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Pyrolysis of *Puspa* Wood Sawdust and Sugarcane Bagasse into Biochar

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Abstract– *Puspa* wood sawdust and sugarcane bagasse are abundantly available but have low carbon content and nutrients. The carbon content and nutrients could be increased by converting biomass into biochar through pyrolysis. The independent variables of pyrolysis were essential to investigate because those inherently influence biochar quality. In this study, the effect of pyrolysis temperature (300, 350, 400, 450, and 500 °C) and time (30, 60, 90 mins) on the biochar characteristic such as pH, yield, and proximate compositions were determined. The total nitrogen, P₂O₅, and K₂O content at optimum condition biochar were also investigated. The data analysis showed that the pyrolysis temperature and time increment positively correlated to the pH, ash content, and carbon content. At the same time, the yield and volatile matter were vice versa. Both biochar's optimum pyrolysis temperature and time were achieved at 500 and 90 minutes. The carbon content and nutrient of biochar were also increased compared to the biomass. The pyrolysis method has enhanced biomass quality, and the biochar may be used as a growing media and soil amendment. It can be concluded that the sugarcane bagasse biochar was more likely favorable than *puspa* wood sawdust biochar due to its higher fixed carbon and nutrient content.

Keywords: *Puspa* Wood Sawdust, Sugarcane Bagasse, Biochar, Pyrolysis.

Introduction

Soil is a natural environment rich in minerals, organic substances, and creatures interacting dynamically. Healthy soil will positively correlate with agricultural crop productivity, while contaminated soil by various pollutants can significantly inhibit the growth and production of crops (Zhang and Chen, 2017; Yu *et al.*, 2019). In contrast, the demand for agricultural crop production is continuously growing, while the availability of fertile land is dwindling (He *et al.*, 2020). Therefore, alternative growing media or soil amendments are needed to improve and remedy soil quality.

Soil quality can be improved by adding lime, zeolite, peat, and biochar materials to the soil (Kaudal *et al.*, 2016). However, some of these materials do not seem to assist the positive sustainability of the environment and many aspects. The use of lime in the long term causes the balance of nutrients in the soil to be disrupted and makes organic matter quantity decline rapidly. The relatively high price of zeolite and improper use make soil quality improvement ineffective and inefficient. In addition, peat requires a long regeneration time; hence it is not renewable material and requires aggregates such as perlite, which are expensive, unsustainable, and harmful to the environment (Lévesque *et al.*, 2020). Biochar is an environmentally friendly, pollution-free, and renewable material compared to others; thus, it can be used as an alternative to either growing media or amendment soil (Lahori *et al.*, 2020).

Biochar can increase soil fertility and plant productivity due to its capability to supply and maintain nutrients (Purakayastha *et al.*, 2019; Zhang *et al.*, 2019; Zhou *et al.*, 2019). Ibn Ferjani *et al.* (2020) reported that the biochar

might be considered slow-release organic fertilizers, which interact well with soil fertility and crop productivity. Biochar is superior to other organic materials due to its high stability against decomposition, and hence it can last longer in the soil and provides long-term benefits (Mensah and Frimpong, 2018). Furthermore, Ahmadi, Ghasemi, and Sepaskhah (2020) demonstrated that incorporating biochar into soil aggregates can reduce soil loss. This increase in soil aggregates is gleaned from the relatively significant contribution of biochar carbon content.

Biomass such as wood waste, agricultural residues, and animal manure have been used as raw materials for biochar (Helmisaari, Kaarakka, and Olsson, 2014). Among the many types of biomass, pupa wood sawdust and bagasse reported having a relatively large cellulose and hemicellulose content. However, this untreated biomass has a low carbon and nutrient content and decomposes in the soil at a higher rate (Racioppi, Tartaglia, and Marra, 2020). The biomass pyrolysis will produce a relatively high carbon content of biochar which inherently increases the nutrient contents (Webber III *et al.*, 2015; Ahmad, Munaim and Said, 2016; Wang *et al.*, 2017). Biochar from this biomass is also more stable than others and has a large surface area and porosity. These characteristics are reported to support soil quality improvement (Palviainen *et al.*, 2020; Pariyar *et al.*, 2020). Furthermore, the production of sugarcane and pupa wood increases every year and will be in line with the increase in waste. The waste produced is generally just thrown away, less valuable, and it is afraid to reduce the environment's quality and aesthetics and can be overcome by converting biomass into biochar (Ahmad, Munaim and Said, 2016; Wright, Lima and Bigner, 2016).

The physicochemical attributes of biochar are intensely impacted by parameters, for example, biomass type and pyrolysis conditions such as temperature and time (Orang and Tran, 2015; Liao and Thomas, 2019; Tang *et al.*, 2019; Tomczyk, Sokołowska and Boguta, 2020). To the best of our knowledge, comparative studies on the pyrolysis of sugarcane bagasse and sawdust of pupa wood at a temperature range of 300-500 °C and a pyrolysis time of 30-90 minutes with a low heating rate to maximize the biochar properties for agricultural purposes have not been well studied. Therefore, this research would be focused on studying the effect of pyrolysis temperature and time of sugarcane bagasse and sawdust of pupa wood on yield, pH, and proximate compositions of biochar. Biochar that gave the highest carbon content would be further analyzed for its nutrient contents such as total nitrogen, K₂O, and P₂O₅ content.

Materials and Methods

Biomass preparation

Sawdust of pupa wood (*Schima wallicbii* (DC.) Korth.) and bagasse (*Saccharum officinarum* L.) were obtained from North Indralaya, Ogan Ilir. For one week, the biomass was cleaned with distilled water and subsequently air-dried under ambient conditions. Next, the biomass was dried at 50 °C for 10 hours to remove moisture (Ahmed *et al.*, 2020). The sugarcane bagasse was chopped into small pieces (< 3–4 cm), whereas the pupa wood sawdust was sieved in the equivalent particle size.

Biomass pyrolysis

An amount of pupa wood sawdust and sugarcane bagasse biomass were pyrolyzed in a cylindrical furnace at 300, 350, 400, 450, and 500 °C for 30, 60, 90 minutes with a heating rate at exactly or nearly the same of 1 °C/seconds and limited O₂ atmosphere. After the furnace temperature reached room temperature, the biochar was retrieved and put into a desiccator. Biochar with the highest carbon content would be further analyzed for its nutrient contents, such as total nitrogen, K₂O, and P₂O₅ content.

Biochar analysis

Biochar yield (BY) was calculated as the mass of biochar formed following pyrolysis (W) divided by the mass of the raw material (W_o) according to equation (1) as follows:

$$BY (\% \text{ w/w}) = \frac{W}{W_o} \times 100 \quad (1)$$

Next, 1 g of biochar was dissolved in 10 mL of boiling distilled water, agitated for 15 minutes, and filtered to determine the pH value. The filtrate was allowed to cool at ambient temperature before measuring using a pH meter. (Hanna HI8010) (Albalasmeh *et al.*, 2020). The ash content of biochar (BA) was assessed utilizing SNI 01-62352-200 by heating the sample in an air atmosphere in a muffle furnace (Thermolyne) at 600 °C for 2 hours.

Similarly, the volatile matter content of biochar (BV) was evaluated according to the SNI 01-1682-1996 by heating the sample in a closed crucible in a muffle furnace (Thermolyne) at 750 °C for 7 minutes. The difference between 100 and the sum of volatile matter and ash contents was used to estimate fixed carbon content (BC). Those calculations were represented according to equation (2)-(4) as follows:

$$BA (\% \text{ w/w}) = \frac{Y_2 - Y_o}{Y_1 - Y_o} \times 100 \quad (2)$$

$$BV (\% \text{ w/w}) = \frac{Y_1 - Y_2}{Y_1 - Y_o} \times 100 \quad (3)$$

$$BC (\% \text{ w/w}) = 100 - (\text{Biochar Ash content} - \text{Biochar Volatile Matter Content}) \quad (4)$$

Y_o was the weight of empty crucible (g), whereas Y_1 and Y_2 were the weight of crucible with biochar and the weight of crucible with heated biochar, respectively.

The total nitrogen was evaluated using the Kjeldahl method (SNI 2803-2012) measured by UV-Vis Spectrophotometry (Shimadzu) at 400 nm using a molybdo vanadate Reagent. Lastly, The K_2O content was determined according to SNI 2803-2012 estimated by a flame photometer (Sherwood M 410). All chemicals for analysis were analytical grade.

Results

Biochar yield

The influence of pyrolysis temperature on biochar yield from puspa wood sawdust and sugarcane bagasse is depicted in Figure 1. It can be seen that the highest biochar yields of both biomass were obtained at a temperature of 300 °C with 58.08 and 52.59 %w/w biochar yield, respectively, while the lowest yields were obtained at 500 °C with 34.40 and 33.07 %w/w biochar yield, respectively. Figure 1 illustrates that the yield of biochar decreases as the pyrolysis temperature rises. This trend was consistent with other reports (Rehrah *et al.*, 2014; El-gamal *et al.*, 2017).

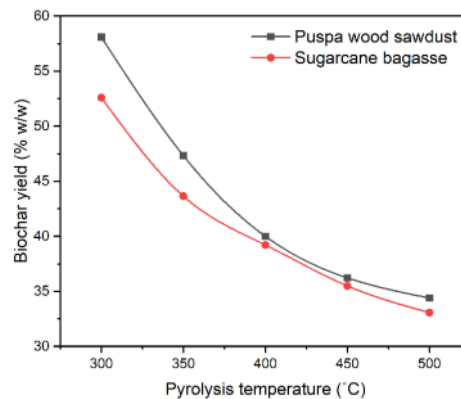


Figure 1. Effect of pyrolysis temperature on biochar yield.

The biochar yield of puspa wood sawdust and bagasse (Figure 1) decreased quite significantly between 300 and 350 °C, with less than 18.51% and 17.02%, respectively. Afterward, during pyrolysis at 350-450 °C, the biochar yield decreased to 15.49-9.45% and 10.15-9.49%, respectively. The biochar yield of puspa wood sawdust and bagasse at high-temperature pyrolysis (450-500 °C) decreased relatively low, was only about 5.02% and 6.82%, respectively. This finding was consistent with another report (Dhar, Sakib, and Hilary, 2020). Figure 2 shows the influence of pyrolysis time on biochar yield from puspa wood sawdust and sugarcane bagasse. It can be seen that the highest biochar yields in sawdust and bagasse were obtained at 30 minutes with 43.14 and 38.09 %w/w biochar yield, respectively, while the lowest biochar yields were obtained at 90 minutes with 31.99 and 28.45 %w/w biochar yield. Figure 2 shows that puspa wood sawdust and bagasse's biochar yield decreases as

the pyrolysis time increases. This finding was consistent with the study (2018) regarding the effect of pyrolysis time on biochar yield.

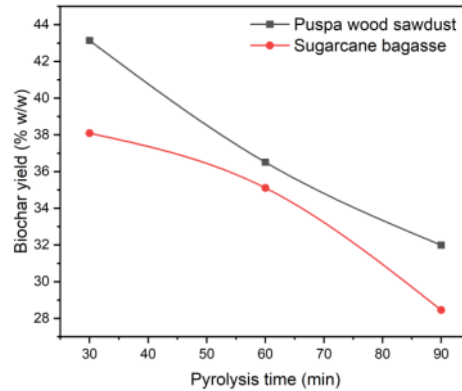


Figure 2. Effect of pyrolysis time on biochar yield.

Biochar pH

Figure 3 represents the effect of pyrolysis temperature on biochar's pH of puspa wood sawdust and sugarcane bagasse. Figure 3 reveals that the pH value of biochar increments with rising pyrolysis temperature. A similar finding has been reported (Zhao *et al.*, 2018). This trend indicated that biochar was relatively acidic at low temperatures (300-400 °C). The pH value gradually increases alongside increasing temperature (450 °C) towards neutral by 7.26 and 7.61 pH values. Furthermore, the pH value of biochar increases at high temperatures (500 °C), resulting in an alkaline biochar pH.

The effect of pyrolysis time on pH biochars of puspa wood sawdust and sugarcane bagasse are shown in Figure 4. Puspa wood sawdust biochar and bagasse had average pH values of 6.09-8.19 and 6.70-9.02, respectively. The highest pH of biochar in puspa wood sawdust and bagasse was 8.19 and 9.02 within 90 minutes, respectively, whereas the lowest pH of biochar was 6.09 and 6.69 within 30 minutes. It can be seen that the longer the pyrolysis time, the higher the pH of the biochar formed. This condition was consistent with Rehrah *et al.* (2014) report.

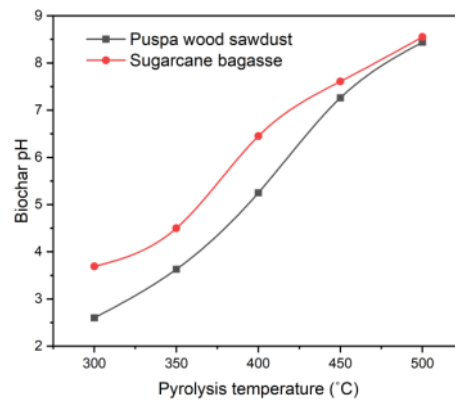


Figure 3. Effect of pyrolysis temperature on biochar pH.

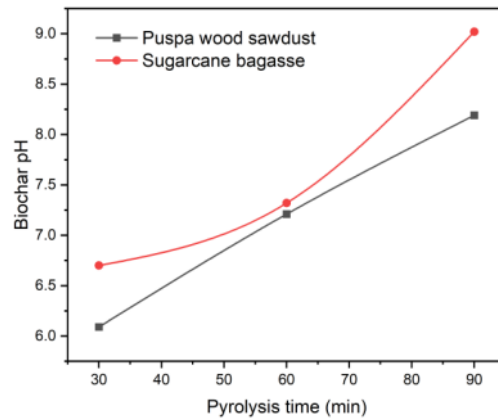


Figure 4. Effect of pyrolysis time on biochar pH.

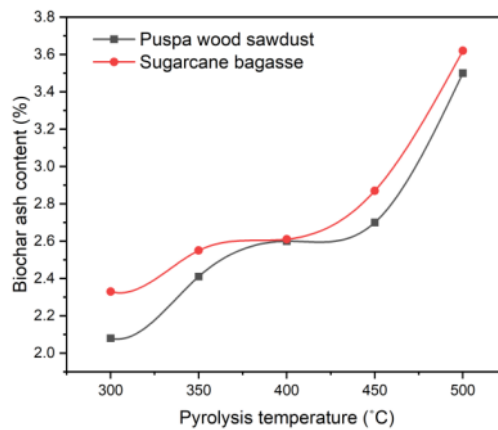


Figure 5. Effect of pyrolysis temperature on biochar ash content.

Biochar proximate composition

The influence of pyrolysis temperature on biochar ash content from puspa wood sawdust and sugarcane bagasse is shown in Figure 5. The highest average ash content of puspa wood sawdust biochar and bagasse obtained at a temperature of 500 °C was 3.50% and 3.62%, respectively, while the lowest average ash content of puspa wood sawdust biochar and bagasse obtained at a temperature of 300 °C was 2.08 and 2.33%, respectively.

The influence of pyrolysis time on biochar ash content from puspa wood sawdust and sugarcane bagasse is shown in Figure 6. The highest biochar ash content in puspa wood sawdust and bagasse obtained at 90 minutes was 2.11 and 6.56%, respectively, while the lowest percentage of biochar ash content obtained at 30 minutes was 1.68 and 3.19%, respectively. Figure 6 shows that the relative pyrolysis time variation affects the ash content of biochar. The increase in pyrolysis time can be observed to be positively correlated with the ash content (Sun *et al.*, 2017). In other words, the ash content increments with the longer pyrolysis time.

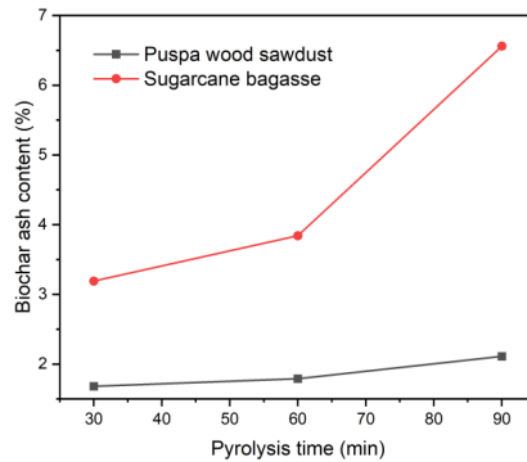


Figure 6. Effect of pyrolysis time on biochar ash content.

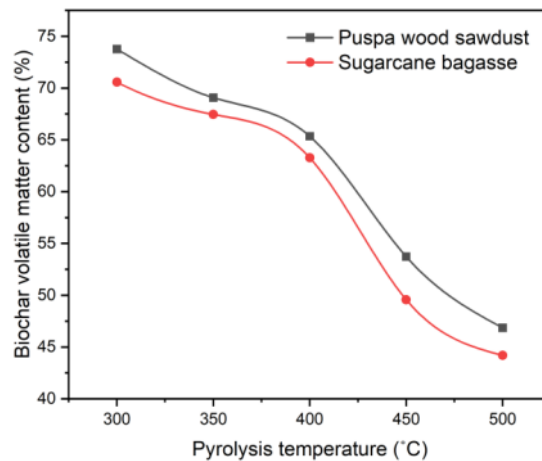


Figure 7. Effect of pyrolysis temperature on biochar volatile matter content.

Figure 7 shows that the highest average volatile matter content of sawdust and bagasse was obtained at a temperature of 500 °C with 73.76% and 70.57%, respectively. In comparison, the lowest average volatile matter content of biochar was obtained at a temperature of 300 °C with 46.86% and 44.19%, respectively. It can be seen that the volatile matter content in biochar had a negative correlation with pyrolysis temperature. A similar finding was reported by Makavana, Sarsavadia, and Chauhan (2020) in their study using shredded cotton stalks as a feedstock.

The effect of pyrolysis time on the volatile matter content of biochar from sawdust of puspa wood and bagasse is shown in Figure 8. The highest volatile content in puspa wood sawdust biochar and bagasse was obtained at 30 minutes of 63.03 and 60.85%, respectively, while the lowest volatile biochar content was obtained at 90 minutes of 45.89, 48.60%, respectively. Similarly, the biochar volatile matter content decreased as pyrolysis time increased.

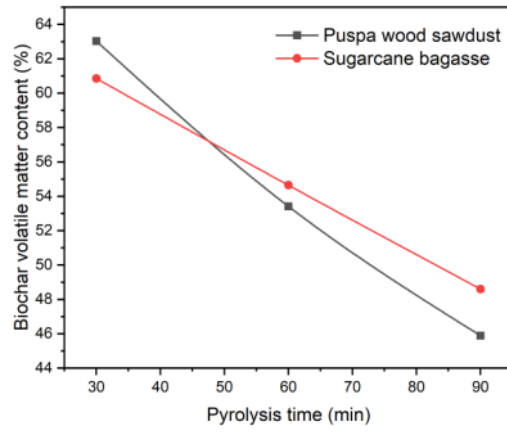


Figure 8. Effect of pyrolysis time on biochar volatile matter content.

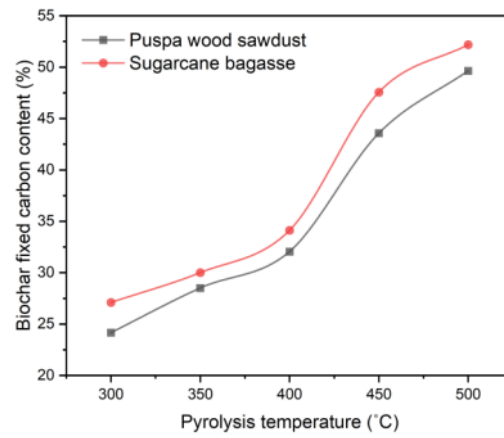


Figure 9. Effect of pyrolysis temperature on biochar fixed carbon content.

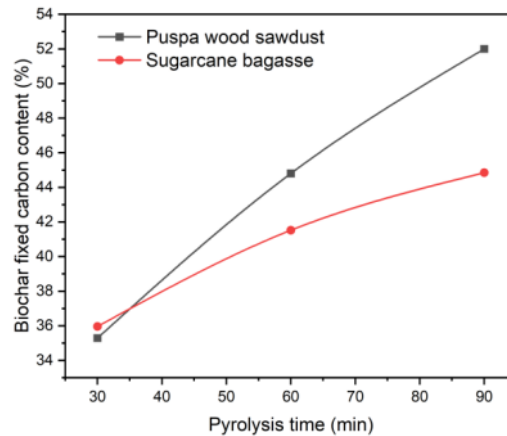


Figure 10. Effect of pyrolysis time on biochar fixed carbon content.

Figure 9 depicts the influence of pyrolysis temperature on biochar fixed carbon content from puspa wood sawdust and bagasse. Figure 9 illustrates that as the pyrolysis temperature expanded, likewise increased the fixed carbon biochar.

The effect of pyrolysis time on biochar fixed carbon content from sawdust of puspa wood and bagasse is presented in Figure 10. The biochar fixed carbon content increased as the time of pyrolysis increased.

Analysis of nutrient content of biomass and biochar

Table 1 shows the nutrient content analysis of biomass and biochar from pyrolysis at 500 °C and 90 minutes. It can be seen that the pyrolysis of biomass could increase the nutrient content of total nitrogen, P₂O₅, K₂O, as well as fixed carbon of biomass.

Table 1. Nutrient content of biomass and biochar.

Sample	Fixed carbon (%)	Nutrient content		
		Total nitrogen (%)	P ₂ O ₅ (%)	K ₂ O (%)
Puspa wood sawdust	13.43	0.14	0.26	0.1
Sugarcane bagasse	17.09	0.17	0.34	0.085
Puspa wood sawdust biochar	43.57	0.87	1.44	0.48
Sugarcane bagasse biochar	47.56	0.93	1.33	0.96

Discussion

Effect of pyrolysis temperature and time on biochar yield

According to Ahmed *et al.* (2020), high-temperature pyrolysis yields less biochar yield than low-temperature pyrolysis. At a low pyrolysis temperature (300 °C), exothermic thermal decomposition occurred with the release of volatiles in the form of condensable substances (groups of organic acids such as phenolic and carboxylic) and non-condensable gasses (CO, CO₂, CH₄, H₂) from the lignocellulosic structure (Intani *et al.*, 2016). Nevertheless, the activation energy required for the thermolysis of the lignocellulosic structure at 300 °C, on the other hand, was likely to be rather high. Hence, the decomposition process of the lignocellulosic structure was incomplete. As a result, the release of volatile substances becomes less and leaves a higher amount of biochar product when compared to the higher pyrolysis temperature.

Figure 1 also shows that pyrolysis at high temperatures did not produce an enormous difference and tended to be stable towards the biochar yield of both biomass. Likewise, a comparative condition was revealed by Sun *et al.* (2017). Pyrolysis at temperatures below 400 °C caused rapid devolatilization, resulting in a sharp decrease in biochar yield. Meanwhile, at temperatures over 400 °C, substances with high boiling points and moderate

volatility would thermally decompose gradually, whereas volatile substances were released completely to form aromatic compounds, resulting in a minor decrease in biochar yield (Mašek *et al.*, 2013).

The increasing pyrolysis time (Figure 2) constructs the more effective collisions between the particles during the thermal decomposition process. As a result, the quantity of volatiles and tars was getting higher and left fewer biochar products than in the short pyrolysis time (Rehrah *et al.*, 2014). Pyrolysis of pupsa wood sawdust and bagasse at the same temperature and time of pyrolysis resulted in different biochar yields. This condition indicated that the biomass type also affected the amount of biochar yield. Savou *et al.* (2019) analyzed the lignocellulosic components of sugarcane bagasse and showed that bagasse contained cellulose, hemicellulose, and lignin of 30.90%, 28.20%, and 9.60%, respectively. Moreover, lignocellulosic analysis of pupsa sawdust was carried out by Joshua, Ahiekpor, and Kuyea (2016) showed that sawdust contained cellulose and lignin of $41.02 \pm 1.5\%$ and $19.02 \pm 1.05\%$, respectively.

Furthermore, Sridevi *et al.* (2015) reported that wood sawdust has a higher cellulose content than sugarcane bagasse. According to Basu (2018), cellulose components decomposed at low temperatures while lignin decomposed at high temperatures. Changes in cellulose and lignin content in biomass correspond to biochar production differences. When pyrolyzed at low temperatures, biomass with a large cellulose content would produce a large biochar yield. On the other hand, the lignin content in the two types of biomass did not differ much; hence the amount of biochar produced was slightly different.

Effect of pyrolysis temperature and time on pH biochar

The increase in pH from neutral to alkaline corresponded to an increase in the inorganic elements composition of biochar (Al-Wabel *et al.*, 2013). In addition, Yuan, Xu, and Zhang (2011) revealed that as pyrolysis temperature increased, the proportion of total oxides content in biochar increased. This condition confirmed the notion that inorganic components influence the increase in the pH of biochar. Besides being associated with its ash content, the pH of biochar was most likely attributed to oxygenated functional units in biochar. During in short time of thermochemical decomposition, more capable oxygenated carbon was retained. As a result, at high pyrolysis rates, the number of carboxyl groups in biochar decreased, leading to a higher alkaline pH of the biochar in suspension (Ronsse *et al.*, 2013).

The increased pH value with increasing reaction time was most likely accompanied by a rise in the relative concentration of inorganic elements (Novak *et al.*, 2009). Bagasse biochar had a higher pH value after 30 minutes of pyrolysis than pupsa wood sawdust biochar. This difference in pH value was probably because the inorganic components in bagasse biomass were greater than pupsa wood sawdust. Biochar with acid and alkaline pH can be used as a growing medium by neutralizing acidic and alkaline soils. This condition was shown by Dhar, Sakib, and Hilary (2020) that applying alkaline pH biochar to acidic soils could adjust the soil pH to be relatively neutral. In biochar as a growing medium, biochar that has neither too high nor low pH indicates the availability of sufficient macro and micronutrients for plant growth (Gentili *et al.*, 2018).

Effect of pyrolysis temperature and time on biochar ash content

Figure 5 shows that the biochar ash content was getting higher alongside the increment in the pyrolysis temperature. This finding was consistent with the Nwajiaku *et al.* (2018) study. Liu *et al.* (2018) stated that pyrolysis of sawdust biomass generally produces an ash content of 3.13-4.44%. Furthermore, the ash content of sugarcane bagasse and sawdust from pupsa wood biochar was relatively low. This condition was in line with Rehrah *et al.* (2014), which stated that the biomass from wood generally contains low ash. Variations in pyrolysis temperature levels resulted in different biochar ash content. The temperature was related to the average kinetic energy of the particles. Pyrolysis of lignocellulosic at low temperatures would produce a low average kinetic energy of the particles. Therefore the decomposition process was not as effective as during pyrolysis at high temperatures; consequently, pyrolysis at low temperatures would leave fewer inorganic or mineral substances than pyrolysis at high temperatures. Pinho *et al.* (2019) stated that the higher the pyrolysis temperature, the more it promotes the thermolysis of lignocellulosic and, on the other hand, the minerals compositions in the biochar accordingly increase the ash content.

The longer the pyrolysis time, the more effective the interaction between the particles and the higher the thermal decomposition of the lignocellulosic components. As a result, it will also leave a large residue of inorganic components. Biochar with high ash content generally contains inorganic CaCO_3 , KHCO_3 , and other minerals (Dhar, Sakib, and Hilary, 2020). When considering biochar as a growing medium or soil amendment, the alkaline

capacity of this inorganic component allows it to neutralize soil acidity, reduce Al^{3+} toxicity also increment soil cation exchange capacity. A high nutritional content was associated with a high cation exchange capacity (Fellet *et al.*, 2011).

Effect of pyrolysis temperature and time on the volatile matter content

The presence of minimum O_2 molecules in the pyrolysis process causes the biomass to decompose, releasing volatile substances (Jafri *et al.*, 2018). The activation energy required to remove volatile matter in biochar at low temperature was relatively high; thus, only a small amount of volatile matter was released from biochar. As a result, the volatile matter remaining in biochar was relatively large (Tag *et al.*, 2016). Meanwhile, at high pyrolysis temperatures, the activation energy was facile, resulting in the more volatile matter being released. As a consequence, the remaining volatile matter in biochar was reduced. In addition, the increasing pyrolysis temperature will result in further cracking of volatile matter into liquid and gas rather than biochar, and this condition would reduce the volatile matter of biochar (Domingues *et al.*, 2017).

The longer the pyrolysis time would make the devolatilization reaction occurs effectively. This condition resulted in the greater release of volatile organic compounds, making the volatile matter content in biochar decrease drastically (Makavana *et al.*, 2018). The volatile matter content of biochar as growing media or amendment soil is relatively important to know. The volatile matter available in biochar was reported to affect the capacity of soil absorption, plant development, and nitrogen accessibility. Rather large contents of volatile matter could inhibit the ability of biochar. The volatile issue also affects the surface and occupies the micropores of the biochar. Therefore, biochar production at high temperatures was very advantageous due to its low volatile matter content (Dhar, Sakib, and Hilary, 2020).

Effect of pyrolysis temperature and time on biochar fixed carbon content

According to Iryani *et al.* (2017), the increases in fixed carbon were caused by the thermal degradation of the lignocellulosic components, which was later followed by the emancipation of volatile matter. The higher the pyrolysis temperature, the higher the volatile matters released, thus giving the high fixed carbon biochar. Similarly, the time pyrolysis also affected the fixed carbon content. The way that might clarify this tendency is that as the time incremented, the volatile matter was readily forced out when pyrolysis occurred, resulting in the formation of fixed carbon (Makavana, Sarsavadia, and Chauhan, 2020). The carbonization causes devolatilization of the lignocellulosic, which results in a decrease in the mass part of the volatile content biomass compared to the mass fraction of the fixed carbon content. As a result, of the release of the volatile biomass component during carbonization, the selected carbon content of biochar increased concurrently. (Oginni and Singh, 2020). According to the results, the biochar formed at temperatures of $500^{\circ}C$ and 90 minutes was chosen for further nutrient content analysis due to its high fixed carbon, high ash, and low volatile matter contents.

Analysis of nutrient content of biomass and biochar

The influence of pyrolysis temperature and time on biochar's composition and chemical structure can considerably impact nutrient content (Claoston *et al.*, 2014). The pyrolysis of biomass alters the nutritional content and availability of organic amendments. The loss of volatile molecules such as carbon, hydrogen, and oxygen from the feedstock can explain the increase in the nutritional content of biomass caused by thermal degradation (Chan and Xu, 2009). The higher fixed carbon content of the biochar compared with the proper carbon content of the biomass feedstock demonstrated the fixation of biomass carbon into a more slow recurrent cyclical form that could potentially exist for a long time, which was suitable for agricultural purposes (Spokas, 2010).

By excessively volatilizing organic carbon and breaking organic P bonds, biomass pyrolysis might greatly enhance plant tissue phosphor availability, resulting in residues with high soluble P salts linked with biochar. As a result, when the biomass is pyrolyzed, these inorganic constituents are expelled from the complex biomass circumstance and remain suitable for plant use (Naeem *et al.*, 2014). Bagasse biochar showed a higher nutrient content than sawdust pupsa wood biochar; this is probably due to the inorganic fraction of bagasse biochar being larger than sawdust pupsa wood biochar. Meanwhile, the availability of nitrogen content was probably from crude protein contained in biomass. Nitrogen and other nutrients are important because they affect plants' vegetative parts, such as roots, stems, and leaves. Nitrogen deficiency could cause plant growth to be disrupted, phosphorus deficiency could cause stunted and small plant growth (Huang *et al.*, 2020; Meng *et al.*, 2021), whereas

common indications of potassium depletion include light brown and curled leaf tips, as well as chlorosis (discoloration) between both the leaf veins (Hafsi, Debez, and Abdelly, 2014).

Conclusion

This study investigates the impact of pyrolysis temperature and time on characteristics of biochar from pupa wood sawdust and sugarcane bagasse. It was found that the yield, as well as volatile matter content of biochar, were inversely proportional to the temperature and time pyrolysis, while the pH, ash, and fixed carbon content of biochar were directly proportional to the temperature and time pyrolysis either. The optimum condition was achieved at a temperature of 500 °C and 90 minutes for both biomass. This study showed that the pyrolysis of biomass could increase the fixed carbon as well as the nutrient content of biochar which is valuable for the utilization of biochar in agricultural purposes. In general, it was found that the sugarcane bagasse biochar was more likely favorable than pupa wood sawdust biochar due to its higher fixed carbon and nutrient content.

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