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CHEMICAL ACTIVATION OF *BULL EYE'S* SEED (BES) FOR THE DEVELOPMENT OF HIGH-SURFACE-AREA ACTIVATED CARBON: A MICROSTRUCTURAL AND POROSITY STUDY

I. I. AJIBADE; & L. SA'ADU
Department of Physics, Federal University Gusau, Zamfara State, Nigeria
Corresponding Author: isaajibade@fugusau.edu.ng
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Abstract

This study investigates the thermal decomposition and structural evolution of Bull Eye Seed (BES) as a precursor for activated carbon production. BES samples were subjected to controlled pyrolysis at 650 °C, 750 °C, and 850 °C, and the resulting materials were characterized using. Thermogravimetric Analysis (TGA), Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Brunauer-Emmett-Teller (BET) surface analysis, and Field Emission Scanning Electron Microscopy (FESEM) removal, devolatilization, and carbonization stages, with increasing mass loss at higher temperatures. FTIR analysis indicated progressive changes in surface functional groups as pyrolysis temperature increased, while XRD revealed a transition toward greater structural ordering. BET analysis showed improved porosity and surface area at elevated temperatures, confirming enhanced pore development in the treated samples. However, the highest temperature also suggested a trade-off between porosity and structural integrity. Overall, the findings show that Bull Eye Seed is a promising biomass precursor for sustainable activated carbon production, and that pyrolysis temperature strongly influences the final material properties.

Keywords: Bull Eye's Seed, activated carbon, pyrolysis temperature, biomass conversion, porosity, thermal degradation

Introduction

Biomass-derived carbon materials have attracted considerable attention in recent years because they offer a sustainable route for producing porous adsorbents and functional carbon materials from renewable feedstocks(Li et al., 2025). Agricultural residues and seed-based precursors are especially appealing because they

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are inexpensive, abundant, and environmentally benign, while also offering the carbon-rich structure needed for thermal conversion into useful carbon products (Gupta et al., 2025). As interest grows in circular and green materials development, researchers continue to explore new biomass sources that can be transformed into activated carbon with desirable textural and chemical properties (Hossen et al., 2026).

Bull Eye Seed is one such underexplored biomass material. Like many lignocellulosic precursors, it has the potential to undergo dehydration, devolatilization, and carbonization during heat treatment, leading to a porous carbonaceous residue. The final quality of the derived carbon, however, depends strongly on processing conditions, especially pyrolysis temperature, heating duration, and the extent of volatile removal (He et al., 2026). These variables influence yield, surface chemistry, pore formation, and structural stability, all of which determine whether the material is suitable for advanced applications.

Temperature is particularly important because it governs the extent of carbonization and the development of pore structure. At lower temperatures, biomass may remain incompletely converted, retaining moisture and unstable organic compounds (Twaróg & Pielichowska, 2026). At higher temperatures, pore development and surface area may improve, but some oxygen-containing functional groups can be removed and structural collapse may begin to occur. For this reason, an optimum thermal condition is usually required to balance porosity, functionality, and mechanical integrity. Recent studies on biomass-derived carbon materials have consistently shown that these thermal effects are central to the performance of the final product (Abdullah et al., 2023; Sahu et al., 2023; Yang et al., 2023).

In addition, recent literature has emphasized the value of biomass conversion for energy and materials applications in developing regions where agricultural wastes are abundant and underutilized. Studies on biomass utilization and carbon materials have shown that locally available feedstocks can be converted into useful products for adsorption, energy storage, and environmental remediation, thereby adding value to waste materials while reducing dependence on nonrenewable resources (Ajibade et al., 2024). Research on related lignocellulosic materials has also demonstrated that thermal treatment can significantly alter surface area, porosity, and structural order, with important implications for material performance (Mahmoud et al., 2023).

Against this background, Bull Eye Seed deserves attention as a potential precursor for activated carbon production. However, its thermal decomposition behavior and structural evolution have not been sufficiently explored, particularly in relation to controlled pyrolysis conditions. Understanding how temperature affects its mass loss, surface characteristics, crystallinity, and pore development is therefore necessary if the material is to be developed into a useful carbon precursor. This study investigates Bull Eye

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Seed at 650 °C, 750 °C, and 850 °C to evaluate its thermal stability and structural transformation, with the broader aim of determining its suitability for activated carbon development.

Despite the abundance of agricultural waste in Nigeria, much of it remains underutilized, creating environmental challenges while representing untapped resources for value-added products (Onwumelu, 2023; Ajien et al., 2023). Bull Eye's Seed (BES) is one such underexplored biomass material with potential for activated carbon production. However, its thermal decomposition behavior, structural evolution, and optimal processing conditions have not been systematically investigated.

Materials and Methods

The Bull Eye Seed used in this study was collected, cleaned, and prepared as the precursor material for thermal conversion into activated carbon. The sample was first washed to remove adhered dirt and impurities, then cut into smaller pieces and oven-dried to reduce moisture content before further processing. After drying, the material was crushed and sieved to obtain a more uniform particle size suitable for heat treatment and subsequent characterization.

For the chemical pretreatment stage, the prepared Bull Eye Seed powder was functionalized by acid treatment using sulfuric acid, followed by repeated washing with deionized water until a near-neutral pH was obtained. The treated sample was then dried again in an oven to remove residual moisture before pyrolysis. This pretreatment step was intended to improve the reactivity of the precursor and support the development of a more porous carbon structure during heating.

Pyrolysis was carried out in a tubular furnace under an inert argon atmosphere to prevent unwanted combustion during carbonization. The sample was heated at controlled temperatures of 650 °C, 750 °C, and 850 °C, with a constant heating rate and a fixed holding time at each temperature. These temperature levels were selected to evaluate how increasing thermal intensity affects mass loss, carbon yield, pore formation, and structural evolution in Bull Eye Seed-derived carbon.

The thermal behavior of the raw precursor was examined using thermogravimetric analysis to determine the major stages of weight loss during heating. The chemical structure of the carbonized samples was assessed using Fourier transform infrared spectroscopy to identify changes in surface functional groups. X-ray diffraction was used to examine changes in crystallinity and structural order, while Brunauer–Emmett–Teller analysis was used to evaluate surface area and porosity. Field emission scanning electron microscopy was also employed to observe changes in surface morphology and pore development after pyrolysis.

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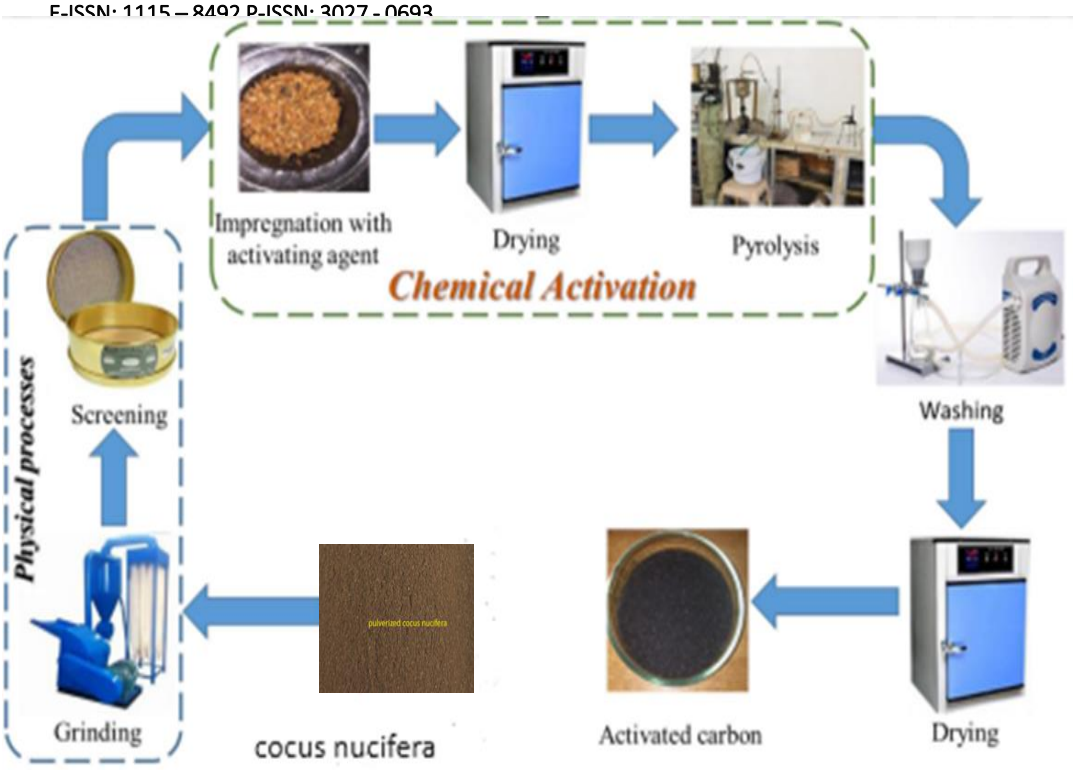


Figure 1: Pyrolysis and functionalization of the BES

Thermogravimetric behavior

The thermogravimetric profile of Bull Eye Seed shows a typical multi-stage decomposition pattern associated with lignocellulosic biomass. The first stage corresponds to moisture removal, during which a small mass loss occurs at relatively low temperature. The second stage is characterized by rapid devolatilization and the breakdown of the main organic components, leading to a sharp reduction in mass as temperature increases. The final stage shows a slower rate of mass loss, indicating the gradual carbonization of the remaining material and the formation of a more stable char residue.

This behavior suggests that Bull Eye Seed is thermally suitable as a carbon precursor, since it undergoes substantial volatile release and carbon enrichment during heating. The low final residue also indicates that the precursor contains a relatively high proportion of organic matter and limited inorganic content. Such a profile is desirable for activated carbon production because it supports the development of a carbon-rich matrix after pyrolysis

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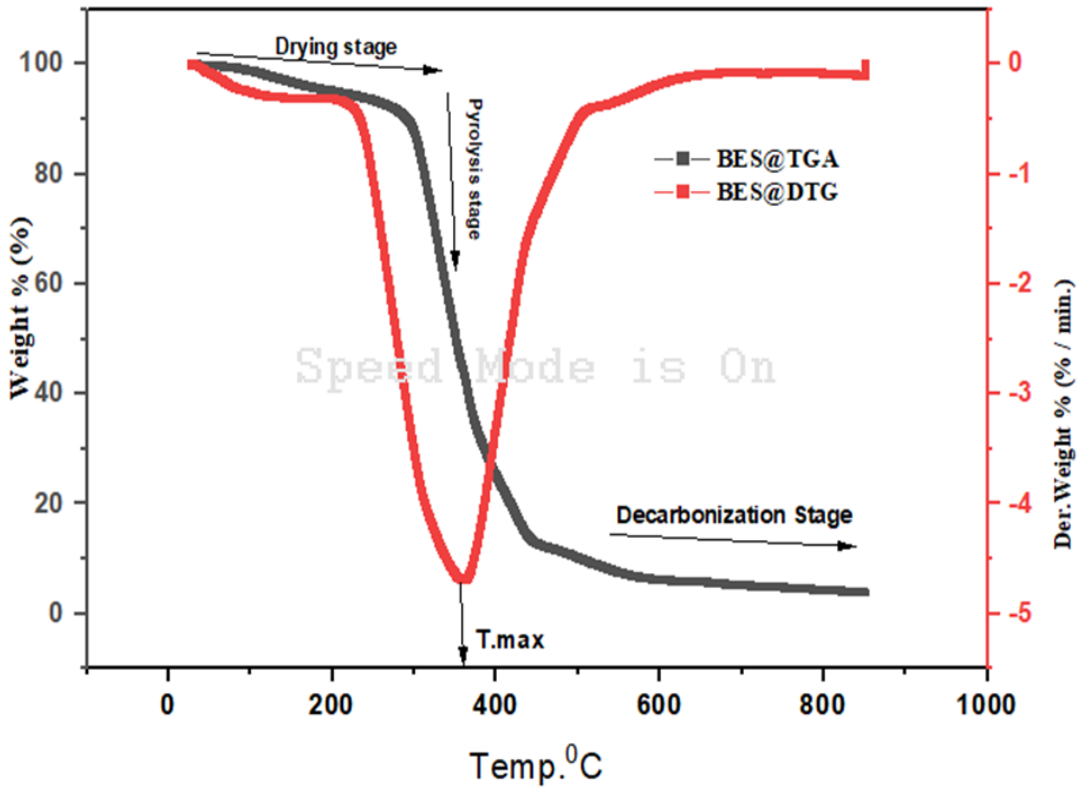


Figure 2: Thermogravimetric (TGA) and Derivative Thermogravimetric (DTG) Profiles of Bull Eye Seed from 0°C to 280°C

FTIR Analysis of Surface Functional Groups

The FTIR spectra show that the surface chemistry of Bull Eye Seed-derived carbon changes progressively with pyrolysis temperature. At lower temperature, more oxygen-containing functional groups remain on the carbon surface, whereas at higher temperature these groups are progressively reduced due to thermal decomposition. This decline in transmittance in the fingerprint region indicates a decreasing abundance of polar surface functionalities and a corresponding increase in carbonization.

These changes are significant because surface functional groups influence wettability, adsorption behavior, and electrochemical performance. While their reduction may improve conductivity and structural order, it may also lower the contribution of faradaic surface reactions. The FTIR results therefore suggest that pyrolysis temperature controls not only the development of carbon structure but also the chemical reactivity of the final material.

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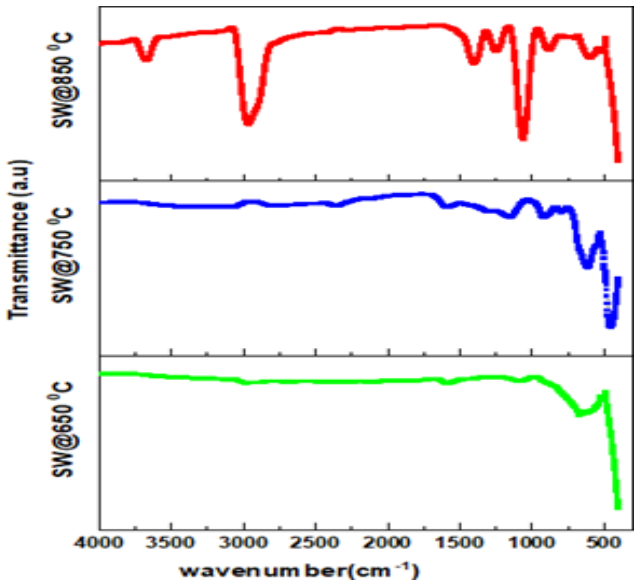


Figure 3:FTIR analysis showing functional group at varying pyrolysis temperature

X-ray Diffraction (XRD) Analysis of Crystallinity and Structural Evolution

Increasing pyrolysis temperature had a clear effect on the extent of mass loss and carbon yield. At lower temperature, carbonization is incomplete, so more volatile matter remains in the material. As the temperature increases, greater decomposition of organic constituents occurs, which reduces yield but enhances pore formation and structural development. This trade-off is important because a higher carbonization temperature may improve surface area and porosity while also reducing the total amount of material recovered.

The observed trend indicates that temperature optimization is necessary to balance yield and textural quality. If the aim is to produce activated carbon with high porosity, the higher-temperature treatment is beneficial. However, excessive heating may also reduce some structural stability and remove useful surface functional groups. Therefore, the most suitable pyrolysis condition is the one that provides a compromise between high carbon yield and desirable pore architecture.

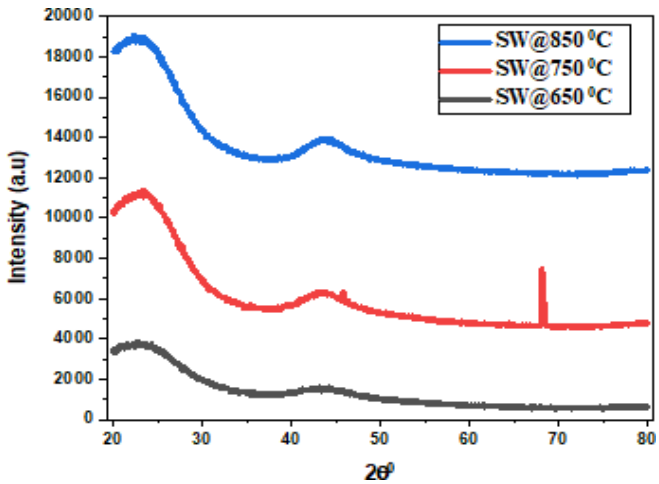


Figure 4: XRD analysis x-raying structural analysis at varying pyrolysis temperature

Nitrogen Adsorption-Desorption (BET) Analysis of Surface Area and Porosity

The BET results show that surface area and pore development increase with pyrolysis temperature. The lower-temperature sample exhibits limited nitrogen uptake, indicating a less developed pore

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network. In contrast, the higher-temperature samples show stronger adsorption behavior, which is evidence of improved micro- and mesoporous structure.

This trend supports the idea that volatile removal at elevated temperature creates more voids and opens up the internal structure of the carbon. Such pore development is highly desirable for activated carbon because it increases accessible surface area and enhances adsorption capacity. At the same time, excessive pore widening may compromise mechanical strength, so the BET results reinforce the need for careful optimization of pyrolysis temperature.

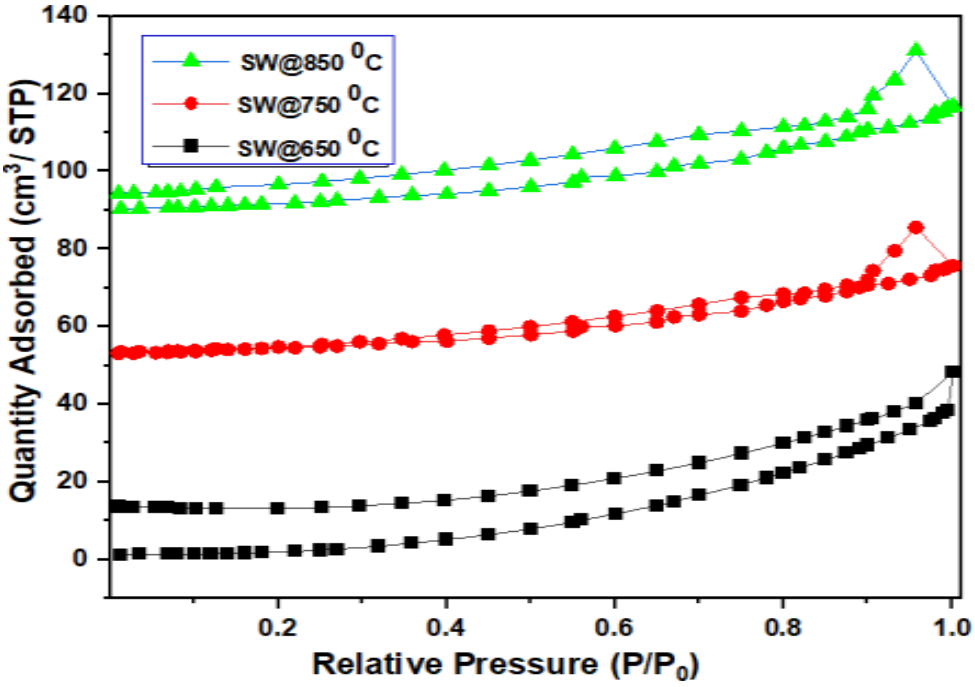


Figure 5: BET analysis showing surface area and porosity at varying pyrolysis temperature

FESEM Analysis

The FESEM images reveal that the surface of Bull Eye Seed-derived carbon becomes increasingly porous and rougher after thermal treatment. Lower-temperature samples retain a more compact surface, while higher-temperature samples show more visible pore channels and fragmented carbon texture. These morphological changes are consistent with the release of volatile compounds during carbonization.

The appearance of a more open and porous surface at higher temperature confirms the results obtained from BET analysis. It also suggests that Bull Eye Seed can produce a carbon structure with a morphology suitable for adsorption-related or electrochemical applications. However, the microstructural benefits of pore formation must still be balanced against possible losses in structural integrity.

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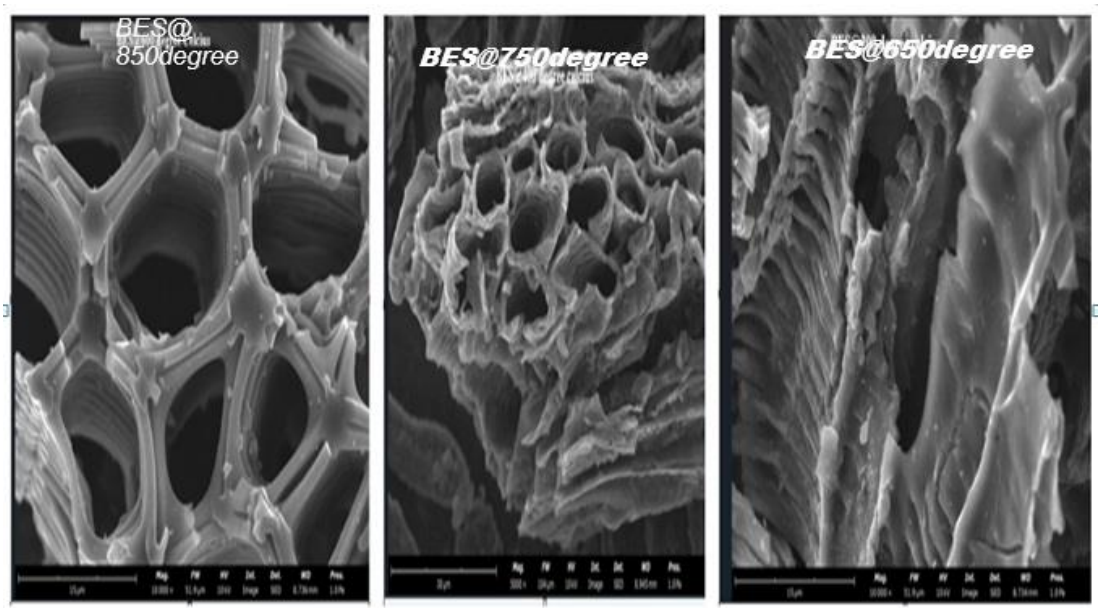


Figure 6: FESEM analysis showing surface morphology at varying pyrolysis temperature

CONCLUSION

Overall, the results show that Bull Eye Seed responds well to pyrolytic treatment and has promise as a precursor for activated carbon production. Increasing temperature improves carbonization, pore formation, and structural order, but also reduces yield and some surface functional groups. The data therefore point to a clear trade-off between porosity, chemical functionality, and material stability.

The most favorable pyrolysis condition will depend on the intended application of the carbon product. If the goal is maximum surface area and porosity, higher temperatures are preferred. If retention of surface oxygen groups or higher yield is more important, a moderate temperature may be better. In either case, the findings support Bull Eye Seed as a viable biomass precursor for sustainable carbon material development. Sequel to our findings, bull eye seed co-doped with other hetero atoms will make it usable in energy storage appliances.

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