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## Evaluating the surface functional groups on banana leaf petioles and the resultant biochar for potential adsorbance

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### Abstract

The presence of surface functional groups is key to the performance of an adsorbent material. The aim of this study was to evaluate the presence of functional groups on banana leaf petiole and on biochar made from banana leaf petiole. These functional groups assist in determining the potential of the material as an adsorbent for pollutants and heavy metals in waste water. Banana leaf petioles were collected from a single plantation and analyzed using the Fourier transform infrared spectroscopy. The material was then pyrolyzed at pyrolytic temperatures of 300°C, 400°C and 500°C, and the resulting biochars were analyzed to identify the surface functional group. The results showed the presence of hydroxyl and carboxyl functional groups on the banana leaf petiole before pyrolysis. The biochars also showed presence of hydroxyl and carboxyl functional groups whose presence and abundance reduced with increase in pyrolytic temperature. The presence of hydroxyl and carboxyl functional groups in a material has been related to its ability to adsorb metals in waste water and thus the banana leaf petiole as well as its resulting biochar would be a promising adsorbent for waste water remediation.

## 1. Introduction

Adsorption technique is a popular method in reducing the amounts of environmental pollutants and researchers are focusing on developing low cost adsorbents from cheap sources to replace the costly adsorbents [1-4]. The process of adsorption is dependent on several factors such as the nature of the adsorbent, the adsorption conditions and the adsorbate. The adsorbent's characteristics may include the surface area, hydrophobicity and the presence of functional groups on the surface of the adsorbing material [5-7]. The surface chemistry of an adsorbent is as a result of presence of heteroatoms such as oxygen, nitrogen, hydrogen and phosphates which form ketones, carboxyl, phenols, ethers, lactones, amines, nitro groups and phosphates [8,9]. The presence of functional groups plays an important role in the adsorption process and molecules that interact with an adsorbent that has functional groups will experience greater adsorption [6,10]

Biochar is produced through Pyrolysis which is an inexpensive technology that can result in thermochemical decomposition of organic materials [11-13]. The pyrolysis process involves a thermochemical conversion technology that operates in the absence or limited oxygen and results in end products such as bio-oils, biochar and gases [14]. Biochar has been considered as a potential surrogate for activated carbon in environmental remediation and water treatment due to its low cost, relative abundance and comparative sorption abilities [15]. Biochar has been shown to exhibit a greater ability

and potential in remediation of contaminated waters than other adsorbents as it contains micro- and/or meso-porous structures, different surface functional groups which include carboxylic groups, hydroxyl groups, carbonyl groups, alcoholic and lactone groups, and inorganic mineral species [16,17,18]. In order to examine the presence of these functional groups on biomass and biochar, Fourier Transform Infrared (FTIR) spectroscopy technique is used. The FTIR spectra produced is used to depict the possible changes in abundance of the surface functional moieties of biomass when compared with the product biochar [19-21]. Pyrolysis has been identified to have a significant effect on the present functional groups in biochars [20].

Various parts of the banana plant have been studied as adsorbents against cationic, anionic and neutral pollutants [2,22,23]. This is due to their advantages which include being readily available, low cost and protecting the environment by preventing methane and carbon dioxide formation where the wastes are dumped in wetlands or burned [2]. Low et al. [24] studied the removal of metal from electroplating waste and synthetic solution using banana pith biochar. Anwar et al. [25] used banana peels biochar to remove lead and cadmium from water. Memon et al. [26] further studied banana peels for the selective removal of Chromium (VI) from industrial waste water. Banana pseudo stem was studied for the removal of colour and Chemical Oxygen Demand (COD) from landfill leachate [27]. Banana trunk activated carbon was studied for remediation of methylene blue contaminated water [23]. Banana peduncle biochar at different pyrolytic temperatures was also studied for the removal of Chromium (VI) [28]. The potential of banana leaf petioles as a potential adsorbent has not been studied. The objective of this study was to evaluate the presence of functional groups responsible for adsorption of organic and inorganic pollutants on the banana petioles and on the biochar prepared from the banana petiole material.

## 2. Material and Methods

### 2.1 Banana Leaf Petiole Collection and Preparation

The Banana leaf petioles for use in this study were collected from a banana plantation in Embu, Kenya. The sample was collected from a single banana species (*Mussa acuminata*). The petioles were harvested and separated from the sheath and leaf parts of the banana plant. These were then washed with tap water to remove dirt on their surfaces and later rinsed with deionized water to remove the metal ions on the surfaces. They were then sun dried to remove the surface water. The leaf petioles were then sliced into small pieces (<2 cm) to increase their surface area for drying and also to fit in the crucibles used in the pyrolysis process.

### 2.2 Preparation of Banana Stalks Samples for Fourier Transform Infrared (FTIR) Spectroscopic Analysis

The sliced banana leaf petioles (<2 cm) were oven dried at a temperature of 105° C to constant mass in order to remove the moisture content. A sample of the dry material was ground using a high-speed universal disintegrator (model FW80-I, China) into powder form and a sample of 10 grams stored in air tight Ziplock bag for use in Fourier Transform Infrared (FTIR) spectroscopy analysis.

### 2.3 Biochar Production

The dried banana leaf petiole material was packed in three crucibles each holding a mass of 35 g of the material and then pyrolyzed using a muffle furnace (Model LH 15/14, Nabertherm, Germany). The muffle furnace was programmed to rise to a temperature of either 300°C, 400°C or 500°C. The temperature rise was maintained at 10°C/min. The holding time for the different pyrolytic temperature was one hour after which the furnace was allowed to cool down to room temperature. The biochar produced in each pyrolysis process was weighed and the mass recorded. The biochar was then packed into air-tight plastic Ziplock bags. This process was replicated seven times.

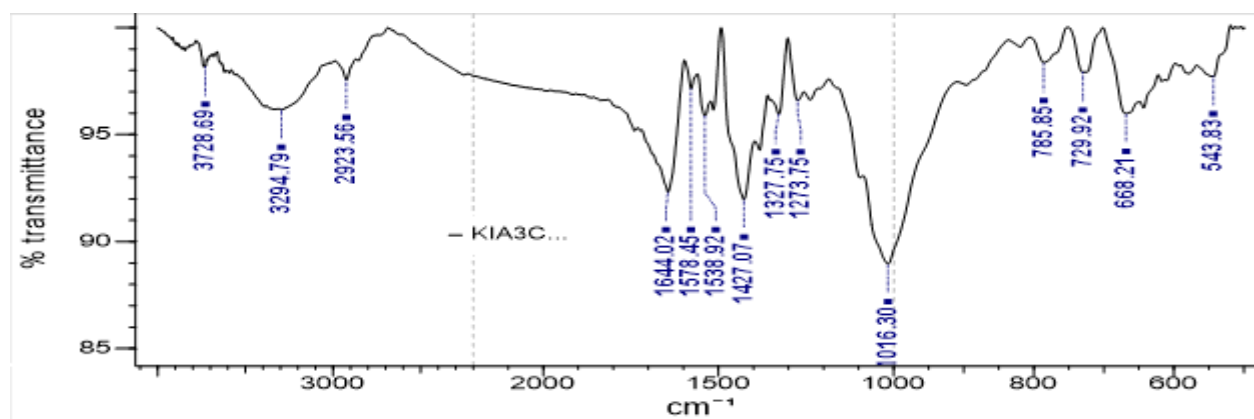
## 2.4 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Analysis for the functional groups present on the samples of dried banana leaf petiole powder and biochars produced at temperatures 300°C, 400°C and 500°C was conducted using an FTIR machine (Model: Jasco, Japan) in attenuated total reflectance (ATR) mode [29, 30]. The scans were conducted from a wavelength of 4000  $\text{cm}^{-1}$  to 500  $\text{cm}^{-1}$  at a scan rate of 50 conducted at a resolution of 4  $\text{cm}^{-1}$ . The infra-red (IR) spectra for each sample was obtained electronically. The samples were analyzed in triplicates.

## 3. Results and discussion

The Infrared spectra depicted in Figures 1, 2, 3 and 4 shows the surface functional groups present in raw banana leaf petiole, biochar pyrolyzed at 300°C, biochar pyrolyzed at 400°C and biochar pyrolyzed at 500°C, respectively.

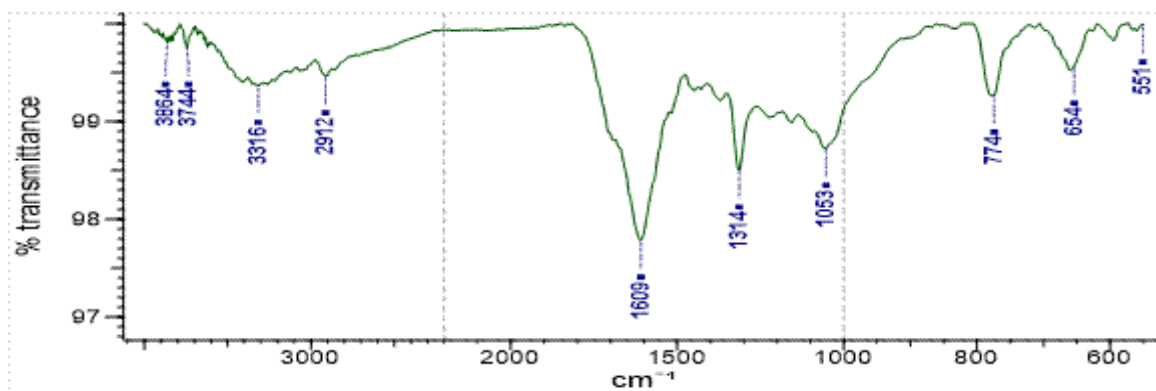
The raw banana leaf petioles FTIR (Figure 1) showed peaks at wavelengths 3294  $\text{cm}^{-1}$  and other peaks at 2923  $\text{cm}^{-1}$ , 1644  $\text{cm}^{-1}$ , 1538  $\text{cm}^{-1}$ , 1427  $\text{cm}^{-1}$  and 1016  $\text{cm}^{-1}$ . These peaks correspond to O-H, C-H stretching, C=O, N-O, O-H bending and C-O surface functional groups respectively. These results corroborate with a study by Dos Santos et al. [31] on functional groups present in raw banana fibre who noted the presence of O-H, C-H stretching, O-H bending, C=O and C-O surface functional groups. The presence of O-H, C-H, C-O, C=O functional groups has also been reported in banana peel FTIR [32].



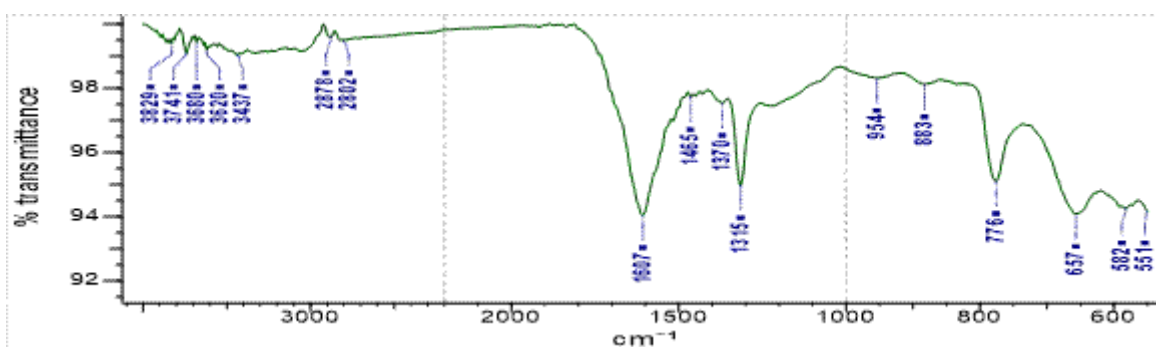
**Figure 1:** Fourier Transform Infrared (FTIR) spectrum of raw banana leaf petiole powder before pyrolysis

The peaks identified on biochar 300°C (Figure 2) were at wavelengths 3625  $\text{cm}^{-1}$ , 2912  $\text{cm}^{-1}$ , 1609  $\text{cm}^{-1}$ , 1314  $\text{cm}^{-1}$  and 1053  $\text{cm}^{-1}$ . These peaks correspond to free O-H, aldehyde C-H, conjugated C=C, amine C-N and stretching C-O groups, respectively. In biochar 300°C, the band shift from 2923  $\text{cm}^{-1}$  before pyrolysis to 2912  $\text{cm}^{-1}$  after pyrolysis, and 1016  $\text{cm}^{-1}$  to 1053  $\text{cm}^{-1}$ , respectively, for the C-H and C-O groups was observed. A similar trend was observed in a different study of banana fibre pyrolyzed at 300°C which showed the presence of O-H, C-H stretching, C=C and C-O groups in biochar [31, 33, 34]. A shift in functional group band after pyrolysis was also confirmed by Li et al. [34], where they reported a shift in C-O peaks after increasing pyrolysis temperature.

The main peaks identified on the surface of biochar 400°C (Figure 3) were at wavelength 3620  $\text{cm}^{-1}$ , 2878  $\text{cm}^{-1}$ , 1607  $\text{cm}^{-1}$  and 1315  $\text{cm}^{-1}$ . The peaks correspond to free O-H, C-H, conjugated C=C and amine C-N groups respectively. A band shift was also noted for the C-H group from 2923  $\text{cm}^{-1}$  before pyrolysis to 2878  $\text{cm}^{-1}$  after pyrolysis. The presence of O-H, C-H, C=C functional groups in biochar 400°C was also reported by Dos Santos et al. [31].

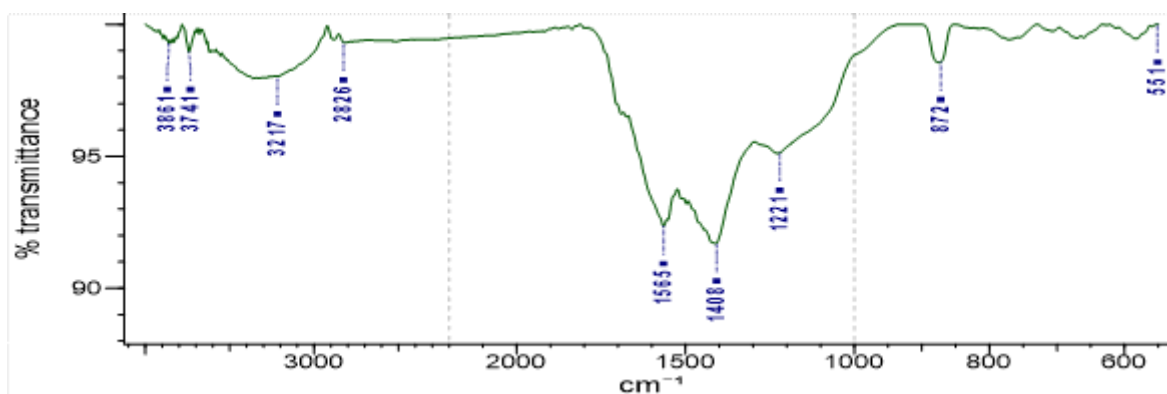


**Figure 2:** Fourier Transform Infrared (FTIR) spectrum of banana leaf petioles pyrolyzed at Temperature 300°C (Biochar 300°C)



**Figure 3:** Fourier Transform Infrared (FTIR) spectrum of banana stalks pyrolyzed at temperature 400°C (Biochar 400°C)

Figure 4 shows the identified surface functional groups were the O-H functional group at  $3217\text{cm}^{-1}$ , a nitro  $\text{NO}_2$  at  $1565\text{cm}^{-1}$ , a C-O stretching group at  $1221\text{cm}^{-1}$  and a peak at  $1408\text{cm}^{-1}$  which could be attributed to S=O stretching sulfate/sulfonyl chloride or O-H bending alcohol or carboxylic acid group. A band shift for the C-O group from  $1016\text{cm}^{-1}$  before pyrolysis to  $1221\text{cm}^{-1}$  after pyrolysis, carboxylic O-H group from  $3294\text{cm}^{-1}$  before pyrolysis to  $3217\text{cm}^{-1}$  after pyrolysis, the O-H bending from  $1427\text{cm}^{-1}$  before pyrolysis to  $1408\text{cm}^{-1}$  after pyrolysis, was observed on biochar  $500^\circ\text{C}$ . The presence of O-H, C-H, C=C functional groups in biochar  $500^\circ\text{C}$  was reported by Dos Santos et al. [31].



**Figure 4:** Fourier Transform Infrared (FTIR) spectrum of banana leaf petioles pyrolyzed at temperature  $500^\circ\text{C}$  (Biochar  $500^\circ\text{C}$ )

The above observations showed that after pyrolysis of the banana leaf petiole stalks, the identified hydroxyl O-H stretching vibrations and the C-O stretching vibrations were attenuated. This indicates that most of the O<sub>2</sub>- containing functional groups such as polysaccharides diminished after pyrolysis

[11, 35]. The functional group C-O which was pronounced in the raw banana leaf petioles FTIR spectrum was noted to have significantly reduced in intensity at biochar 300°C and was missing in both biochar 400°C and 500°C. This change could be attributed to the loss of C-O or C-OH functional groups as a result of dehydration and rearrangement of molecules at high pyrolytic temperatures [33, 36]. Pyrolysis therefore can lead to alternation of carbon to oxygen, hydrogen to carbon and carbon to nitrogen ratios and may modify functional groups leading to instances such as increase in aromatic C=C or a decrease in O-H and C-H [29] a case observed on biochar 300°C and biochar 400°C in this study.

## Conclusion

The banana leaf petiole powder and resultant biochar prepared at different pyrolytic temperatures showed the presence of hydroxyl and carboxyl surface functional groups. The presence of these surface moieties is related to the ability of the material to adsorb metals and pollutants, and thus, banana leaf petiole powder and its biochar can be considered as a promising adsorbent.

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