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Comparative Characterization of Derived *Vignasubterranea (L.) verdc.* Adsorbents, Using Chemical and Steam Activation Methods

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ABSTRACT

Low-cost adsorbents were produced from Bambara nut (*Vignasubterranea (L.) verdc***.)** shells via chemical and physical activation using phosphoric acid and steam respectively. Acid activated Bambara nut shells (A-BBNSAC) and steam activated Bambara nut shells (S-BBNSAC) were characterized using Fourier Transform infrared (FTIR), Brunauer–Emmet–Teller (BET), Scanning electron microscope (SEM), Energy dispersive X-ray (EDX), Transmission electron microscope (TEM) and other physico-chemical properties. FTIR analysis indicated the presence of functional groups on both surfaces and the surface morphology showed the presence of well developed pores that are uniformly distributed over the surfaces and the elemental analysis revealed that carbon and oxygen were the major constituents in both adsorbents and the carbon contents were found to be 64.70 and 45.20 % for A-BBNSAC and S-BBNSAC respectively while the BET surface area for A-BBNSAC and S-BBNSAC were determined to be 580.42 and 1442.67 m^2/g respectively. The study concluded that S-BBNSAC could be used as adsorbent for removal of pollutants from aqueous solution.

Keywords: Activated carbon, Activation, Bambara nut, Chemical, Steam

INTRODUCTION

Activated carbon is an amorphous carbonaceous material with high degree of porosity and large surface area, usually produced from activation and carbonization of any carbonaceous materials with high carbon content and low inorganic contents such wood, shells, lignocellulosic materials and other agricultural by-products (Saleem *et al*., 2019). Activated carbon can be produced from different varieties of both natural and synthetic materials. Other less-expensive and renewable agricultural by-products such as nut shells, rice husk and lignocellulosic materials with high carbon and low ash content are also used in activated carbon production (Onyeji and Aboje, 2011). However, other expensive and non-renewable materials like petroleum residues, anthracite, coal, peat and lignite could also be used in activated carbon production for commercial purposes (Ahmedna, *et al*., 2000). The choice of starting materials in activated carbon production plays a very vital role in influencing the overall performance and properties of the resulting activated carbon (Campbell *et al*., 2012). The carbon content of activated carbon produced from agricultural by-products is generally lower than that of coal, peat or anthracite. However agricultural based activated carbons are cheaper compared to other materials (Malik *et al*., 2006). Different varieties of agricultural wastes that have been successfully used as adsorbents mainly for the removal of toxic pollutants such as dyes and heavy metals from aqueous solution includes; neem leaves (Ibrahim *et al*., 2015), pilli nut shells (Nwosu *et al*., 2107), date seeds (Theydon, 2018), rubber seed shells (Jiang and Sun, 2010), palm kernel, coconut and groundnut shells (Boadu *et al*., 2018). Yue *et al*. (2013a) reported a comparative study on activated carbons derived from leather waste using chemical and physical activation with phosphoric acid and steam respectively. The finding of the study revealed that the surface areas for chemical and steam based active carbons were 328.69 and 420.05 m^2/g respectively, the corresponding pore sizes were 3.198 and 3.083 nm respectively. However, the percentage yields obtained at carbonization temperatures of 400 and 700 °C were 40 and 18.25 % respectively. In another study conducted by (Yue *et al*. 2013b), the adsorptive performance of activated carbon obtained from black liquor lignin using steam activation was investigated for the removal of methylene blue dye from aqueous solution. The maximum adsorption capacity was found to be 92.51 mg/g at pH range of 5 – 6. Kim *et al*. (2013) investigated porous properties of activated carbon derived from polyacrylonitrile based nanofibers using chemical and physical activations with potassium hydroxide and steam respectively. The total surface areas were found to be 1040 and 2500

m^2/g for alkali and steam based activated carbons respectively while their corresponding micro volumes were determined to be 0.73 and 0.34 cm^3/g respectively. Adsorbent derived from cattle hair waste of tannery industry has been utilized for removal of textile dyes, namely acid brown 414 and acid orange 142 from aqueous solution. The study showed the maximum percentages removal of dyes at pH 3.65 were found to be 51.95 % and 49.73 % for acid brown 414 and acid orange 142 respectively (Mella *et al.,* 2019). Rice husk has been used as adsorbent for removal of heavy metals; Mn (II) and Fe (II) from aqueous solution, the findings of the study revealed that the maximum adsorption capacities obtained at 100 mg/L and pH 3 - 6 were 3.21 and 18.84 mg/g for Mn (II) and Fe (II) ions respectively (Adekola *et al.*, 2016).

In the present study, physico-chemical and spectroscopic characterization of activated carbons produced from Bambara nut *(Vignasubterranea (L.) verdc.)* shells via chemical activation with phosphoric acid and physical activation with steam were compared and reported.

MATERIALS AND METHODS

Materials

Bambara nut shells were used to prepare activated carbons by chemical and physical activation using phosphoric acid and steam respectively.

Methods

The precursor, Bambara nut shells (*Vignasubterranea (L.) verdc.)* was obtained from Dawakin - Kudu Town, Dawakin - Kudu Local Government Area Kano State Nigeria (11°50’05’’N 8°35’53’’E). The shells were washed with distilled water to remove all the adhered materials and other impurities. The Bambara nut shells were dried at room temperature for two weeks and finally dried in an oven at 105 °C for 2 hours. The shells were then ground using mortar and pestle and then sieved to obtain particles of less than 0.5 mm (500 µm) size and kept in an air-tight container for further use.

Preparation of activated carbon via chemical activation

A 50 g Bambara nut shells were impregnated using 100 mL of 2 M H_3PO_4 and then heated in an oven maintained at 110 °C for 7 hours. The Carbonization was done using a horizontal tubular furnace in the absence of air. The horizontal furnace was first degassed by allowing N_2 to flow into the pyrolyser at 500 mL/min for 30 minutes. The activated samples were then carbonized in a horizontal tubular furnace at 400 °C and at a heating rate of 16°C/min under the flow of N_2 gas (500 mL/min) for 2 hours. The carbonized samples were cooled to room temperature under N_2 flow, washed several times with de-ionized water until neutral pH. It was then dried in oven at 110 °C for 7 hours. The dried samples were stored in an air-tight plastic container (Gomez-Tamayo *et al*., 2008).

Preparation of activated carbon via steam activation

Oxidation, carbonization and activation processes

A known quantity (70 g) of the sample was loaded in a hollow quartz glass tube and placed in activation horizontal tubular reactor furnace. N_2 gas at a flow rate of 750 mL/min was allowed to pass through the reactor for 30 minutes and the sample was then pyrolysed at 400 °C for 30 min in the presence of N_2 at flow rate of 1000 mL/min and heating rate of 20 °C/min. The activation process involved separate heating of sample under presence of nitrogen/steam mixture that was achieved via nitrogen supply with flow rate of 750 mL/min through a heated water bath kept at constant temperature of 90 ± 2 °C to a specified final temperatures of 400 °C for 30 min. Figure 1 shows the schematic diagram for the steam activation laboratory reactor coupled with horizontal tube furnace. A heating belt was used to cover the quartz glass and avoid condensation of vapours and thus prevent glass breakage. The activated carbon sample was finally allowed to cool inside quartz tube under flow of nitrogen/steam mixture (Nwosu *et al*., 2011).

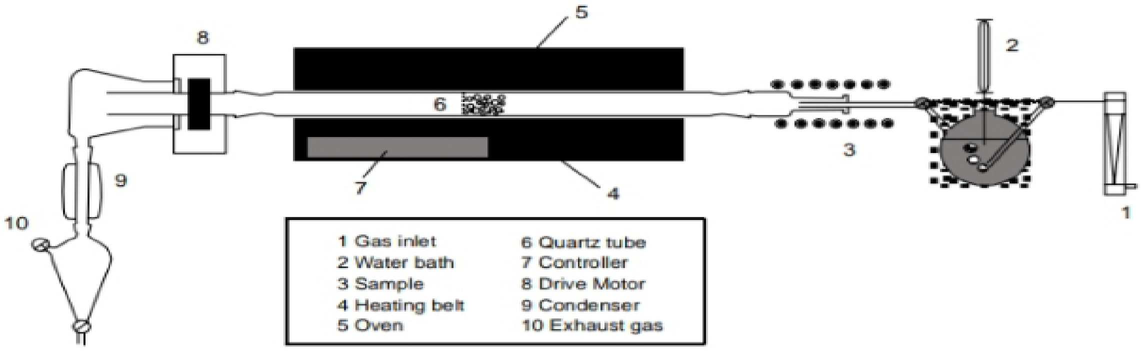


Fig. 1: Schematic diagram of the horizontal tube furnace for steam activation process (Nwosu *et al*., **2011)**

Determination of moisture and ash content

A clean and dried empty crucible was placed in an oven for about 30 minutes at 100 °C and it was allowed to cool in a desiccator and then weighed as W_0. A 2.0 g of the sample was weighed into the crucible and weighed as W_1 and it was then heated in an oven at 105˚C until constant weight was obtained. The crucible and its content was allowed to cool in a desiccator and then weighed as W_2. While for ash content, 1 g of the sample was placed in a crucible of known weight and then heated at 500 °C for 2 hours in a murfle furnance (carbolite ELF 11/1AB). The sample was allowed to cool in desiccator and weighed and it was done triplicates (AOAC, 1990). Moisture and ash contents were determined using Equations. 1 & 2.

$$\text{Moisture (\%)} = \frac{W_0 - W_2}{W_1 - W_0} \times 100 \qquad (1)$$

$$\text{Ash (\%)} = \frac{W_1 - W_2}{W_1 - W_0} \times 100 \qquad (2)$$

W_0 = Weight of the empty crucible, W_1 = weight of the crucible + sample before drying and
W_2 = weight of the crucible + sample after drying/ashing

Determination of volatile content

A 2g of the sample was heated to about 300˚C for 10 minutes in a partially closed porcelain crucible placed in a muffle furnace. The crucible and its content were removed and allowed cooled in a dessicator. This was done in triplicates. The difference in weight was recorded and the percentage of volatile content was determined using equation 3 (Olaniyi *et al*., 2012).

$$V_c(\%) = (W_o - W_a) \times 100 \qquad (3)$$

Where Vc = volatile content, W_0 = initial weight of the sample and Wa = final weight of the sample after cooling

Determination of fixed carbon

Fixed carbon indicates solid combustible residue that remains after volatile matter is removed. The fixed-carbon content of sample was determined from moisture, ash and volatile matter by equation 4 (Olaniyi *et al*., 2012).

$$\text{Fixed carbon (\%)} = 100 - V_m + A + M \qquad (4)$$

Where Vm (%) = volatile matter, A (%) ash content and M (%) is the moisture content

Determination of bulk density

A clean and dried 10 mL measuring cylinder was weighed and recorded as W_0, then the sample was poured inside the clean and previously weighed 10 mL measuring cylinder. The cylinder with the sample was then tapped for 200 counts, thereby compacting the sample so that the volume of the sample dropped to a volume V (mL). The measuring cylinder and the sample was then weighed and recorded as W_2. This was done triplicates (Okeimen *et al.*, 2004).The bulk density was determined by equation 5

$$\text{Bulk density (g/cm}^3\text{)} = \frac{W_2 - W_0}{V} \qquad (5)$$

Determination of pH

A known quantity of the sample was weighed separately and dissolved in 100 mL of de-ionized water. The mixture was then heated to 100 ˚C and kept at that temperature for 15 minutes after which it was allowed to cool to 70 °C and then filtered. The filtrate was then allowed to cool to room temperature. The pH of the filtrates was then measured and recorded using a digital pH meter (HI 9813-6) and it was run in triplicates (Okeimen *et al*., 2004).

Determination of point of zero charge (PZC)

Point of zero charge (P_{ZC}) was determined using pH method by adding 0.1 g of the sample to 200 mL of 0.1 M NaCl. The initial pH (pHi) of NaCl solutions in different flasks to which the samples were added was adjusted with 0.1 M NaOH or 0.1 M HCl to pH value 1–12. The flasks were covered and shaken for 24 h after which the final (pHf) was measured using pH meter INOLAB pH 7310. From the graph of plot of change in pH (pHi–pHf) against the initial pH, the point of intersection gives pHpzc (Ekpete and Horsfall, 2011).

Determination of iodine number

Iodine number is defined as the milligrams of iodine adsorbed by 1.0 g of activated carbon.

Activated carbon sample was treated with 10.0 mL of 5% HCl and boiled for 30 seconds and subsequently cooled. About 100 mL of 0.1 N iodine solution was added to the mixture and stirred for 30 seconds. The resulting solution was filtered and 50 mL of the filtrate was titrated with 0.1 N sodium thiosulfate and using starch as indicator until the solution turns to pale yellow. 2 mL of starch indicator solution was added and the titration was continued with 0.1 N sodium thiosulfate until one drop produces a colorless solution (ASTM, 2006).

The iodine amount adsorbed per gram of activated carbon (*X/M*) was determined as follows:

$$\text{Iodine number } X/M \text{ (mg/g)} = \frac{[A-(DF)(B)(S)]}{M} \qquad (6)$$

Where A = N_2× 12693, B =N_1×126.93, DF = Dilution factor equals to 2.2 when 10 mL of HCl and 50 mL of the filtrate are used, S (mL) = Volume sodium thiosulphate used, N_1 = Normality of iodine, N_2 = Normality of sodium thiosulphate and M (g) = mass of the activated carbon used.

Surface/structural characterization of the activated carbons

The functional groups present in the activated carbons were determined using Fourier Transform Infrared Spectrometer (Nicolet IS10 FTIR spectrometer). The specific surface areas and pore volumes were determined by Brunauer–Emmet–Teller (BET) method using nitrogen adsorption at 77K by using automated surface area analyzer (JW-DA 76502057en). The surface morphology and elemental compositions were determined using scanning electron microscopy (SEM) coupled with EDX (JOEL-JSM-7600F) while Transmission Electron Microscopy (TEM-ARM200F-G Verios 460L) was used to determine the shape and sizes of the activated carbon.

RESULTS AND DISCUSSION

The physicochemical properties of activated carbons derived from Bambara nut shells using chemical and physical activations are presented in Table1.

Table 1: Physicochemical properties of activated carbons

Parameters	A-BBNSAC	S-BBNSAC
Yield (%)	41.67±0.33	24.59±1.24
Moisture content (%)	5.99±0.31	2.19±0.06
Ash content (%)	8.1±0.01	8.1±0.01
Bulk Density (g/cm^3)	0.518±0.004	0.518±0.004
Volatile matter (%)	31.30±0.12	31.30±0.12
Fixed carbon (%)	54.61±0.03	58.41±0.05
pH	6.87±0.05	7.53±0.40
pH_{PZC}	6.4	7.5
Iodine number (mg/g)	1102.77±8.11	406.62±11.47

The Percentage yields of the activated carbons produced were found to be 41.67±0.33 and 24.59±1.24 % for A-BBNSAC and S-BBNSAC respectively. It was found that the percentage yield obtained for chemical based activated carbon was higher than that of steam based activated carbon. However, the carbon yield obtained in A-BBNSAC fell within the reported values (41.4 - 58.6 %) required for industrial applications (Raffiea *et al*., 2012). It was also observed that the percentage yields of both activated carbons were found to be lower in comparison to the reported yields of 55.7 % (Momcilovic *et al*., 2011) and 62.73 % (Anisuzzaman *et al*., 2015).

Moisture content is the amount of water present in the sample and its presence has no significant influence on the overall performance on adsorption capacity (Moyo *et al*., 2013) The moisture contents were found to be 5.99±0.31 and 2.19±0.06 % for A-BBNSAC and S-BBNSAC respectively. The results indicated that the steam based activated carbon had the least moisture content in comparison to chemical based activated carbon and the value obtained in S-BBNSAC could be attributed to high carbonization temperature during manufacturing processes and the value was also lower than the reported values of 7.43 % (Nwosu *et al*., 2011) and 12.0 %; (Dada *et al*., 2012).

Ash content indicates amount of inorganic constituents present in the sample and it usually increases with an increase in carbonization temperature and decrease in the percentage of volatile matter. The ash content was obtained from the raw sample and it was found to be 8.1±0.01 % for both A–BBNSAC and S-BBNSAC. The ash content generally has a significant influence on the adsorption capacity, low ash content in the precursor is an indication of good activated carbon and thus leads to better adsorption performance (Anisuzzaman *et al*., 2015). The values obtained in the present study fell within the range of ash content values (0.2 – 13.4 %) for most of the agricultural products such as rice straw, corn cobs, cotton stalks (Ioannidou and Zabaniotou, 2007).

Bulk density indicates the fiber contents of the precursor. It could be observed from Table 1 that the bulk density value for the precursor (Bambara nut shell) was determined to be 0.518±0.04 g/cm^3. Bulk density value of less than 1.2 g/cm^3 is an indication of good adsorbent, low bulk density value usually leads to better adsorption performance (Moyo *et al*., 2013). However, the value obtained is in good agreement with some of the reported values 0.52 g/cm^3 (Moyo *et al*., 2013), 0.34 g/cm^3 (Theydan, 2018) obtained using different precursors, but higher than that of commercial activated carbon 0.35 g/cm^3 (Nwosu *et al*., 2017).

Volatile matter is the amount of combustible matter present in the activated carbon precursor when subjected to a high temperature. The values were found to be 31.3±0.12 % for both A-BBNSAC and S-BBNSAC, higher than the range of values (19.8 – 24.5 %) reported elsewhere in the literature (Raffiea *et al*., 2012). However, 40.34 % have been reported from activated carbon derived from black liquor lignin via physical activation with steam (Yue *et al*., 2013). It has been reported that at longer carbonization period, more volatiles are released from the char and usually results in higher burn off and subsequently lower the carbon yield (Martinez *et al.*, 2006). Fixed carbon represents the amount of solid combustible residue that remains after volatile matter has been removed from the sample and it was found that the values for A-BBNSAC and S-BBNSAC were 54.61±0.03 and 58.41±0.05 % respectively. The value obtained for A-BBNSAC in the present study was in good agreement with reported value (54.80 %) obtained via acid activation (Kibami *et al.*, 2014). However, the value obtained S-BBNSAC was much higher than the reported value (13.27 %) via steam activation (Yue *et al.*, 2013).

pH is measure of acidity or alkalinity of the adsorbent and it depends on many factors such as method of preparation, inorganic matter content, chemical active groups on the adsorbent surface as well as the type of treatment to which the adsorbent was subjected (Gan *et al.*, 2004). The pH values for A-BBNSAC and S-BBNSAC were 6.87 and 7.53 respectively. The study revealed that A-BBNSAC was slightly acidic in comparison to S-BBNSAC and this could be attributed to the presence of phosphoric used during manufacturing process whereas the alkalinity nature of the adsorbent could be due dissociation of hydroxyl ion OH^- present in the compound when dissolved in water due to hydrolysis (Adegoke *et al.*, 2020). However, pH values of 7.31 and 4.06 were reported for activated carbons obtained via chemical and steam activation respectively (Kibami *et al.*, 2014; Nwosu *et al.*, 2011).

Point of zero charge (pH_{pzc}) is pH at which the net charge on the surface of adsorbent is equals to zero. It has been reported that at pH < pH pzc the adsorption of anions is favoured while at pH > pH pzc adsorption of cations is favoured (Govindasmay *et al.*, 2009). pH_{pzc} for A-BBNSAC and S-BBNSAC were determined to be 6.4 and 7.5 respectively. This suggested that both adsorbents would favour the adsorption of cations (Mall *et al.*, 2006).

Iodine number is most important parameter that used to characterize the performance of activated carbon. The value of iodine number obtained for A-BBNSAC (1102.77±8.11 mg/g) was much higher than that of S-BBNSAC (406.62±11.47 mg/g). However, iodine value of 190 mg/g (Raffiea *et al.*, 2012) and 901 mg/g (Nwosu *et al.*, 2011) has been reported. Iodine number can also be used to measure of activity level and it gives a rough estimate of the surface area of the activated carbon at room temperature and it can also be used as an indicator of the porosity of the adsorbent surface as well adsorbent adsorption performance (Raffiea *et al.*, 2012).

INSTRUMENTAL CHARACTERIZATIONS

FTIR analysis

FTIR analysis is very useful in determining the surface functional groups present on the surface of activated carbon, presence of oxygen functional group on the surfaces promotes iron-exchange mechanism which eventually improve the adsorption efficiency towards uptake of metal ions (Sun *et al.*, 2010). The FTIR spectra for A-BBNSAC and S-BBNSAC activated carbons are presented in Figs. 2 & 3. The presence of a broad absorption bands at 3465 and 3441 cm^{-1} as shown in the FTIR spectra of A-BBNSAC and S-BBNSAC are typically attributed to the presence of hydroxyl (O-H) group of aliphatic alcohol, phenol, or adsorbed water molecules. It has also been observed in both spectra that the presence of absorption peaks located between 2934.47 - 2870.92 cm^{-1} could be assigned to C-H stretching (Anisuzzaman *et al.*, 2015). Absorption band located around 1637.14 cm^{-1} in the FTIR spectrum of A-BBNSAC could be attributed to O-H bending vibration while absorption band around 1799.38 cm^{-1} could be due to stretching vibrations of C=O (Anisuzzaman *et al.*, 2015). However, it could be observed from FTIR spectrum of A-BBNSAC that the presence of peaks located between 1161.00 - 1127.00 cm^{-1} could be caused as a result of stretching vibrations of phosphorus containing groups such as P-O-C linkage or P=OOH and similar observation has been reported (Puziy *et al.*, 2002). Similarly, the presence of absorption peaks in A-BBNSAC and S-BBNSAC situated at 599.78 and 366.38 cm^{-1} respectively could due to metal-oxygen stretching vibration.

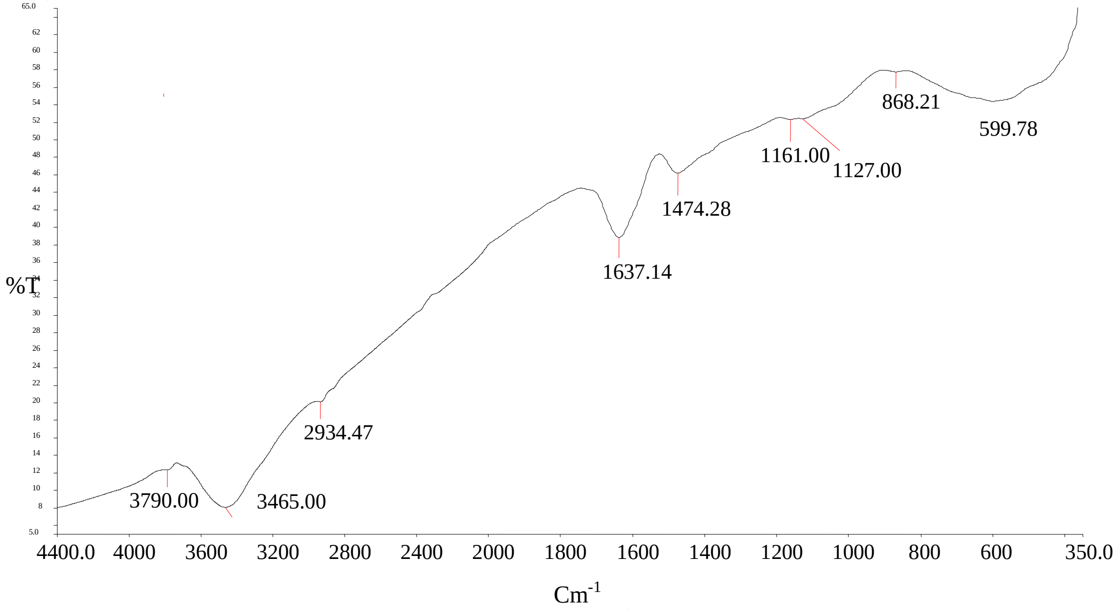


Fig. 2: FTIR spectrum of A-BBNSAC

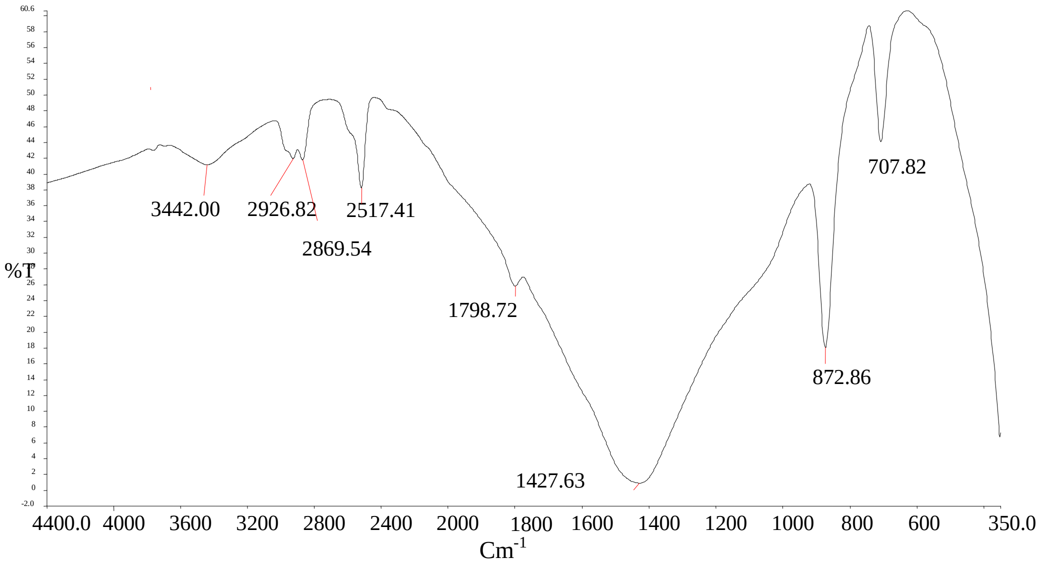


Fig. 3: FTIR spectrum of S-BBNSAC

BET Analysis

Table 2 presents the BET surface area, pore volume and pore size of the prepared activated carbons. It was observed that A-BBNSAC had lower surface area in comparison to S-BBNSAC and their corresponding values were 580.42 and 1442.67 m^2/g respectively. However, both A-BBNSAC and S-BBNSAC had a good surface areas that fell within the minimum range (400 – 1500 m$^{2/}$g) required for industrial applications and the higher surface of activated carbon is an indication of its suitability to be used as adsorbent in waste water treatment (Bansal and Goyal, 2005). Micropore volumes for A-BBNSAC and S-BBNSAC were found to be 0.12 and 0.15 cm^3/g respectively and these variations could attributed to carbonization temperature, generally at low temperature, microspores are predominant, but with rise in temperatures they becomes enlarge and the walls between pores collapsed and thus formed mesopores. This observations is in line with other findings (Jiang and Sun, 2010). The corresponding total pore volumes were found to be 0.54 and 0.45 cm^3/g for A-BBNSAC and S-BBNSAC respectively. Pore volumes of 0.708 and 0.67 cm^3/g have been reported (Jain *et al*., 2018; Jiang and Sun, 2010).

Table 2: Surface area and porosity measurement of activated carbons

Sample	BET surface area (m^2/g)	Micropore volume (cm^3/g)	Mesopore volume (cm^3/g)	Total pore volume (cm^3/g)	Pore size (nm)
A-BBNSAC	580.42	0.12	0.42	0.54	1.84
S-BBNSAC	1442.67	0.15	0.30	0.45	3.44

The pore sizes were found to be 1.84 and 3.44 nm for A-BBNSAC and S-BBNSAC respectively. However, according to IUPAC classification, pore sizes have been classified into micropore (1-2 nm), mesopore (2-50 nm) and macropores (greater than 50 nm). It could be observed in the present study that the value obtained in A-BBNSAC fell within 1-2 nm which indicates the affinity of the derived adsorbents for micro sized pollutants such as toxic metal removal while for S-BBNSAC, the value obtained lies between 2-50 nm and thus indicating mesoporous material (Williams and Reed, 2006).

SEM-EDX analysis

The results of physical surface morphology for A-BBNSAC and S-BBNSAC are presented in Figs. 4 & 5. It was observed that the SEM analysis for A-BBNSAC revealed the presence of porous surface with wider exterior opening that resembles a honeycomb pattern. A similar observation has been reported (Adegoke *et al*., 2017). However, SEM analysis for S-BBNSAC showed the presence of rough surface consisting of long horizontal tubes with well developed opened pores arranged in a regular pattern distributed over the surface of the material. The presences of pores in both A-BBNSAC and S-BBNASC have strongly indicated their applicability as adsorbent for the removal of metal ions and other contaminants from aqueous solution (Akpomie and Dawodu, 2015).

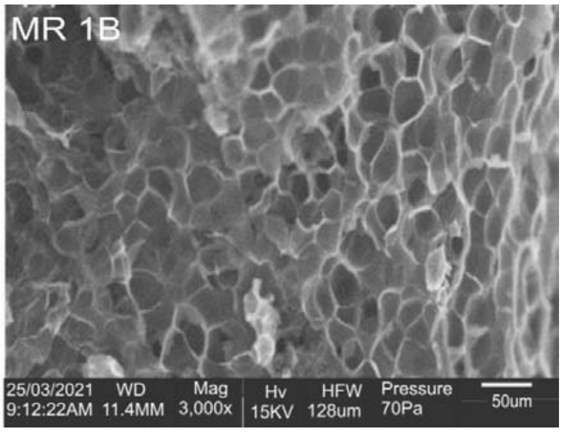


Fig. 4: SEM micrographs of A-BBNSAC

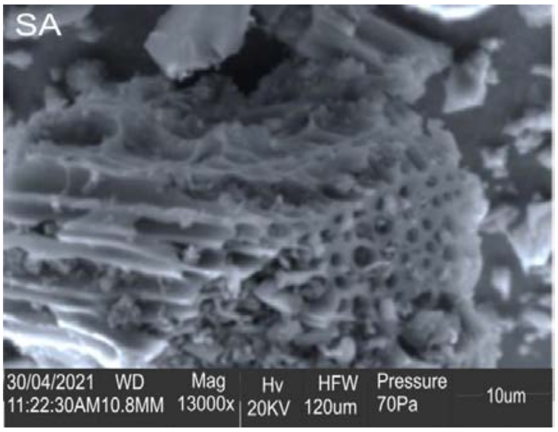
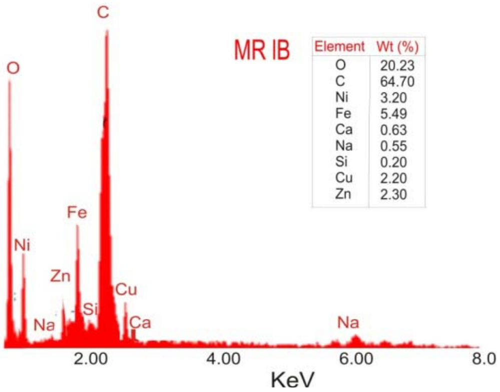


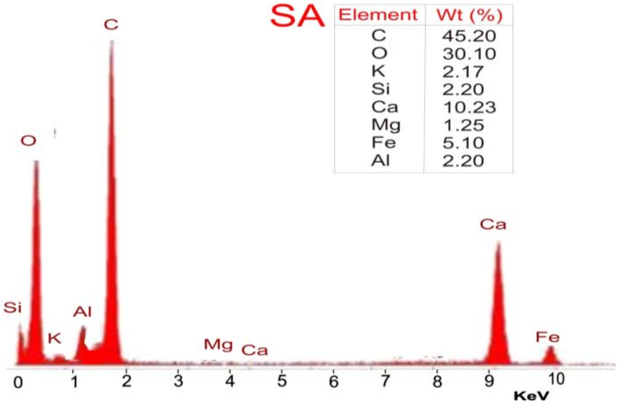
Fig. 5: SEM micrographs of S-BBNSAC

The EDX analysis for elemental compositions are shown in Figs. 6 & 7 and it was observed that carbon and oxygen constituted the major elements with corresponding percentages of 64.7 % carbon and 20.3 % oxygen in A-BBNSAC and 45.20 % carbon, 30.10 % Oxygen for S-BBNSAC. Presence of carbon high amount in both prepared samples is an indication of the presence of activated carbon (Arogundade *et al*., 2021; Jain *et al*., 2018). However, other elements presents in the samples might have been originated from the plant source or during manufacturing processes.



Element	Wt (%)
O	20.23
C	64.70
Ni	3.20
Fe	5.49
Ca	0.63
Na	0.55
Si	0.20
Cu	2.20
Zn	2.30

Fig. 6: EDX spectrum of A-BBNSAC



Element	Wt (%)
C	45.20
O	30.10
K	2.17
Si	2.20
Ca	10.23
Mg	1.25
Fe	5.10
Al	2.20

Fig. 7: EDX spectrum of S-BBNSAC

TEM analysis

TEM analysis for size and shape was conducted only on A-BBNSAC and it was revealed from Fig. 8 that the prepared adsorbent indicated the presence of mono dispersed and spherical shaped particles with an estimated particle sizes between 11.1 – 24.4 nm.

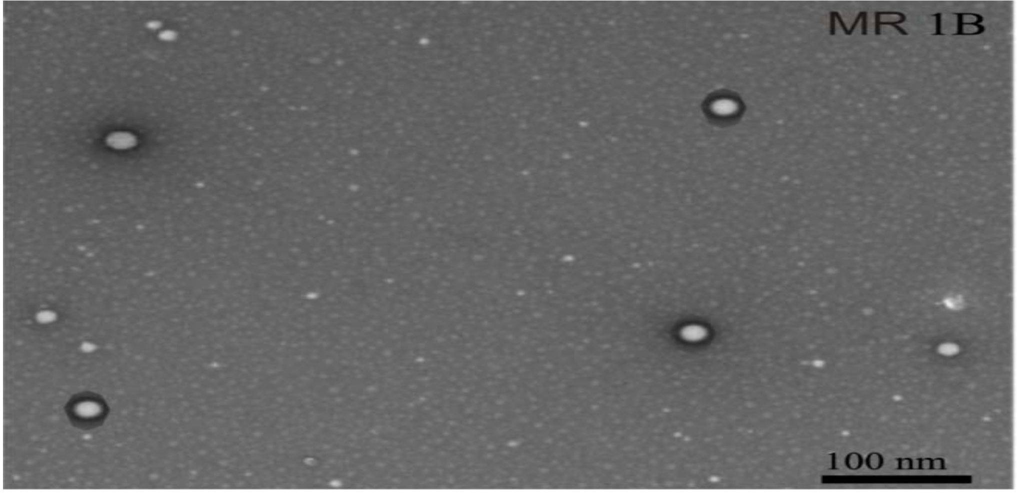


Fig. 8: TEM micrograph of A-BBNSAC

CONCLUSION

The present study demonstrated the possibility of using locally available agricultural waste material derived from Bambara nut shells as adsorbents for the removal of pollutants from aqueous solutions. Carbon and oxygen were found to be the major constituents in both adsorbents and also the various surfaces were found to contain micro porous structures and thus indicating their applicability as adsorbent. However, it was observed the activated carbon produced using physical activation with steam was found to have low moisture content, high fixed carbon and better surface area indicating its suitability for use as adsorbent in comparison to its corresponding chemical based activated carbon.

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CONFLICT OF INTEREST:

The authors declare no any conflict of interest

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