Activated carbon derived from cashew branches via chemical activation with a weak dibasic acid: production and characterization

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Abstract

The aim of this study was to produce and characterize activated carbon prepared from cashew tree branches, used as a local biomass precursor. The process involved chemical activation using 20% orthophosphoric acid (H_3PO_4).

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The branches were impregnated for 24 hours at a ratio of 0.172 g·mL^{-1} (50 g of precursor for 290 mL of activating agent) and then dried. Carbonization was carried out at 550 °C for 3 hours and 47 minutes, yielding an average carbonization rate of $35.36 \pm 0.014\%$. Characterization based on the iodine index — a key test for assessing microporosity — revealed excellent performance. The highest iodine index value reached 913.68 mg/g, well above the 500 mg/g threshold considered indicative of good microporosity. These results confirm the effectiveness of chemical activation in creating and enlarging pores and demonstrate that this activated carbon derived from plant biomass can serve as a cost-effective alternative for various purification, separation, and catalytic processes.

1. Introduction

Waste management, recovery, and disposal represent major environmental challenges, particularly in developing countries where treatment options are constrained by cost and ecological impact. Activated carbons are microcrystalline compounds obtained through thermal decomposition of carbonaceous materials followed by activation, which imparts a porous structure essential for adsorption in a wide range of purification, separation, and catalytic processes. Chemical activation, which requires lower temperatures than physical activation, is increasingly favored to reduce energy consumption [1]. The activated carbon industry is experiencing rapid growth due to rising demand for gas and liquid depollution processes [2].

Traditionally derived from mineral, animal, or plant materials, current research emphasizes the valorization of agricultural by-products and waste for sustainable production, as demonstrated by recent studies on the use of nut shells [3], aligning with circular economy principles. Utilizing these new materials expands application possibilities, notably for wastewater treatment [4] and industrial uses [5]. However, many African countries continue to import this material, highlighting strong dependency [6], whereas the use of agricultural biomass, as explored by Nko'o et al. [2], offers a promising local alternative. In light of the need to explore pathways for valorizing local biomass, the general objective of this study is to contribute to the production and characterization of activated carbon prepared from local biomass—specifically cashew branches—for pollutant adsorption in biogas, ultimately aiming at filter design. To achieve this, the specific objectives are to collect and prepare the precursor, produce various activated carbons from cashew branches, and characterize the resulting products.

2. Material and Methods

2.1. The precursor

Côte d'Ivoire has established itself as the world's leading producer of cashew nuts, with production increasing from 400,000 tons in 2011 to approximately 1,000,000 tons in 2024 [7]. Specifically, 944,673 tons of cashew nuts were marketed in 2024, according to official data from the Ministry of Agriculture. The main cultivation areas are located in the northern region of the country, particularly around Katiola, Dabakala, Korhogo, and Bondoukou. For this study, the branches used were collected from the sub-prefecture of Gouméré, specifically from the village of Yaokokoroko, at the heart of this high-production region. Figure 1 illustrates the raw precursor material.

Figure 1. Crushed and sieved cashew branches.

2.2. Preparation of the precursor

Once in the laboratory, the cashew branches were cut into twigs of approximately five (5) centimeters. The dried twigs were then crushed in a mortar to obtain smaller fragments. The crushed precursor was subsequently sieved and stored in containers for further use. During sieving, fractions passing through an 8 mm mesh and retained on a 4 mm mesh were selected.

2.3. Preparation of the activating agent

Phosphoric acid (H_3PO_4) is a triprotic mineral oxoacid (capable of donating three protons), colorless, and widely used in fertilizers, detergents, water treatment, metal restoration (rust removal), and the food industry (acidifier, E338, cola flavor). Its tetrahedral structure centered on phosphorus gives it distinct acidic properties, though weaker than strong acids such as sulfuric acid, making it useful as a catalyst and buffering agent.

H_3PO_4: Phosphoric acid (molar mass=97.994 g/mol; density=1.88 g/cm³).

The activating solution at 20% H_3PO_4 was prepared from the stock solution (Figure 2). The stock solution was 85% with an initial concentration $C_0 = 14.65$ mol/L.

The dilution was calculated using:

$$Cf = \% \times ds \times \rho water/M$$

where:

- % = desired concentration of the diluted solution
- ds = density of the solution at the target percentage (at CSTP, 20% → ds = 1.1134 for H_3PO_4)
- ρwater = density of water (1000 g/L)
- M = molar mass of the solution

The volume to dilute was determined using:

$$V_0 = Vf \times Cf/C_0 \quad \text{with } Vf = 1000 \text{ mL.}$$

The required volume of the stock solution was measured into a beaker and diluted with distilled water to reach 1000 mL.

Figure 2. Weighing and preparation of the activating agent (H_3PO_4) at 20%.

2.4. Impregnation

Impregnation was carried out at a ratio of 0.172 g·mL^{-1} for 24 hours, meaning that for 50 g of precursor, 390 mL of H_3PO_4 were used (Figure 3).

Figure 3. Impregnation of cashew branch samples with H_3PO_4.

2.5. Drying

After impregnation, the samples were oven-dried for 24 hours (Figure 4).

Figure 4. Oven for drying impregnated precursors.

2.6. Carbonization

Carbonization was performed at 550 °C in a muffle furnace (Figure 5) for 3 hours 47 minutes. The process involves several stages [5]:

- **Pre-pyrolysis**, characterized by water removal, carbonyl formation, and slight mass loss;

- **Decomposition** of lignocellulosic material;

- **Formation of solid residues**, i.e., activated carbon.

Figure 5. Muffle furnace for carbonization of precursors.

2.7. Washing and final drying

After carbonization, the obtained carbon was washed repeatedly until the rinse water reached a pH close to seven (7). This step removes residual carbonization by-products and clears some pores. The samples were then oven-dried for 24 hours before iodine index testing (Table 1).

Table 1. Summary of activated carbon production parameters

Impregnation				Drying		Carbonisation	
Activating Agent	Concentration	Impregnation Ratio	Impregnation time	duration	T°C	T°C	Duration
H_3PO_4	20%	50g/290 mL	24 hours	24 hours	105°C	550	3h47

2.8. Characterization of activated carbon

2.8.1. Carbonization yield

The yield is the ratio between the amount of precursor and the amount of activated carbon produced. A measured quantity of precursor (m_0) was carbonized, and the resulting carbon mass (m_1) was recorded. The yield (%) is calculated using the formula [8]:

$$R\ (\%) = [(m_1 / m_0)] \times 100$$

Iodine index (Id)

The iodine index test determines the carbon's capacity to adsorb small molecules and it is a key indicator of microporosity. The method applied follows steps [9]:

- 0.05 g of carbon was placed in a 100 mL beaker.

- 15 mL of 0.1 N iodine solution was added and stirred for 5 minutes before filtration.

- 10 mL of the filtrate was titrated with 0.1 N sodium thiosulfate until complete decolorization, using starch as an indicator (3 drops).

A blank test under the same conditions yielded Vb = 5.4 mL. The iodine index (mg/g) was calculated using:

$$\text{Iodine index (mg/g)} = \frac{(Vb - Vs) * N * 126.9 * 1.5}{M}$$

where:

- Vb = volume (mL) of thiosulfate for blank

- Vs = volume (mL) for sample

- N = normality of thiosulfate solution

- 126.9 = atomic mass of iodine

- M = adsorbent mass (g), M = 0.05 g

Figure 6 shows the measurement set-up.

Figure 6. Setup for measuring the iodine index.

3. Results

3.1. Carbonization yield

The average carbonization yield was $35.36 \pm 0.014\%$. The tests that produced this average are summarized in Table 2. This result demonstrates that the selected precursor is suitable for activated carbon production. The

yield obtained is higher than values reported in other studies; for example, Mukendi et al. [10] reported a yield of 10.2% after activation of various wood species.

Table 2. Carbonization yield.

Different tests	Test 1	Test 2	Test 3	Test 4
Initial Mass (g)	274	194	15	15
Final Mass (g)	89	71	5,5	5,3
Yield (%)	32,5	37	36,66	35,3

3.2. Iodine index

The iodine index calculated under the operating conditions of this study was 913.68 mg/g. This high value indicates that the activated carbon from cashew branches is microporous. The iodine index is a key characteristic for evaluating micropores [11]. The results confirm that chemical activation not only creates new pores but also enlarges existing ones. Furthermore, the activating agent used significantly influences the efficiency of the carbon. Activated carbon is considered to have good microporosity when its iodine index is ≥ 500 mg/g [12]. This test also provides insight into the specific surface area, as a higher iodine index corresponds to greater adsorption capacity. Activated carbons with predominantly micropores are particularly suitable for removing biogas pollutants such as hydrogen sulfide [13].

4. Conclusion

This study successfully produced and characterized activated carbon from cashew branches using chemical activation with 20% phosphoric acid (H_3PO_4). The findings highlight the significant influence of operational parameters such as activating agent concentration, carbonization temperature, and duration on the properties of the resulting carbon. The results are noteworthy: an average yield of 35.36% and a maximum iodine index of 913.68 mg/g, well above the 500 mg/g threshold, indicating excellent microporosity. These performances confirm that chemical activation promotes pore creation and enlargement, thereby enhancing adsorption capacity. This work demonstrates the potential for valorizing abundant local biomass, such as cashew branches, to produce efficient adsorbent materials. This approach aligns with sustainable development and agricultural waste reduction. Further studies (specific surface area, adsorption isotherms, pore volume and diameter, point of zero charge, etc.) are planned to optimize activated carbon properties and broaden their applications in various treatment and purification processes.

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