protection.

2. Materials and Methods

This study was conducted in 2024 at the Department of Agricultural Engineering, Aditya University, Surampalem, Andhra Pradesh, India (latitude: 17.081386, longitude: 82.057058). The raw materials were procured from the nearby village of Surampalem. The raw materials used in this project included activated carbon derived from coconut shells, rice husks, corn cobs, groundnut shells, and sugarcane waste. The chemicals utilized during this study were hydrochloric acid, sodium thiosulfate, iodine solution, starch, 1N sulfuric acid, and 1N sodium hydroxide. The following instruments were employed; i. *Muffle Furnace:* Used to heat materials to high temperatures while isolating them from external contaminants (Oyekanmi, *et al*., 2022). ii. *Tray Dryer*: An enclosed, insulated chamber with stainless steel trays used for drying materials (Escudero-Curiel *et al*., 2023) [4]. iii. *Weighing Machine*: A precision instrument for measuring mass. iv. *BET Surface Area Analyzer*: Utilized to measure the surface area of porous materials based on gas adsorption principles. v. *Digital pH Meter*: Employed to measure the acidity or alkalinity of solutions. vi. *Mercury Porosimeter:* Used to determine the porosity and pore volume of materials by measuring mercury intrusion (Tiwari *et al*., 2022) [26]. vii. *Scanning Electron Microscope* (SEM): Provides detailed images of the sample's surface morphology and porous structure. viii. *UV-Visible Spectrophotometer*: Used to analyse the chemical structure of substances by measuring light

absorbance in the UV and visible spectra (Blanchard & Mekonnen, 2024) [2].

2.1 Proximate Analysis

Proximate analysis was conducted to determine the moisture content, ash content, volatile matter, and fixed carbon content of the activated carbon samples, following ASTM D121 standards. i. *Moisture Content*: A known weight of the activated carbon sample was heated at 105–110°C for 1.5 hours. After cooling in a desiccator, the weight loss was used to calculate the moisture content. ii. *Ash Content*: Approximately 1 gram of the sample was heated in a muffle furnace at 750°C for 1.5 hours. The residue remaining after heating was weighed to determine the ash content (Silva *et al*., 2024) [24]. iii. *Volatile Matter Content*: A known quantity of the sample was heated to 925°C for 7 minutes in a muffle furnace. The weight loss during this process was used to calculate the volatile matter content. iv. *Fixed Carbon Content*: Fixed carbon content represents the proportion of solid carbon present in a material after volatile matter and moisture have been removed during combustion (Blasi *et al*., 2024; Muhammad *et al*., 2022; and Lou *et al*., 2023) [12, 15]. It is a crucial parameter in evaluating the quality of activated carbon and other carbonaceous materials, as it directly influences their adsorption capacity and combustion efficiency.

Fixed carbon (FC) = 100 – (moisture content (%) + volatile matter (%) + ash content (%))

2.2 Iodine Number

The iodine number, indicating the micro-pore content of the activated carbon, was determined following ASTM D4607–94 (2006). A sample of activated carbon was treated with hydrochloric acid, boiled, cooled, and then mixed with a 0.1N iodine solution. After shaking and filtering, the filtrate was titrated with 0.1N sodium thiosulfate to determine the iodine adsorption capacity (Capanoglu *et al*., 2022) [4].

2.3 Methylene Blue Number

To assess the ability of activated carbon to adsorb high molecular weight substances, 50 ml of a 200ppm methylene blue solution was shaken with 0.1 g of activated carbon for 30 minutes (Sharma *et al*., 2022) [23]. The mixture was then filtered, and the filtrate's absorbance was measured using a UV-Visible spectrophotometer to determine the methylene blue number.

2.4 Adsorption Capacity Comparison

A 100 ml solution of methylene blue (50 ppm) was adjusted to pH 5 using 1N sulfuric acid or 1N sodium hydroxide as needed. Then, 0.6 g of activated carbon was added, and the mixture was shaken for 60 minutes. Afterward, the solution's absorbance was measured using a UV-Visible spectrophotometer to determine the final concentration. The percentage removal of methylene blue was calculated, and this procedure was repeated for each type of activated carbon to compare their adsorption capacities (Guardia *et al*., 2018; Vishnu Priyan *et al*., 2024) [29].

3. Results and Discussion

3.1 Bulk density

It provides a bird eye view regarding the floatability property of the adsorbent

(Fig. 3.1). It suggests that if the activated carbon is added to water, it will sink and that with result in better contact with the adsorbate and thereby leading to effective adsorption process. Similar results were obtained by El-Hout *et al*., in the year 2022.

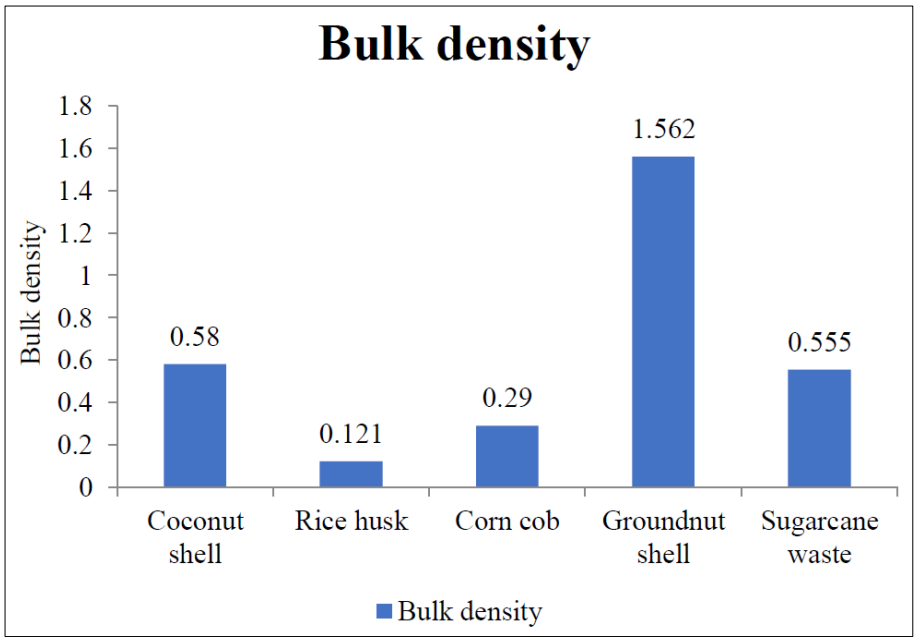

Fig 2: Bulk density of different types of activated carbon

3.2 SEM images of coconut shell activated carbon:

SEM images for coconut shell, corn hub and sugarcane waste at X250 and X500 zoom are discussed below. Scanning electron microscope images were taken to observe the surface topography of the sample (Jaria *et al*., 2022; Oyekanmi *et al*., 2022; Blasi *et al*., 2023) [6, 3]. Basically, the pore structures of the activated carbons were observed. The micrographs of the activated carbon are shown in plates 1, 2, 3, 4 and 5.

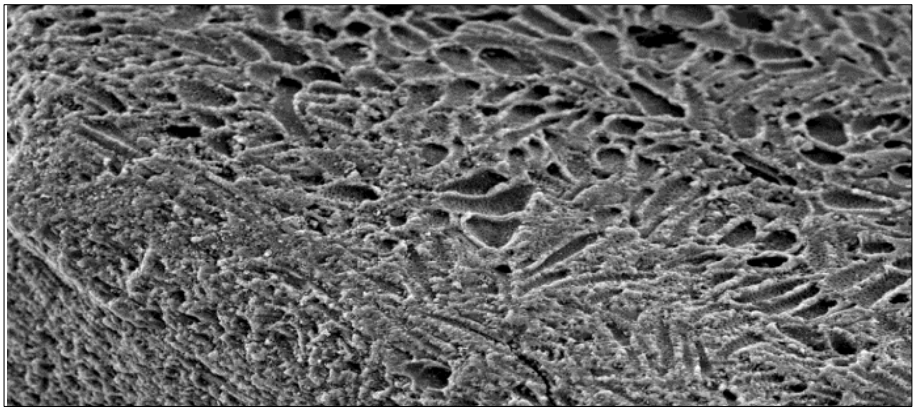

Plate 1: SEM image of activated carbon of coconut shell at X250 zoom

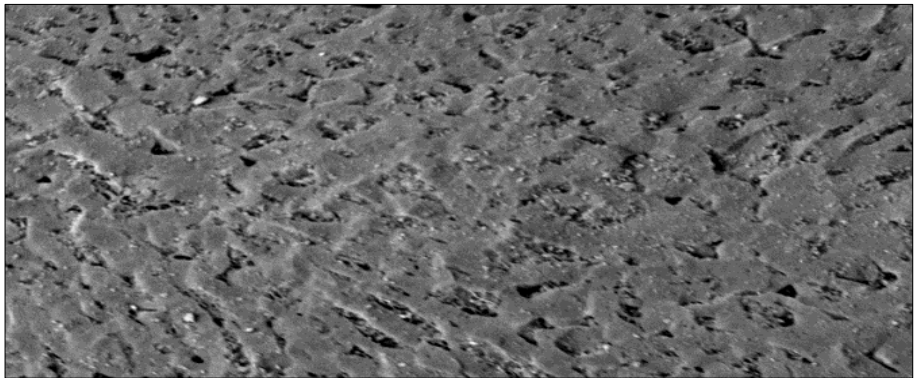

Plate 2: SEM image of activated carbon of coconut shell at X500 zoom

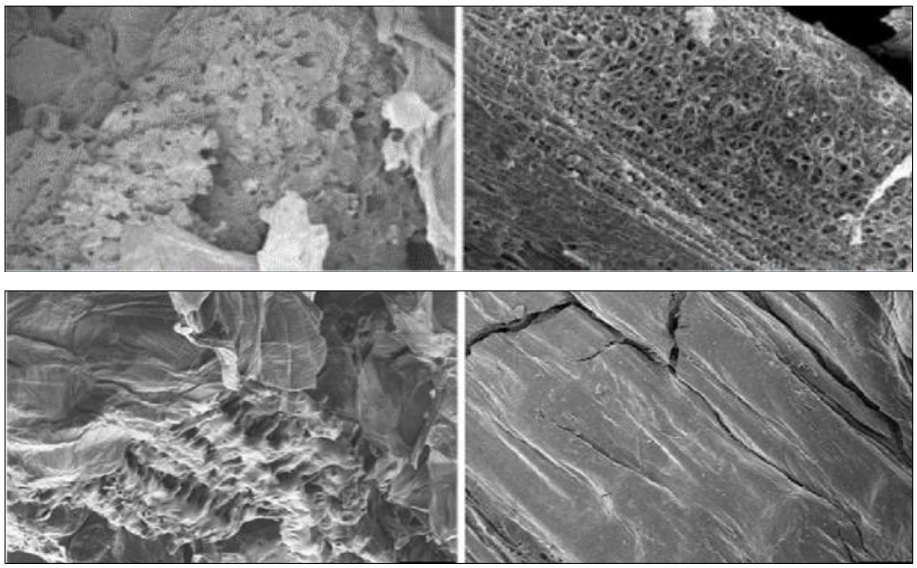

Plate 3: SEM image of activated carbon of corn cob at X500 zoom

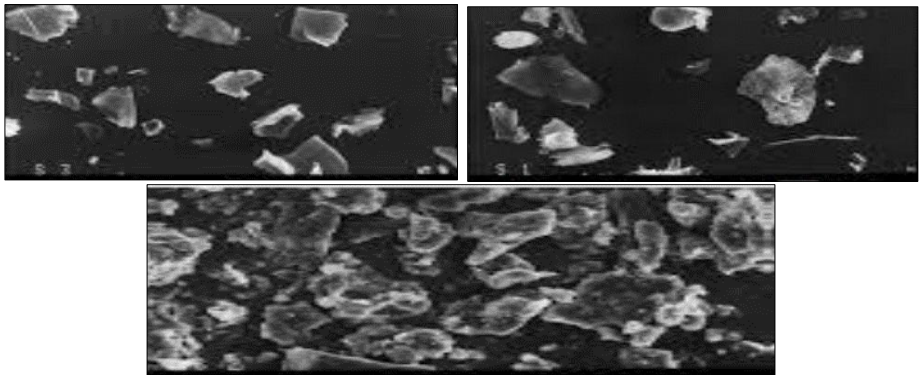

Plate 4: SEM image of activated carbon of sugarcane at X388 zoom

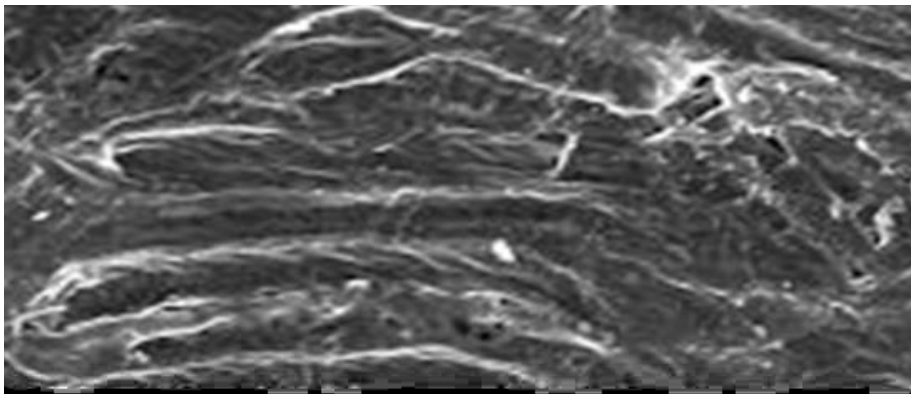

Plate 5: SEM image of activated carbon of groundnut at X500 zoom

3.3 Proximate analysis

According to ASTM D 121, proximate analysis is the determination of moisture content, ash content, volatile matter, and fixed carbon content by prescribed methods. The proximate analysis of the different type of activated carbon was done and data are represented in Fig. 3.2.

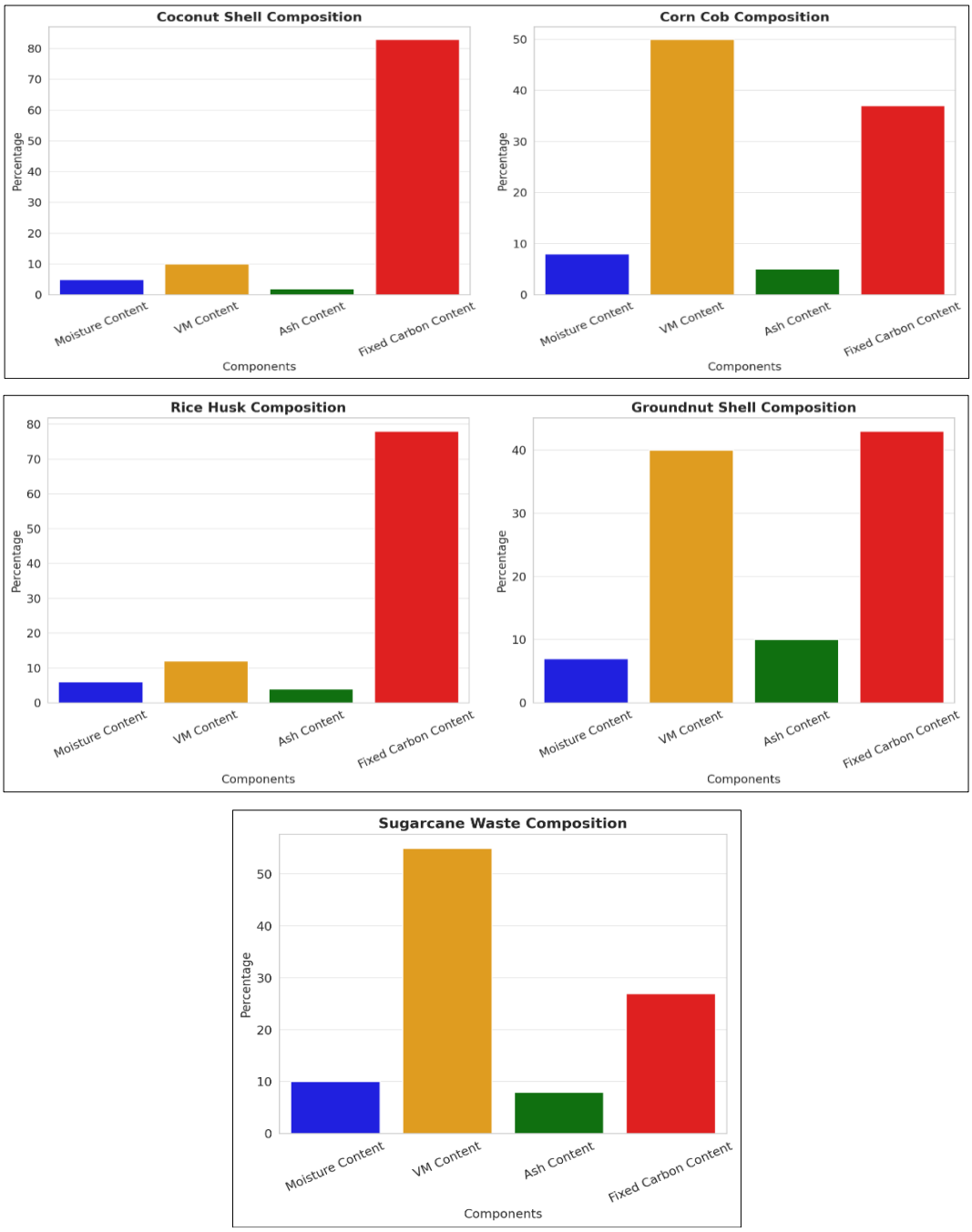

Fig 3: Pie chart representing coconut shell data

It helps us to assess the amount of moisture, volatility and ash content with the residual carbon available in the sample. It shows that the moisture content of activated carbon prepared from coconut shell is high while the volatile and ash content are the least. Due to its high fixed carbon, it is preferred adsorbent with respect to other four.

3.4 Iodine Number

The iodine number represents the amount of iodine, in milligrams, that one gram of activated carbon can absorb from a 0.1N iodine solution when the equilibrium concentration reaches 0.02N. It serves as an indicator of the micro-pore volume within the activated carbon. A higher iodine number suggests greater micro-porosity in the material.

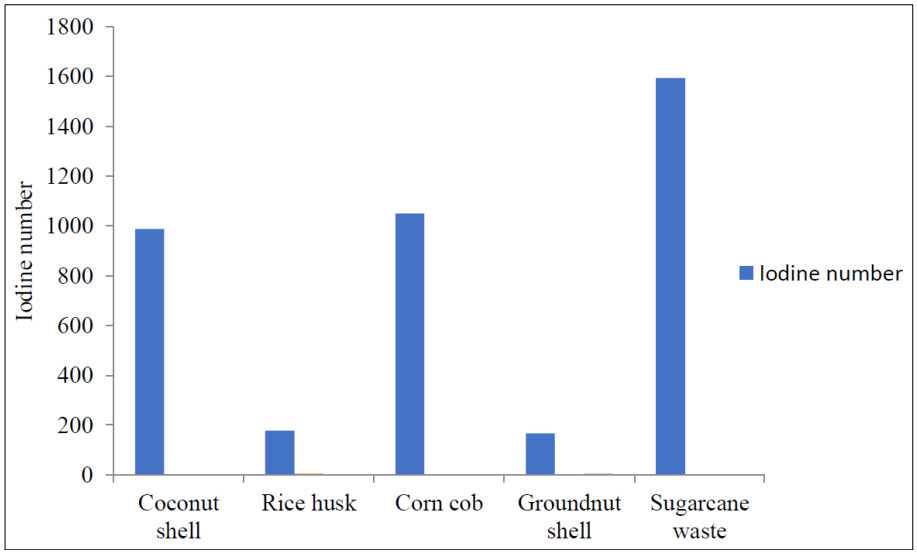

Fig 4: Iodine Number for different bio-materials

From Fig. 3.3, it is observed that the iodine number of activated carbons of sugarcane was highest among the selected commodities. It signifies that sugarcane waste has more micro pores. Due to high pores, it acts as better adsorbent for adsorption process (Yap *et al*., 2023) [32].

3.5 Compilation of characteristics of three type activated carbon

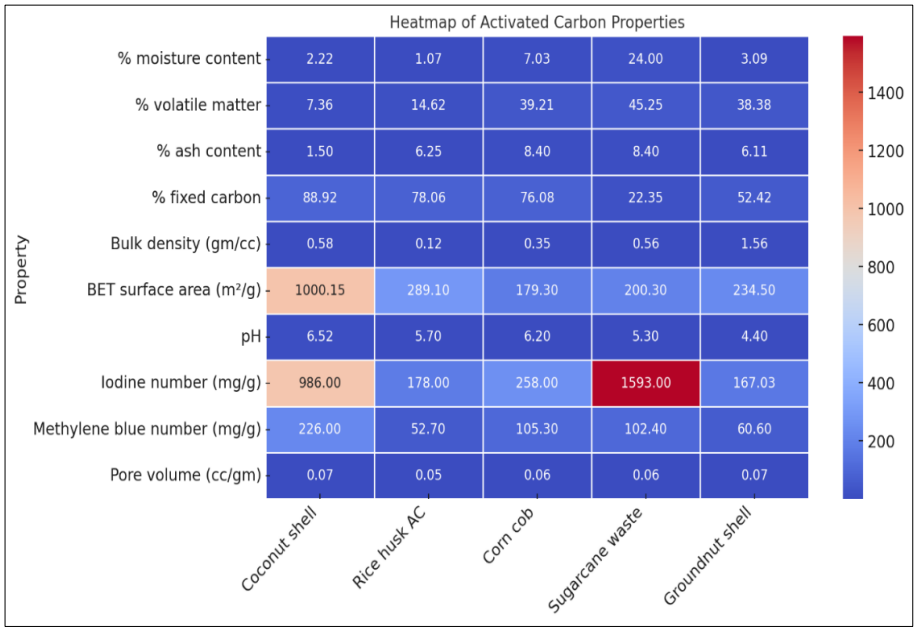

Fig 5: Properties of different types of Bio-Materials

From Fig. 5., it is known that the ash is non-carbon or mineral additives, that does not combine chemically with the carbon surface. It consists of various undesired mineral substances, which become more concentrate on activation and comprises of 1-20 % and primarily depends on the type of raw material.

A high ash content in activated carbon is undesirable as it weakens its mechanical strength and diminishes its adsorption capacity. The iodine adsorption method, commonly referred to as the iodine number, is a quick and effective way to assess the adsorptive ability of activated carbon. Studies have shown that activated carbon derived

from sugarcane waste exhibits the highest iodine number, indicating a greater surface area (Adeniyi *et al*., 2023) [1].
Similarly, methylene blue value helps us to determine the surface area and the pore size distribution of activated carbon. The methylene blue value represents the adsorptive capacity of activated carbon for molecules with dimension like methylene blue and the surface area which results from the presence of pore sizes greater than 1.5 nm (Mollaei *et al*., 2024) [14]. The methylene blue value for coconut shell activated carbon was maximum with respect to rice husk and oil cake activated carbons.

3.6 Adsorption capacity of each activated carbon:

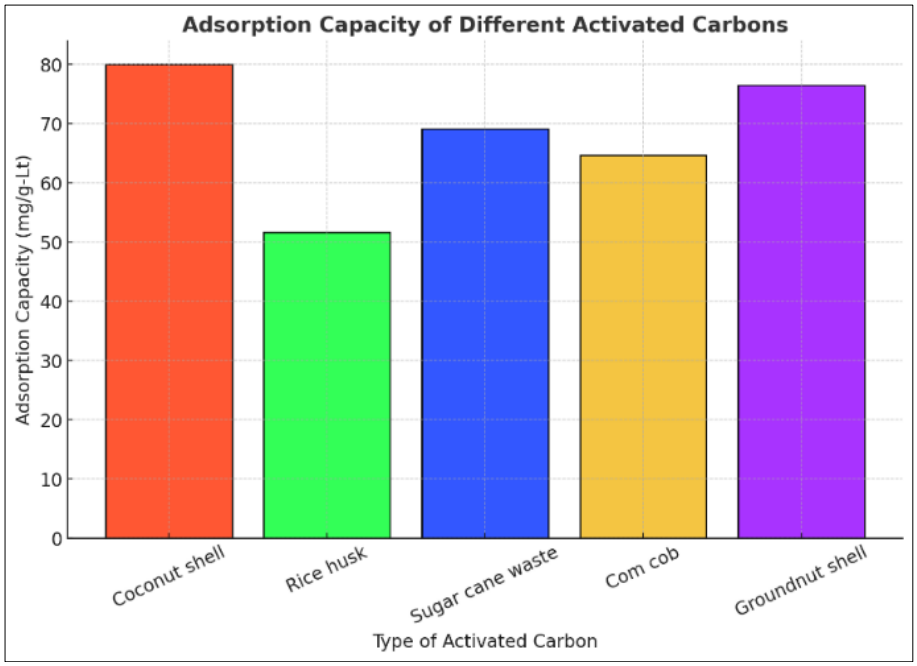

Fig 6: Absorption capacity of various activated carbon

From the above Fig. 6, it is observed that the adsorption capacity of activated carbon of coconut shell is better than the other two. Also, groundnut shell is high holding absorption capacity (mm/g-Lt). Similar trend was found by Mollaei *et al*., in the year 2024 [14].

4. Conclusion

This study involved multiple characterization techniques, including proximate analysis, bulk density measurement, BET surface area analysis, pH determination, pore volume estimation, iodine number testing, and methylene blue number testing. These were followed by an adsorption experiment to identify the most effective adsorbent. Finally, the SEM analysis of the best-performing adsorbent was conducted to examine its pore structure.
Proximate analysis provided insights into the physical properties of the activated carbon samples. The results revealed that coconut shell-based activated carbon had the highest fixed carbon content among the five materials. It also exhibited higher moisture content but lower volatile and ash content, making it a superior adsorbent. Bulk density measurements indicated that groundnut shell-based activated carbon had the highest density, suggesting better flow consistency and packaging potential for solid fuel applications. The experimental findings showed that the BET surface area of coconut shell-based activated carbon was 1000.15 m^2/g, the highest among all samples. The iodine number test further supported this, revealing an iodine number of 986 mg/g. Since the iodine number is directly proportional to micro-porosity, this result confirms that coconut shell-based activated carbon possesses superior microporosity compared to the other four materials. Additionally, it had the highest pore volume, further enhancing its adsorption capacity.
The methylene blue number test indicated that coconut shell-based activated carbon had the highest methylene blue number (226 mg/g), reinforcing its effectiveness in dye adsorption. The adsorption experiment confirmed that it outperformed rice husk, corn cob, sugarcane waste, and groundnut shell in removing methylene blue dye. Given these favourable results, coconut shell-based activated carbon was identified as the most effective adsorbent. Subsequently, SEM analysis was conducted to observe its pore structure, further validating its superior adsorption potential.

5. References

1. Adeniyi AG, Iwuozor KO, Emenike EC, Sagboye PA, Micheal KT, Micheal TT, *et al*. Biomass-derived activated carbon monoliths: A review of production routes, performance, and commercialization potential. Journal of Cleaner Production. 2023;423:138711.
2. Blanchard R, Mekonnen TH. Valorization of plastic waste via chemical activation and carbonization into activated carbon for functional material applications. RSC Applied Polymers. 2024;2(4):557-82.
3. Blasi A, Verardi A, Lopresto CG, Siciliano S, Sangiorgio P. Lignocellulosic agricultural waste valorization to obtain valuable products: An overview. Recycling. 2023;8(4):61.
4. Capanoglu E, Nemli E, Tomas-Barberan F. Novel approaches in the valorization of agricultural wastes and their applications. Journal of Agricultural and Food Chemistry. 2022;70(23):6787-804.

5. Escudero-Curiel S, Giraldez A, Pazos M, Sanroman A. From waste to resource: Valorization of lignocellulosic agri-food residues through engineered *hydrochar* and *biochar* for environmental and clean energy applications—a comprehensive review. Foods. 2023;12(19):3646.
6. Jaria G, Calisto V, Esteves VI, Otero M. Overview of relevant economic and environmental aspects of waste-based activated carbons aimed at adsorptive water treatments. Journal of Cleaner Production. 2022;344:130984.
7. Karic N, Maia AS, Teodorovic A, Atanasova N, Langergraber G, Crini G, *et al*. Bio-waste valorisation: Agricultural wastes as *biosorbents* for removal of (in)organic pollutants in wastewater treatment. Chemical Engineering Journal Advances. 2022;9:100239.
8. Kosheleva RI, Mitropoulos AC, Kyzas GZ. Synthesis of activated carbon from food waste. Environmental Chemistry Letters. 2019;17:429-38.
9. Kumar V, Kumaran A. Removal of *methylene blue* by mango seed kernel powder. Biochemical Engineering Journal. 2005;27:83-93.
10. Laine J, Calafat A, Labady M. Preparation and characterization of activated carbons from coconut shell impregnated with *phosphoric acid*. Carbon. 1989;27:191-5.
11. Lotfy HR, Roubik H. Water purification using activated carbon prepared from agriculture waste—Overview of a recent development. Biomass Conversion and Biorefinery. 2023;13(17):15577-90.
12. Lou J, Babadi MR, Otadi M, Tarahomi M, Van Le Q, Khonakdar HA, *et al*. Agricultural waste valorization towards (nano)*catalysts* to produce chemicals and materials. Fuel. 2023;351:128935.
13. Nourouzi MM, Chuah TSG. Adsorption of reactive dyes by palm kernel shell activated carbon: Application of film surface and film pore diffusion models. E-Journal of Chemistry. 2009;6(4):949-54.
14. Mollaei M, Karbasi F, Haddad AS, Baniasadi H. Fabrication of *biocomposite* materials with *polycaprolactone* and activated carbon extracted from agricultural waste. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2024;702:135175.
15. Muhammad S, Abdul Khalil HPS, Abd Hamid S, Albadn YM, Suriani AB, Kamaruzzaman S, *et al*. Insights into agricultural-waste-based nano-activated carbon fabrication and modifications for wastewater treatment application. Agriculture. 2022;12(10):1737.
16. Kannan N, Sundaram MM. Kinetics and mechanism of removal of *methylene blue* by adsorption on various carbons—a comparative study. Dyes and Pigments. 2001;51(1):25-40.
17. Otaru AJ, Amah CU, Abdelkarim AS, Odigure JO, Okafor JO. Development and characterization of adsorbent from rice husk ash to bleach vegetable oils. Journal of Applied Chemistry. 2013;4:42-9.
18. Othmani A, Magdouli S, Kumar PS, Kapoor A, Chellam PV, Gokkuş O. Agricultural waste materials for adsorptive removal of *phenols*, *chromium (VI)*, and *cadmium (II)* from wastewater: A review. Environmental Research. 2022;204:111916.
19. Mallick PK. Dye removal from wastewater using activated carbon developed from *sawdust*: Adsorption equilibrium and kinetics. Journal of Hazardous Materials. 2001;113(1-3):81-88.
20. Piccirillo C. Preparation, characterisation, and applications of *bone char*, a food waste-derived sustainable material: A review. Journal of Environmental Management. 2023;339:117896.
21. Malik R, Ramteke DS, Wate SR. Physicochemical and surface characterization of adsorbent prepared from *groundnut shell* by $ZnCl_2$ activation and its ability to adsorb color. Indian Journal of Chemical Technology. 2006;13:319-28.
22. Rao P, Rathod V. Valorization of food and agricultural waste: A step towards a greener future. The Chemical Record. 2019;19(9):1858-71.
23. Sharma G, Sharma S, Kumar A, Lai CW, Naushad M, Shehnaz, *et al*. Activated carbon as a super adsorbent and sustainable material for diverse applications. Adsorption Science & Technology. 2022;2022:4184809.
24. Silva KF, Brazil TR, Giroto AS, Valente GT, Domingues RA, Goncalves M. Activated carbon from agricultural industry waste for use as an adsorbent of *sulfamethazine*: Fascinating and environmentally friendly process. Biomass and Bioenergy. 2024;190:107388.
25. Sosa JA, Laines JR, García DS, Hernández R, Zappi M, de los Monteros AEE. Environmental Engineering Research. 2023;28(3).
26. Tiwari SK, Bystrzejewski M, De Adhikari A, Huczko A, Wang N. Methods for the conversion of biomass waste into value-added *carbon nanomaterials*: Recent progress and applications. Progress in Energy and Combustion Science. 2022;92:101023.
27. Ufitikirezi JD, Filip M, Ghorbani M, Zoubek T, Olsan P, Bumbalek R, *et al*. Agricultural waste valorisation: Exploring environmentally friendly approaches to *bioenergy* conversion. Sustainability. 2024;16(9):3617.
28. Vadiyelan V, Kumar KV. Equilibrium, kinetics, mechanism, and process design for the absorption of *methylene blue* onto *rice husk*. Journal of Colloid and Interface Science. 2005;286:90-100.
29. Vishnu Priyan V, Sathasivam J, Kumar A. Valorisation of agricultural waste into a low-cost adsorbent: Perspective. Agricultural Waste to Value-Added Products: Bioproducts and Its Applications. 2024;125.
30. Wu HY, Chen SS, Liao W, Wang W, Jang MF, Chen WH, *et al*. Assessment of agricultural waste-derived activated carbon in multiple applications. Environmental Research. 2020;191:110176.
31. Yak SM, Sharf. Characterization of activated carbon prepared by *phosphoric acid* activation of *olive stones*. Arabian Journal of Chemistry. 2011;4(4):210-6.
32. Yap YW, Mahmed N, Norizan MN, Abd Rahim SZ, Ahmad Salimi MN, Abdul Razak K, *et al*. Recent advances in the synthesis of *graphite* from agricultural bio-waste material: A review. Materials. 2023;16(9):3601.