

Research Article

Comparative Analysis of Activated Carbon Derived from Coconut Shell and Oil Palm Biomass at Various Carbonization Temperatures

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ABSTRACT

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This study compared the optimal conditions for producing activated carbon from coconut shell and oil palm biomass via chemical activation using 70% H₂SO₄. Carbonization was conducted at 400, 500, and 600 °C for 2 h. At 600 °C, partial combustion occurred in both precursors, leading to ash formation, whereas no such effects were observed at 400 °C and 500 °C. Therefore, activated carbons obtained at 400 °C and 500 °C were further characterized using Fourier Transform Infrared (FTIR) Spectroscopy, Scanning Electron Microscopy (SEM), and Brunauer–Emmett–Teller (BET) surface area analysis. FTIR spectra of both coconut shell and palm-derived samples showed broad O–H stretching bands around 3440–3450 cm⁻¹ and peaks at 1610–1630 cm⁻¹ corresponding to C=O and C=C stretching vibrations. Notably, the palm-based sample carbonized at 500 °C displayed slight variations in its FTIR spectra compared with the other three conditions. Consistently, SEM images revealed that the P500 sample exhibited distinct surface morphologies compared with the others. BET analysis further indicated that the specific surface areas of C400, C500, P400, and P500 were 342.82, 322.67, 196.93, and 208.13 m²/g, respectively, demonstrating that coconut shell-derived carbons developed substantially higher surface areas than palm-based carbons. The high surface areas and well-developed porosity of these activated carbons suggest their suitability for applications in wastewater treatment, heavy metal and organic pollutant adsorption, and potential use as adsorbents in catalysis or separation processes.

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1. Introduction

Activated carbon (AC), characterized by its high porosity, has been extensively applied in fields such as water purification, gas adsorption, and chemical recovery, owing to its large surface area, strong adsorption capacity, and chemical stability (Ioannidou and Zabaniotou, 2007). Growing environmental concerns and the demand for sustainable production have, in recent years, driven increasing attention toward the use of agricultural waste as a precursor for activated carbon production. Among the different agricultural residues, coconut shells and oil palm biomass especially empty fruit bunches

(EFB) and palm kernel shells (PKS) have been highlighted as promising precursors because of their richness in carbon, low ash levels, and wide availability in tropical regions (Tan *et al.*, 2015). These materials, often considered waste, present a valuable and renewable source for producing high-quality activated carbon through physical or chemical activation methods. AC derived from coconut shells is well known for its hardness and microporous structure, making it ideal for gas-phase adsorption applications. On the other hand, oil palm waste offers a cost-effective and sustainable alternative due to its availability in large volumes, particularly in palm oil-producing countries such as Indonesia, Malaysia, and Thailand (Ahmed *et*

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et al., 2016). The utilization of these wastes not only enhances the economic value of agricultural residues but also represents a sustainable approach to waste management and environmental preservation.

A comprehensive review of coconut-derived biomass highlights that coconut shell possesses a well-defined lignocellulosic structure, consisting predominantly of lignin, cellulose, and hemicellulose in proportions that differ markedly from those of coconut husk and other agricultural residues. Proximate and ultimate analyses consistently report that coconut shell contains relatively low moisture and ash contents, coupled with high levels of volatile matter and substantial fixed carbon. Its elemental composition further reveals a notably high carbon fraction, typically around 52.6 wt%, which is considerably higher than that of many comparable biomass feedstocks. This combination of physicochemical characteristics particularly the elevated fixed-carbon content, structural rigidity associated with high lignin content, and low inorganic impurities collectively contributes to the superior thermal stability and carbon yield of coconut shell during thermochemical conversion processes. Consequently, coconut shell is widely recognized as an excellent and efficient precursor for the production of biochar and activated carbon, offering favourable textural development, enhanced porosity, and improved adsorption performance in various environmental and industrial applications (Ajien *et al.*, 2023). In contrast, studies on palm derived biomass, particularly palm kernel shell a major byproduct of the palm oil industry emphasize its widespread availability and low production cost, which make it an economically attractive feedstock for valorization. Chemical analyses reveal that palm kernel shell possesses a favourable composition, characterized by relatively high carbon content and low ash levels, alongside moderate volatile matter and fixed carbon fractions. These intrinsic properties not only enhance its thermal stability during pyrolysis but also promote the development of porous structures during activation processes. As a result, palm kernel shell has gained considerable attention as a sustainable and efficient precursor for the production of activated carbon, offering promising potential for applications in adsorption, catalysis, and environmental remediation (Herawan *et al.*, 2013).

The escalating global demand for sustainable materials has intensified interest in converting agricultural residues into value-added products. Traditionally derived from coal, the production of AC from renewable biomass sources, particularly coconut shells and oil palm residues, has gained prominence due to their abundance in tropical regions and favourable physicochemical properties. Coconut shells and oil palm residues are rich in carbon content and exhibit low ash formation, making them ideal precursors for AC production. Recent studies have demonstrated the efficacy of chemical activation methods, employing agents like phosphoric acid (H_3PO_4), potassium hydroxide (KOH), and zinc chloride (ZnCl_2), in enhancing the

surface area and porosity of AC derived from these biomasses. Some studies report that sulfuric acid (H_2SO_4) is highly reactive, facilitating the dehydration of carbohydrates and the breakdown of organic precursors during chemical activation to produce carbon. In addition, H_2SO_4 promotes the removal of mineral matter (ash) from lignocellulosic biomass, effectively acting as a de-ashing agent and thereby enhancing the quality and purity of the resulting carbon material (Kundu *et al.*, 2024). For instance, research (Chew *et al.*, 2023) highlighted the potential of various activating agents in optimizing the properties of AC produced from agricultural residues. The optimization of AC production involves adjusting parameters such as impregnation ratio, activation temperature, and activation time to achieve desired characteristics. Studies have shown that these parameters significantly influence the yield and quality of AC. For example (Lee *et al.*, 2023) investigated the effects of activation conditions on the surface properties of AC derived from palm kernel shells, emphasizing the importance of process optimization.

This study aims to conduct a comprehensive comparative analysis of AC production from coconut shells and oil palm residues using chemical activation by optimizing key parameters, the research seeks to identify the most effective precursor and activation conditions, thereby contributing to the sustainable utilization of agricultural residues and the advancement of environmental remediation technologies.

AC derived from biomass is typically obtained through a carbonization step, in which the raw material undergoes thermal decomposition at elevated temperatures. During this process, activating agents may be applied to generate a porous structure, thereby increasing the surface area and adsorption capability of the carbon. In general, two principal activation approaches are employed: (i) physical activation and (ii) chemical activation (Siipola *et al.*, 2018). The resulting material exhibits high adsorption efficiency, making it suitable for the removal of impurities and hazardous contaminants.

Activated carbon is commonly available in powdered, granular, and pellet forms, with the selection depending on the specific application. It has been widely employed across various industries, such as decolorization in the sugar industry, odor removal in beverage, beer, and wine production, and solvent purification for reuse in synthetic fiber and printing industries (Nilufur *et al.*, 2023). In water treatment, AC is utilized for color and odor removal in municipal water supplies, in household and industrial purification systems, as well as in wastewater treatment. It is also applied in air purification systems and as a key material in protective gas masks. More recently, producers have introduced innovative consumer products, such as aesthetically designed air fresheners for use in cars and refrigerators, reflecting the growing diversity of activated carbon applications (Scholz, 2023).

2. Materials and Methods

2.1 Materials

Coconut shells were obtained from market in Mueang District, Narathiwat Province, while oil palm biomass was collected from a palm plantation at the Faculty of Agriculture, Princess of Naradhiwas University. The raw materials were washed thoroughly with distilled water to remove adhering dirt and soluble impurities, followed by oven-drying at 110 ± 2 °C for 24 h to reduce their moisture. The dried materials were subsequently ground and sieved to obtain particle sizes of <2 mm prior to further processing. Sulphuric acid (H_2SO_4) was purchased from QRec and employed as activating agent in chemical activation. Deionized water was used for washing during sample preparation and post-activation neutralization.

2.2 Carbonization process

The physicochemical properties of the activated carbons were evaluated using standard characterization techniques. Coconut shell and palm kernel shell precursors were first washed, dried, and ground to a uniform particle size before chemical activation. The activation was performed using H_2SO_4 at a predetermined impregnation ratio. The carbonization process was carried out in a tubular furnace under a continuous nitrogen (N_2) flow to maintain an inert atmosphere and prevent oxidation. The samples were heated at a controlled rate of 10 °C/min to the target temperatures of 400 °C and 500 °C and held for 1 h to ensure complete carbonization. After cooling to room temperature under N_2 , the activated carbons were washed thoroughly with deionized water to remove residual chemicals and dried at 105 °C.

Surface area and porosity were determined using nitrogen adsorption–desorption isotherms and calculated via the Brunauer–Emmett–Teller (BET) method (Micromeritics ASAP 2460). The surface morphology was examined using Scanning Electron Microscopy (SEM; Model: SEM-Apreo), while functional groups were identified by Fourier Transform Infrared Spectroscopy (FTIR; Model: INVENIO S, Bruker) over the range of 400–4000 cm^{-1} . These analyses collectively provided comprehensive insights into the structural, textural, and chemical properties of the produced activated carbons.

2.3 Chemical activation

The carbonized materials were impregnated with the selected activating agents (H_2SO_4). The mixtures were stirred at room temperature for 12 h to ensure uniform penetration of the activating agent. After impregnation, the samples were dried at 110 °C for 24 h. Activation was performed in a tubular furnace under a continuous nitrogen flow of 100 mL/min. The impregnated samples were heated at activation temperatures ranging 400, 500 600 °C with a holding time of 60 min. The activated carbon obtained was cooled, thoroughly washed with hot distilled water until the pH of the filtrate was approximately neutral, and then oven-dried at 110 °C for 12 h.

2.4 Characterization of activated carbon

The physicochemical properties of the activated carbons were evaluated using standard characterization techniques. Surface area and porosity were assessed via nitrogen adsorption–desorption isotherms using the BET method (Micromeritics ASAP 2460). The surface morphology of the samples was examined by SEM, while functional groups were identified through FTIS over the range of 400–4000 cm^{-1} .

3. Results and Discussion

Activated carbon were synthesized from coconut shell and oil palm biomass through chemical activation using 70% H_2SO_4 . The carbonization process was performed at three different temperatures: 400, 500, and 600 °C. At 600 °C, partial combustion occurred in both raw materials, leading to significant ash formation. Therefore, the activated carbon obtained at 400 °C and 500 °C were selected for further characterization using FTIR spectroscopy, SEM, and BET surface area analysis.

To facilitate discussion, the samples were designated with abbreviated codes according to their raw material and activation temperature. Coconut shell-derived carbons are denoted as C, while oil palm-derived carbons are denoted as P. The numbers following the abbreviations indicate the carbonization temperature (°C). The sample codes are summarized in Table 1.

Table 1 Sample code from coconut shell and oil palm.

Raw material	T (°C)	Sample code
Coconut shell	400	C400
	500	C500
Oil palm	400	P400
	500	P500

3.1 FTIR spectroscopy

The FTIR spectra of the activated carbon samples revealed the presence of characteristic functional groups on the carbon surface. A broad band observed at 3450–3440 cm^{-1} corresponded to O–H stretching vibrations of hydroxyl groups, which may originate from alcohols, phenols, or adsorbed water. Additionally, the band at approximately 1630–1610 cm^{-1} was assigned to C=C stretching vibrations of aromatic rings, confirming the graphitic backbone structure of the activated carbon. The peaks observed at 1236.4 and 1240.2 cm^{-1} are attributed to C–O stretching vibrations of alcohols, ethers, and phenolic groups in the C500 and P500 samples, respectively. The FTIR spectra are presented in Figure 1.

The FTIR spectra confirmed that the produced activated carbon contained abundant oxygenated functional groups, including hydroxyl (–OH), carbonyl (C=O), carboxyl (–COOH), and ether (C–O) groups. These functionalities are critical in determining the adsorption behavior of activated carbon. The broad O–H stretching band around 3400 cm^{-1} is particularly

significant, as hydroxyl groups can promote hydrogen bonding interactions with polar adsorbates, thereby enhancing adsorption performance (Yang *et al.*, 2019). The observed aliphatic C–H vibrations suggest the presence of hydrophobic domains, which facilitate the adsorption of non-polar organic molecules (Rao *et al.*, 2006). Meanwhile, the C=O stretching peak near 1700 cm^{-1} indicates the presence of acidic surface groups, which enhance cation exchange and metal ion binding capacity (Foo and Hameed, 2012). The presence of aromatic C=C bonds around 1600 cm^{-1} further supports the carbonaceous structure, which is known to promote π – π interactions with aromatic pollutants. Moreover, the C–O vibrations detected in the range of 1100 – 1250 cm^{-1} suggest the existence of ether and phenolic groups that contribute to adsorption through electron donor–acceptor mechanisms (Zhu *et al.*, 2016).

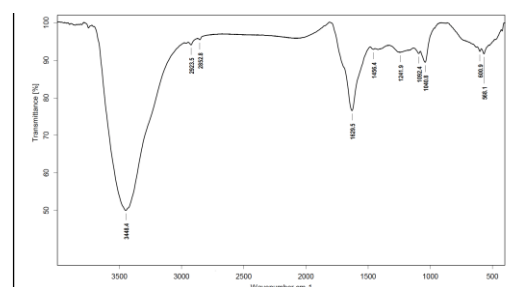
Overall, these findings indicate that the functional groups identified by FTIR spectroscopy not only confirm successful activation but also suggest enhanced potential for adsorption of both organic and inorganic pollutants. The coexistence of hydrophilic and hydrophobic functional groups makes the produced activated carbon a promising material for environmental remediation applications, particularly in wastewater treatment.

3.2 SEM analysis

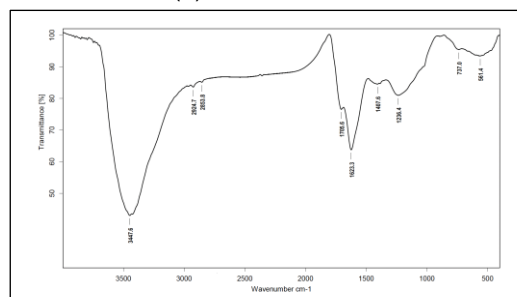
The surface morphology of the samples was examined using SEM images, and the representative micrographs are presented in Figure 2. The SEM images reveal that the surface structure is highly porous with irregular cavities and heterogeneous particle distribution. Such morphology is consistent with the expected structural changes induced during the preparation process, which promotes the development of pores and increases the surface area available for adsorption.

Distinct variations in surface texture, pore structure were observed among the samples, indicating the strong influence of activation conditions on the development of porosity. At $400\text{ }^{\circ}\text{C}$ activation temperatures, the SEM micrographs revealed relatively smooth surfaces with limited pore formation. Only a few irregular cavities were observed, suggesting incomplete decomposition of volatile matter and insufficient development of micropores. This observation is consistent with earlier reports that lower activation temperatures often hinder effective pore development due to limited devolatilization and structural rearrangement (Foo and Hameed, 2012).

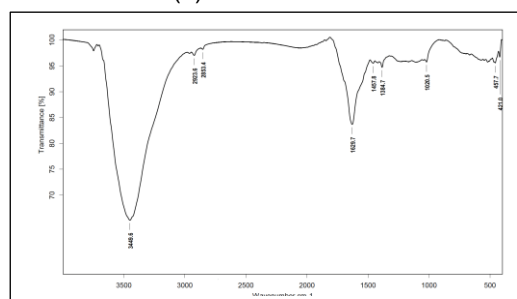
In contrast, the sample activated at $500\text{ }^{\circ}\text{C}$ exhibited a significantly rougher surface with numerous well-developed pores distributed across the carbon matrix. The pore walls appeared thinner and more fragmented, reflecting the enhanced release of volatiles and the opening of internal channels. This morphological improvement corresponds with an increase in surface area and pore accessibility, which are crucial for adsorption applications (Ahmed *et al.*, 2016).



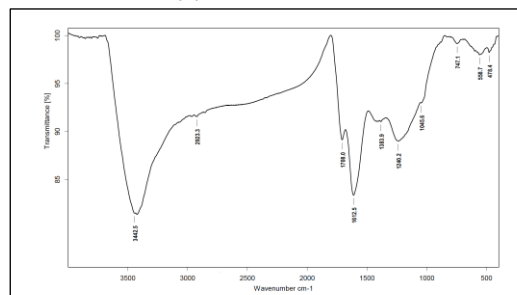
(a) FTIR of C400



(b) FTIR of C500



(c) FTIR of P400



(d) FTIR of P500

Figure 1 FTIR spectra of activated carbon-based coconut shell and oil palm at different temperatures.

Furthermore, differences between the precursors were noticeable. Oil palm–derived samples (P500) activated carbon generally exhibited a denser structure with more uniform micropores, whereas coconut shell–derived (C500) displayed irregular and heterogeneous pores. These morphological differences are attributed to the inherent structural composition of the raw materials, such as lignin and cellulose content, which strongly influence carbon matrix formation during thermal treatment (Ioannidou and Zabaniotou, 2007).

Overall, SEM analysis confirmed that both activation temperature and precursor type play critical roles in the development of porous morphology. Optimal conditions (around $500\text{ }^{\circ}\text{C}$ under controlled activation) yielded activated carbon with

a well-developed pore structure, whereas low temperatures resulted in poor morphological characteristics. These observations align with the physicochemical analyses reported

in related studies and highlight the importance of carefully optimizing activation parameters for efficient production of activated carbon.

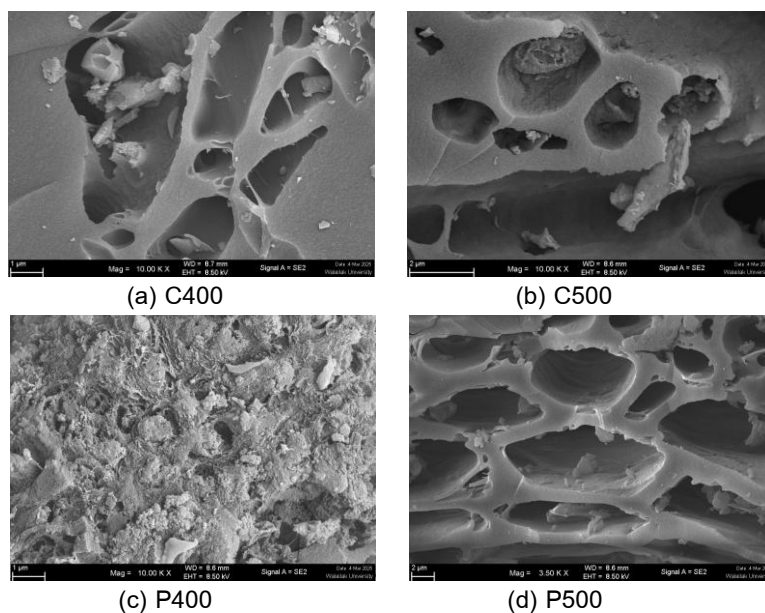


Figure 2 SEM micrographs of activated carbon samples prepared under different conditions: (a) C400 (1 μm), (b) C500 (2 μm), (c) P400 (1 μm), and (d) P500 (2 μm).

3.3 BET analysis

The textural properties of the activated carbon samples were evaluated using nitrogen adsorption–desorption isotherms, and the results are summarized in Table 2. The BET surface areas of the samples varied notably, reflecting the influence of both the precursor type and activation temperature.

The BET surface areas obtained in this work (coconut shell: C400 = 342.8172 m^2/g , C500 = 322.6710 m^2/g ; oil-palm shell: P400 = 196.9333 m^2/g , P500 = 208.1293 m^2/g) are moderate compared with values reported in the literature. Coconut-shell activated carbons have been reported with a wide range of BET surface areas depending on the activating agent and process conditions from several hundred to over 2000 m^2/g under aggressive chemical activation or optimized steam/ CO_2 activation. For example, Gratueto *et al.* and Yang *et al.* reported coconut-shell AC with surface areas in the hundreds to >2000 m^2/g depending on activation route and process parameters (Gratueto *et al.*, 2008)

Among the coconut shell–based samples, C400 exhibited the highest BET surface area followed by C500. In contrast, the palm-based samples showed comparatively lower surface areas, with P400 and P500. The higher surface areas observed in the coconut shell–derived carbons can be attributed to their more rigid and heterogeneous structure, which facilitates the formation of a highly porous network during chemical activation. Interestingly, increasing the activation temperature from 400 $^\circ\text{C}$ to 500 $^\circ\text{C}$ resulted in a slight decrease in the BET surface area of the coconut shell sample, likely due to partial collapse or widening of micropores into mesopores.

The average pore diameters, calculated from adsorption data, were 19.1273, 19.5205, 19.6759, and 21.1993 $\text{\AA}$ for C400, C500, P400, and P500, respectively. These values indicate that all samples predominantly possessed mesoporous structures, with a slight increase in pore size observed for palm-based carbons at higher activation temperature. The formation of wider pores in P500 may compensate partially for the lower surface area, enhancing accessibility for larger adsorbate molecules

Overall, the BET results showed that coconut shell–derived activated carbons have superior surface area, whereas palm-based carbons tend to develop slightly larger mesopores. These structural characteristics are expected to influence adsorption performance, with C400 potentially exhibiting the highest adsorption capacity due to its combination of high surface area and well-developed mesoporous network.

4. Conclusion

This study successfully synthesized activated carbon from coconut shell and oil palm precursors through chemical activation at different carbonization temperatures. Comprehensive characterization techniques were employed to evaluate the structural, morphological, and textural properties of the resulting materials. FTIR analysis confirmed the presence of oxygen-containing functional groups, such as hydroxyl, carbonyl, and C–O groups, which contribute to enhanced surface reactivity and adsorption capacity. SEM images revealed heterogeneous surfaces with well-developed porous structures, particularly for P500, indicating efficient pore development during activation. BET surface area and pore

structure analyses further corroborated these findings, showing that coconut shell-derived carbons possessed higher surface areas (C400: 342.82 m²/g; C500: 322.67 m²/g) than palm-based carbons (P400: 196.93 m²/g; P500: 208.13 m²/g). The average pore diameters ranged from 19.13 to 21.20 Å, suggesting a predominance of mesoporous structures. Although palm-based carbons exhibited slightly larger pore sizes, coconut shell-

derived carbons demonstrated superior overall textural properties and greater adsorption potential. Overall, the findings highlight that both the choice of precursor and the activation conditions play critical roles in determining the physicochemical characteristics of activated carbon, with C400 emerging as the most promising candidate for adsorption and environmental remediation applications.

Table 2 BET surface area and pore structural parameters of activated carbon samples.

Sample name	Degas Temperature of sample cleaning (°C)	Parameters	Unit	Results
C400	200 °C (15 hours) by heating ramp rate 10 °C/min	BET	m ² /g	342.8172
		surface area		
Adsorption average pore diameter		Å	19.1273	
C500		BET	m ² /g	322.6710
		surface area		
Adsorption average pore diameter		Å	19.5205	
P400		BET	m ² /g	196.9333
		surface area		
P500	Adsorption average pore diameter	Å	19.6759	
	BET	m ² /g	208.1293	
		surface area		
		Adsorption average pore diameter	Å	21.1993

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6. References

- Ahmed, M.B., Zhou, J.L., Ngo, H.H. and Guo, W. 2016. Insight into biochar properties and its cost analysis. **Bioresource Technology** 214: 836-851.
- Ajien, A., Idris, J., Md Sofwan, N., Husen, R. and Seli, H. 2023. Coconut shell and husk biochar: A review of production and activation technology, economic, financial aspect and application. **Waste Management & Research** 41(1): 37-51.
- Chew, T.W., H'Ng, P.S., Luqman Chuah Abdullah, B.C.T.G., Chin, K.L., Lee, C.L., Mohd Nor Hafizuddin, B.M.S. and TaungMai, L. 2023. A review of bio-based activated carbon properties produced from different activating chemicals during chemical activation process on biomass and its potential for Malaysia. **Materials** 16(23): 7365.
- Foo, K.Y. and Hameed, B.H. 2012. Preparation, characterization and evaluation of adsorptive properties of orange peel based activated carbon via microwave induced K₂CO₃ activation. **Bioresource Technology** 104: 679-686.
- Gratuito, M.K.B., Panyathanmaporn, T., Chumnanklang, R.-A., Sirinuntawittaya, N. and Dutta, A. 2008. Production of activated carbon from coconut shell: Optimization using response surface methodology. **Bioresource Technology** 99: 4887-4895.
- Herawan, S.G., Hadi, M.S., Ayob, M.R. and Putra, A. 2013. Characterization of activated carbons from oil-palm shell by CO₂ activation with no holding carbonization temperature. **The Scientific World Journal** 624865: 1-6.
- Ioannidou, O. and Zabaniotou, A. 2007. Agricultural residues as precursors for activated carbon productionA review. **Renewable and Sustainable Energy Reviews** 11(9): 1966-2005.

- Kundu, S., Khandaker, T., Mia Anik, M.A.-A., Hasan, M.K., Dhar, P.K., Dutta, S.K., Latif, M.A. and Hossain, M.S. 2024. A comprehensive review of enhanced CO₂ capture using activated carbon derived from biomass feedstock. **RSC Advances** 14: 29693.
- Lee, C.L., Chin, K.L., H'Ng, P.S., Hafizuddin, M.S. and Khoo, P.S. 2023. Activation temperature and particle size of palm kernel shell vs. the surface properties of activated carbon. **Bioresources** 18(2): 345-358.
- Nilufur, A.B., Thirumalaisamy, R. and Harini, S. 2023. Activated carbon from coconut shell: Synthesis and its commercial application-A recent review. **Applied Science and Engineering Progress** 16(2): 1652.
- Rao, M.M., Ramesh, A., Rao, G.P.C. and Sessaiah, K. 2006. Removal of copper and cadmium from aqueous solutions by activated carbon derived from Ceiba pentandra hulls. **Journal of Hazardous Materials** 129(1-3): 123-129.
- Scholz, M. 2023. How activated carbon can help you-processes, properties and technological applications. **Technologies** 11(6): 153.
- Siipola, V., Tamminen, T., Källi, A., Lahti, R., Romar, H., Rasa, K., Keskinen, R., Hyväluoma, J., Hannula, M. and Wikberg, H. 2018. Effects of biomass type, carbonization process, and activation method on the properties of bio-based activated carbons. **BioResources** 13(3): 5976-6002.
- Tan, X., Liu, Y., Zeng, G., Wang, X., Hu, X., Gu, Y. and Yang, Z. 2015. Application of biochar for the removal of pollutants from aqueous solutions. **Chemosphere** 125: 70-85.
- Yang, X., Wan, Y., Zheng, Y., He, F., Yu, Z., Huang, J., Wang, H., Ok, Y.S., Jiang, Y. and Gao, B. 2019. Surface functional groups of carbon-based adsorbents and their roles in the removal of heavy metals from aqueous solutions: A critical review. **Chemical Engineering Journal** 366, 608-621.
- Zhu, G., Deng, X., Hou, M., Sun, K., Zhang, Y. and Li, P. 2016. Comparative study on characterization and adsorption properties of activated carbons by phosphoric acid activation from corncob and its acid and alkaline hydrolysis residues. **Fuel Processing Technology** 144: 255-261.