

# Production, characterization and application of activated carbon from cocoa pod husk and banana peel using chemical impregnation (sulphuric acid) for soil amendment

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**Abstract:** This research produced and characterised cocoa pod husk activated carbon (CPHAC) and banana peel activated carbon (BPAC) and applied them to degraded soils. The samples were characterised using Brunauer-Emmett-Teller (BET) and Barrett-Joyner-Halenda (BJH) methods to determine the surface area and pore volume of the activated carbons. A composite sampling technique was employed to obtain soil samples from agricultural land. The study used a completely randomised block design to amend the soil. The amended soils were analysed using standard methods. The results indicated that the surface areas for impregnated and non-impregnated CPHAC and BPAC, as determined by BET, were 570 m<sup>2</sup> g<sup>-1</sup> and 533 m<sup>2</sup> g<sup>-1</sup>, respectively, while their Dubinin-Radushkevich micropore volumes were 0.201 cc g<sup>-1</sup> and 0.190 cc g<sup>-1</sup>, respectively, implying that CPHAC and BPAC exhibited a higher adsorptive capacity than their non-impregnated counterparts, increasing the NPK levels from 1.48, 7.38, and 0.22 to 2.62, 28.45, and 1.32, respectively. The results included that CPHAC and BPAC increased the NPK levels in the soil by 1.77, 3.86, and 6 times, respectively. The CPHAC and BPAC as organic fertilisers are effective in amending degraded soils. Cocoa pod husk and banana peel can be used as activated carbon for soil amendment and enhancing crop production.

**Keywords:** cocoa husk pod, banana peel, chemical impregnation, activated carbon, soil amendment

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## 1 Introduction

Activated carbon (AC) is the most suitable material for water purification, discolouration, and biogas purification because of its relatively low cost, pore volume, high adsorbent energy, high porosity, and high surface area (Tiegam et al., 2021). Plantain peels and other lignocellulosic materials that are high in carbon are common sources of it (Tamfuh et al., 2021), cocoa

pod husk (CPH) (Cruz et al., 2012), rice husk (Zhou et al., 2021), and bamboo (Kuti et al., 2018a). However, more research is needed on banana peels with CPH. The production of CPH and banana peels is a source of revenue generation in Ecuador (Velázquez-Araque et al., 2023). CPH and banana peel were significantly produced in Nigeria, as both crops increased our economy and released high environmental pollution rates. Changing the form of agricultural wastes can

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reduce environmental pollution and generate income and organic fertiliser. Agricultural wastes could be modified using activated carbon (Kuti et al., 2018a). Activated carbon involves the burning of wastes in the furnace at higher temperatures, ranging from 350 °C to 650 °C, and impregnated CPH and banana peel using either physical or chemical activation (Cruz et al., 2012; Kuti et al., 2018a; Velázquez-Araque et al., 2023). Conversion of agricultural wastes into activated carbon would effectively reduce odor, reduce the growth of harmful micro-organisms, and minimize pollutants associated with waste decomposition.

Cocoa husk pods serve as a raw material for adsorbent, removal of dye from aqueous solutions, and removal of four-nitrophenol from aqueous solution treatment water (Theivarasu and Mylsamy, 2010; Bello et al., 2011; Ahmad et al., 2011), removal of heavy metals from water/wastewater (Cruz et al., 2012). Cocoa husk pods also have no effects on soil organisms (Beesley et al., 2011), remove dye from aqueous solutions, and remove four-nitrophenol from aqueous solution treatment water (Theivarasu and Mylsamy, 2010; Bello et al., 2011; Ahmad et al., 2011). In addition, Zhou et al. (2021) produced rice husk activated to sequester harmful pollutants from contaminated soils effectively. It was also produced to treat heavy metals like arsenic in the surface and groundwater, which was effective (Cruz et al., 2012). Furthermore, Velázquez-Araque et al. (2023) produced activated carbon from CPH and banana peels using phosphoric acid ( $H_3PO_4$ ) and sulphuric acid ( $H_2SO_4$ ). Their results showed that activated carbon with sulphuric acid has a high surface area, but they did not apply this biochar to either treat water/wastewater or amend degraded soil, indicating a lack of practical knowledge gap. This research produced cocoa pod husk activated carbon (CPHAC) and banana peel activated carbon (BPAC) from CPH and banana peel because it would minimize waste litter around farmland, eliminate foul odours, reduce the breeding of pathogenic micro-organisms, amend degraded soils, and serve as an alternate organic fertiliser. It also

hypothesised the following research question: (i) can CPHs and banana peels produce activated carbon that would amend the soil, (ii) can  $H_2SO_4$  be used to produce activated carbon that amends the soil.

## 2 Materials and methods

The materials used for this study include: CPH, banana peel, and soil. The reagents used for this study were as follows: distilled water, sulfuric acid ( $H_2SO_4$ ) (Loba Chemie PVT. Ltd, Manufacture date: June 2022), and liquid nitrogen (Sheda Science and Technology complex). The equipment used for this study was as follows: muffle furnace (model number: HSX-2-6-13 and serial number: 20220412), electronic weighing balance (Metlab electronic compact scale, SF-400C), ultraviolet spectrophotometer (Jenway, Model 6300), cutlass, porosimeter (ASAP 2020 model from micrometric), oven dryer (model number: PBS118SF and serial number: 94L234), buhr mill (model number: XM0240X90 and year: June 2022), crucible, oven (hot air oven, drier box AX-OV73), flame photometer (Jenway, Model PFP7), and nova 4200e (model number:1413052102).

### 2.1 Preparation of activated carbon

CPH and banana peels were sun-dried, reduced to smaller sizes (Plate I), and washed with distilled water to remove external waste particles. The washed CPH and banana peel pieces were dried in an oven (model number: PBS118SF and serial number: 94L234) at 105 °C for 24 hours to remove moisture content (Figure 1).



Figure 1 Pieces of cocoa pod husk and banana peel during sun-dried and oven-dried



Figure 2 Carbonisation of cocoa pod husk and banana at the Muffle furnace

The sample was later crushed to sizes of 0.25 mm and 0.5 mm (Figure 3a and Figure 3b) with a buhr mill

(model number: XM0240X90 and serial number: 80220452).



(a) Crushed cocoa pod husk



(b) Crushed banana peel

Figure 3 Crushed cocoa pod husk and banana peel before impregnation



(a) Cocoa pod husk



(b) Banana peel

Figure 4 A Impregnation of cocoa pod husk and banana peel with sulfuric acid ( $H_2SO_4$ )

The crushed samples were divided into two portions and accurately weighed 50 grams each. The first sample was non-impregnated, and the second sample was impregnated with sulfuric acid of 10% concentration level for 24 hours until the mixed sample turned into a paste to the level of activation carbon properties as shown in Figure 4a and Figure 4b (Kuti et al., 2018a; Rangari and Chavan, 2017). Each sample was impregnated with sulphuric acid independently, a

process that has not been documented in the literature. The impregnated sample was neutralized with distilled water and then filtered; the residue remaining after filtering was collected and dried at 105 °C for 2 hours (Kuti et al., 2018a). In this study, 1 kg of CPHAC and BPAC was measured, and their mixture ratio was 4:1, which implies that 750 g of CPH and 250 g of banana peel were manually mixed.

## 2.2 Characterization of activated carbon

This research used the Brunauer-Emmett-Teller (BET) theory, which relates the amount of adsorbate on the surface to its pressure, to test the applicability of the activated carbon produced from CPH and banana peel on the soil. The surface area and porosity of the CPHAC and BPAC would also adsorb the soil, thereby increasing the soil nutrients. CPHAC and BPAC would also help mitigate soil acidity, improving pH levels conducive to crop production. It also enhances the physical soil properties, including structure and water retention capacity. Using CPHAC and BPAC would provide an alternative organic fertilizer and cost-effective materials for soil amendment, contributing to waste reduction and sustainable agricultural practices. Therefore, this study aims to produce, characterize, and apply CPHAC and BPAC to amend degraded soils in the farmland at the Federal University of Technology, Minna, Gidan Kwano Campus.

The BET theory was used to determine the surface area of the CPH and banana peel according to Brunauer et al. (1938) and Rouquerol et al. (2013), respectively. The samples were degassed at 523°C for 3 hours for moisture and removal. The degassed samples were then analysed for physisorption of the adsorbate (nitrogen) by the adsorbent in liquid nitrogen environment on the surface (Ishaq et al., 2015). Every sample weighing about 0.05 g was utilised in each adsorption experiment.

### 2.3 Soil sample collection

This study collected soil samples at the 0-30 cm depth (rooting zone) from agricultural farmland at the Federal University of Technology Minna, Gidan Kwano campus. A single composite sample was formed from the site (Kuti et al., 2018b), placed in clean plastic, labelled, and taken to the laboratory for analysis. The composite soil sample was divided into three parts, one of which served as a control. The experiment was carried out at the Laboratory for 24 hours. The Nitrogen (N), Phosphorus (P), and Potassium (K) in each sample were also analysed as described by Okalebo et al. (2002).

### 2.4 Design of experiment

#### 2.4.1 Experimental design

The study used a completely randomised block design with three factors: a control soil sample, agricultural soil, CPHAC, and BPAC with sulphuric acid, and agricultural soil, CPHAC, and BPAC without sulphuric acid. The factors were replicated three times, making them 9 pots (Appendix III). The pots were kept in the laboratory for 24 hours and subjected to nitrogen, phosphorus, and potassium.

#### 2.4.2 Determination of nitrogen, phosphorus, and potassium in the amended soil

The amended soils were subjected to nitrogen, phosphorus and potassium tests as follows:

##### 2.4.2.1 Nitrogen

The procedure began with weighing 1 g of the air-dried soil sample and placing it into a 500 mL Kjeldahl digestion tube. A tablet of Selenium was then added as a catalyst to the tube, followed by the addition of 20 ml of concentrated sulfuric acid ( $H_2SO_4$ ). The digestion tube was transferred to a digestion block, where it was allowed to digest for three hours at 400 °C until a colorless solution was obtained (Okalebo et al., 2002). After digestion, the sample was removed and allowed to cool. Distilled water was added to the bottle containing the digested sample. Once properly mixed, the sample was carefully transferred into a sample bottle and made up to the 50 mL mark with distilled water. 10 ml of boric acid, along with three drops of mixed indicator, was added into a 100 mL conical flask, ensuring that the tip of the condenser was placed in this solution. The Kjeldahl flask was then attached to the distillation apparatus, and 10 mL of 40% sodium hydroxide (NaOH) was added through the distillation flask by opening the funnel. The concentration and distillation processes were then initiated while maintaining a cold temperature of 30°C in the condenser by allowing sufficient cold water to flow through and regulating the heat source to minimize frothing and prevent any suck-back. 50 mL of distillate was collected and titrated with 0.1N hydrochloric acid (HCl) to determine the nitrogen content in the sample.

##### 2.4.2.2 Phosphorus

A porcelain crucible was filled with 1.0 g of the soil. The sample was then poured into a different porcelain crucible, which was placed inside a muffle furnace. The temperature gradually rose over an hour until it reached 550 °C, where it was maintained for an additional hour. After this heating period, the crucible was removed from the furnace and allowed to cool before digestion with 10ml Aqua Regia for 30 minutes. The sample was then filtered into a 100 mL polypropylene bottle using a whatman filter paper. A 10 mL aliquot of the extract was then pipetted into a 50 mL volumetric flask that had been adjusted with water to the mark. A spectrophotometer was used to determine the phosphorus content in the soils.

#### 2.4.2.3 Potassium

0.5 g of ground, sieved soil (with particle size less than 1 mm) that had been either oven- or air-dried was weighed and placed into an acid-washed porcelain crucible. The crucible was then placed in a muffle furnace, where the temperature gradually increased to 500 °C for 2 hours, allowing it to sit in the furnace for a minimum of 4 additional hours. After this period, the crucible was removed from the furnace and allowed to cool. Once cooled, the crucible was filled with 10 mL of 6 M HCl and then covered (Okalebo et al., 2002). It was preheated in a steam bath for 15 minutes. Following this, 1 mL of nitric acid (HNO<sub>3</sub>) was added, and the mixture was heated in a water bath for 30 minutes. 10 mL of water was also added, along with swirling in another 1 mL of 6 M HCl, and the mixture was reheated in the steam bath once more to achieve total disintegration. After allowing the mixture to cool, it was strained through Whatman No. 541 filter paper into a 50 mL volumetric flask, with water added to reach the appropriate level. A flame photometer was used to determine the potassium content in the soil.

#### 2.5 Soil amendment

The composite soil sample, predominantly sandy soil, was taken from the agricultural land at Gidan Kwano (Latitude: 9.5387 N, Longitude: 6.4480 E; Latitude: 9.5384 N, Longitude: 6.4475 E; Latitude: 9.5387 N, Longitude: 6.4457E; Latitude: 9.5382 N, Longitude: 6.4471 E). The sample was labelled as samples A and B,

respectively. Two cylinders labelled A and B were used for this study. The quantity of CPHAC and BPAC needed was determined by estimating the cylinder area where the soil was kept, with a height of 25 cm and a diameter of 30 cm. 5 g of both impregnated and non-impregnated CPHAC and BPAC were added to the soil in the two cylinders. This study used a proportion ratio, and 2.5 t ha<sup>-1</sup> of fertiliser was determined for the soil in each cylinder.

#### 2.6 Data analysis

The surface areas of both impregnated and non-impregnated CPHAC and BPAC were determined using the BET method with Nova 4200e (Ishaq et al., 2015). The equipment analyzed and generated results in descriptive statistics such as mean values and correlation coefficients.

### 3 Results and discussion

#### 3.1 Characterization of bamboo activated carbon

Both CPHAC and BPAC with sulphuric acid were characterized by Nitrogen gas analysis at 523 °C. Appendices I and II showed multi-point BET plots for CPHAC and BPAC with and without sulphuric acid. Also, the results showed linear and nonlinear, indicating correct and incorrect BET plots for both CPHAC and BPAC with sulphuric acid and without CPHAC and BPAC. The CPHAC and BPAC impregnated with H<sub>2</sub>SO<sub>4</sub> has a correlation coefficient and slope values of 0.9996 and 3.864, respectively. Furthermore, the CPHAC and BPAC without impregnation have correlation coefficients and slope values of 0.9992 and 3.029, respectively. Appendices I and II have positive constant C; however, the value for the non-impregnated sample was higher (2.801). The Multi-BET surface area for the CPHAC and BPAC with sulphuric acid had a mean of 570.114 m<sup>2</sup> g<sup>-1</sup>, implying a significant difference in BET area obtained in different relative pressure ranges (Table 1). Its Langmuir surface area also had a mean of 13958.46 m<sup>2</sup> g<sup>-1</sup> (Table 1), implying that the CPHAC and BPAC with sulphuric acid had a large surface area under the BET and Langmuir method. The curves (Appendices I and II) sharply increase at low relative pressure,

showing a high adsorptive capacity for CPHAC and BPAC impregnated with sulphuric acid. This finding aligns with related studies (Kuti et al., 2018a; Ademiluyi and David-West, 2012). However, the materials used for the activated carbon differ.

The Dubinn-Radushkevich (DR) method micropore pore volume and average pore width for CPHAC and BPAC impregnated with sulphuric acid ( $H_2SO_4$ ) were  $0.201 \text{ cc g}^{-1}$  and  $6.52 \text{ nm}$ , respectively. In comparison, the values for CPHAC and BPAC without acid were  $0.190 \text{ cc g}^{-1}$  and  $6.50 \text{ nm}$ , respectively, as shown in Table 1. CPHAC and BPAC impregnated with sulphuric acid ( $H_2SO_4$ ) were better than CPHAC and BPAC without acid, as evidenced by a remarkable increase of 36.25% in the Langmuir surface area, as shown in Table 1. These results are consistent with related studies (Kuti et al., 2018a). However, Kuti et al. (2018a) utilized bamboo as a precursor with different chemical activation methods, and their findings indicated that sulfuric acid treatment resulted in a higher surface area (Langmuir). Similarly, agricultural waste (bamboo) had a higher surface area than carbons activated with zinc chloride (Ademiluyi and David-

West, 2012). The correlation between the two samples is positive and very high (1). The Barrett-Joyner-Halenda surface area, pore volume, and pore diameter were like the Multi-BET surface area (Table 1). However, the micropore analysis (Dubinin-Astakhov (DA) method) had the highest pore volume followed by BJH pore volume (Table 1). The study revealed that the micropore analysis (DA method) is preferred over other methods in terms of pore volume (Sdanghi et al., 2020). A study conducted by Velázquez-Araque et al. (2023) revealed that the CPHAC and BPAC had the highest surface area of  $838.52 \text{ m}^2 \text{ g}^{-1}$ , with a 50% sulfuric acid solution and aligns with the finding of this study, although with 10% sulphuric acid. Cruz et al. (2012) also discovered that the highest surface area obtained for zinc chloride that removed arsenic from the water was  $780 \text{ m}^2 \text{ g}^{-1}$ . Similarly, the adsorption efficiency of CPH biochar for mercury ranged from 99.97% to 99.99% (Abbey et al., 2023), implying that CPH had a higher affinity for mercury removal. The activated carbon from CPH and banana peel amended degraded soils, but it has not been used before for soil amendment.

**Table 1 Textural porous characteristics of cocoa pod husk (CPH) and banana peel (BP) activated carbon using  $H_2SO_4$**

Characteristics	Impregnated cocoa pod husk and banana peel with sulfuric acid ( $H_2SO_4$ )	Non-impregnated cocoa pod husk and banana peel without sulfuric acid ( $H_2SO_4$ )
Multi-point BET surface area ( $\text{m}^2 \text{ g}^{-1}$ )	570.114	533.94
DA micropore volume ( $\text{cc g}^{-1}$ )	0.502	0.475
DA pore volume (nm)	$3.00 \text{ e}^{+00}$	$3.00 \text{ e}^{+00}$
BJH surface area ( $\text{m}^2 \text{ g}^{-1}$ )	570.91	552.64
BJH pore volume ( $\text{cc g}^{-1}$ )	0.278	0.272
BJH pore diameter (nm)	2.135	2.105
Langmuir surface area ( $\text{m}^2 \text{ g}^{-1}$ )	13958.46	10244.66
DR micropore volume ( $\text{cc g}^{-1}$ )	0.201	0.190
DR micropore surface area ( $\text{m}^2 \text{ g}^{-1}$ )	564.58	536.00
DFT pore volume ( $\text{cc g}^{-1}$ )	0.144	0.137
DFT surface area ( $\text{m}^2 \text{ g}^{-1}$ )	118.93	113.24
DR Absorption energy ( $\text{KJ mol}^{-1}$ )	3.987	3.998
DR average pore width (nm)	6.52	6.50

Note: Brunauer-Emmett-Teller (BET), Barrett-Joyner-Halenda (BJH)

### 3.2 Amendment of soil using impregnated and non-impregnated cocoa pod husk and banana peel activated carbon

Table 2 shows the concentration of Nitrogen, Phosphorus, and Potassium (NPK) in Gidan Kwano

agricultural soil. CPHAC and BPAC impregnated with  $H_2SO_4$  increased the level of NPK from 1.48, 7.38, and 0.22 to 2.62, 28.45, and 1.32, respectively. At the same time, CPHAC and BPAC without  $H_2SO_4$  also increased from 1.48, 7.38, and 0.22 to 2.58, 28.26, and

1.96, respectively. The findings suggest that CPHAC and BPAC adequately amended the soils. Research conducted by Tamfuh et al. (2021) demonstrated that CPH and plantain peel (PP) non-impregnated powder significantly improved organic matter for okra cultivation and ranked fourth and fifth positions. This finding aligns with the findings of this study, which found that CPHAC and BPAC contributed positively to soil NPK levels. Barrezueta-Unda et al. (2023) produced cocoa pod husks (CPH-B) and banana stalks (BC), applying them between banana plants as an effective organic fertilizer that enhanced root weight and height in banana crops. This outcome is consistent with these findings that CPHAC and BPAC can effectively amend soil. The nutrient composition of non-activated carbon from plantain and CPH were analysed, and their results revealed that plantain peel had higher potassium than CPH (Tamfuh et al., 2021).

**Table 2 Soil amendment with impregnated and non-impregnated cocoa pod husk and banana peel activated carbon**

Parameter	Nitrogen (N) mg kg <sup>-1</sup>	Phosphorus (P) mg kg <sup>-1</sup>	Potassium (K) mg kg <sup>-1</sup>
Control sample soil	1.48	7.38	0.22
Agricultural soil, cocoa pod husk, and banana peel activated carbon with H <sub>2</sub> SO <sub>4</sub> (Impregnation)	2.62	28.45	1.32
Agricultural soil, cocoa pod husk, and banana peel activated carbon without H <sub>2</sub> SO <sub>4</sub> (Impregnation)	2.58	28.26	1.96

The results of this study showed that average potassium concentrations had a mean value of 1.32 mg kg<sup>-1</sup> in impregnated CPH and BP and 1.92 mg kg<sup>-1</sup> in non-impregnated CPH and banana peel and align with previous study (Tamfuh et al., 2021). However, cocoa pod and banana peel were impregnated with 10% sulphuric acid. The difference is that the earlier study used powder plantain, while our study used activated carbon from CPH and banana peel. The findings of this study are consistent with those of Tiegam et al. (2021), who reported an average potassium concentration of 0.141 mg kg<sup>-1</sup> in dry CPH. However, the results showed

higher potassium levels compared to those reported by Tiegam et al. (2021).

## 4 Conclusion

The experiment indicates that the surface area obtained through multi-point BET for CPHAC and BPAC impregnated with sulfuric acid was significantly higher, with a mean value of 570.11 m<sup>2</sup> g<sup>-1</sup>. Other methods, such as Langmuir method (13,958.46 m<sup>2</sup> g<sup>-1</sup>) and DR micropore (564.58 m<sup>2</sup> g<sup>-1</sup>), were also determined. Compared to those without sulfuric acid, the multi-point BET had a mean value of 533.94 m<sup>2</sup> g<sup>-1</sup>, followed by Langmuir (10,244.66 m<sup>2</sup> g<sup>-1</sup>) and DR micropore (536 m<sup>2</sup> g<sup>-1</sup>). The findings also indicate that the percentage difference in surface area obtained through the multi-point BET method for samples with sulfuric acid compared to those without is 6.77%. Other methods, such as Langmuir and DR micropore, had percentage differences of 36% and 5%, respectively. It implies that the CPHAC and BPAC exhibit superior absorption capabilities, larger surface areas, and higher total pore volumes, making them more effective in improving degraded soils. Notably, the application of these activated carbons increased the nitrogen levels by 1.55%, followed by phosphorus (0.67%) and potassium (32.65%). It is recommended that CPH and banana peel be used as activated carbon for soil amendment and enhancing crop production. Using CPH and banana peel could lead to sustainable agricultural practices and improved soil fertility.

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## References

- Abbey, C. Y. B., A. B. Duwiejuah, and A. K. Quianoo. 2023. Removal of toxic metals from aqueous phase using cacao

- pod husk biochar in the era of green chemistry. *Applied Water Science*, 13(2): 57.
- Ademiluyi, F. T., and E. O. David-West. 2012. Effect of chemical activation on the adsorption of heavy metals using activated carbons from waste materials. *International Scholarly Research Notices*, 2012(1): 674209.
- Ahmad, F., W. M. A. W. Daud, M. A. Ahmad, and R. Radzi. 2011. Using cocoa (*Theobroma cacao*) shell-based activated carbon to remove 4-nitrophenol from aqueous solution: Kinetics and equilibrium studies. *Chemical Engineering Journal*, 178: 461-467.
- Barrezueta-Unda, S. A., H. Azuero-Caamaño, and I. R. Gootman Jadan, 2023. Development of banana (*Musa AAA*) under different doses of biochar and chemical fertilisers. *Revis Bionatura*, 8(3): 85.
- Beesley, L., E. Moreno-Jiménez, J. L. Gomez-Eyles, E. Harris, B. Robinson, and T. Sizmur. 2011. A review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils. *Environmental Pollution*, 159(12): 3269-3282.
- Bello, O. S., M. A. Ahmad, and T. T. Siang. 2011. Utilisation of cocoa pod husk for the removal of Remazol Black B reactive dye from aqueous solutions: kinetic, equilibrium and thermodynamic studies. *Trends in Applied Sciences Research*, 6(8): 794.
- Brunauer, S., P. H. Emmett, and E. Teller. 1938. Adsorption of gases in multimolecular layers. *Journal of the American Chemical Society*, 60(2): 309-319.
- Cruz, G., M. Pirilä, M. Huuhtanen, L. Carrión, E. Alvarenga, and R. L. Keiski. 2012. Production of activated carbon from cocoa (*Theobroma cacao*) pod husk. *Journal of Civil and Environmental Engineering*, 2(2): 1000109.
- Ishaq, K., A. A. Saka, A. O. Kamardeen, M. I. Alhassan, B. M. Temitope, and J. O. Tijani. 2015. Studies on the suitability of alumina as bimetallic catalyst support for MWCNTs growth in a CVD reactor. In *First International Engineering Conference, School of Engineering and Engineering Technology, Federal University of Technology*, 296-305. Minna, Nigeria, 15<sup>th</sup>-19<sup>th</sup> October 2015.
- Kuti, I. A., B. A. Adabembe, P. A. Adeoye, J. J. Musa, I. M. Animashaun, M. S. Issa, and M. O. Ogunwale, 2018a. Production and characterisation of bamboo activated carbon using different chemical impregnations for heavy metals removal in surface water. *Nigerian Research Journal of Engineering and Environmental Sciences*, 3: 177-182.
- Kuti, A. I., B. A. Adabembe, J. J. Musa, P. A. Adeoye, M. I. Animashaun, H. Aroboinsen, and M. E. Akhare. 2018b. Assessment of Soil Salinity and Irrigation Water Quality of Chanchaga Irrigation Scheme I, Minna, Niger State. *FUOYE Journal of Engineering and Technology*, 3(1): 57-60.
- Okalebo, J. R., K. W. Gathua, and P. L. Woomer. 2002. *Laboratory Methods of Soil and Plant Analysis: A Working Manual*. 2nd ed. Nairobi, Kenya: Sacred Africa.
- Rangari, P. J. and P. Chavan. 2017. Preparation of activated carbon from coconut shell. *International Journal of Recent Research in Science, Engineering and Technology*, 7(6), 598- 603. [www.ijrrset.com](http://www.ijrrset.com)
- Rouquerol, J., F. Rouquerol, P. Llewellyn, G. Maurin, and K. S. Sing. 2013. Adsorption by powders and porous solids: principles, methodology and applications. San Diego, USA: Academic press. Pp 239
- Sdanghi, G., S. Schaefer, G. Maranzana, A. Celzard, and V. Fierro. 2020. Application of the modified Dubinin-Astakhov equation for a better understanding of high-pressure hydrogen adsorption on activated carbons. *International Journal of Hydrogen Energy*, 45(48): 25912-25926.
- Tamfuh, P. A., S. T. Agbor-Ambang, D. Bitondo, G. M. Ndzana, A. A. Singwa, L. W. Ngonjang, J. T. Nji, and E. Temgoua. 2021. Soil fertility amendment using cocoa pod husk and plantain peels powders for Okra (*Abelmoschus esculentus*, kirikou variety) production in Dschang (Cameroon Western Highlands). *International Journal on Agricultural and Biological Research*, 37(6): 204-212.
- Tiegam, R. F. T., D. R. T. Tchuiwon, R. Santagata, P. A. K. Nanssou, S. G. Anagho, I. Ionel, and S. Ulgiati. 2021. Production of activated carbon from cocoa pods: Investigating benefits and environmental impacts through analytical chemistry techniques and life cycle assessment. *Journal of Cleaner Production*, 288, 125464. <https://doi.org/10.1016/j.jclepro.2020.125464>
- Theivarasu, C., and S. Mysamy. 2010. Equilibrium and kinetic adsorption studies of Rhodamine-B from aqueous solutions using cocoa (*Theobroma cacao*) shell as a new adsorbent. *International Journal of Engineering Science and Technology*, 2(11): 6284-6292.
- Velázquez-Araque, L., A. O. Chávez, and M. C. Calle. 2023. Production of activated carbon from cocoa pod husks and banana peels using H<sub>3</sub>PO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub> as activating agents. In *31<sup>st</sup> European Biomass Conference and Exhibition*, 544-551. Bologna, Italy, 5-8 June 2023.
- Zhou, Z., D. Yao, S. Li, F. Xu, Y. Liu, R. Liu, and Z. Chen. 2021. Sustainable production of value-added sulfonated biochar by sulfuric acid carbonisation reduction of rice husks. *Environmental Technology and Innovation*, 24: 102025.

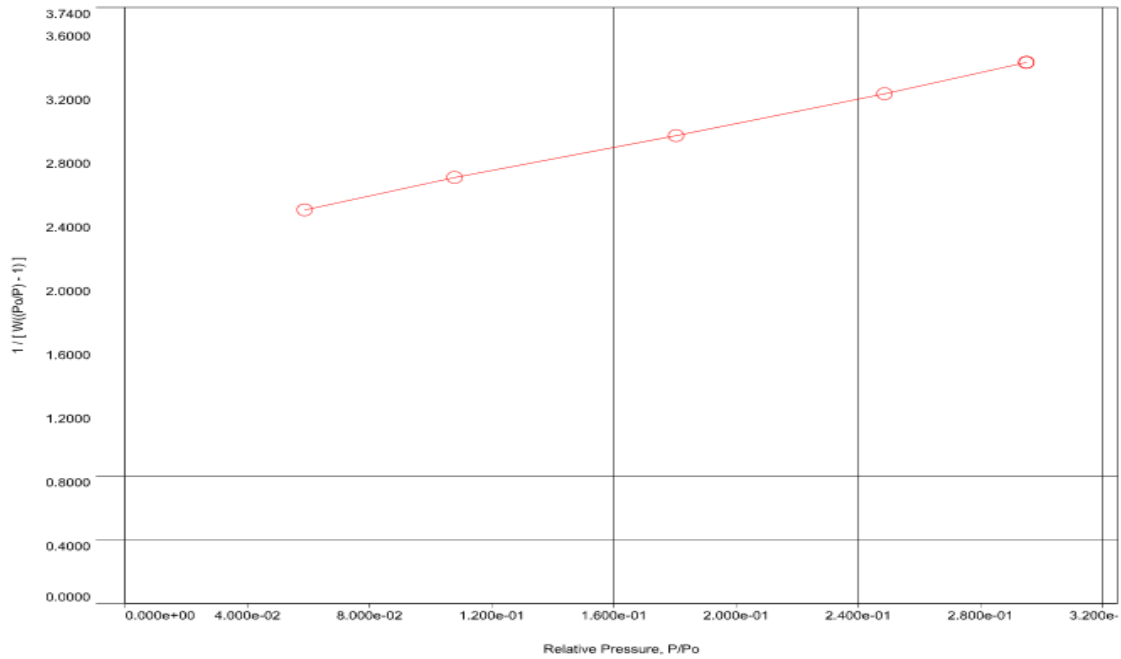
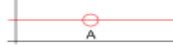
Appendices

Appendix I: BET analysis for Impregnated Sample

<b>Analysis</b>		<b>Report</b>	
<b>Operator:</b>	Abdulrahman Abdulkareem	<b>Operator:</b>	Abdulrahman Abdulkareem
<b>Sample ID:</b>	Modified Banana Peel	<b>Date:</b>	2023/12/30
<b>Sample Desc:</b>		<b>Filename:</b>	Modified Banana Peel.qps
<b>Sample weight:</b>	0.1 g	<b>Comment:</b>	
<b>Outgas Time:</b>	3.0 hrs	<b>Sample Volume:</b>	1 cc
<b>Analysis gas:</b>	Nitrogen	<b>Outgas Temp:</b>	250.0 C
<b>Press. Tolerance:</b>	0.100/0.100 (ads/des)	<b>Bath Temp:</b>	273.0 K
<b>Analysis Time:</b>	109.0 min	<b>Equil time:</b>	60/60 sec (ads/des)
<b>Cell ID:</b>	2	<b>End of run:</b>	2023/12/30 13:13:11
		<b>Equil timeout:</b>	240/240 sec (ads/des)
		<b>Instrument:</b>	Nova Station B

Multi-Point BET Plot

<b>Adsorbate</b>	Nitrogen	<b>Data Reduction Parameters</b>	
	Molec. Wt.: 28.013	<b>Temperature</b>	77.350K
		<b>Cross Section:</b>	16.200 Å <sup>2</sup>
		<b>Liquid Density:</b>	0.808 g/cc



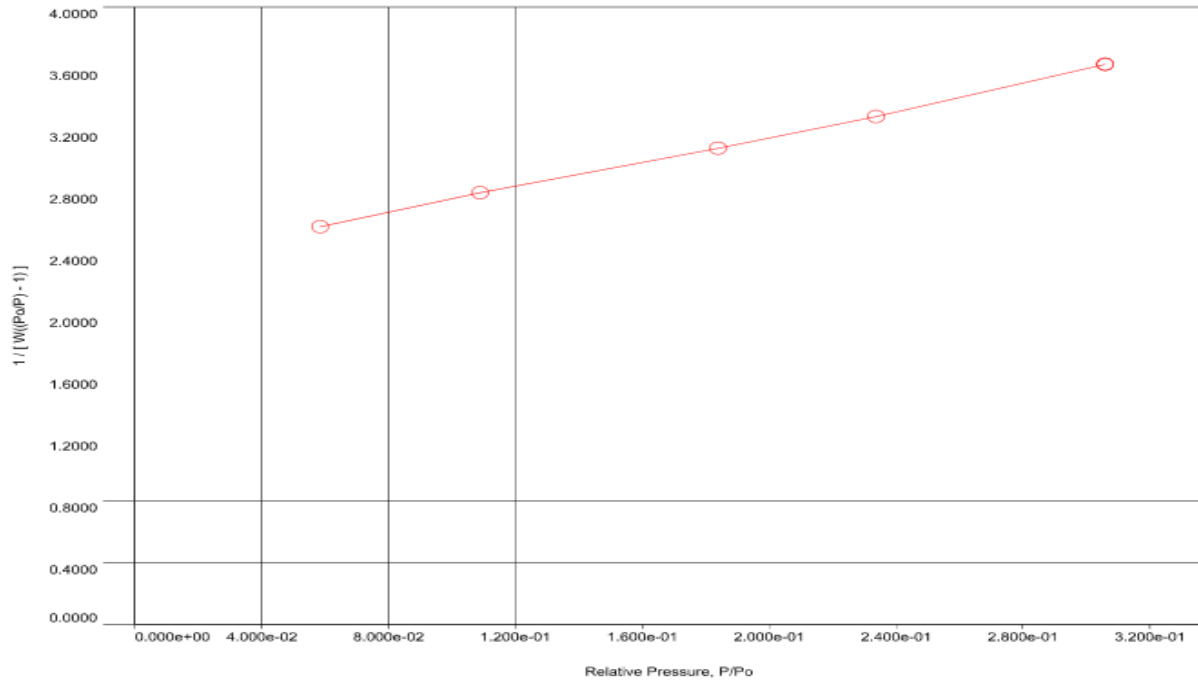
<b>BET summary</b>	
<b>Slope =</b>	3.864
<b>Intercept =</b>	2.245e+00
<b>Correlation coefficient, r =</b>	0.999699
<b>C constant =</b>	2.721
<b>Surface Area =</b>	570.114 m <sup>2</sup> /g

Appendix II: BET analysis for Non-impregnated Sample

<b>Analysis</b>		<b>Report</b>	
<b>Operator:</b>	Abdulrahman Abdulkareem	<b>Operator:</b>	Abdulrahman Abdulkareem
<b>Sample ID:</b>	Cocoa & Banana	<b>Filename:</b>	Cocoa Pod Husk & Banana Peel.qps
<b>Sample Desc:</b>	Cocoa Pod Husk & Banana	<b>Sample Volume:</b>	1 cc
<b>Sample weight:</b>	0.2 g	<b>Outgas Temp:</b>	250.0 C
<b>Outgas Time:</b>	3.0 hrs	<b>Bath Temp:</b>	273.0 K
<b>Analysis gas:</b>	Nitrogen	<b>Equil time:</b>	60/60 sec (ads/des)
<b>Press. Tolerance:</b>	0.100/0.100 (ads/des)	<b>End of run:</b>	2023/12/30 10:53:41
<b>Analysis Time:</b>	112.6 min	<b>Equil timeout:</b>	240/240 sec (ads/des)
<b>Cell ID:</b>	3	<b>Instrument:</b>	Nova Station C

Multi-Point BET Plot

<b>Adsorbate</b>	Nitrogen	<b>Data Reduction Parameters</b>	
<b>Molec. Wt.:</b>	28.013	<b>Temperature</b>	77.350K
		<b>Cross Section:</b>	16.200 Å <sup>2</sup>
		<b>Liquid Density:</b>	0.808 g/cc



<b>BET summary</b>	
<b>Slope =</b>	4.194
<b>Intercept =</b>	2.328e+00
<b>Correlation coefficient, r =</b>	0.999297
<b>C constant =</b>	2.801
<b>Surface Area =</b>	533.943 m <sup>2</sup> /g

Appendix III: completely randomised block design with three factors

Parameters	Nitrogen mg kg <sup>-1</sup>			Phosphorus mg kg <sup>-1</sup>			Potassium mg kg <sup>-1</sup>		
Control sample soil	1.44	1.45	1.54	7.37	7.36	7.41	0.21	0.21	0.23
Agricultural soil, cocoa pod husk, and banana peel activated carbon with H <sub>2</sub> SO <sub>4</sub> (Impregnation)	2.60	2.62	2.63	28.44	28.43	28.50	1.32	1.31	1.32
Agricultural soil, cocoa pod husk, and banana peel activated carbon without H <sub>2</sub> SO <sub>4</sub> (Impregnation)	2.54	2.56	2.64	28.26	28.24	28.30	1.96	1.95	1.98