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DETERMINATION OF SUITABLE BIOCHAR PRECURSOR AS ALTERNATIVE FOR ENABLING ACCESS TO CLEAN WATER SUPPLY IN RURAL AREAS

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Abstract: This study aims to determine suitable biochar precursor for local production of biochar as an alternative low-cost solution to address the persistent water supply issue in rural areas in Sarawak. A series of physicochemical characterization and adsorption studies were conducted for biochar pyrolysed from bamboo, dried leaves, wood shavings, rice husk, tree branch and wood chip, in a stainless-steel canister (without oxygen) at 600°C for three hours using a muffle furnace. Bamboo was the only precursor which fulfilled the requirements for water treatment in rural areas, i.e., biochar yield, structural integrity in water and adsorption characteristics. The pyrolysis of bamboo achieved a biochar yield of 32.8%, which attributed to the high fixed carbon content of 70.9% required for adsorption. The biochar consisted of homogeneous carbon structures with BET surface area of 317 m^2/g, total pore volume of 0.189 cm^3/g and micropores averaging 1.218 nm, which demonstrated favourable adsorption characteristics. The selection of bamboo as precursor is practical in rural areas as it is easily obtained and safe to be pyrolyzed into biochar. The application of biochar for water treatment helps to overcome the water supply issues and promote sustainable biomass waste management in rural areas.

Keywords: Physical characterisation, adsorption, sustainability, pyrolysis, biomass management.

Introduction

Accessibility to clean water remains an uphill challenge in rural areas despite the advancement in water treatment technologies. Many rural communities still do not have access to clean water and are reliant on untreated mountain water. The quality of which is subjected to weather conditions, clear on sunny days but limited supply or sufficient supply on rainy days with eroded sediments.

The development of rural villages is typically primitive by modern standards, impeded mainly by the limited accessibility and lacking utility and municipal services. The slow socio-economic development has resulted in scarce income opportunities and limited financial affordability to commute to obtain necessities. Therefore, many rural villages are agro based, where the communities typically resort to subsistence agriculture by growing paddy, vegetables and fruit trees.

The limited accessibility and slow socio-economic development are among the key reasons delaying the provision of proper water treatment system in rural areas. Thus, there is an urgent need for alternative measures to enable their access to clean water supply sooner for supporting good hygiene to safeguard their well-being especially amidst the COVID-19 pandemic (Gwenzi *et al.,* 2017).

Mountain water is typically sourced from pristine environments, containing trace concentrations of constituents and thus, can be treated using a simple filtration system. A viable alternative is through self-production of biochar using local material as most rural villages are agro-based and surrounded by plants growing naturally (Gwenzi *et al.,* 2017).

Biochar is a lightweight carbon rich charcoal derived from dried biomass through thermal decomposition under oxygen deficient conditions, known as pyrolysis. Biochar is

widely used in small farms for improving soil fertility by regulating the moisture and nutrient content in the soil, resulting in the carbon content being stable in soil for a longer time. In addition, a biochar reactor can be self-replicated using frugal and trial-and-error approaches as found on the Internet such as Youtube (Warm Heart Worldwide, 2016).

Biochar has also been traditionally used for treating water as it can adsorb a plethora of organic and inorganic compounds (Hu *et al.,* 2020) due to its favourable surface area, microporous structure and carbon content. Albeit inferior to that of activated carbon, biochar is the most economically and technically viable material to remove potential harmful contaminants in water supply widely used in remote and impoverished areas of Brazil, Ghana, India, China and Thailand (Gwenzi *et al.,* 2017; Kearns, 2014). Nevertheless, adsorption studies for treating water have advanced with activated carbon as the predominant adsorbent, focusing on techniques to enhance the adsorption affinity and capacity.

The studies on biochar for treating water are typically focused on specific precursors, thus, it is often challenging to directly compare the diverse characteristics of biochar which can vary due to factors such as precursor properties and pyrolysis conditions (Nartey & Zhao, 2017). It is important and practical to identify a suitable precursor for producing biochar with consistent quality for treating water as the biochar needs to be regularly replaced when it becomes saturated.

Therefore, there is a need to understand the physicochemical and adsorption characteristics of biochar to practically identify suitable precursors from a myriad of potential biomasses in rural areas.

A practical way to determine suitable precursor to be pyrolyzed into biochar for treating water is based on the biochar yield, physicochemical properties and attributes of adsorbent favourable for water treatment i.e., structural integrity in water and adsorption capacity. Biochar yield refers to the mass of biochar produced from the initial mass of precursor, which indicates the mass of organic contents thermally decomposed via pyrolysis.

A favourable biochar yield is typically around 30 wt% indicates a favourable composition of recalcitrant carbons such as lignin (Jindo *et al.,* 2014). Biochar yields lower than 30% is not a suitable precursor as it requires relatively greater effort and resources (precursor and fuel) to produce a specific amount of biochar. Therefore, the biochar yield around 30% is set as a criterion for determining the suitable precursor. A good adsorbent should have favourable adsorption capacity, achieve concentration equilibrium rapidly and always remain intact in water.

In this study, methylene blue (MB) was used as an indicator for rapid observation and colorimetric measurement. In addition, the water sample from a pristine water catchment contained trace concentration of constituents which was not suitable for evaluating the adsorption capacity of the biochar produced.

The adsorption capacity of MB molecules indicated its ability in adsorbing MB per unit weight of biochar, thus the greater the adsorption capacity the better the adsorbent. The ability of biochar to achieve potential removal or concentration equilibrium in two hours was set as a criterion based on the adsorption behaviour demonstrated by commercially activated carbon. The structural or physical integrity of biochar in water referred to the physical response of the biochar in water as in whether it remained intact or disintegrated into powder, contributing to the cloudiness of the water and affecting its appeal for consumption. The structural integrity of the biochar in water was assessed qualitatively via observation on the appearance of solution at the end of the 24 hours of batch adsorption test.

This study was motivated by persistent water supply issues and having insufficient water levels during the dry season and murky water supply during the rainy season as has been faced by the rural community in Long Lamai for over half a century. This has greatly impeded their well-being and socioeconomic development.

The determination of a suitable precursor is essential for promoting local production of biochar for water treatment and subsequently enable their access to clean water supply, which is in line with the aspiration of community and Sustainable Development Goals. The potential precursors identified and collected from Long Lamai is representative for rural villages in the tropical rural environment.

Materials and Methods

Synthesis of Biochar

The pyrolysis of precursor into biochar was conducted in laboratory scale under controlled thermal conditions to determine suitable precursors and investigate the effect of precursor properties on corresponding biochar and its adsorption performance. The pyrolysis was achieved by heating precursors in a 50 mm (diameter) x 100 mm (hour) stainless steel canister, which prevented direct contact between the precursor and oxygen.

A variety of agriculture wastes like tree branches, dried leaves, wood chips, wood shavings, rice husk, old (brown) bamboo were obtained from a rural village to determine suitable biochar precursors for treating water. All precursors were air dried for two weeks and cut into lengths down to 3 cm, except for rice husk.

Each precursor was filled to about 90% in a canister (177 mL) (Figure 1 (a)) to provide space for filling sand. The canister was weighed using a digital balance before and after filling with precursor. The sand layer was sandwiched between two sheets of 60 µm stainless steel mesh (Figures 1 (b)-(d)) to separate the sand from the precursor.

The sand was used to prevent direct contact between precursor and heat and allowed for the release of vapour and gas produced in the canister during pyrolysis. The lid of the canister had holes (Figure 1 (e)) to allow pressure to release from the canister at high temperatures. The canister was overturned and placed in

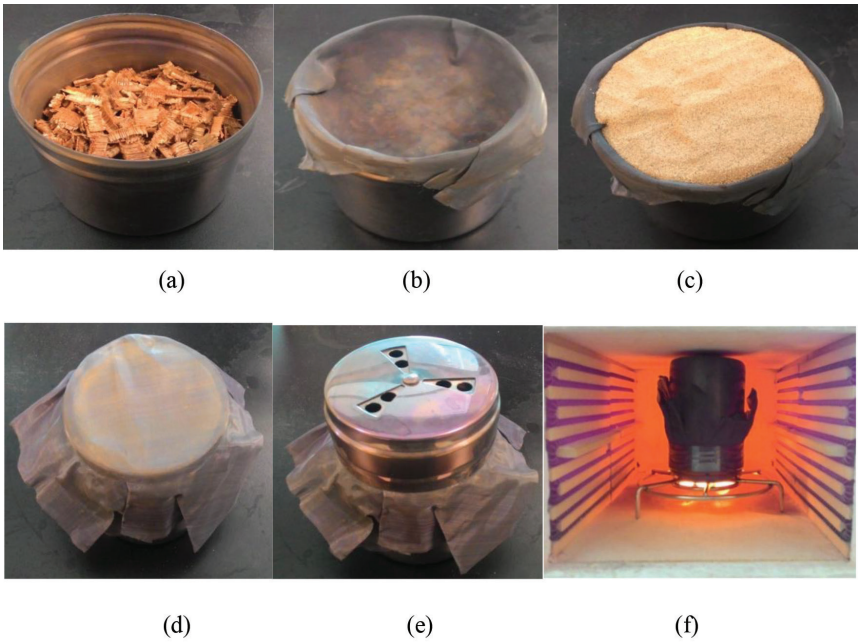


Figure 1: Preparation of precursor for laboratory scale pyrolysis (a) Filling air dried precursor up to 90% of a 50 mm (dia) x 100 mm (h) stainless steel canister, (b) A sheet of 60 µm stainless steel mesh placed on precursor, (c) Sand filled on the mesh up to the brink of canister, (d) A sheet of 60 µm stainless steel mesh placed on sand, (e) The canister was closed tightly using the lid with holes to allow pressure release during pyrolysis and (f) The canister was overturned and placed in a muffle furnace

a Thermolyne 48000 Series muffle furnace (Figure 1 (f)) at 600°C for three hours (Kearns *et al.,* 2014). The canister was left to cool to room temperature, on removing the mesh and sand, it was weighed to determine the weight of the precursor before and after the pyrolysis.

The difference in the weight of precursor was the result of thermal decomposition of organics in the precursor as most of the organic compounds were burnt off at 500°C (Cardenas-Aguilar *et al.,* 2017). The biochar was pulverized and sieved using a 200 US mesh (0.074 mm) and subsequently rinsed using distilled water to remove any impurities. The biochar was dried in an oven at 105°C overnight to remove moisture trapped within the pores.

The biochar was weighed to obtain its which could then be used for water treatment. The biochar was then tested for its physicochemical and adsorption characteristics to investigate the effect of the precursor on the structure of biochar and adsorption behaviour.

Physicochemical Characterization of Biochar

All the biochar synthesized from various precursors in this study were characterised for the physicochemical properties to determine the suitable precursors for producing biochar for water treatment. The physicochemical characterization encompassed elemental analysis, pH, textural analysis and scanning electron microscopy (SEM) analysis. All the biochar samples were pulverised and sieved through a 2 mm mesh prior to physicochemical characterisation.

Elemental Analysis

An elemental analysis was conducted for the biochar samples to determine the carbon (C), nitrogen (N) and hydrogen (H) compositions. 5 mg biochar was filled into a tin capsule and placed in an autosampler drum to remove any atmospheric nitrogen. The sample was then analysed using a Carlo Erba EA1110 elemental analyser. The sample was ignited at 1,000°C in a helium/hydrogen ratio of 95%: 5%, to generate compound gases of elements such as carbon monoxide (CO). The compound gases were measured using a gas chromatography to determine the ratio of elements in the sample. The composition of oxygen (O) was calculated using the below Equation 1 (ASTM D1762-84):

$$\text{O (\%w/w)} = 100 - \text{ash (\%w/w)} - \text{C (\%w/w)} - \text{N (\%w/w)} - \text{H (\%w/w)} \quad (1)$$

pH

The pH of biochar is among the key parameters affecting its application for water treatment and soil conditioning. The pH of biochar can be affected by the pyrolysis temperature and properties of precursor (Tomczyk *et al.,* 2020). Therefore, the pH of biochar was investigated in this study using a method reported by Raikovich *et al.* (2012). The biochar sample was mixed into distilled water in a 1:25 biochar: water (g/mL) ratio and shaken using a digital orbital shaker for 24 hours to achieve sufficient contact between biochar and water. The pH of biochar was determined by measuring the pH of the solution near the biochar.

Textural Characterisation

Surface area is a key factor governing the capacity of the adsorption properties of porous materials. The surface area, pore size distribution and pore volume of the biochar and precursor samples were measured using a Quantachrome Instrument automated gas sorption system, based on the gas adsorption technique (Hietala *et al.,* 1993). The sample was degassed at 250°C for three hours to remove any alien substances from the sample, followed by N_2 adsorption at 77 K. The specific surface area was determined based on the volume of N_2 adsorbed to the surface of sample, using the Brunauer, Emmett and Teller (BET) theory.

Scanning Electron Microscopy (SEM) Analysis

The surface morphology of the biochar sample was investigated through SEM-EDX micrographs captured using a Supra 55VP field emission scanning electron microscope (FESEM). The biochar sample was dried at 60°C

overnight in an oven. The sample was gold-coated using a Cressington SC 7640 sputtering device to ensure clear SEM imaging (Leslie & Mitchell, 2007).

Adsorption Study

Batch adsorption study was conducted to determine the adsorption behaviour of biochar, particularly the adsorption kinetics and adsorption isotherm to determine the adsorption type and capacity. The adsorption study was conducted by adding 1 g of biochar sample to 100 mL of 10 mg/L MB solution.

The mixture was shaken using an IKA KS501 digital orbital shaker at 150 rpm for 24 hours at room temperature. The appearance of biochar in the solution was observed to check whether it was physically intact or if it had disintegrated into powder. After 24 hours, the mixture was filtered through a 0.22 µm PTFE filter to separate biochar from the solution, which could interfere the colorimetric measurement.

The solution was analysed using a Perkin Elmer Lambda 35UV-Vis spectrophotometer at 664 nm to measure the MB concentration. Each batch of adsorption test was duplicated as a measure to validate the results. The MB concentration obtained from the batch adsorption test was used to calculate the amount of MB adsorbed at a specific time, q_t, calculated using Equation 2:

$$q_t = \frac{V(C_0 - C_t)}{w} \quad (2)$$

where C_o and C_t are the liquid-phase concentrations of MB at initial and at time taken in mg/L, respectively. V is the volume of the MB solution in container in L and w is the mass of dry biochar used as adsorbent in grammes.

Results and Discussion

Biochar Yield

The changes to the samples were assessed quantitatively through the biochar yield, which represented the percentage of carbonaceous content of a precursor. The biochar yield in the ascending order was dried leaves (15.0%), wood shaving (17.4%), wood chip (21.8%), tree branches (26.8%), dried bamboo (30.0%) and rice husk (40.9%) (Table 1). Dried leaves (Figure 2 (b)) and wood shavings (Figure 2 (d)) showed a low biochar yield of less than 20% as the samples were in flakes due to the larger ratio of exposed surface area for thermal decomposition (Kearns *et al.,* 2014).

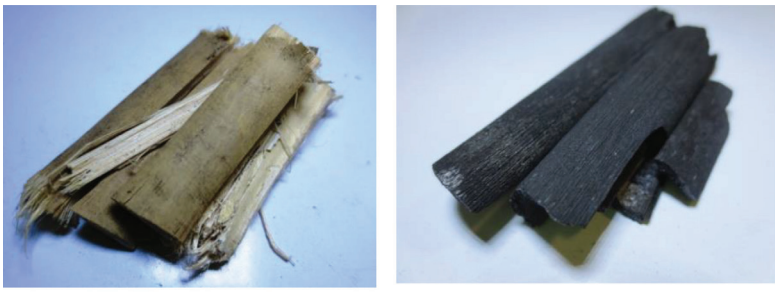
Despite having similar properties to that of wood shaving, bulky samples such as wood chip (Figure 2 (c)) and tree branches (Figure 2 (f)) showed biochar yield greater than 20% due to the smaller surface area exposed to thermal decomposition, promoting carbonization within the precursors. Bamboo (Figure 2 (a)) showed biochar yield greater than 30% due to the 70.91% content of recalcitrant carbon such as lignin (Kearns *et al.,* 2014; Zhang *et al.,* 2019), thus, categorized as Class 1 biochar (Panwar *et al.,* 2019).

Rice husk (Figure 2 (c)) showed the highest biochar yield of 40.9%, which was consistent with what was reported by Jindo *et al.* (2014). Unlike bamboo, the high yield was due to the silica content as the elemental analysis showed that the carbon content was only 42.52%. However, the biochar derived from rice husk had a significant amount of powder, making it less appealing for water treatment.

The appearance of precursors and the corresponding biochar are shown in Figures 2 (a)-(f). There was no major change in the overall appearance of the samples except for the reduction in volume and markedly clean and shiny black mass.

The shrinkage was due to the dehydration and thermal decomposition of organic matter under oxygen deficient conditions, which released vapour (H_2O) and carbon dioxide (CO_2), respectively, resulting in a carbonaceous (black) residue (Barr *et al.,* 2021; Panwar *et al.,* 2019). Carbon was found to be intact within the sample as it did not stain ones finges when handling the biochar, unlike charcoal.

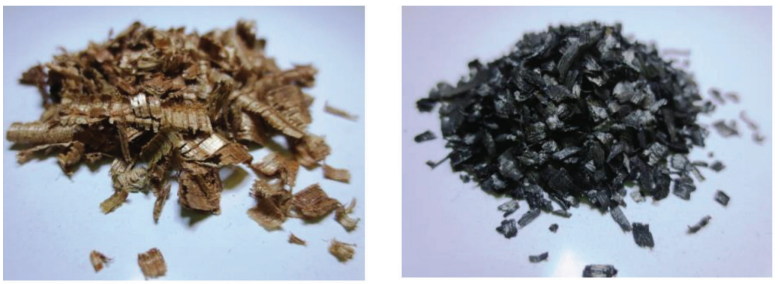
The shrinkage of sample was greater with decreasing biochar yield as the mass reduction was mainly due to the dehydration and decarboxylation reactions, releasing vapour (H_2O) and carbon dioxide (CO_2), respectively. This could be observed in all the biochar samples because of the decrease in hydrogen (H) and oxygen (O) contents, resulting in the increase in carbon content (Table 1). The decrease in H/C and O/C ratios indicate the removal of labile carbon and oxygen contents in the form of volatile matter (Jindo *et al.,* 2014; Kearns *et al.,* 2014).



(a)

(b)

(c)



(d)

Figure 2: Appearance of precursors (left) with the corresponding biochar (right) for (a) bamboo, (b) dried leaves, (c) wood chips, (d) wood shaving, (e) rice husk and (f) tree branches

Physicochemical Characteristics of Biochar

The physical properties of all the samples were determined using textural analysis to determine the surface area, pore volume and pore size and scanning it under the electron microscopy (SEM) to probe the surface morphology. The textural analysis revealed that the pyrolysis at 600°C for three hours increased the BET surface area by two orders of magnitude for all precursors except wood shavings and wood chips by one order of magnitude (Table 1). The BET surface area decreased in the order of activated carbon (control) > bamboo > wood shavings > rice husk > dried leaves > wood chips > tree branches.

The bamboo showed the greatest increase of BET surface area from 1.400 to 317.467 m^2/g, which was consistent with that of 288 m^2/g reported by Kearns *et al.* (2014). The pore volume increased 6-fold from 0.031 to 0.174 cm^3/g and pore size from 0.341 to 1.234 nm. Nevertheless, these physical parameters of biochar were smaller than that of commercial coconut shell-based activated carbon, as the latter was synthesized at a high temperature of 1,200°C.

The increase of pore volume and size, as well as BET surface area was attributed to the thermal decomposition of cellulose and hemicellulose (Figure 3 (a)), resulting in well-developed and homogeneous tubular turbostratic carbon micropores (Figure 3 (b)) (Tomczyk *et al.,* 2020). The thermal decomposition of cellulose and hemicellulose decreased the volatile matter, which mainly consisted of labile carbon, hydrogen and oxygen.

The effect of thermal decomposition on the increase of BET surface area for woody materials i.e., wood shavings, wood chips and tree branches were similar to that of bamboo, subjected to the composition of recalcitrant carbons such as lignin (Jindo *et al.,* 2014). The biochar derived from wood shaving had BET surface area, pore size and total pore volume of 254.548 m^2/g, 1.299 nm and 0.192 cm^3/g, respectively.

The biochar derived from tree branches and wood chips had pores larger than 2 nm (mesopores), however, the surface area was smaller than 60 m^2/g and total pore volume was

less than 0.002 cm^3/g. The difference between wood shavings and wood chips was the physical form of the precursor in which wood shavings (Figure 2 (d)) had larger ratio of exposed to total surface area of precursor for pyrolysis as compared to wood chips (Figure 2 (c)) (Nartey & Zhao, 2014).

The physical changes to the dried leaves were similar to that of wood shavings, which could be attributed to the physical form of the precursor. The increase of the BET surface area from 3.874 to 195.307 m^2/g was due to the significant removal of cellulose and hemicellulose as indicated through the biochar yield of 15%. The removal of moisture and the significant decomposition of chemical bonds and volatile matter resulted in the shrinkage of the structure, as observed when comparing the cross-sectional structure in Figures 3 (c) and 3 (d) (Barr *et al.,* 2021). Contrary to bamboo, the biochar derived from dried leaves did not have any homogeneous structure as the cross section revealed the micropores while the longitudinal section had a relatively smooth surface (Figure 3 (d)).

The pH of all the precursors was in the acidic range between 5.32 and 6.45 (Table 1) due to the presence of labile organic matters in the form of pith (Figures 3 (a) and 3 (c)). The pH of all the biochar samples was in the alkaline range between 8.30 and 9.81 (Table 1) due to the formation of carbonates and release of inorganic alkaline content from pyrolytic structure at 600°C (Tomczyk *et al.,* 2020). The

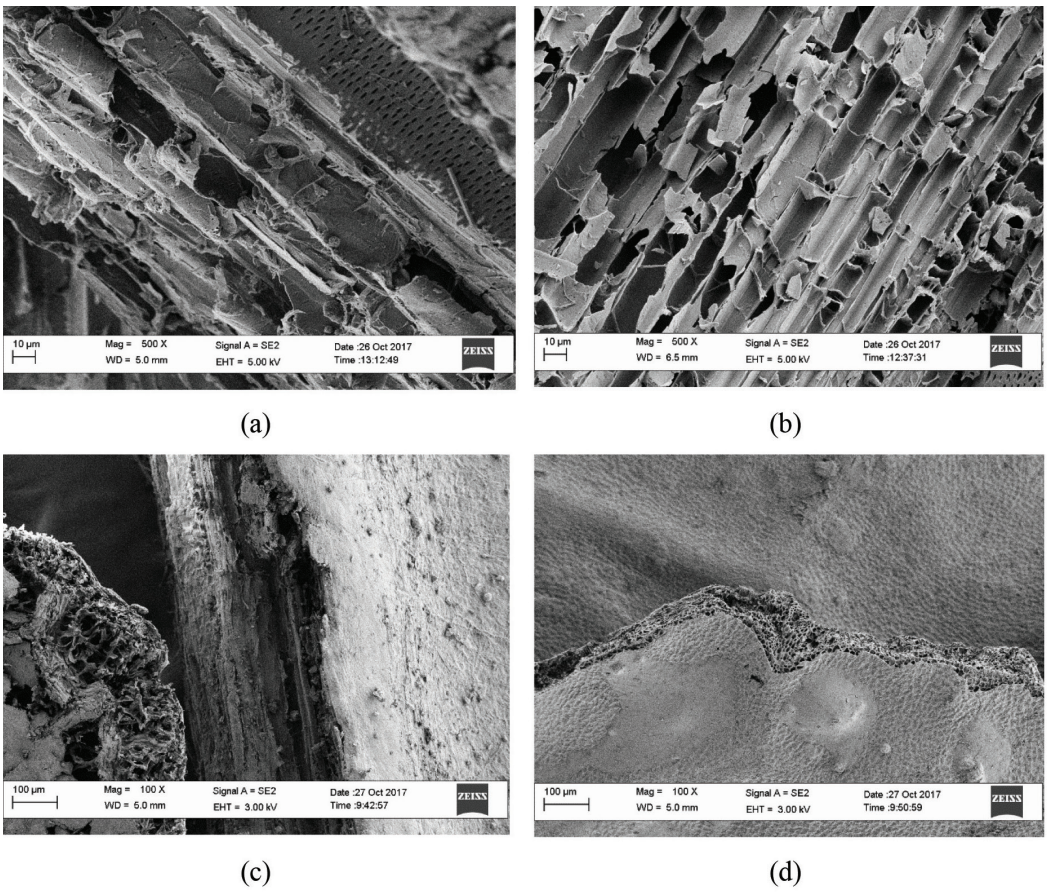


Figure 3: SEM image of (a) dried bamboo, (b) bamboo-based biochar magnified at 500 x, (c) dried leaves and (d) dried leaves-based biochar magnified at 100 x

Table 1: Physical parameters of biomass and corresponding biochar pyrolyzed under controlled conditions at 600°C for three hours using a muffle furnace

Sample	Biochar Yield (wt%)	Elemental Analysis							BET Surface Area (m^2/g)	Total Pore Volume (cm^3/g)	Average Pore Size (nm)	pH
		C (% w)	H (% w)	N (% w)	O (% w)	Ash (% w)	H/C (% mol)	O/C (% mol)				
Activated carbon	-	92.29	0.02	0.00	7.69	0.00	0.00	0.06	744.118	0.436	2.343	-
Bamboo	-	43.63	0.51	13.20	40.97	0.21	0.14	0.70	1.400	0.031	0.341	5.32 ± 0.02
Biochar	32.8	70.91	0.00	2.52	26.58	0.04	0.00	0.28	317.467	0.189	1.218	9.71 ± 0.04
Dried leaves	-	38.05	1.02	12.00	36.07	0.18	0.32	0.71	3.874	0.161	1.133	6.25 ± 0.01
Biochar	15.0	63.64	0.00	2.03	34.10	0.03	0.00	0.40	195.307	0.142	1.113	8.30 ± 0.01
Wood shavings	-	34.51	0.43	10.30	52.53	0.13	0.15	1.14	11.193	0.003	4.697	5.89 ± 0.01
Biochar	17.4	73.23	0.00	3.44	23.13	0.05	0.00	0.24	254.548	0.192	1.299	9.81 ± 0.02
Rice husk	-	29.94	1.54	9.92	38.35	0.19	0.62	0.96	11.692	0.003	2.467	6.45 ± 0.01
Biochar	40.9	42.52	0.01	1.69	55.68	0.04	0.00	0.98	201.761	0.150	1.362	8.43 ± 0.02
Tree branch	-								0.292	0.001	2.769	
Biochar	26.8								43.219	0.001	2.198	
Wood chip	-								1.287	0.002	3.097	
Biochar	21.8								51.376	0.002	2.439	

high pH and negative surface charge made the biochar favourable for adsorbing cation (Wang *et al.,* 2020).

Adsorption Characteristics

The adsorption study was carried out to determine suitable biochar for treating water in terms of structural integrity of water and its adsorption characteristics. The solution turned colourless after 24 hours, indicating that most of the MB had been adsorbed by the samples (Figure 4).

The biochar sample was observed for structural integrity in water at the end of experiment, whether the biochar sample remained intact or disintegrated in water. The solutions containing activated carbon and biochar derived from bamboo, dried leaves and rice husk were clear, indicating that the samples remained intact in water.

The solutions containing biochar derived from tree branches and wood chips were clouded with biochar powder, indicating that the biochar disintegrated in water. There was also some biochar powder suspended in the solution containing biochar derived from wood shaving. The disintegration in water disqualified the respective biochar from being considered for treating water.

All the biochar samples showed an adsorption pattern similar to that of the control sample, activated carbon. The amount of MB adsorbed on the adsorbent (biochar and activated carbon) increased with time until it reached a dynamic equilibrium, at which point the desorption rate was equal to that of adsorption (Tan *et al.,* 2008).

The contact time required to achieve equilibrium was about two hours, except biochar derived from dried leaves and rice husk which required 24 hours (Figure 5). The adsorption capacity at equilibrium (mg/g) was in the descending order of which rice husk (1.05), bamboo (0.99), wood shavings (0.99), dried leaves (0.95), tree branches (0.86) and wood chips (0.81), with control sample, activated carbon (1.02). The adsorption capacity of biochar derived from bamboo, dried leaves, wood shavings and rice husk were comparable to that of activated carbon.

The biochar derived from dried bamboo and wood shavings achieved their potential capacity in the shortest time, which was attributed to the higher BET surface area and total pore volume of micropores (Table 1) (Wang *et al.,* 2020), high carbon content (> 70%) and homogeneous tubular micropores (Figure 3 (b)).

The biochar derived from tree branches and wood chips also achieved their potential capacity in two hours, due to the larger pore size but lower adsorption capacity due to smaller BET surface area and pore volume. The gradual increase of MB adsorption by the biochar derived from dried leaves was most likely due to the diffusion of MB molecules into the micropores on the cross section of the biochar (Figure 3 (c)).

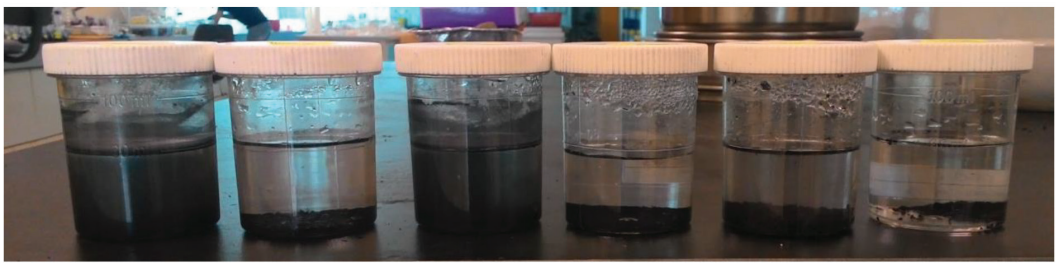


Figure 4: Appearance of solution after 24 hours of batch MB adsorption experiment using (from left to right) tree branches, dried leaves, wood chips, rice husk, wood shavings and commercial activated carbon as control test. Experimental condition: 1 g adsorbent in 100 mL of 10 mg/L MB solution shaken at 150 pm under ambient condition

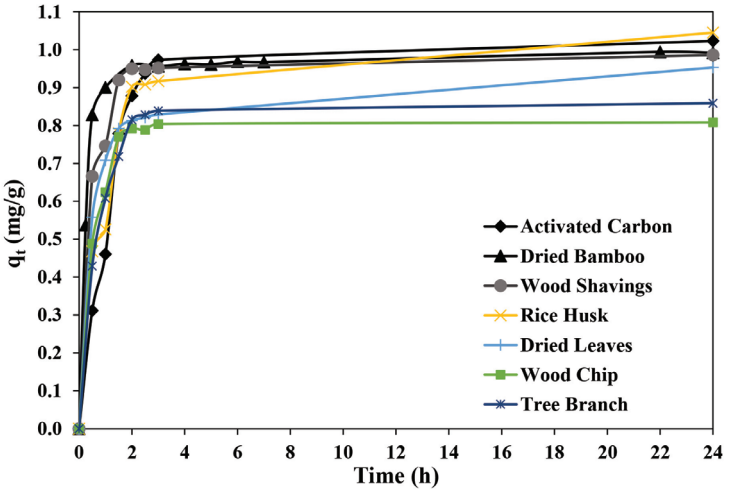


Figure 5: MB uptake of biochar synthesized from various precursors and commercial activated carbon (control)

Determination of Suitable Biochar Precursor

The determination of suitable biochar precursor for water treatment is summarized in Table 2. Dried bamboo was selected as the precursor for producing biochar to treat water as it fulfilled all the criteria in terms of favourable biochar yield circa 30%, well-defined and homogenous pores, structural integrity in water and superior adsorption performance. Besides technical considerations, bamboo can easily be obtained as it grows naturally along riverbanks in rural areas and it is free of synthetic chemicals, making it safe in the production of biochar for water treatment.

The familiarity with bamboo among the community helps the adoption of producing biochar locally for treating their water supply. Dried leaves, tree branches and wood chips are more suited as fuel for combustion due to their greater organic composition, thus producing more heat and less ash. Despite the highest biochar yield of 40.9%, the biochar derived from rice husk was considered not suitable for water treatment due to its high composition of fines and lower carbon content. In addition, some farmers might apply chemicals such as pesticides, which could release carcinogens when pyrolyzed, making it unsafe for treating water.

Table 2: Determination of suitable precursor based on criteria of biochar yield and suitability for water treatment

Precursor	Biochar Yield > 30% w	Structural Integrity in Water	MB Removal > 90%	Achieved Potential Capacity in Two Hours
Activated carbon	-	Yes	Yes	Yes
Dried bamboo	Yes	Yes	Yes	Yes
Dried leaves	No	Yes	Yes	No
Wood shavings	No	No	Yes	Yes
Rice husk	Yes	Yes	Yes	No
Tree branch	No	No	No	Yes
Wood chip	No	No	No	Yes

Conclusion

The present investigation showed that bamboo was the suitable precursor for producing biochar to treat water due to the favourable physicochemical and adsorption characteristics and structural integrity in water. The pyrolysis of bamboo at 600°C decomposed volatile matter to emanate the fixed carbon structure, resulting in a biochar yield of 32.8% which was practical for producing biochar in rural areas.

The biochar derived from bamboo showed favourable structural integrity in water and adsorption capacity due to the high BET surface area and total pore volume of micropores. Bamboo is free of synthetic chemicals as it grows naturally along riverbanks, making it safe for producing biochar for water treatment.

This study showed promises for local production of biochar from bamboo to enable rural communities' access to clean water supply. Bamboo is recommended to be applied as biochar precursor in the subsequent studies in our research on developing a biochar reactor for application in rural areas.

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