Evaluation of Sembilang Bamboo (*Dendrocalamus giganteus*) Charcoal for Potential Utilization

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Potential application of Sembilang bamboo (*Dendrocalamus giganteus*) as a fuel source or an adsorbent was investigated, due to its large diameter, fast growth speed, and growth type. Samples of *D. giganteus* were carbonized at various temperatures, and then their physicochemical, fuel, and adsorption properties were analyzed and compared to the properties of Moso bamboo (*Phyllostachys edulis*), which is widely used as a raw material for charcoal in Northeast Asia. The volume, weight, and density of the *D. giganteus* samples were greatly reduced between carbonization temperatures of 200 °C and 400 °C. It is possible that the high levels of SiO_2 and K in *D. giganteus* may cause a high electric conductivity value in *Dendrocalamus giganteus* charcoal, which is a poor fuel source because of its high ash content and low calorific value. The acidity of *D. giganteus* disappeared at a carbonization temperature of 400 °C and the pH of *D. giganteus* increased up to 10.3. The adsorption power of *D. giganteus*, in terms of iodine and methylene blue, was higher than that of *P. edulis*. Based on the results of this experiment, the proper utilization of Sembilang bamboo charcoal was suggested as a chemical adsorbent.

Keywords: Sembilang bamboo; Moso bamboo; Carbonization; Physicochemical properties, Fuel properties; Adsorption properties

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INTRODUCTION

Bamboo is a readily available carbon storage source according to Lobovikov *et al*. (2009), and it has become known as the "poor man's carbon sink". Bamboo has a rapid growth rate, as crops can be harvested after three to four years, and it does not require an expensive investment for its production and maintenance. Bamboo can be processed into various products such as charcoal, bioethanol, and biodiesel *via* different treatments (Asada *et al*. 2002; Sun *et al*. 2011). Bamboo occupies 3.2% of the world's forest area, and approximately 65% of this bamboo is grown in Asia. Moreover, in Indonesia, 10% (1.4 million ha) of bamboo grows (Park *et al*. 2019). In general, bamboo is one of the major non-timber forest resources in Indonesia and has achieved a maximum annual export value of $3 million (UN 2014). However, exports are steadily declining because of the advent of alternative products such as plastics, as well as competition from neighboring countries. Therefore, the Indonesian government has urged the development of Indonesian bamboo resources to overtake the current export issue (Hardiani and Dewy 2014). The goal of replacing wood resources to bamboo is ultimately aimed at establishing an industrial system that includes the participation of local people.

In Indonesia, about 118 of native bamboo species and 17 of introduced bamboo species were grown and 200 million ha (5% of world distribution) of bamboo forest were distributed (Lobovikov 2007). Particularly, Sembilang bamboo (*Dendrocalamus giganteus*), also known as dragon or giant bamboo, is a dense-clumping tropical and subtropical species native to the Java province in Indonesia. Sembilang bamboo is one of the largest bamboo species in the world, and it grows typically 30 meters in height. Moreover, it grows in clumps consisting of a large number of closely growing culms, and it is called the sympodial growth type (Fig. 1). Because of large diameter and growing in intensive area, Sembilang can be harvested with mass volume at one time. The advantages of superior productivity and easy cultivation management can be considered to be consistent with the overall goal of the Indonesian government (Park *et al.* 2019).

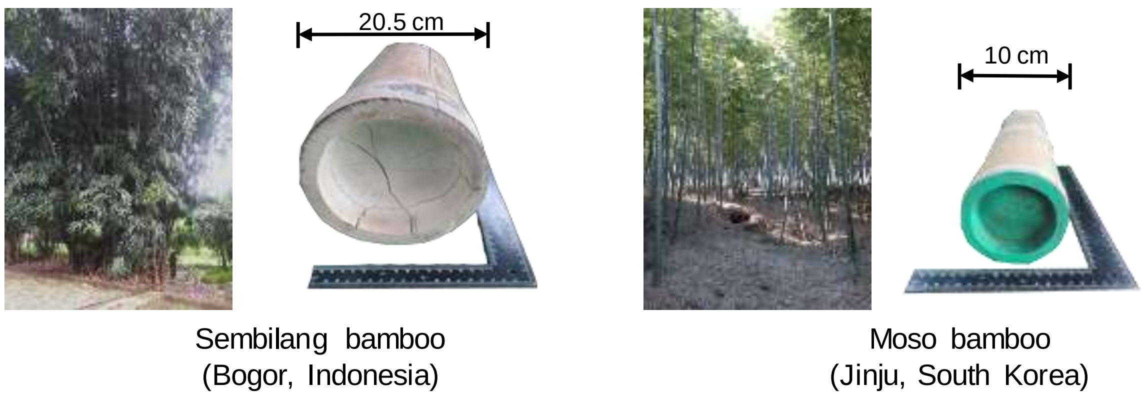

Fig. 1. Sampling sites and bamboo samples used in this study

Fuels and adsorbent are representative ways to use bamboo resources with high value. Recently, there has been a growing interest in the utilization of bio-energies that not only can solve global climate change, but also can function as a sustainable source of energy. To date, wood and grain have served as the primary bioenergy sources used to address this issue (Sulistyo *et al.* 2011). However, this has resulted in a shortage of wood resources and caused a food supply problem. Shortages in bioenergy sources have resulted in the emergence of herbaceous materials, such as bamboo, as a promising new source of raw materials. Carbonization is a basic technique to convert biomass to fuel or adsorbent (Basu 2009). Bamboo charcoal takes advantage of the production of functional products such as fuel, fertilizer, anti-bacterial deodorant, cosmetics, and underclothing in Northeast Asia (Park 2016). In particular, bamboo charcoal is considered to be an attractive material of original resource for commercial activated carbon. Many studies for utilization of bamboo charcoal as fuel or adsorbent have been carried out in other countries with their domestic species. However, Indonesian bamboo as such as Sembilan has not been studied for potential utilization.

In this study, Sembilang bamboo resources and carbonization technique were combined in order to achieve Indonesian government's goal "high value added goal through simple process". This research would be meaningful as a starting point for technical distribution and motivation for bamboo application research in Indonesia. Sembilang bamboo was converted charcoal under different temperatures, and its basic characteristics were investigated as well as functionality. In addition, overall comparison was conducted with Moso bamboo, which is used as major bamboo resources in Northeast Asia.

EXPERIMENTAL

Materials

The Sembilang bamboo (*D. giganteus*, 5 years old) was collected from an experimental bamboo plantation at Bogor Agricultural University (West Java, Indonesia, 6° 20' 21" S, 106° 33' 58" E). The Moso bamboo (*Phyllostachys edulis*, 5 years old) was collected from the Forest Biomaterial Research Institute (Jinju, Korea, 35° 10′ 44″ N, 128° 6′ 34″ E). During the procurement of the samples, the bamboo culm from the second node from the ground level was collected, and each dried for three months. The bamboo samples (25 mm (R) x 40 mm (L)) were carbonized at 200 °C, 400 °C, 600 °C, 800 °C, and 1,000 °C. Using the methods described in Park *et al.* (2019), the samples were wrapped in paper and aluminum foil and placed in a small rectangular heat-resistant container with a cover to prevent oxidation during the carbonization process. A heat-resistant container was placed in a laboratory electrical furnace (TST BT-F724, Daeyang Ins., Yeoju, Korea), and the carbonization process was carried out at a heating rate of 50 °C/h. The carbonization process was carried out for two h at the target temperature. After the samples had cooled and remained at room temperature for 2 h, the carbonized samples were taken out of the container. The raw and carbonized samples were named as listed in Table 1.

Table 1. Summary of Samples and Treatment

Bamboo species	Control	200 °C	400 °C	600 °C	800 °C	1000 °C
Sembilang	S-C	S-2	S-4	S-6	S-8	S-10
Moso	M-C	M-2	M-4	M-6	M-8	M-10

Methods

Physicochemical and fuel properties

The volume reduction, weight reduction, and density were measured according to KS F 2199 (2016) and KS F 2198 (2016) methodologies. The hydrogen ion concentration (pH) was determined according to TAPPI 435 (2006) methodology, using a pH meter (HM-30R, SECHANG, South Korea). Electric conductivities of the raw and carbonized samples were measured according to KS M ISO 6587 (2017) methodology. The mixed solution of 1 g of the oven-dried sample powder and 100 mL of distilled water was measured using an electric conductivity analyzer (CM-30R, DKK-TOA Corporation, Tokyo, Japan). The inorganic components of the bamboo samples were determined using an energy dispersive x-ray analyzer (410-EDS, Bruker, Billerica, MA). After setting the electric stimulation of the equipment to 10 KV, the silicon, potassium, calcium, and magnesium content was measured. An ATR FT-IR spectrophotometer (Nicolet 6700, Thermo Fisher Scientific Inc., Waltham, MA) was used to observe the chemical structure of the raw and carbonized bamboo samples. The spectrum was obtained at a mid-infrared region of 650 cm^{-1} to 4,000 cm^{-1}, and the spectral analysis was conducted using OMNIC software (Version 9.2, Thermo Fisher Scientific Inc., Waltham, MA). Proximate and ultimate analysis were carried out to determine fuel properties. The moisture content of the bamboo samples was measured according to KS F 2199 (2016) methodology. The ash content was measured according to KS E ISO 562 (2012) methodology. A crucible containing 1 g of the sample was placed in an electric furnace (TST BT-F724, Daeyang Ins., Yeoju, Korea), and then heated at 750 ± 25 °C for 1.5 h. The evaluation of the volatile matter was conducted according to KS E ISO 1171 (2002). The closed crucible with 1 g of sample was placed into an electric furnace heated at 920 ± 20 °C and maintained for 7 min. A calorimeter (Parr 6400 calorimeter, Parr Instrument Company, Moline, IL) was used to measure the calorific value and analyzed according to KS E 3707 (2016) methodology. The calorific value was measured with 0.5 g of sample and repeated three times. An elemental analyzer (Elementar Vario MACRO cube, Elementar Analysensysteme GmbH, Langenselbold, Germany) was used to measure the carbon and hydrogen content. Approximately 30 ± 5 mg of sample was wrapped in silver foil and placed in a sampler. The oxygen content was calculated by subtracting the sum of the carbon and hydrogen components.

Adsorption properties

In order to evaluate the adsorption ability of raw and carbonized bamboo samples, iodine and methylene blue (MB) adsorption experiments were carried out according to KS M 1802 (2003) methodology. The iodine values were calculated by measuring the mg of adsorbed iodine by 1 g of sample in a 0.1 N solution at an equilibrium concentration of 0.02 N. After being placed into a conical flask, 0.5 g of the mixed solution sample and 50 mL of 0.1 N iodine was shaken on a stirrer for 15 min. After being centrifuged at 2000 rpm for 5 min, 10 mL of supernatant solution was obtained. The filtrate solution was titrated with a 0.1 N sodium thiosulfate solution until the yellow coloration disappeared. A 1 mL sample of starch collusion was added, and then titrated again, until the blue coloration disappeared.

Table 2. Equations for Determining Adsorption Properties

No.	Equation	Variables
(1)	$qe\ (mg \cdot g^{-1}) = \frac{(Co - Ce)V}{W}$	C_o: Initial liquid-phase concentrations C_e: Equilibrium liquid-phase concentration V: Volume of the solution W: Weight of samples
(2)	$\frac{Ce}{qe} = \frac{1}{Qob} + \frac{Ce}{Qo}$	C_e: The equilibrium concentration of the adsorbate (MB) (mg/L) q_e: The amount of adsorbate adsorbed per unit mass of adsorbate (mg g^{-1}) Q_o: Langmuir constants related to the adsorption capacity b: Langmuir constants related to the rate of adsorption
(3)	$\log qe = \log KF + \frac{1}{n}\ \log Ce$	q_e: the amount adsorbed at equilibrium C_e: the equilibrium concentration of the adsorbate K_F: Freundlich constants related to the adsorption capacity of the adsorbent n: Freundlich constants related to the indication of how favorable the adsorption process was

The MB adsorption values were measured in terms of the mg of adsorbed MB by the 1 g of sample; these values indicated the medium-pore content of sample. A 1200 $mg \cdot l^{-1}$ MB solution was prepared and diluted to obtain five samples with five different solution concentrations in order to produce a standard calibration curve using a UV spectrometer (Lambda 465, PerkinElmer Inc., Waltham, MA) at 664 μm. Adsorption isotherms were performed in a set of 60 Erlenmeyer flasks (250 mL) using dye solutions (200 mL) with different initial concentrations (100 mg·l^{-1}, 200 mg·l^{-1}, 300 mg·l^{-1}, 400 mg·l^{-1}, and 500 mg·l^{-1}). Samples with a particle size of 0.2 g (150 μm) were added to the dye solutions and kept in an isothermal shaker (at 25 ± 1 °C) for 48 h to reach equilibrium of the solid-solution mixture. The residual concentration of the MB was measured *via* calibration curve. The equilibrium liquid phase concentration (C_e) and the equilibrium solid phase adsorbate concentration (q_e) were calculated according to Eq. 1 (Table 2). The relationship between the adsorbent concentration and the adsorption amount at a constant temperature is referred to as the adsorption isotherm (Haghseresht *et al*. 1998). Langmuir and Freundlich equations have been typically used to understand adsorption isotherms. According to respective constants from the previously calculated Eqs. 2 and 3 (Table 2), the constants needed to evaluate the adsorption capacity were derived.

RESULTS AND DISCUSSION

Production yield

The approximate production yield was calculated from the diameter, thickness, height, and number of bamboo columns. The number of bamboo column was calculated according to collecting site in this study (Bogor in Indonesia and Jinju in South Korea). The bamboo column per cubic meter was calculated by diameter and interval of column at the harvesting time in 2017 year (Fig. 2). The result was shown in Table 3, and the production yield of Sembilang bamboo was 19 times more than that of Moso bamboo. Higher production yield influences both producer and consumer in term of economic aspect.

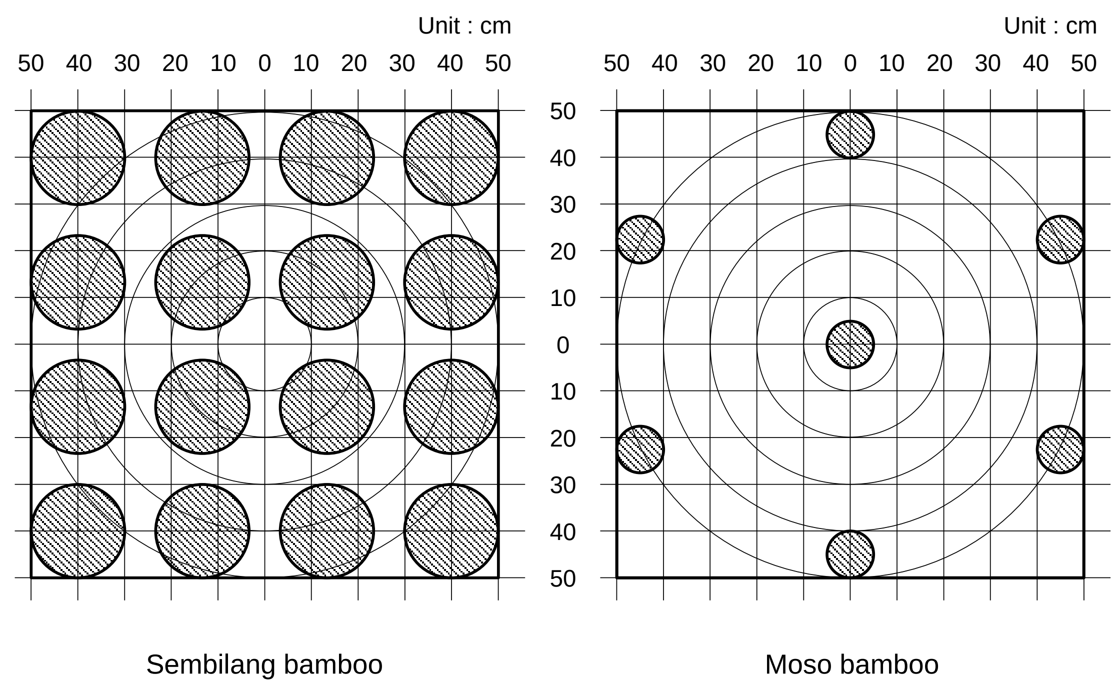

Fig. 2. The diagram of bamboo column distribution on site (Sembilang at Bogor, Moso at Jinju)

Table 3. Approximate Calculation of Production Yield for Bamboo

Species	Growth type	Diameter (cm)	Thickness (mm)	Height (m)	Column/m^3 (unit)	Total output (m^3)
Sembilang	Sympodial	20.5	16.5	30.5	16	4.765
Moso	Running	10.0	6.7	18.2	7	0.250

Physicochemical and Fuel Properties

The volume and weight reduction rate of both of the bamboo samples indicated a rapid change, especially in S-2 and S-4 (as shown in Table 4). The change from S-6 to S-10 was not major, and *Phyllostachys edulis* also showed the same tendency. The density of Sembilang bamboo was lower than that of Moso bamboo, and the density of both species decreased up until 400 °C. At 600 °C, the density showed a slight increase in both of the bamboo samples. In general, during the carbonization progress, a majority of the oxygen and hydrogen evaporated from bamboo as vapor or volatile gases until 400 °C. After that the remaining carbon, which was converted from bamboo, was covalently bonded with the application of steady compression and heat (Khandaker *et al.* 2018). The electric conductivity is an index of the strength of the electrolyte ions in solution and is expressed in terms of the inverse of resistance. Therefore, the greater the number of electrolyte ions in the solution, the greater the electric conductivity. Bamboo is known to contain a large amount of water-soluble, inorganic substances (Sims 2004). It was observed that the electric conductivity of both the bamboo species increased until 800 °C, then decreased. The electric conductivity was generally measured by index of ion in electrolyte. In the case of carbonized materials, electric conductivity was closely related with inorganic substance which from ash. In the process of carbonization, ash is melted and hardened as a clinker at the high temperature above melting point (750 °C) (Basu 2009). Therefore, decreasing of electric conductivity may be caused by this process. Park *et al*. (1998) also reported that the increase of hardness by clinker on bamboo charcoal surface was caused decreasing electric conductivity.

The moisture content of the raw bamboo samples was 7 to 10 %. At carbonization temperatures of 200 to 600 °C, the moisture content decreased to less than 6%, except for samples S-8 and S-10. The pyrolysis or the carbonization process was generally initiated by the evaporation of the free water inside the bamboo at temperatures of 100 °C or higher (Basu 2009). The bound water in the amorphous region of the cellulose chain was released in the form of volatile matter, which occurred along with the decomposition of cellulose at temperatures of near 200 °C. At temperatures above 800 °C, compression of the remaining carbon matrix occurred, and the residual cracks created by the release of the volatile components remained as fine pores. These pores are physically capable of adsorbing small molecules such as water, which increased the moisture content (Wang *et al*. 2010). A similar trend was shown in both bamboo species, with the most rapid decline of volatile matter observed between 200 and 400 °C. This was because cellulose, which is one of the main components of bamboo, decomposed between 250 to 370 °C (Mui *et al.* 2008). Since the fixed carbon amount is calculated in relation to moisture, the highest fixed carbon values (in the form of volatile matter and ash content), were observed in sample M-10. The calorific value (MJ/kg) is the amount of heat released when the fuel of a unit of mass is completely burned, which is an important criterion in fuel evaluation.

Table 4. Physicochemical and Fuel Properties of Bamboo Samples

Physical Properties			
Samples	Volume Reduction (%)	Weight Reduction (%)	Density (g cm^{-2})
S-C	-	-	0.60
S-2	7.88	21.78	0.55
S-4	34.66	63.49	0.36
S-6	49.95	68.68	0.40
S-8	52.31	70.17	0.40
S-10	54.91	70.34	0.43
M-C	-	-	0.78
M-2	10.29	24.52	0.66
M-4	37.97	57.20	0.53
M-6	48.03	66.57	0.49
M-8	58.78	67.44	0.58
M-10	61.64	69.41	0.61

Inorganic contents and electric conductivity					
Samples	Electric Conductivity (ms/cm)	Silicon (%)	Potassium (%)	Calcium (%)	Magnesium (%)
S-C	0.27	0.79	0.24	0.22	0.39
S-2	0.36	1.33	0.34	0.26	0.44
S-4	0.24	2.79	0.51	0.32	0.52
S-6	0.39	2.90	0.45	0.18	0.29
S-8	0.45	2.45	0.20	0.17	0.30
S-10	0.41	2.21	0.32	0.20	0.32
M-C	0.08	0.11	0.14	0.03	0.04
M-2	0.15	1.01	0.10	0.08	0.14
M-4	0.34	1.54	0.02	0.05	0.16
M-6	0.56	2.34	0.01	0.11	0.17
M-8	0.59	2.34	0.02	0.18	0.28
M-10	0.54	2.07	0.03	0.22	0.24

Fuel Properties					
Samples	Moisture Content (%)	Volatile Matter (%)	Ash (%)	Fixed Carbon (%)	Calorific Value (MJ·kg^{-1})
S-C	8.81	73.39	2.04	15.76	18.40
S-2	5.01	72.89	3.44	18.66	19.95
S-4	4.68	30.53	8.17	56.62	28.41
S-6	5.01	18.73	8.24	68.02	29.58
S-8	7.65	15.13	7.49	69.73	28.29
S-10	6.76	10.95	8.50	73.79	28.31
M-C	8.52	79.58	1.45	10.45	18.75
M-2	4.48	73.42	2.20	19.90	21.53
M-4	3.97	30.36	3.88	61.79	31.68
M-6	4.27	13.22	4.00	78.51	33.07
M-8	4.89	9.78	4.18	81.15	31.92
M-10	5.78	9.81	4.44	79.97	31.47

Chemical Properties				
Samples	pH	Carbon (%)	Hydrogen (%)	Oxygen (%)
S-C	5.2	48.23	5.99	45.36
S-2	5.5	50.72	5.41	43.38
S-4	7.5	70.39	2.86	26
S-6	10.2	80.92	1.74	16.47
S-8	10.3	82.49	0.76	15.68
S-10	10.3	84.43	0.47	14.16
M-C	5.7	53	6.58	40.08
M-2	5.7	56.52	5.86	37.14
M-4	8.6	78.87	3.14	17.28
M-6	9.1	93.33	2.14	3.7
M-8	9.1	96.38	0.82	1.67
M-10	9.6	97.18	0.42	1.39

The calorific value of both species showed the same tendency, and increased up to temperatures of 600 °C. This was due to the interactions achieved from the decrease in volatile matter because the combustion heat of carbon is generally higher than that of the volatile matter. Above 600 °C, the calorific values decreased, which was related to the increase in the ash content (Klass 1998). Hidayat *et al*. (2017) reported that the calorific value of Indonesian woody charcoal which was produced at carbonization temperature of 600 °C from Albizia (*P. falcataria*) and Gmelina (*G. arborea*) indicated 32.0 and 28.0 MJ·kg^{-1}, respectively. Overall, the fuel capacity of Sembilang bamboo sample could be comparable with those of wood.

The pH of bamboo samples was still acidic up to temperatures of 200 °C. It was confirmed that the samples became more alkaline at temperatures greater than 600 °C, with pH of 7.5 for sample S-6 and 8.56 for sample M-6. The pH of samples was increased to 10.3 for S-10 and 9.6 for M-10, respectively. Park (1998) reported that the pH of Moso bamboo charcoal ranged from 6 to 8.5. The pH of Sembilang was higher than that of Moso bamboo. Similar trends in the C, H, and O contents between the species were observed after carbonization. The C content increased, while the H and O contents decreased. These increased contents were most noticeable between 200 and 400 °C. These results were correlated with the pH, which is the logarithm of the concentration of hydrogen ions contained in a liquid.

Adsorption Properties

The iodine adsorption of the raw samples had an average weight of 175 mg g^{-1} mg. A decrease-increase-decrease tendency was observed in both species (as shown in Fig. 3). The raw samples simultaneously experienced chemical adsorption and physical adsorption. At the carbonization process, the overall adsorption power decreased because the major components associated with chemical adsorption were released. The lowest amount of iodine adsorption was observed at 400 °C. This may have been due to physical adsorption, but it did not show a sufficient effect because the pore formation was still proceeding. As the carbonization process proceeded, the components were emitted, and the remaining gaps and cracks formed into pores.

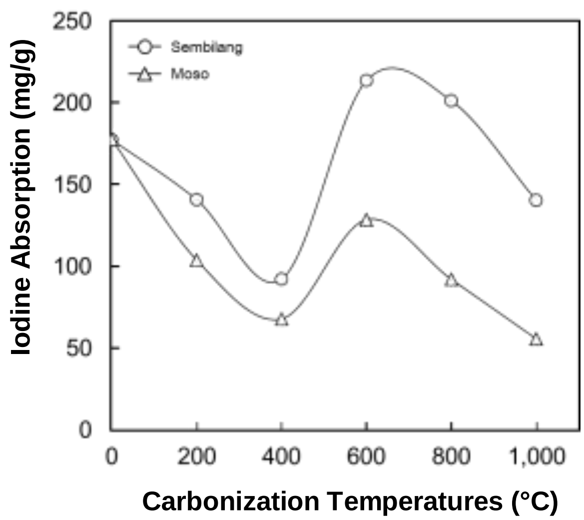

Fig. 3. Amount of iodine adsorbed by raw and carbonized bamboo samples

Methylene blue is well known for its strong adsorption of solids and is often used as a model compound to remove organic contaminants and chromosomes from aqueous solutions. Equilibrium adsorption data can help to understand the dye molecule adsorption mechanism of carbon adsorbent (Hameed *et al*. 2007). The adsorption isotherms of MB were determined using the Langmuir and Freundlich equations, which are widely used in adsorption studies (Table 5). The coefficient of determination R^2 of the equation was greater than or equal to 0.95, confirming that the equation was valid for the measured adsorption isotherm. Methylene blue adsorption of isotherms was calculated according to the Langmuir equation. Results included the equilibrium concentrations (C_e) of adsorbate, the adsorption amount (q_e) of adsorbate per unit mass, and the Langmuir constants (R^2 and R_L). A straight line with slope Q_o was obtained when $C_e\ q_e^{-1}$ was plotted against C_e (as shown in Figs. 4 and 5).

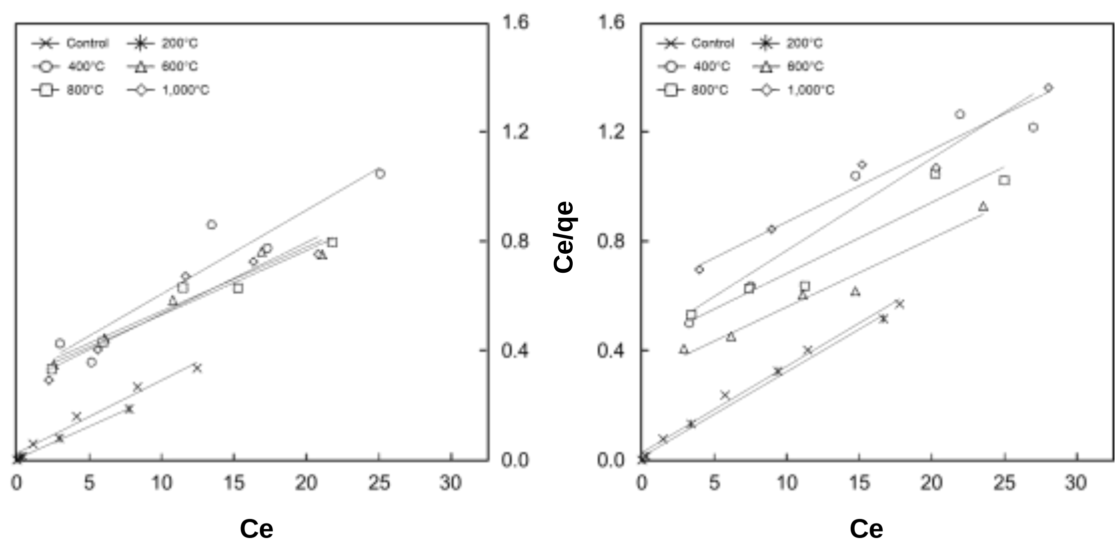

Fig. 4. Langmuir adsorption isotherms of methylene blue (Left: Sembilang; Right: Moso)

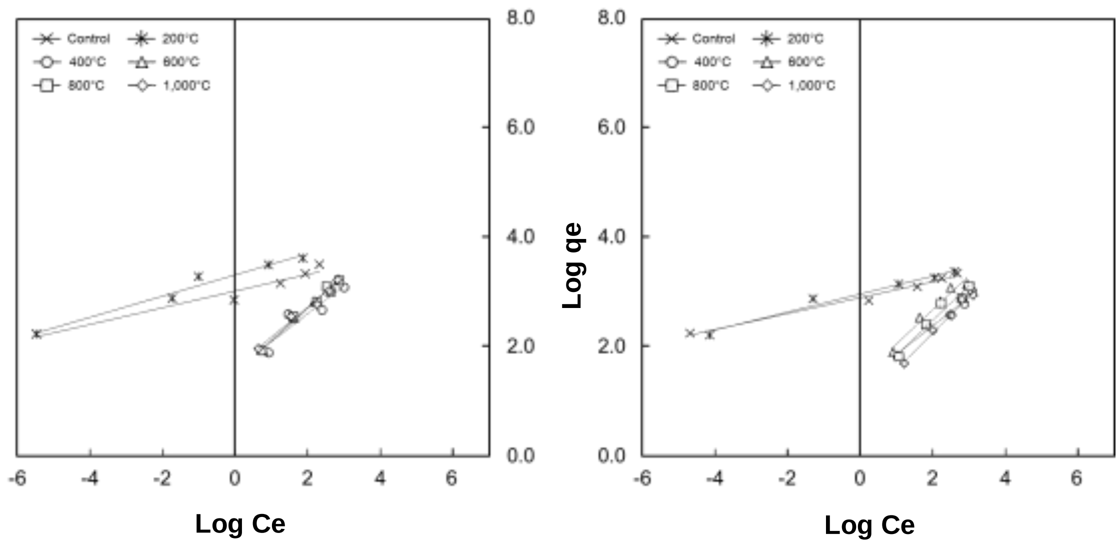

Fig. 5. Freundlich adsorption isotherms of methylene blue (Left: Sembilang; Right: Moso)

Table 5. Langmuir and Freundlich Isotherm Constants of Bamboo Samples

Samples	Langmuir Isotherm Constants			Freundlich Isotherm Constants		
	Q_o (mg/g)	K_L	R^2	Q_F	N	R^2
S-C	37.31	1.011	0.974	21.85	0.153	0.952
S-2	41.84	5.196	0.995	26.20	0.195	0.969
S-4	32.47	0.099	0.893	4.65	0.515	0.864
S-6	42.37	0.074	0.949	4.19	0.608	0.990
S-8	42.37	0.077	0.959	4.32	0.604	0.988
S-10	38.17	0.093	0.911	4.91	0.545	0.981
M-C	31.55	1.078	0.990	19.10	0.146	0.982
M-2	32.05	2.197	0.995	30.00	0.165	0.973
M-4	29.59	0.076	0.915	3.58	0.528	0.969
M-6	39.84	0.782	0.966	3.89	0.627	0.960
M-8	38.31	0.060	0.920	3.10	0.639	0.953
M-10	37.88	0.042	0.957	2.26	0.674	0.988

This demonstrated that the adsorption of the samples in this study followed the Langmuir isotherm, as well as the formation of a single layer of dye molecules on the surface of carbonized bamboo. The intrinsic properties of the Langmuir isotherm are represented by the dimensionless equilibrium parameter (R_L) (Weber and Chakkravorti 1974). The value of R_L indicates the type of the isotherm is either unfavorable (R_L is greater than 1), linear (R_L equals 1), favorable (R_L is greater than 0, but is less than 1), or irreversible (R_L equals 0). The value of R_L was found to be 0.004 and confirmed that the activated carbon was suitable for the adsorption of MB dye under the conditions used in this study (Hameed *et al*. 2007).

The experimental data obtained from the equilibrium adsorption experiments of bamboo samples were linearized to the log-log coordinates. The linear slope was obtained according to the logarithmic form of the Freundlich model, and this slope meant that the MB adsorption of the carbonized bamboo samples in this study followed the Freundlich isotherm (as shown in Figs. 4 and 5). From this slope, the value of the Freundlich constants, *e.g.* K_F and n^{-1}, could be determined. First, K_F can be defined as the adsorption or partition coefficient and represents the amount of dye adsorbed on the adsorbent per unit at equilibrium concentration. The slope n^{-1} ranged between 0 and 1 and is a measure of the adsorption intensity or surface heterogeneity, which becomes more heterogeneous as its value gets closer to zero (Haghseresht *et al*. 1998). A value of n^{-1} below one indicates a normal Langmuir isotherm while an n^{-1} above one indicates a cooperative adsorption (Fytianos *et al*. 2000). The highest adsorption amount was found in the order of S-C, M-C, S-2, and M-2, according to the Freundlich equation. This may be related to chemical adsorption, *e.g.* electric charge and acid-base interaction. Methylene blue is known as a basic dye, with the molecular structure of $C_{16}H_{18}N_3SCl{\cdot}3H_2O$. When MB is dissolved in a solvent, it is ionized to $C_{16}H_{18}N_3S^+$ and Cl^- (Lee *et al*. 2013). The primary constituents of bamboo, which have a large number of hydroxyl groups, are well preserved below 250 °C (as shown in Fig. 6). The acidity and carboxyl groups were detected in samples S-C, S-2, M-C, and M-2. Sembilang bamboo showed a greater adsorption capacity than Moso bamboo.

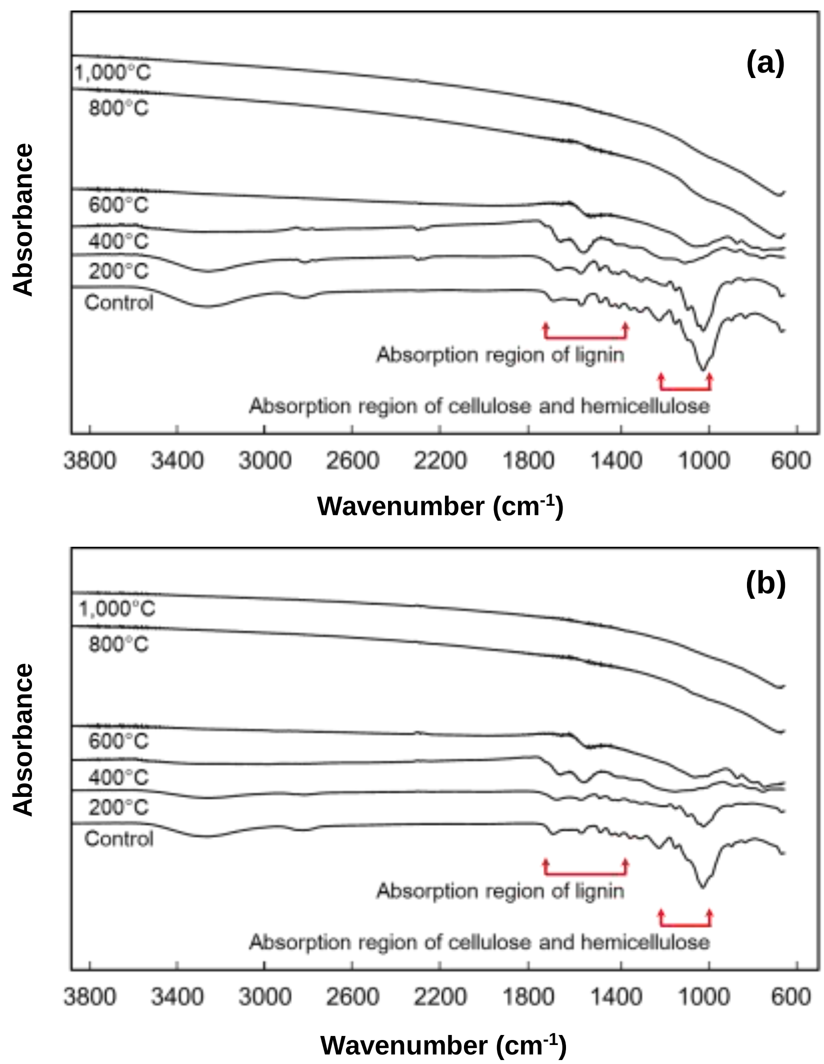

Fig. 6. FTIR analysis of raw and carbonized Sembilang (a) and Moso (b) bamboo samples

The carbonized bamboo of this study was confirmed to be insufficient in comparison with the adsorption capacity of the adsorbent specified in Hameed *et al.* (2007). It was mentioned that the activation process was essential to produce an adsorbent which can replace conventional fossil fuel-based activated carbon. In contrast, the adsorbent had different adsorption capacities depending on their utilization. Therefore, the use of carbonized bamboo produced at low temperatures as an adsorbent was considered (as shown in Fig. 7). Yang *et al*. (2017) reported that green algae or tide was effectively removed by using charged torrefied wood flour. It was suggested that the usage of an adsorbent produced *via* low temperature pyrolysis instead of the existing biomass adsorbent produced at high temperatures was a competitive alternative.

Fig. 7. Filtered 100 mL concentration methylene blue (MB) aqueous solution with different adsorbent samples (From left: S-C, S-2, S-4, S-6, S-8, and S-10)

CONCLUSIONS

1. In the world, bamboo charcoal is widely used as an energy source for industry and cooking. Sembilang bamboo has not been studied to obtain the basic biomass information. The production yield of Sembilang bamboo was 19 times more than that of Moso bamboo. Therefore, Sembilang bamboo can be a good resource for fuel, fertilizer, anti-bacterial deodorant, and adsorbents.
2. The results of various characteristics of carbonized Sembilang bamboo have been summarized. The fuel performance of Sembilang bamboo, such as calorific value and fixed carbon, was comparable to those of Moso bamboo. According to calorific value and total mass, Sembilang bamboo charcoal showed higher fuel properties than wood charcoal and pellets.
3. Sembilang bamboo has a relatively high amount of minerals, and it is expected to be of high value as a fertilizer. Especially it contains a lot of silicon, which can greatly help in plant growth.
4. Based on the adsorption properties, original Sembilang and Moso bamboo showed higher adsorption performance than carbonized bamboo. During the carbonization process, inorganic materials in bamboo was melted and hardened onto surface of materials, so adsorption performance decreased by increasing carbonization temperature. Sembilang and Moso bamboo should be used without heat treatment for as adsorbents.

5. At the carbonization temperature of 400 °C, the char yield, calorific value, fixed carbon and adsorptive powers were significantly changed, so 400 °C is the fiducial point for determining usage and industrial production standards.

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