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Characteristics of biochar produced from the harvesting wastes of meranti (*Shorea* sp.) and oil palm (*Elaeis guineensis*) empty fruit bunches

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Abstract. The objective of this study was to determine the properties of biochar from meranti (*Shorea* sp.) and oil palm (*Elaeis guineensis*) empty fruit bunches (OPEFB). Biochar was produced using a traditional kiln with a temperature of 400°C and 600°C. The char yield, pH, and proximate analysis were evaluated. The results showed that the maximum char yield was obtained at 400°C, and the increase in temperature resulted in decreased char yield. At the same pyrolysis temperature, char yield was higher in meranti than OPEFB. The results revealed that the pH of meranti and OPEFB changed into basic after pyrolysis, which is essential when biochar is added to soil to neutralize soil acidity and increase the soil cation exchange capacity. The results also showed an increase of fixed carbon in meranti and OPEFB after pyrolysis at 400°C and 600°C. The higher heating values (HHV) in meranti and OPEFB increased after pyrolysis, with a remarkable increase of HHV observed in meranti than OPEFB, showing a higher potential of biochar from meranti to be used for bioenergy application than OPEFB.

Keywords: Biochar, meranti wood, oil palm empty fruit bunch, pyrolysis

1. Introduction

Indonesia is an agricultural country that has abundant biomass resources from forestry and agriculture. Timber harvesting and wood processing operations generate a considerable amount of residues. The previous study [1] reported that timber harvesting of industrial plantation forests in Indonesia generates logging residues of 7.45% of the volume of harvested timber in the form of biomass. Including excessive stump height, left out clear bole stem, defective stems, cracked/split stems, branches, and twigs above clear bole stem. Wood processing generated wood residues between 15-60% by volume in sawmills and 40-70% by volume in plywood processing [2]. A previous study [3] reported biomass residues potential in Indonesia from timber harvesting of 4.5 million ton/year, sawn timber residues of 1.3 million ton/year, and plywood and veneer production residues of 1.5 million ton/year.

Palm oil residues are one of the most abundant biomasses from agriculture. The area of oil palm (*Elaeis guineensis*) plantations in Indonesia reached 14.33 million ha in 2018 (BPS, 2019) and made Indonesia the largest producer of crude palm oil in the world [4]. The increase in the area of oil palm plantations was accompanied by an increase in palm oil mill (POM) from 604 POMs in 2014 [5] to 742 in 2017 [6]. Hence the potential for biomass waste from POM was also increased. Solid biomass waste from POM consists of oil palm empty fruit bunch (OPEFB), mesocarp fiber, and palm kernel shell. OPEFB reaches 21% of fresh fruit bunches' weight and is the largest percentage of solid waste [5]. However, OPEFB has not been optimally utilized, where it is commonly used as fertilizer and compost production [7,8]. A previous study [3] reported biomass residues potential in Indonesia from OPEFB of 3.4 million tons/year.

One of the most promising technologies for converting non-merchantable forest and agriculture residues into high-value products is pyrolysis. Pyrolysis is a thermo-chemical process of biomass conducted at a temperature ranging between 300-800 °C in the absence of oxygen. During pyrolysis, biomass's chemical components undergo severe cross-linking, decomposition, and depolymerization, converting biomass into a carbon-rich solid residue called biochar, along with a condensable and non-condensable component (including water, highly oxygenated bio-oil, and synthesized gas) [9]. Biochar can be used to increase soil productivity, improve soil and environmental quality, produce energy, and sequester carbon [10–14]. Its quality and potential uses are affected by the types of biomass and the process parameters during pyrolysis, such as temperature, heating rate, and residence time [15]. In this context, this study's objective was to evaluate the characteristics and potential applications of biochar from forest and agriculture residues after pyrolysis at different temperatures using a traditional kiln.

2. Materials and Methods

2.1. Materials

Meranti (*Shorea* sp.) wood and oil palm (*Elaeis guineensis*) empty fruit bunches (OPEFB) were used as materials to produce biochar. Meranti woods were obtained from plantation forest in Jambi Province, Indonesia. The OPEFBs were obtained from a palm oil mill (PT. Anaktuha Sawit Mandiri) in Lampung Province, Indonesia. The average density of meranti and OPEFB was 0.48 g/cm^3 and 0.31 g/cm^3, respectively. Meranti woods used for biochar production were already in air-dry condition with an average moisture content of 11.6%. In comparison, the OPEFB was in wet condition with an average moisture content of 84.4%. Drying of the materials was not conducted before transferred into the biochar kiln. The meranti woods were cut to the length of 40 cm before put into the biochar kiln, while the OPEFBs were kept in their original form.

2.2. Production of Biochar

Biochars from meranti woods and OPEFBs were produced using two similar traditional kilns with a capacity of 12 m^3 in the research and development facility of PT. Kendi Arindo Lampung, a commercial charcoal producer in Lampung Province. The kilns were equipped with five control holes to control the supply of oxygen during the pyrolysis process. Meranti woods were horizontally stacked in the kiln until they reached the kiln's maximum capacity. The wood stack was burned on its upper part, and after the upper part burned, the control holes were subsequently closed to limit the kiln's oxygen supply.

Production of biochar from OPEFB used materials in wet conditions. Therefore the OPEFBs were not directly burned. Brick stacks with 40 cm height were covered with thin metal plates, and dry rubber woods were put under the metal plates as the fuel during biochar production from OPEFB (Figure 1). Before the OPEFBs were put into the kiln, holed-metal pipes were arranged vertically inside the kiln to distribute hot gas produced from the rubberwood burning during the process. The OPEFBs were then put into the kiln. The dry rubber woods under the metal plates were then burned.

The biochar production of meranti wood and OPEFB was conducted at a peak temperature of 400°C and 600°C. The kiln temperature was measured every hour and regulated by opening the control hole(s) when the peak temperature decreased and closing it when the peak temperature increased. One production batch was conducted for each type of biomass and temperature. Each batch was conducted for 14 days, from burning, maintaining peak temperature, to cooling.

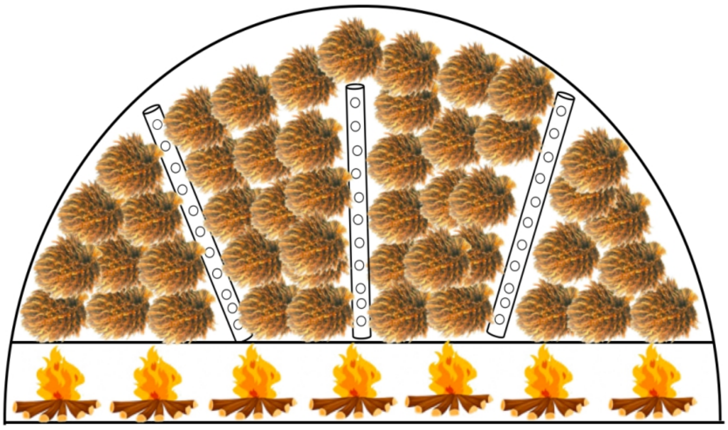

Figure 1. Arrangement of OPEFB inside the kiln

2.3. Characterization of Biochar

Char yield was determined using the following equations:

$$\text{Char yield} = \frac{\text{Weight of biochar}}{\text{Weight of origin biomass}} \times 100\%$$

The pH was determined using a mixed solution of 1 g oven-dried biochar powder and 100 ml distilled water following TAPPI 435 [16]. The solution was then boiled for 10 min and cooled down until reaching room temperature. pH was measured with a pH meter (InoLab pH Level 2).

For proximate analysis, volatile matter and ash content were evaluated following KS E ISO562 [17] and KS E ISO1171 [18], respectively. In addition, fixed carbon content was calculated using the equation:

$$\%\ \text{FC} = 100 - (\%\ \text{Ash} + \%\ \text{VM})$$

where % FC, % Ash, and % VM, mean the mass percentages of fixed carbon, ash, and volatile matter of the sample, respectively.

The higher heating value (HHV) of biochars from meranti and OPEFB was calculated using a correlation for calculating HHV from proximate analysis of solid fuels [19]:

$$\text{HHV (MJ/kg)} = (0.3536 \text{ x FC}) + (0.1559 \text{ x VM}) - (0.0078 \text{ x Ash})$$

The energy densification ratio (EDR) and energy yield (EY) was determined using the following equations [20]:

$$\text{EDR} = \frac{\text{HHV of biochar}}{\text{HHV of control}} \times 100\%$$

$$\text{EY (\%)} = \text{Char yield} \times \text{Energy densification ratio}$$

3. Results and Discussion

3.1. Char Yield

The char yield of meranti and OPEFB after pyrolysis at 400°C and 600°C was ranging between 15.90 – 34.2% (Figure 2). The results showed that the char yield of meranti was remarkably higher than OPEFB. The results were in line with the previous study [11], stating that char yield strongly correlated with the biomass's initial density, in which biomass with higher initial density resulted in a higher char yield.

The results also showed that char yield decreased with increasing temperature due to increased weight loss during the process. Weight loss occurred due to the evaporation and degradation of wood's main chemical constituents (cellulose, hemicellulose, and lignin) in the cell walls during pyrolysis [9]. A previous study [21] found that the average commercial charcoal yield does not exceed 30%, not only because the raw material influences the charcoal yield but also due to the process of conversion used.

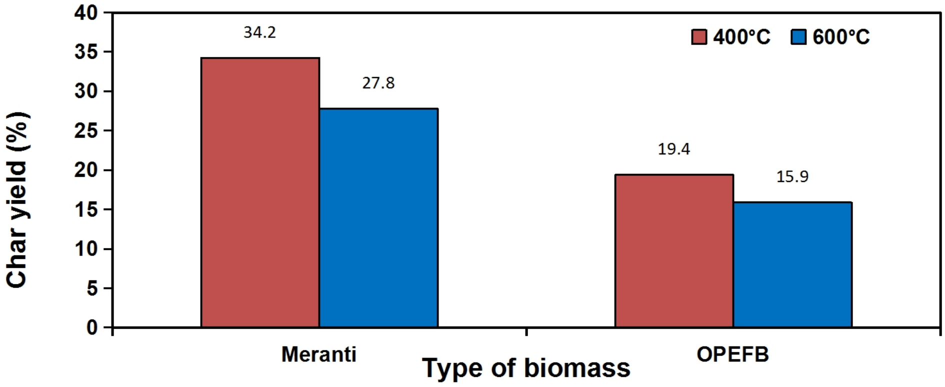

Figure 2. Char yield of meranti wood and OPEFB after pyrolysis at 400°C and 600°C

3.2. pH

The pH increased with increasing the temperatures, as shown in Figure 3. In other words, the pH of meranti and OPEFB changed into basic after pyrolysis. Generally, the lower the pyrolysis temperature resulted in the lower pH in the char structure due to the remaining carboxyl and hydroxyl groups on its structure [22]. A previous study [22] reported that *M. giganteus* became weakly basic (pH= 7.81) after pyrolysis at 350°C. In contrast, it turned to be strongly basic (pH= 10.80) at a higher pyrolysis temperature of 700°C. The high pH of charcoal from meranti and OPEFB is essential to increase the soil cation exchange capacity when such biochars are added to soil and neutralizing soil acidity and providing conditions suitable for micro-organisms [22,23].

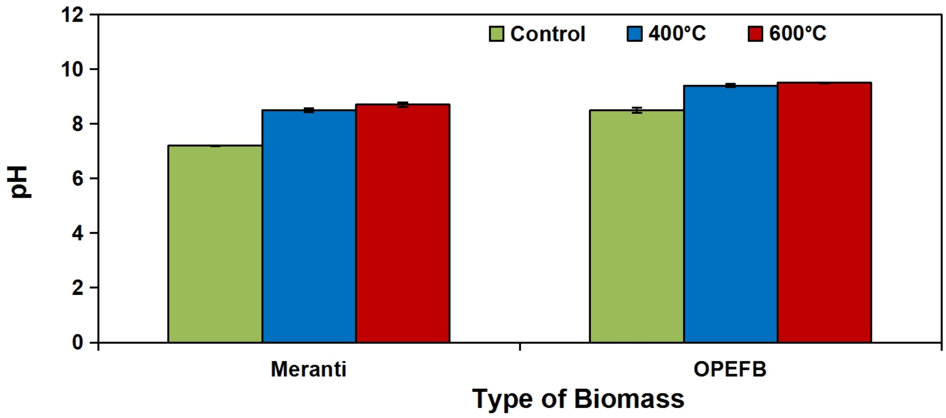

Figure 3. pH of meranti wood and OPEFB before and after pyrolysis at 400°C and 600°C

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3.3. Proximate analysis

Proximate analysis is commonly used to establish the rank of charcoal and other solid fuels for the suitability of combustion, pyrolysis, and gasification. Table 1 shows the proximate analysis of meranti and OPEFB before and after pyrolysis. The results showed that the fixed carbon of biochar from meranti and OPEFB was superior to control because most of the components with less stable bonds are degraded during pyrolysis, such as extractives, hemicelluloses, and celluloses [9]. Pyrolysis remarkably decreased the volatile matter of meranti and OPEFB, hence increased its fixed carbon value. The results showed that fixed carbon of pyrolyzed meranti and OPEFB increased with the increase of temperature.

Table 1. Proximate analysis of meranti wood and OPEFB before and after pyrolysis at 400°C and 600°C

Type of Biomass	Temperature (°C)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)
Meranti	Control	0.08 (0.03)	89.29 (4.39)	10.63 (4.40)
	400	0.76 (0.10)	42.62 (5.41)	56.62 (5.39)
	600	2.54 (0.25)	31.11 (5.68)	66.35 (5.88)
OPEFB	Control	5.89 (0.86)	86.67 (2.98)	7.44 (2.59)
	400	33.74 (3.29)	34.83 (4.71)	31.43 (1.63)
	600	38.98 (3.80)	23.48 (2.13)	37.55 (2.15)

Notes: The means are averages of 3 replicates. The numbers in parenthesis are standard deviations.

Using the proximate analysis data, the higher heating value (HHV) of biochar from meranti and OPEFB are shown in Table 2. The HHV of biochars from meranti and OPEFB increased with the increase of temperature. A remarkable improvement of HHV after pyrolysis was observed in meranti. The HHV of OPEFB slightly increased after pyrolysis, which was mainly attributed to the high ash content. Overall, the heating values of biochars from meranti and OPEFB at different temperatures met the requirement (minimum heating value of 8 MJ/kg) of the Indonesian Standard SNI 01-1506-1989 [24]. The energy densification ratio (EDR) and energy yield (EY) of biochar from meranti were remarkably higher than OPEFB. The results showed a higher potential of biochar from meranti to be used for bioenergy applications than OPEFB.

Table 2. Bioenergetic property of meranti wood and OPEFB before and after pyrolysis at 400°C and 600°C

Type of Biomass	Temperature (°C)	HHV (MJ/kg)	EDR	EY (%)
Meranti	Control	17.68 (0.87)	-	-
	400	26.66 (1.06)	1.51 (0.11)	51.69 (3.89)
	600	28.29 (1.20)	1.61 (0.15)	44.62 (4.08)
OPEFB	Control	16.10 (0.48)	-	-
	400	16.28 (0.34)	1.01 (0.03)	19.63 (0.58)
	600	16.63 (1.02)	1.03 (0.08)	16.45 (1.31)

Notes: HHV = higher heating value, EDR = energy densification ratio, EY = energy yield. The means are averages of 3 replicates. The numbers in parenthesis are standard deviations.

4. Conclusions

Maximum char yield was obtained at 400°C, and the increase in temperature resulted in a decrease of char yield. At the same pyrolysis temperature, char yield was higher in meranti than OPEFB. The results revealed that the pH of meranti and OPEFB changed into basic after pyrolysis, which is essential when biochar is added to soil to neutralize soil acidity and increase the soil cation exchange capacity. The results also showed an increase of fixed carbon in meranti and OPEFB after pyrolysis at 400°C and 600°C. The higher heating values (HHV) in meranti and OPEFB increased after pyrolysis, with a remarkable increase of HHV observed in meranti than OPEFB, showing a higher potential of biochar from meranti to be used for bioenergy application than OPEFB.

Acknowledgments

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