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SYNTHESIS AND PRODUCTION OF ACTIVATED CARBON FROM SUGARCANE BAGASSE FOR THE ADSORPTIVE REMOVAL OF METHYLENE BLUE DYE FROM WASTEWATER

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ABSTRACT

A major global environmental challenge is water pollution from synthetic dyes. Conventional remediation techniques such as coagulation-flocculation, chemical oxidation, membrane filtration, ion exchange, and biological treatment can be expensive and frequently fail to effectively remove low pollution levels. The production and analysis of activated carbon from sugarcane bagasse (ScBAC) utilizing a chemical activation procedure with sulfuric acid (H_2SO_4) is the main objective of this study. The research assesses the material's capacity to adsorb and extract methylene blue (MB) dye from wastewater. After carbonizing raw sugarcane bagasse at 250°C, it was steeped in H_2SO_4 for 24h at a 1:3 (w/v) ratio. The final product was properly described, dried in an oven, and carefully rinsed until neutral. Three primary phases of heat degradation were identified by thermogravimetric analysis (TGA), involving the breakdown of cellulose and hemicellulose between 200 and 450°C. ScBAC is primarily amorphous, with large peaks between 23–26° and 43° (2θ) that correspond to the disordered structure of graphitic carbon, using X-ray diffraction (XRD) research. According to Brunauer-Emmett-Teller (BET) measurements, the chemical activation significantly enhanced the material's textural characteristics, raising the micropore volume from 0.096 to 0.225 cc/g and the specific surface area from 112.836 m^2/g to 254.612 m^2/g. ScBAC was able to eliminate up to 99.28% of MB and noted maximum adsorption capacity of 36.83mg/g in just 25 minutes of contact using 0.2 g ScBAC per 100 mL of 74.2 mg/L MB solution, in accordance with UV-visible spectrophotometry. These promising findings demonstrate that sugarcane bagasse, a plentiful and reasonably priced agricultural waste, may be transformed into a highly efficient adsorbent for dye removal, providing an environmentally benign and sustainable method for treating industrial wastewater. To access the effects of competing ions and organic pollutants, more research utilizing actual wastewater systems is needed.

Keywords: Sugarcane Bagasse, Activated Carbon, Methylene Blue, Chemical Activation, Wastewater Treatment

INTRODUCTION

Water pollution has become a major worldwide concern due to the substantial increase in pollution of this resource. Global water quality has been steadily declining over the past few years due to the worsening of the situation (Tadesse et al., 2025; Han et al., 2024). Water is a necessary resource for life to continue on earth (Tadesse et al., 2025; Iwuozor et al., 2023). The aquatic ecology, human health, and other species are all at risk due to this reduction in water quality (Lin et al., 2023; Kumaravel et al., 2024; Kouassi et al., 2022). One of the most significant environmental issues in recent decades, industrial wastewater contamination is now a widespread issue in the majority of nations (Kerrou et al., 2021).

Dyes used in several industries, including printing, food, cosmetics, and pharmaceuticals, but especially in the textile sector, are considered industrial discharges (Siqueira et al., 2020; Kerrou et al., 2021; Zhou et al., 2022; Wasilewska et al., 2024). Because organic dyes are extremely toxic, carcinogenic, mutagenic, and teratogenic, their direct discharge into the environment can cause major environmental problems as well as health risks to people and other living things (Zhou et al., 2022). Among the dyes released in aqueous systems is Methylene Blue dye (MB) (Elshabrawy et al., 2023; Murthy & Sahu 2025; Kouassi et al., 2022). This dye possesses ecotoxicity, with zooplankton which is highly sensitive and at low concentrations, it can seriously harm the ecosystem (Li et al., 2023). Because of this, a lot of work goes into investigating various methods of treating trash before it is released into the environment in order to comply with regulatory requirements (Zeitoun et al., 2020). The WWDR 2024 report and more recent SDG 6 monitoring show that wastewater treatment coverage is improving but 40 – 42% of wastewater worldwide is still not adequately treated (UN WWDR 2024). In order to reduce pollution and safeguard water resources, efficient wastewater monitoring and treatment techniques are crucial (Kadadou et al., 2024).

Filtration, coagulation, flocculation, membrane technology, plasma-activated treatment, chemical precipitation, reverse osmosis, and electrochemical treatment are some of the methods used to remove pollutants from wastewater (Zhou et al., 2022; Majamo et al., 2024; Tadesse et al., 2025). Yet, these traditional techniques frequently fail to eliminate low-concentration pollutants, have significant operating costs, and result in secondary pollution (Tadesse et al., 2025). As a result, scientists are looking into more environmentally friendly and sustainable wastewater treatment options. Due to its widespread application in water treatment, adsorption continues to be one of the simpler technologies (Kerrou et al.,

2021). In adsorption science, the term "adsorbent" refers to the solid surface that provides the adsorption sites, while "adsorbate" refers to the substances that are adsorbed at the solid surface (Alaei Shahmirzadi et al., 2018). With benefits including high specific surface area, affordability, and ease of use, activated carbon-based adsorption is a successful method for removing dyes from wastewater. However, the manufacturing of conventional activated carbon depends on forestry biomass (wood) or nonrenewable resources (coal), which makes it expensive and restricts its broad use (Husien et al., 2022).

The ability of a wide range of inexpensive adsorbents, including peat, bentonite, steel-plant slag, fly ash, China clay, maize cob, wood shavings, and silica, to remove color from wastewater has been studied. These inexpensive adsorbents must be employed in large quantities because they often have limited adsorption capabilities. Finding novel, affordable, readily accessible, and extremely efficient adsorbents is therefore necessary (Siqueira et al., 2020).

Sugarcane bagasse-based water treatment systems have demonstrated significant promise in eliminating dissolved particles, organic matter, and heavy metals to a variety of water and wastewater types (Iwuozor et al., 2023). major amounts of sugarcane bagasse are created during the sugar extraction process, and a major portion of this bagasse is burned in the field, which contributes to air pollution. Sugarcane bagasse has demonstrated promise for advantageous processing, despite the fact that this method is detrimental to the environment. It has high percentages of cellulose, hemicellulose, and lignin and is inexpensive and easily accessible (Naqvi et al., 2020; Siddiqi et al., 2019; Inthapat et al., 2025). As a result, using it as a carbon source provides a useful solution to get rid of sugarcane bagasse while creating vast amounts of inexpensive carbon-based material that may be utilized as an adsorbent for treating wastewater (Mahawong et al., 2025; Hiranobe et al., 2024). Apart from its high carbon content and low commercial value, sugarcane bagasse has a number of advantages over other biomass sources. Because of its low ash content, non-carbon residues that may have an impact on pore structure and adsorption effectiveness are less likely to occur. It produces activated carbon with a well-developed pore network because of its fibrous, porous structure, which promotes pore development. Additionally, sugarcane offers a sustainable and renewable material source because it is harvested once a year (Mahawong et al., 2025).

On the whole, chemical activation and physical activation are the two conventional techniques for producing AC. By impregnating the raw material with dehydrating chemicals like H_3PO_4, $ZnCl_2$, K_2CO_3, NaOH, or KOH and then carbonizing it in an inert environment at the appropriate temperature, chemical activation combines one-step carbonization and activation. In order to improve the internal structure, physical activation, which is commonly used to generate AC for commercial use, involves carbonizing the raw material and then placing it in an oxidizing gas condition of CO_2, water steam, air, or some combination of these activating agents at a relatively high temperature (800–1100◦C) (Somyanonthanakun et al., 2023). Because chemical activation yields carbons with greater surface areas, higher porosity, and improved adsorption capacity at lower activation temperatures and shorter durations, it is often regarded as more efficient than physical activation. Additionally, the technique offers better control over the distribution of pore sizes, and the yield of activated carbon is frequently higher (Bogale et al., 2025). Chemical activation using sulfuric acid was selected due to its strong dehydrating ability, low cost, and proven effectiveness in creating microporous structures at moderate temperatures.

Since sugarcane bagasse activated carbon has been the subject of several studies, the H_2SO_4 activation process still has to be optimized under unified condition particularly for real complex wastewaters and for simultaneously improving adsorption performance, expense, and environmental impacts, despite the fact that numerous studies have shown that sugarcane bagasse-derived activated carbons can efficiently remove dyes, pharmaceuticals, heavy metals, and organic substances from aqueous solutions utilizing different activation routes and process conditions (Ahmed et al., 2023; Mahawong et al., 2025; Ismail et al., 2023). With an emphasis on enhancing carbonization parameters, characterizing structural as well as surface characteristics, and evaluating adsorption performance using contact time, this study attempts to generate activated carbon from sugarcane bagasse via a chemical activation procedure and assess its efficacy in eliminating methylene blue dye from wastewater.

MATERIALS AND METHODS

Raw Materials and Chemicals

The main raw material for this research was sugarcane, which was obtained from Lapai Market in Niger State, Nigeria. After the liquid was extracted from the fresh sugarcane stalks by hand, the fibrous residue known as sugarcane bagasse was gathered and saved for additional processing. The chemical activating agent used was sulfuric acid (H_2SO_4), which has a molecular mass of 98.08 g/mol. The Chemistry Department of Ibrahim Badamasi Babangida (IBB) University in Lapai, Niger State, provided this reagent. Furthermore, the Center for Applied Science and Technology Research (CASTER), Ibrahim Badamasi Babangida University, IBB University, Lapai, Niger State, provided the distilled water used in all of the experimental processes.

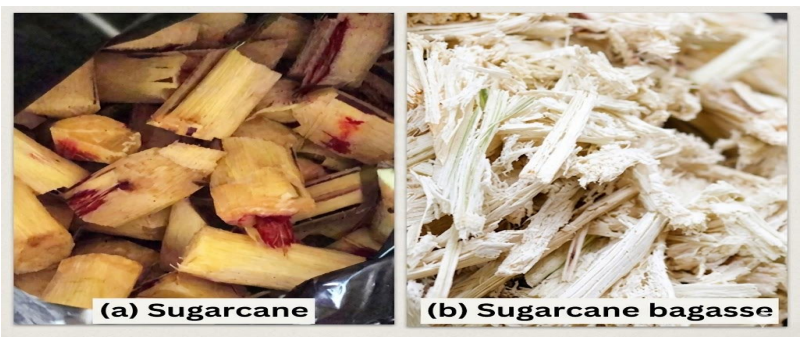

Figure 1: Biomass Physical Transformation: (a) Sugarcane Feedstock and (b) Sugarcane Bagasse Following Juice Extraction, Before Carbonization

Instrumentations
A muffle furnace, an analytical weighing scale, crucibles, beakers, measuring cylinders, test tubes, filter sheets, funnels, Petri dishes, and sample containers are among the tools and equipment utilized in this investigation.

Methods
Preparation of Sugarcane Bagasse Activated Carbon (ScBAC)
After properly cleaning the sugarcane bagasse with distilled water to remove surface contaminants, it was air-dried in the sun to lower its moisture content. The sample was dried out further in an oven for a period of 45 minutes to guarantee total elimination of any remaining moisture. After that, it was moved to a muffle furnace and carbonized for 25 minutes at 250°C. An analytical weighing scale was used to record the sample's initial mass prior to carbonization, allowing the percentage mass loss related to ash production to be calculated later. The sample was put back in the muffle furnace and heated to 250°C for half an hour after the initial carbonization. After the material was turned into charcoal, it was taken out and left to cool to normal temperature. Prior to the charcoal being ground into a fine powder, the post-carbonization mass was measured.

Chemical Activation Process for Sugarcane Bagasse Activated Carbon (ScBAC)
At room temperature of 25°C for 24hours, a determined amount of 12.40 g of sugarcane bagasse powder was impregnated in a 1:3 (w/v) concentration of sulfuric acid (H_2SO_4) under static condition. The purpose of this impregnation process was to enhance the surface area and pore structure of the final activated carbon. Following the impregnation period, the sample was filtered, and the solid that was obtained was repeatedly rinsed with distilled water to get rid of any remaining acid until pH indicator paper verified that the filtrate had a neutral pH. After being dried in an oven at 70°C for 12 hours, the acid-free activated carbon was kept in a sealed plastic container for further examination and characterization.

(a) The-impregnated Sugarcane Bagasse Powder (b) Sugarcane Bagasse Activated Carbon

Figure 2: Visual Depiction of the Precursors: (a) Sugarcane Bagasse Powder that has been Impregnated and (b) Sugarcane Bagasse Activated Carbon (ScBAC) after H_2SO_4 Chemical Activation

Characterization of Sugarcane Activated Carbon (ScBAC)
The aforementioned characterization and analysis were done in this research. Thermogravimetric analysis (TGA) was performed on a 15.226 mg sample of sugarcane bagasse utilizing a PerkinElmer thermal analyzer to determine the ideal carbonization temperature at which significant thermal decomposition starts. X-ray diffraction (XRD) analysis was performed to determine whether the synthesized ScBAC was crystalline or amorphous. Brunauer-Emmett-Teller (BET) technique was used to analyze the surface area and pore structure and volume.

Batch Adsorption and Analysis
The amount of methylene blue (MB) that remained in solution following contact with ScBAC at various time intervals was measured using UV-visible spectrophotometry. Each of the six water samples, one raw and untreated control and five treated samples (C1 – C5), each containing 0.2 g of ScBAC in 100mL of MB solution and initial concentration of 74.189mg/L. The samples were exposed to contact times of 5, 10, 15, 20, and 25 minutes, respectively.
All experiments were conducted in duplicate and mean values reported. Before UV-Vis measurement, all samples were filtered with Whatman (1) filter paper to eliminate suspended carbon particles. Using the Beer-Lambert law calibration at the typical maximum absorption wavelength of MB ($\lambda_{ma}{}^{x}$ = 664 nm), the absorbance observations were transformed into concentration values.

The percentage of dye removal was calculated using the equation (1) below:

$$\% \text{ Removal} = \frac{C_o - C_e}{C_0} \times 100 \quad (1)$$

Where Co represents the initial dye concentrations (mg/L) and Ce is the dye concentration at time t (mg/L) (Elshabrawy et al., 2023)
The equilibrium adsorption capacity q_e (mg/g) was calculated using the mass-balance equation:

$$q_e = \frac{(C_o - C_e)V}{M} \quad (2)$$

Where V is the volume of solution (L) and m is the mass of adsorbent (g) (Zhou et al., 2022)

RESULTS AND DISCUSSION
TGA Analysis of Sugarcane Bagasse Activated Carbon
Thermogravimetric analysis (TGA) was performed on a 15.226 mg sample of sugarcane bagasse utilizing a PerkinElmer thermal analyzer to determine the ideal carbonization temperature at which significant thermal decomposition starts. The sample was heated from 30 °C to 950 °C at a controlled rate of 10 °C per minute in an atmosphere containing nitrogen.
Three different thermal deterioration locations are highlighted by the Thermogravimetric Analysis (TGA) curve, as shown in Fig. 3. Because of the evaporation of adsorbed moisture and free-standing water molecules trapped within the bagasse's lignocellulosic matrix, the first, which occurs

between 30 and 150 °C, results in a slow and mild weight loss of about 5–7%. This first loss does not indicate structural breakdown; rather, it is typical of biomass materials. This is consistent with the results of Raut et al. (2023) and Najafi et al. (2024), whose work determined that the dehydration phase of biomass was the initial breakdown stage below 150 °C and 423 K (150 °C), respectively.

The sample mass after moisture removal at approximately 150°C was taken as the baseline (100% dry mass). The TGA curve shows a prominent and steep sigmoidal drop in the second and critical section, which is about between 200 and 450 degrees Celsius. From 300 degrees Celsius, weight loss increases dramatically. The sample mass of the three primary parts of the structure of sugarcane bagasse decreases from around 93% at 200 °C to about 13% at 450 °C, a net loss of about 87% over this time. At about 200°C to 320°C, hemicellulos begins to break down first. The basic structural component of bagasse, cellulose, rapidly decomposes at the main vertical drop (about 320°C–400°C). Nazbakhsh et al. (2025) reported similar findings, with hemicellulose breaking down between 200 and 310 °C and large cellulose breaking down between 310 and 400 °C. According to Najafi et al. (2024), the primary stage of sugarcane biomass degradation is active pyrolysis, which occurs between 548 and 673 K (275 and 400 °C). This zone's rapid mass loss is in line with the lignocellulosic material's active pyrolysis phase, which releases volatile organic chemicals and gaseous byproducts such CO, CO_2, H_2O, and tar fractions (Apaydın Varol et al., 2023; Chen et al., 2026).

The third region exhibits a more slow and asymptotic mass loss above 450 °C, stabilizing at about 5% residual mass by 850 °C. The mostly inorganic ash fraction, silicates, and mineral oxides that are left over after full organic combustion are represented by this plateau. There is a slight inflection point about 450–500 °C, which probably indicates that the remaining cellulosic fractions have burned almost completely. This is in line with the results of Nazbakhsh et al. (2025), who similarly saw a slowdown in degradation after 400 °C because of the slow degradation of lignin and ash stabilization, and Raut et al. (2023), who saw essentially flat TGA curves above 400 °C with minor weight loss beyond 600 °C.

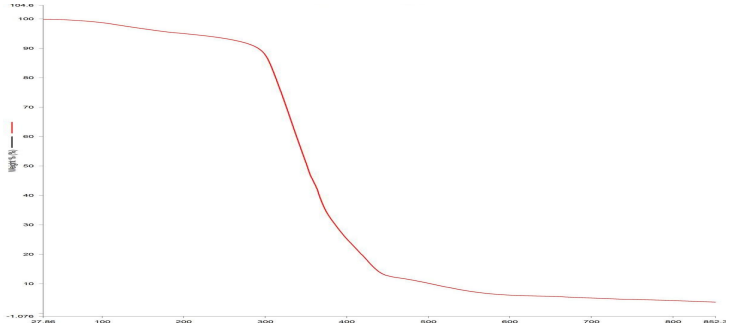

Figure 3: TGA Thermogram of Sugarcane Bagasse Showing Weight Percentage Loss as a Function of Temperature

X-Ray Diffraction (XRD) Analysis of Sugarcane Bagasse Activated Carbon (ScBAC)

To analyze the XRD, a diffractogram was obtained using a Rigaku diffractometer using Cu Kα radiation (λ = 1.540598 Å), scanning across a 2θ range of 10° to 80° at a scan rate of 0.04° per seconds (2.4° min^{-1}).

Two broad, distinct crystalline peaks may be seen in the ensuing XRD pattern, which is shown in Fig. 4. The predominant broad background diffraction, a characteristic of amorphous materials, verifies that the atomic arrangement of the ScBAC is mostly disordered. The (002) plane of disordered carbon is shown by the broad hump centered about 23°–26° (2θ), which indicates short-range graphitic ordering commonly seen in activated carbons obtained from biomass. Turbostratic carbon structures, which constitute a state of structural ordering halfway among totally amorphous and well-crystallized graphite, are linked to the second broad plateau near 43° (2θ) designated as the (100)/(101) reflections. The occurrence of disordered graphitic carbon layers typical of biomass-derived activated carbons was confirmed by Mohamed et al. (2022), who found a similar peak at about 23.98° that was attributed to the (002) plane of hexagonal carbon-like structures. This lends credence to the theory that turbostratic or amorphous carbon with short-range graphitic ordering makes up the majority of the ScBAC structure. In a similar vein, Ismail et al. (2025) discovered a wide hump in sugarcane bagasse activated carbon within 20°–30° (2θ), which they attributed to a highly disordered carbon structure with increased porosity that was inherited from the lignocellulosic progenitor. This indicates that such amorphous characteristics are typical of successful biomass activation and directly justifies the broad scope of the ScBAC peak.

The presence of a feature around 43° (2θ) in the ScBAC pattern is also consistent with literature reports. Nazbakhsh et al. (2025) assigned a peak near 43.5° to the (100) plane of sp^2-hybridized carbon, representing graphitic microdomains embedded within an amorphous matrix. This supports the interpretation that ScBAC contains limited but significant turbostratic ordering, which is beneficial for electron transfer and adsorption processes.

The ScBAC pattern's characteristic at about 43° (2θ) is likewise in line with reports from the literature. According to Nazbakhsh et al. (2025), the (100) plane of sp^2-hybridized carbon has a peak at about 43.5°, which represents graphitic microdomains embedded in an amorphous matrix. This lends credence to the idea that ScBAC has limited and restricted turbostratic ordering, which is advantageous for adsorption and electron transfer processes. Furthermore, Mohamed et al. (2022) and Ismail et al. (2025) both stressed that the lack of distinct cellulose-related peaks indicates that lignocellulosic structures have completely broken down, resulting in a framework of mostly amorphous carbon. The lack of crystalline biomass signals in the ScBAC pattern is immediately explained by this.

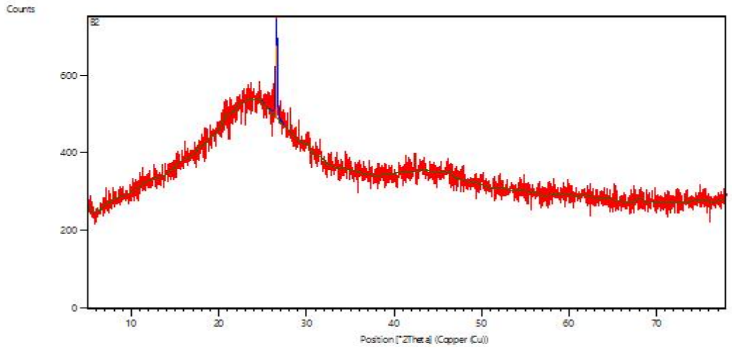

Figure 4: XRD Pattern of Sugarcane Bagasse Activated Carbon Showing Characteristic Peaks

BET Surface Area and Pore Structure Analysis

The particular surface area, pore volume, and distribution of pore sizes of the ScBAC samples were measured both before and after chemical activation with H_2SO_4 using the Brunauer-Emmett-Teller (BET) technique.

Table 1: Textural Characteristics ScBAC before and after H_2SO_4 Chemical Activation

Textural Parameters	Before Chemical Activation	After Chemical Activation
BET Specific Surface Area	112.836 $m^2\ g^{-1}$	254.612 $m^2\ g^{-1}$
DA Micropore Volume	0.096 cc/g	0.225 cc/g
Pore Diameter	2.580 nm	3.000nm
Correlation Coefficient (r)	0.996943	0.998538
BET C Constant	9.580	2.820

The BET function, $[1/W(P_0/P - 1)]$ and relative pressure (P/P_0) show a linear connection throughout the range in the multi-point BET plots for the unactivated and activated ScBAC sample (Fig. 5a and 6a). The intrinsic porosity created by pyrolysis alone is reflected in the pre-activation sample's computed BET surface area of 112.836 m^2/g. This surface area, which represents the cellular and fibrous pore structure that comes up during the high-temperature carbonization that constitutes the lignocellulosic structure of bagasse, is already significant for an unactivated char even though it is lower than post-activation values. The chemically activated ScBAC's BET surface area is determined to be 254.612 m^2/g, which is higher than the pre-activation value. In contrast, even greater values (~407 m^2/g) for activated carbon derived from sugarcane bagasse were reported by Salatein et al., (2025), confirming that the results fall well within the anticipated range for activated acid bagasse carbon. The moderate increase in surface area compared with existing findings in this research may be due to the relatively low activation temperature, limited acid concentration, H_2SO_4 concentration, residual sulfur blocking pores, and incomplete washing.

A unimodal pore volume distribution with a mode pore diameter of 2.580 nm to 3.00 nm is revealed by the Dubinin-Astakhov (DA) the distribution of pore sizes plot for the pre-activation and activated ScBAC (Fig. 5b and 6b). The overall micropore volume rises significantly from 0.096 to 0.225 cc/g, respectively, suggesting that H_2SO_4 activation essentially increases existing pores through regulated chemical etching and opens blocked pores. Because methylene blue is a rather big cationic dye molecule, this mesopore enlargement is especially advantageous for methylene blue adsorption. According to Jawad et al. (2021), sugarcane bagasse-derived activated carbons usually have mixed micro-mesoporous architectures, where micropores aid in adsorption capacity and mesopores increase diffusion. The observed micro-mesoporous shift (2.58–3.00 nm) clearly fits with this finding. While Jawad et al. (2022) and Salatein et al. (2025) stressed that hierarchical pore systems improve adsorption efficiency for dye molecules due to better accessibility, Rahmawati et al. (2021) clearly verified that 2–50 nm mesopores facilitate MB diffusion. With all aspects considered, the ScBAC in this work is a substantially activated carbon material with a moderate increase in surface area and a well-balanced mixture of micro and mesopores. Because of this, it works quite well for adsorption.

After H_2SO_4 activation, the BET C constant dropped from 9.580 to 2.820. According to traditional BET theory, poorer adsorbent–adsorbate interactions are frequently linked to lower C values. However, as adsorption behavior in porous carbon materials can differ from the presumptions of the traditional BET model, this interpretation might not be immediately relevant. Significant pore growth following activation is demonstrated by the concurrent increases in BET surface area (112.836–254.612 m^2/g) and micropore volume (0.096–0.225 cm^3/g). Therefore, rather than weaker adsorbent–adsorbate interactions, it is more reasonable to explain the decrease in C to changes in adsorption behavior linked to the newly formed pore structure. Shimizu and Matubayasi (2022) stressed that BET-derived parameters in porous materials should be evaluated cautiously since adsorption may entail processes that do not strictly adhere to standard BET assumptions. This interpretation is in line with their findings.

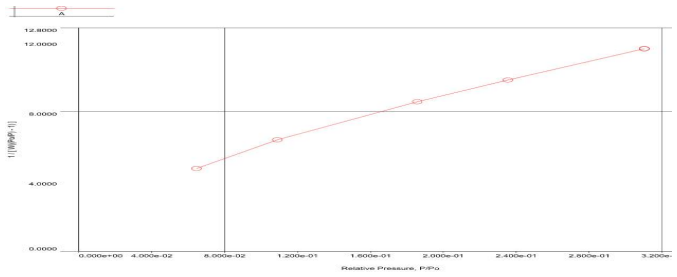

Figure 5: Multi-Point BET Plot of ScBAC before Chemical Activation

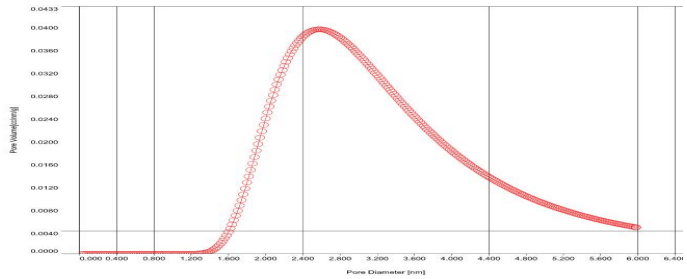

Figure. 6: DA Pore Size Distribution Plot of ScBAC before Chemical Activation

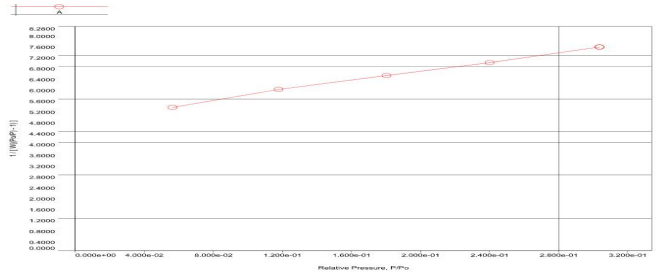

Figure 7: Multi-Point BET Plot of ScBAC after H_2SO_4 Chemical Activation

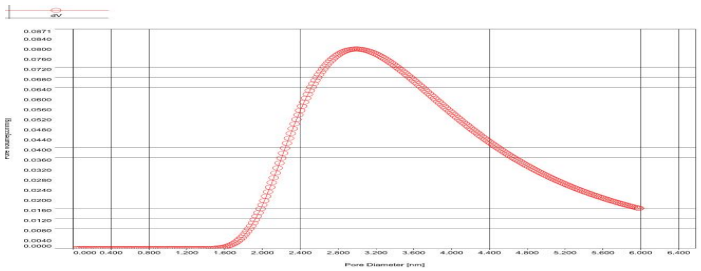

Figure 8: DA Pore Size Distribution Plot of ScBAC after H_2SO_4 Chemical Activation

UV-Visible Spectrophotometric Analysis of Methylene Blue Adsorption

The amount of methylene blue (MB) that remained in solution following contact with ScBAC at various time intervals was measured using UV-visible spectrophotometry. Table 2 summarizes the findings, and Fig. 7 provides a graphic representation.

Table 2: UV-Vis Analysis Displaying the Percentage Clearance and Concentration of Methylene Blue at Different Contact Times

Sample ID	Contact Time (Mins)	Adsorbent Dosage (g)	Ce (Mg/L)	% Removal	q_e(Mg/g)
RAW	0.00	0.00	74.189	Reference	-
C1	5.00	0.20	11.667	84.27	31.26
C2	10.00	0.20	9.650	87.00	32.27
C3	15.00	0.20	4.177	94.37	35.01
C4	20.00	0.20	0.965	98.70	36.61
C5	25.00	0.20	0.535	99.28	36.83

All treated samples are compared to the original concentration of the raw, untreated methylene blue solution, which is 74.189 mg/L. The concentration decreases to 11.667 mg/L during the shortest contact time of 5 minutes (C1), which indicates a removal effectiveness of roughly 84.27% and an adsorption capacity of 31.26 mg/g. This quick, high absorption at the earliest point clearly indicates MB molecules can quickly access a sizable portion of the

ScBAC's surface sites, with the substantial concentration differential between the solutions with the carbon surface driving the first adsorption. This result is in line with that of Ismail et al. (2025) and Kerrou et al., (2021), who each noted that the strong affinity between dye molecules and accessible adsorption sites led to extremely quick methylene blue adsorption during the early contact phase.

The second slower adsorption stage recorded by both experiments as equilibrium approaches is consistent with the gradual improvement in removal capacity from 87.0% (10 minutes, qe = 32.27mg/g) to 99.28% (25 minutes, qe = 36.83 mg/g), with a corresponding increase in adsorption capacity, which indicates ongoing adsorption through slower diffusion into interior pores. Possible adsorption mechanisms may include pore filling, π–π interactions between aromatic carbon structures and methylene blue molecules, and electrostatic interactions. However, pH was neither measured nor controlled. According to Vasiljević et al. (2025), methylene blue efficiency of removal rose with contact duration until equilibrium was attained, at which point no discernible change was seen. This study's removal efficiency demonstrates that sugarcane bagasse activated carbon works well as an adsorbent for removing methylene blue from wastewater.

The maximum adsorption capacity of 36.83 mg g^{-1} in this study is less than the 136.5 mg g^{-1} obtained by Jawad et al. (2021) for KOH-activated sugarcane bagasse carbon, which enjoyed a surface area of 709.3 m^2 g^{-1} and a highly developed microporous structure. Jawad et al. (2021) attributed the improved adsorption performance to extensive pore development from KOH activation in addition to hydrogen bonding, electrostatic attraction, and π–π interactions between the adsorbent surface and methylene blue molecules. However, the capacity discovered here is comparable to the 49.26 mg g^{-1} documented by Kerrou et al. (2021), who used sugarcane bagasse to remove methylene blue.

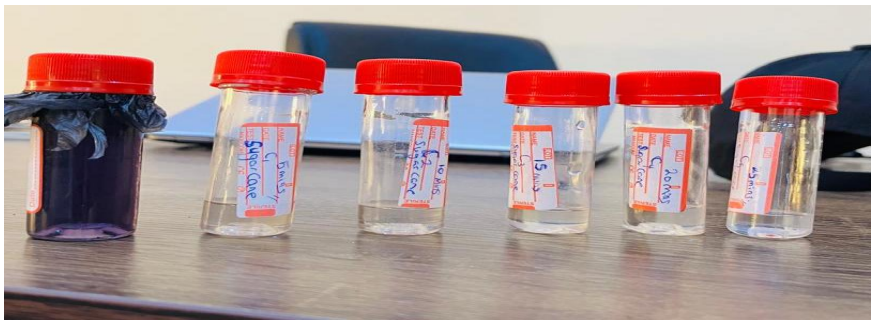

Figure. 8: Untreated and ScBAC-treated Water Samples at Different Contact Times.

CONCLUSION

This study provides a meaningful baseline for sugarcane bagasse chemically activated with sulfuric acid to form activated carbon, which can then be used to remove methylene blue colour from wastewater. The study focused on establishing the adsorption capability of the material using key parameters such as initial dye concentration, contact time, removal efficiency, and adsorption capacity. Three different thermal deterioration locations are highlighted by the Thermogravimetric Analysis (TGA) curve and validated the selected carbonization settings by confirming that the primary thermal breakdown of the lignocellulosic components took place between 200 and 450°C. A mostly amorphous carbon structure with broad reflection at 23 - 26° and 43° (2θ), with turbostratic and short-range graphitic ordering, which promotes favorable adsorption behavior, was found by XRD examination. By more than doubling the specific surface area from 112.836 to 254.612 m^2/g and expanding the micropore volume from 0.096 to 0.225 cc/g, H_2SO_4 activation greatly improved the material's textural qualities, according to BET analysis. The decrease in the BET(C) constant from 9.580 to 2.820 after H_2SO_4 activation indicates a change in the adsorption of the material following pore development. This immediately improved the material's ability to absorb dye molecules.

The findings of the adsorption studies were promising and with a low adsorbent dosage of 0.2 g, and initial concentration of 74.189mg/L, ScBAC was able to remove approximately 99% of the methylene blue in just 25 minutes with adsorption capacity of 36.83mg/g under the tested experimental conditions. Removal effectiveness surpassed 84% even after five minutes of contact, indicating a robust initial dye uptake propelled by the activated carbon's well-developed pore network.

Despite these encouraging outcomes, a few restrictions should be noted. Performance under actual wastewater systems with competing ions, varying pH, and complex matrices was not evaluated because the adsorption tests were carried out in controlled laboratory settings using methylene blue solution at a fixed initial concentration. Furthermore, important operational factors including pH, temperature, ionic strength, and agitation conditions were not thoroughly examined, which limited our ability to fully understand how they affect adsorption behavior. Besides that, ScBAC's regeneration and reusability were not assessed, which limited the evaluation of its long-term application. The BET surface area is similar to other carbons obtained from biomass, but it is still less than the values documented in the literature, indicating that activation condition altering could improve performance even more.

Future research should concentrate on adsorbent regeneration studies, comprehensive kinetic and isotherm modeling under various conditions, and actual wastewater applications. Notwithstanding these drawbacks, our work offers solid basis for the creation of inexpensive activated carbon generated from biomass for the elimination of methylene blue.

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