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Characterization of Physicochemical Properties of Biochar from Different Agricultural Residues

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A B S T R A C T

Biochar production from agricultural residues, manure and human waste as a recycling option is gaining more attention in many countries. Biochar has potential to enhance soil fertility and increase crop yield and to be used as renewable energy source. The study was conducted to determine the physicochemical properties of biochar produced from empty fruit bunch (EFB) of oil palm, rice straw and sugarcane bagasse and their effects on soil fertility. The EFB, rice straw and sugarcane bagasse were pyrolyzed in a muffle furnace at a temperature of 450°C and a holding time of 30 minutes. Different types of biomass showed different pH, moisture and ash content. Rice straw showed the highest biochar yield of 35.5% and the highest ash content of 25% compared to that of EFB biochar and sugarcane bagasse biochar. The moisture content of EFB biochar was the highest at 3.8%. All the biochar produced have similar functional groups such as hydroxyl, carboxyl, alkanes, alkenes, carbonyl and nitrogen groups. Rice straw biochar has a good adsorption property towards inorganic compounds and can enhance adsorption of fertilizer and pesticide in the soil. Biochar can increase soil fertility as indicated by a pot trial using corn seedlings and park choy vegetable plants grown in soil enriched with rice straw biochar. The beneficial effects of biochar derived from agricultural wastes using the pyrolysis technique should be explored as a sustainable approach to improve soil fertility and crop growth.

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INTRODUCTION

An increase in agricultural activities to support the growing human population can lead to an increase in the agricultural wastes produced. The global annual production of agricultural residues is estimated to be more than 500 million tons [1]. Currently, biomass from agricultural wastes in the form of biochar can be used as an renewable energy source for biosustainability. Biochar showed potential as a valuable soil amendment material to enhance crop productivity. Biochar can be produced from a wide range of organic feedstocks under different pyrolysis conditions. Biochar from three agricultural wastes; namely oil palm empty fruit bunch, rice straw and sugarcane bagasse were used in this study using an analytical approach, soil fertility and crop growth studies.

Pyrolysis is one of the most promising processes to convert biomass to solid (biochar), liquid (bio-oil) and gas [2]. There are two types of pyrolysis system mostly used in biochar production which is fast and slow pyrolysis. The differences between these two pyrolysis systems depend on heating rate, heating time [3] and heating temperature [4]. For biochar production, slow pyrolysis is more favored as it maximizes biochar yield over production of bioenergy [5,6].

The conversion of agriculture wastes into value added products such as biofuel and biochar has attracted tremendous interest attributed to the high energy demand and concerns over greenhouse gas emission as well as worldwide soil degradation. As one of the most popular bioenergy conversion technologies, thermal pyrolysis of carbon-rich biomass is unique because it produces biochar in addition to biofuel. It has recently been proposed to convert the biomass to biochar via pyrolysis and subsequently add the derived biochar to soils, particularly soils with low-fertility, to improve soil fertility and enhance crop growth performance [7,8].

In this study, the slow pyrolysis of oil palm empty fruit bunch (EFB), rice straw and sugarcane bagasse were investigated using a muffle furnace. The influence of pyrolysis temperature and holding time on biochar

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production was studied. In addition, the aim of this work was to determine the physicochemical properties of biochar produced from oil palm empty fruit bunch, rice straw and sugarcane bagasse and their influence on soil fertility.

MATERIALS AND METHODS

In this study, oil palm empty fruit bunch, rice straw and sugarcane bagasse were collected from Malaysia Northern states. The samples were grinded using a grinder (Chyun Tseh Industrial Co., Taiwan). The samples were sieved using an aperture sieve to obtain particle size in the range <500μm. Later, the samples were dried at 105°C in an oven (Binder, Germany) for 24 hours to remove surface moisture [9].

Two grams from each sample were pyrolyzed inside a muffle furnace (Carbolite, UK) at 450°C for 30 minutes. Heating rate used in the production of biochar was 30°C min^{-1}. The percentage of biochar obtained was calculated using the following formula:

$$\text{Yield (\%)} = \frac{m_a}{m_b} \times 100 \quad (1)$$

where, m_a and m_b is mass of sample after and before heating, respectively.

Elemental C and N concentrations were determined by CHNS/O Analyzer (Perkin Elmer Series II 2400, USA). The ash content of the biochar samples was tested using standard test method, ASTM E1755. The moisture content of 0.1 g of biochar was determined using the moisture analyzer (Sartorius MA 35, Germany). pH of biochar was determined by adding biochar into the de-ionized water in a mass ratio of 1:20. The solution was shaken and allowed to stand for 5 minutes before measuring the pH using a pH meter (Ohaus, USA) [10].

The functional groups of biochar were identified using Fourier transform infrared (FTIR) instrument (Perkin Elmer Spectrum 65, USA). A small amount of biochar was mixed well with KBr to make a disk. The disk was placed in the sample holder of the FTIR instrument and the spectra were obtained.

The adsorption ability of biochar was determined by testing the effect of initial concentration of methylene blue (MB) on biochar produced. Concentrations of 20-100 ppm of MB were prepared and their absorbance measured at 660 nm on a UV/Visible spectrophotometer (Perkin Elmer Lamda 25, USA). The calibration curve of absorbance against concentration of MB was determined and the curve indicated that the Beer–Lambert law is obeyed up to a concentration of 100 ppm. To determine the adsorption of MB on biochar, 0.5 g of biochar was added to 100 mL of different initial MB concentrations (40 ppm, 60 ppm, and 80 ppm) and shaken at 150 rpm and 30°C. For the contact time test, 1 mL of sample was taken each time. In the first hour, sample was taken every 15 minutes. In the second to fourth hour, sample was taken every 30 minutes. The last sample was taken after 24hr. The 1mL mixture then centrifuged and diluted with 9 ml distilled water before the adsorption reading was taken.

The pot trial was conducted by growing corn and park choy in the soil as indicator crops with addition of 7% rice straw biochar and a control pot was conducted using soil without biochar. The corn seeds were germinated to obtain the same height of corn seedlings before the pot trial was conducted. The planting process was done in greenhouse under controlled of environmental condition. The plants height, root and stalk weight were taken after 4 weeks of planting.

RESULTS AND DISCUSSION

Biochar Yield:

The biochar yield from different sources of agricultural residue is as shown in Table 1. After pyrolysis of the agricultural biomass, the yield was highest for rice straw, 35.5%, compared to empty fruit bunch and sugarcane bagasse (Table 1). This shows that type of agricultural residue can also influence the yield of biochar. The different type of agricultural residues gives different yield of biochar due to the dissimilar decomposition rate of hemicelluloses, cellulose and lignin content [11, 12].

Table 1: The biochar yield, moisture content, ash content and pH value of biochar from different agricultural residues.

Sample	Yield (%)	Ultimate Analysis [a]			C/N	Moisture (%)	Ash (%)	pH
		C (%)	N (%)	S (%)				
Rice straw (RS) biochar	35.5	34.3	1.0	0.8	34.3	2.4	25.0	9.5
Empty fruit bunch (EFB) biochar	30.8	33.8	1.2	0.9	28.9	3.8	21.0	10.4
Sugarcane bagasse (SB) biochar	29.0	31.2	0.4	0.7	84.3	2.8	12.0	8.2

[a] Weight percentage on dry ash-free basis.

Physicochemical Analysis:

The results of physicochemical analysis of agricultural residues are given in Table 1. The biochar from EFB contains the highest moisture content (3.8%).

The highest ash content was from rice straw (25.0%) followed by empty fruit bunch (21.0%) and sugarcane bagasse (12.0%). The highest ash content in biochar from rice straw shows that the rice straw char contains a lot of minerals. Therefore, rice straw is a good biowaste for biochar production. This will help to enhance nutrient content especially in marginal soils. Carbon and nitrogen content of rice straw biochar analyzed using CHONS analyzer were also high as compared to empty fruit bunch and sugarcane bagasse. This further enhanced the fertility of the soil and crop yield.

The pH of empty fruit bunch, rice straw and sugarcane bagasse biochar are 10.4, 9.5 and 8.2, respectively (Table 1). In general, the pH of all biochar was greater than 8 (pH > 8) and the results showed that biochar is alkaline in nature. The high pH of the biochar gives an advantage to the growth of crop especially in tropical soils like Malaysia where the pH of soil is generally low at around pH 4. Addition of biochar to tropical soils will help to improve the soil pH and soil properties; therefore nutrient uptake is higher. Improvement in nutrient uptake will help to enhance crop productivity [9-10, 13, 14].

FTIR Analysis:

The presence of functional groups in the different types of biochar was determined using the FTIR. The FTIR spectra of empty fruit bunch, rice straw and sugarcane bagasse are shown in Figure 1. Several absorption bands were detected for the different types of biochar. The band around 3400 cm^{-1} was assigned to O–H stretching, 2900 cm^{-1} to aliphatic C–H stretching and 800–1600 cm^{-1} to C–H, C=C, C=O stretching (aromatic) (Table 2). Absorption intensities at the bands 3400 cm^{-1} and 2900 cm^{-1} decreased with higher temperature, indicating a reduction of O, H and aliphatic C–H bonds, but the adsorption at the band 1400cm^{-1} was intensified, which indicates an increase of aromatic C. From all spectra it can be inferred that the fingerprint region for biochar is from 1500–400 cm^{-1}. This region is very useful in compound identification. The pattern of fingerprint region for raw biomass and biochar produced from empty fruit bunch, rice straw and sugarcane bagasse is different. This is an indication that some compounds could be lost during pyrolysis process as shown in earlier research works [11, 14]. The spectra also show the presence of nitrogen groups. Therefore, carbon and nitrogen ratio (C:N) of the biochar samples which is shown in Table 1. Nitrogen is an essential nutrient to enhance plant growth.

Table 2: Summary of Functional groups for each sample of biochar

Wavenumbers (cm^{-1})	Functional Group
Oil Palm Empty Fruit Bunch	
3391.23	Phenols & alcohols O-H
2918.74	Alkanes C-H
2849.30	Carboxylic acid C=O
2327.30	Nitrile C=N (Could be CO2 impurities)
1578.59	Nitro group N=O
Rice Straw	
3440.36	Phenols & alcohols O-H
2924.78	Alkanes C-H
2861.80	Carboxylic acid C=O
1611.12	Alkenes C=C
Sugarcane Bagasse	
3411.98	Phenols & alcohols O-H
2924.70	Alkanes C-H
2871.30	Carboxylic acid C=O
2324.20	Nitrile C=N (Could be CO_2 impurities)
1607.52	Alkenes C=C

Adsorption Ability of Biochar:

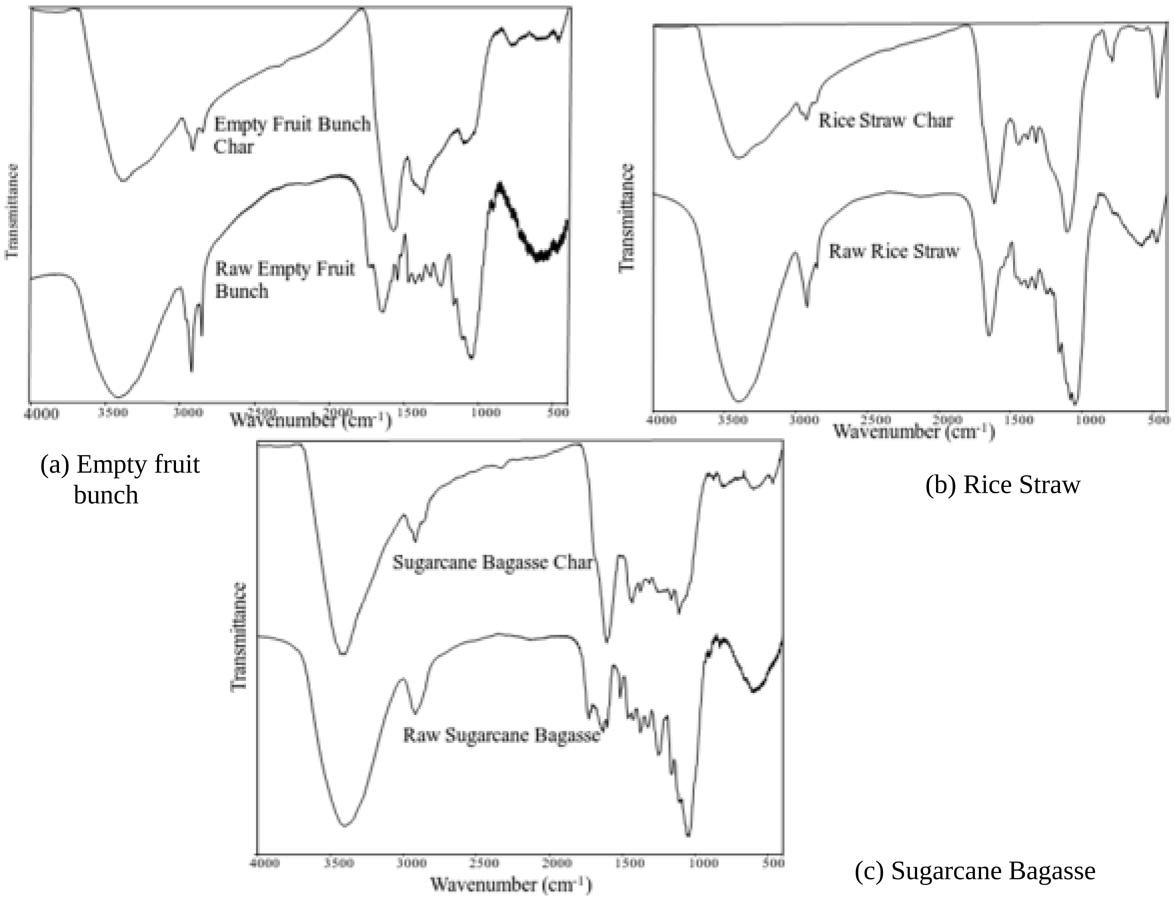
Adsorption can be define as adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface which this process creates a film of the adsorbate on the surface of the adsorbent [15]. Biochar addition can improve the sorption of fertilizer and pesticide applied to the soil. Biochar application is, therefore, expected to improve the overall sorption capacity of soils [12]. This will also enhance the nutrient uptake by soils.

Effect of initial dye concentration and contact time was conducted to see the effect of the initial concentration on the adsorption capacity at 30°C and at pH ranges of 6–7. The solutions were kept in contact in the shaker for 24 hour.

From Figure 2, the adsorption results revealed that the uptake of the adsorbate was fast at the initial stage of the contact period, and then it became slower near to the equilibrium. This is probably due to larger surface area of the biochar being available at beginning for the adsorption of methylene blue.

Figure 2 also show when the initial concentration increases the percentage absorbance also decreases. The percentage asdorption of methylene blue by the rice straw decreased from 95.2% to 57.0% as the initial concentration was increased from 40 to 80 mg/L. This may be due to the saturation of the adsorption sites at higher methylene blue concentrations [16].

Figure 2 indicated that the rice straw biochar has higher efficiency to adsorb the methylene blue as it has higher percentage of absorbance compared to the other type of biochar. The result also showed that the sugarcane bagasse has lower efficiency to absorb the methylene blue as it has the lowest percentage of absorbance that is only 16.31% to 8.94% when the concentration increase from 40 to 80 mg/L.

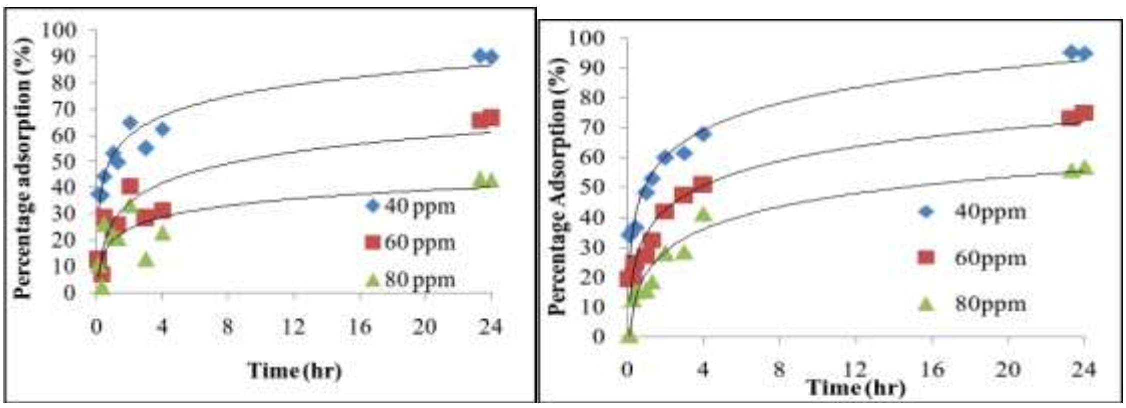


(a) Empty fruit bunch

(b) Rice Straw

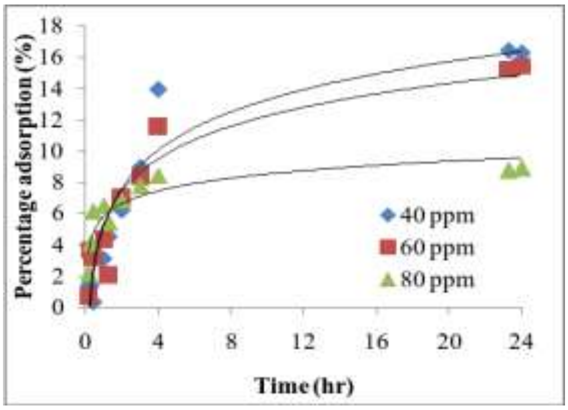
(c) Sugarcane Bagasse

Fig. 1: Infrared spectra of raw and biochar of (a) empty fruit bunch, (b) rice straw and (c) sugarcane bagasse



(a) Biochar from empty fruit bunch

(b) Biochar from rice straw



(c) Biochar from sugarcane bagasse

Fig. 2: Effect of initial dye concentration and contact time on the uptake of methylene blue onto biochar derived from (a) empty fruit bunch (b) rice straw and (c) sugarcane bagasse

Biomass Yield Production:

(a)

(b)

(c)

(d)

Fig. 3: Corn plant grown (a) without and (b) with biochar derived from rice straw Park Choy grown (c) without and (d) with biochar derived from rice straw

Table 3: The height and weight of corn and park choy plants grew with or without biochar

Plant	Parameter	Height of plant (cm)	Weight of stalk (g)	Weight of root (g)
Sweet Corn	Soil (control - soil only)	13.58	40.83	4.17
	Soil + 7% rice straw biochar	17.80	59.98	7.18
Park Choy	Soil (control – soil only)	25.23	66.60	8.40
	Soil + rice straw biochar	30.23	102.10	11.23

In addition, a pot trial experiment was conducted using corn and park choy as an indicator crop. The corn plant was grown in soil mixed with and without rice straw biochar. From Table 3, it can be seen that the park choy grown with soil and 7% biochar derived from rice straw gave the highest yield in terms of height (30.23 cm), weight of stalk (102.10 g) and root (11.23g) as compared to control pot and sweet corn plant. This demonstrated biochar has an effect on crop growth and development. Based on Figure 3 and Table 3, it can be said that addition of biochar to soil either directly or as a form of biofertilizer will enhance crop growth and increase yield. Therefore, biochar has a great potential as biofertilizer. In the Northern region of Penisular Malaysia especially Perlis and Kedah, the rice bowl of Malaysia, farmers dispose the rice straw after harvesting by open burning which resulted environmental pollution. Instead of doing so, there is a great potential to convert the rice biowaste to biochar which can enrich the soil and enhance soil productivity.

Conclusion:

In this study, pyrolysis of oil palm empty fruit bunches (EFB), rice straw and sugarcane bagasse in a muffle furnace converts agricultural residue into biochar. Different type of feedstock gives different biochar properties and results showed that the agricultural residue being used differs in their pH, ash content, moisture content, and adsorption capability. These differences will affect the functionality of biochar when it is applied to soil. Rice straw gives the highest conversion yield of biochar production. It also contains the highest ash content. All the biochar samples have high pH (pH > 8) and therefore the biochar will improve the soil pH and soil properties. Carbon and nitrogen content of rice straw biochar were also high as compared to empty fruit bunch and sugarcane bagasse. The functional groups of all biochar samples have been identified using FTIR. The functional group of hydroxyl, carboxyl, alkanes, alkenes, carbonyl and nitrogen group were present in all biochar. Rice straw gave better adsorption ability. Crop growth and biomass production of corn grown in soil enriched with rice straw biochar is also enhanced. Thus biochar can be beneficial to improve soil fertility and enhance crop growth. Agricultural wastes conversion to biochar using pyrolysis technology showed great potential in sustainability of agricultural practices.

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