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ORIGINAL RESEARCH

Physicochemical properties of biochar produced from biodegradable domestic solid waste and sugarcane bagasse

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Abstract

Purpose This research aims to characterize the physical and chemical properties of biochar derived from biodegradable domestic solid waste and sugarcane bagasse, in order to evaluate their possible uses in agronomic and environmental applications.

Method Biodegradable domestic solid waste and sugarcane bagasse-based biochar were pyrolyzed at two pyrolysis temperatures (500 and 700 °C). Biochar properties included the determination of several physical and chemical parameters, i.e., pH, electrical conductivity (EC), cation exchange capacity (CEC), carbon content, iodine number, pH point of zero charge and surface morphology.

Results Under the investigated conditions, biochar properties were greatly affected by both pyrolysis temperature and feedstock type. The pH, EC, CEC, pH_{pzc}, iodine number and carbon content in biochar increased as the increasing pyrolysis temperature from 500 °C to 700 °C, whilst the opposite trend was found for biochar yield. Between the two biochar, at the same pyrolysis temperature, the sugarcane bagasse biochar possessed lower EC values (118.93 - 126.17 µS/cm) and carbon content (37.42 – 38.8%), but higher CEC values (18.62 - 20.12 cmol/kg) and iodine number (424.04 - 261.34 mg/g) than the biodegradable domestic solid waste biochar. SEM images of sugarcane bagasse biochar exhibited greater porosity than the biodegradable domestic solid waste biochar at both pyrolysis temperatures.

Conclusion The results implied that sugarcane bagasse biochar have better potential to be used in applications including the improvement of soil characteristics, the removal of contaminants from aqueous media, and the remediation of contaminated soil. To provide a better evaluation of the biochar's performance, a further demonstration in soil or water test experiments should be conducted.

Keywords Biochar, Biodegradable domestic solid waste, Physicochemical properties, Sugarcane bagasse

Introduction

Biochar, defined as a carbon-rich product, created through the pyrolysis of biomass or bio-waste in anaerobic conditions. A large range of biomass have been effectively utilized for biochar production, such as tree bark, wood chip, rice straw, rice husk, cotton stalk, and sewage sludge (Amalina et al. 2022). Because of its highly porous structure, biochar is being

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used for the amendment of polluted soils, for the removal of soil/water pollutants, and for the sequestration of carbon (Oni et al. 2019). Biochar addition to soils can help with the water-retention and cation-exchange capacity, also organic carbon storage by simultaneously either reducing nutrient leaching or neutralizing hydrogen ion of soils (Vijay et al. 2021; Shetty and Prakash 2020). Biochar is also being applied to remove organic and inorganic pollutants from aqueous media (Ambaye et al. 2021).

When biochar is applied to improve soil properties or to address a given environmental issue, it is of utmost importance to determine the properties of employed biochar. The pyrolysis temperature and the feedstock material are the two primary factors influencing biochar properties (Chun et al. 2021). For instance, higher pH, surface area, microporosity, hydrophobicity and adsorption properties were found in biochar produced at higher temperatures (>400 °C) (Tomczyk et al. 2020; Hassan et al. 2020). High temperature biochar also possesses greater carbon proportion and carbon sequestration (Hailegnaw et al. 2019; Wei et al. 2019).

Biochar properties usually include the investigation of several parameters, with each one of them playing a different role in the potential biochar applications. For example, biochar pH can have important agronomic benefits for a wide variety of soils. Biochar are often moderately to highly alkaline, the application of alkaline biochar to soil; therefore, can increase soil pH and reduce problems related to low soil pH (Li et al. 2019). The point of zero charge (pH_{PZC}), the pH value at which the surface charge of biochar is zero, is another important characteristic of biochar. When the solution pH is less than pH_{PZC}, the biochar is positively charged and binds to anions; by contrast, when the solution pH is higher than pH_{PZC}, the biochar is negatively charged and binds to cations (Li et al. 2019). Determining the electrical conductivity of biochar can reveal their effect on soil quality, especially, on salt-sensitive plants (Karabay et al. 2021). Measuring the cation exchange capacity of biochar can predict their ability in absorbing cations, thus, preventing nutrient leaching (Nguyen et al. 2018). Biochar iodine number can be considered as an indication of the presence of micropores (< 2 nm) on biochar, thus, it can used as a useful indicator of the adsorption capacities toward small-sized pollutants in soil or water medium (Castiglioni et al. 2021).

Sugarcane bagasse is a lignocellulosic fibrous residual material obtained from sugarcane culm, after the culm is milled and the juice is extracted. Like most agricultural wastes, bagasse is an abundant carbon-rich natural resource, very abundant in many tropical parts of the world and suitable for the production of biofuel or biochar (Miranda et al. 2021; Kumar et al. 2021). The potential of using sugarcane bagasse biochar for application in C sequestration, and improved overall soil fertility has been investigated (Alves et al. 2021). Besides sugarcane bagasse residues, biodegradable domestic solid waste is also considered as an abundant and promising source of raw materials to produce biochar (Taherymoosavi et al. 2017).

Pyrolysis studies have assessed the physicochemical properties of sugarcane bagasse biochar (Raul et al. 2021; Saleh and Hedia 2018; Vimal et al. 2019). However, pyrolysis of biodegradable domestic solid waste has received less attention. In the literature there is a limited number of studies evaluating the differences on the characterization of biochar sugarcane bagasse and biodegradable domestic solid waste biochar. The present study contributes to this regard, by characterizing biochar of sugarcane bagasse and biodegradable domestic solid waste pyrolyzed at two different temperatures, i.e. 500 and 700 °C, to evaluate the effects of feedstock materials and pyrolysis temperature on biochar properties. This study focuses on a detailed analysis of pH, EC, CEC, C content, iodine number, and pH_{pzc}. On the basis of the obtained results, the potential application of each biochar for either agronomic or environmental purposes were determined.

Materials and methods

Materials

Raw biodegradable domestic solid waste was collected from households in urban areas of Mekong Delta, Vietnam. Whereas the raw sugarcane bagasse was collected from commercial sugarcane juice making machines, in the same urban areas. After collection, the raw materials were initially oven dried at 105 °C until reached constant weight, then they were cut into small pieces of sizes 1-2 mm thick and formed into cylindrical pellets. A pyrolysis furnace (Model VMF 165, Yamada Denki, Adachi, Tokyo, Japan) was used. The operating parameters were as follows: pyrolysis temperature of 500 and 700 °C; heating rate of 10 °C/min; holding for 120 min. Carrier gas (N_2) with a flow rate of 3 L/min was pumped into the furnace (for 30 min) prior pyrolysis to remove any air remaining inside the furnace. The solid products were collected and were ground into a homogeneous powder (<45 µm), finally stored in a desiccator until analysis.

Methods

The physico-chemical properties of the raw materials

Lignin, cellulose and hemicellulose contents of the raw biodegradable domestic solid waste and sugarcane bagasse samples were analysed following the TAPPI method (TAPPI 2002) and (Do et al. 2019) method. The moisture content was analysed by heating the materials at 105 °C for 2 h, while the ash content was determined by heating the materials at 750 °C for 6 h.

The biochar pH and EC

The pH of biochar was measured using a pH meter (METER HM-31P), while the EC was measured using an EC meter (Milwaukee Mi306 EC/TDS/NaCl/Temp Conductivity Salinity Water Meter Temp Salt) at a 1:10 solid/water ratio after shaking for 60 min on a reciprocating shaker (Bioshaker BR-23FH, Taitec Co., Saitama, Japan) at 100 rpm and 25 °C (Singh et al. 2017).

Determination of CEC (cmol/kg)

CEC was determined using the 0.1 M $BaCl_2$ (1:50 w/v) protocol. Then add 0.02 M $MgSO_4$ solution to replace the Ba^{2+}. The CEC has been calculated as the difference between the amount of original Mg^{2+} concentration and the Mg^{2+} remaining concentration in the standard solution (Nguyen et al. 2018).

The yield of biochar

The yield of biochar was calculated based on the following equation:

$$Biochar\ yield\ (\%) = \frac{Mass\ of\ biochar\ (g)}{Oven\ dry\ mass\ of\ raw\ material\ (g)} \times 100\%$$

The carbon content

The ash content was determined by weight loss after combustion at 750 °C for 6 h in a muffle furnace, calculated as follow:

$$Ash\ content\ (\%) = \frac{Weight\ of\ ash}{Dry\ mass\ of\ biochar} \times 100\%$$

With an acceptable error range of 2 to 10%, calculating the carbon of the material was calculated as follows:

$$\%C = \frac{100 - \%\ Ash}{1.724}$$

In which: 1.724 was organic matter containing 58% carbon.

Iodine number

Iodine number was determined by the sodium thiosulphate ($Na_2S_2O_3$) oxidation reduction method using starch to improve the end point, according to JIS test method (K1474:2014). The quantity of iodine adsorbed A_I (mg/g) is calculated based on the following equation:

$$A_I = \frac{(10 * f' - K * f) * 12.69 * 5}{S}$$

Where S is the quantity of biochar (g); f'is the factor of 0.05N I_2; f is the factor of 0.1N $Na_2S_2O_3$; K is the average quantity of 0.1N $Na_2S_2O_3$ (mL).

pH at the point of zero charge (pH_{pzc})

The pH value of the biochar at the point of zero charge (pH_{pzc}) was determined using the protocol of Hafshejani et al. (2016). Preparing 0.1 M NaCl solution, measuring initial pH values (pH_i) of 0.1 M NaCl adjusted from pH 2 to pH 11 (2, 3, 4, 5, 6, 7, 8, 9, 10, 11) by adding 0.1 M NaOH or 0.1 M HCl. Weighing 0.1 g of biochar into a 50 mL centrifuge tube, then adding 50 mL of NaCl (0.1 M). Transferring the centrifuge tubes to a shaker and shaking for 24 hours at 180 rpm. Then filter the solution with Whatman filter paper No. 6 and measure the final pH (pH_f). The difference between initial and final pH values ($\Delta pH = pH_i - pH_f$) were plotted against the initial pH value (Hafshejani et al. 2016).

Surface morphology analysis

The surface morphology of biochar was determined by a SEM (TM1000, Hitachi, Japan), being recorded at different magnifications with a 20 kV electron beam.

Statistical analysis

Data were expressed as the mean ± standard deviation. The significance of the differences between the biochar based on the pyrolysis temperature and feedstock type was determined by the One-way ANOVA. Post hoc comparison of means was performed using Tukey-HSD procedure for the differences between the pyrolysis temperature of the same biochar. Statistical analysis was performed by using SPSS 20.0 software (SPSS Inc., Chicago, IL, USA). The statistical significance was set at a p-value of less than 0.05.

Result and discussion

The physico-chemical composition of the raw materials

The lignin, cellulose and hemicellulose compositions of the raw materials are shown in Table 1. Sugarcane bagasse material generally had higher proportions of lignin, cellulose and hemicellulose compared with biodegradable domestic solid waste material. In particular, the lignin, cellulose and hemicellulose contents of sugarcane bagasse material were 20.08±1.73%, 44.64±1.10% and 17.20±0.40%, respectively; slightly higher that of biodegradable domestic solid waste material, with 18.93±1.57% lignin, 42.9±3.69% cellulose, and 12.30±1.08% hemicellulose.

Table 1 Analytical results of the raw material for the physico-chemical properties

Parameters	Biodegradable domestic solid waste	Sugarcane bagasse
Lignin (%)	18.93 (1.57)**	20.08 (1.73)**
Cellulose (%)	42.90 (3.69)**	44.64 (1.10)**
Hemicellulose (%)	12.30 (1.08)*	17.20 (0.40)*
Moisture (%)	6.8 (0.13)**	5.07 (0.09)**
Ash (%)	20.66 (0.57)*	0.98 (0.35)*

*Indicates statistical significance $p < 0.05$; **indicates statistical significance $p < 0.01$

The yield of biochar and the carbon content of biochar

There are various factors that affect the yield of biochar, including feedstock type and pyrolysis temperature. The biochar yield from the two materials is given in Fig 1. The yield of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse pyrolyzed at 500 °C, 700 °C ranged from 24.7±0.18% to 28.33±2.89% and from 21.29±0.24% to 28.44± 5.54%, respectively.

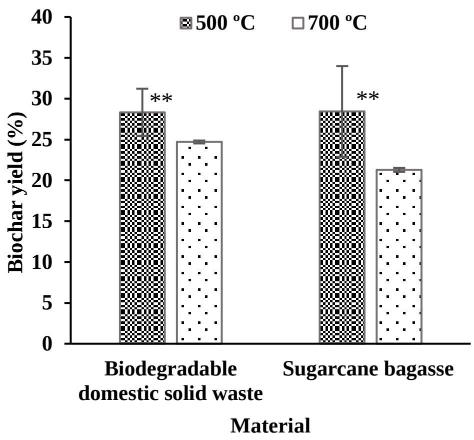

Fig. 1 The yield of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse source pyrolyzed at 500 °C and at 700 °C

From Fig 1, it was found that the yields of biochar for the two feedstocks were reduced with increasing pyrolysis temperature from 500 to 700 °C. Yield of the sugarcane bagasse biochar was more strongly influenced by increasing temperature, where its yield at 500 °C was 28.44% and it decreased to 21.29% at 700 °C. This trend is consistent with other studies (Nguyen et al. 2018; Zhang et al. 2020). The decrease in pyrolysis yield with increasing temperature has been associated with decomposition of cellulose, hemicellulose and lignin contents, as well as with dehydration of hydroxyl groups (Karthik et al. 2020). Table 1 indicated that the raw feedstock materials were composed of cellulose, hemicellulose, and lignin. During the thermal decomposition process, these components undergo different reactions, leading to the formation of biochar (Tan et al. 2021).

Besides, differences in the moisture and mineral (ash) contents of the original feedstock also affect biochar yield (Ali et al. 2022). A high moisture in the feedstock was favourable for the biochar yield (Nanda et al. 2016). The moisture and ash contents of the raw sugarcane bagasse and biodegradable domestic solid waste are also given in Table 1. It is observed that the biodegradable domestic solid waste material generally possessed higher amounts of moisture and ash contents than the sugarcane bagasse material. The sugarcane bagasse feedstock with the lower ash content (only 0.98±0.35% ash content) produced the lower biochar yield as compared to the biodegradable domestic solid waste feedstock (with 20.66±0.57% ash content) at the same pyrolysis temperature.

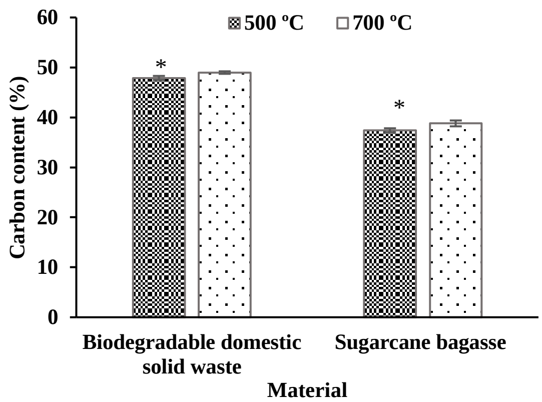

Fig. 2 The carbon content of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse pyrolyzed at 500 °C and at 700 °C

Fig 2 shows the dependency of the carbon content on the type of feedstock and the temperature of pyrolysis. The carbon content values were higher in the biodegradable domestic solid waste biochar and was seen to increase with increased temperature from 500 °C to 700 °C and ranged from 47.89±0.41% to 48.97± 0.25%, while the sugarcane bagasse biochar ranged from 37.42±0.4% to 38.8±0.59% (These comparisons were statistically significant at $p < 0.05$ as indicated by the * in the footnote of Fig 2). The high carbon content of biodegradable domestic solid waste biochar makes it a more suitable substrate for carbon sequestration purposes than the sugarcane bagasse biochar (Do et al. 2019).

From the results of yield and carbon analyses, it was observed that there is an inverse relation between the biochar yield and pyrolysis temperature, while the carbon content showed a direct relation with the pyrolysis temperature. In particular, the biochar yield decreased with an increase in the temperature from 500 °C to 700 °C, while the carbon content was increased. Therefore, the carbon content related inversely to the yield. The effect of the gradually increasing temperature on the carbon content and biochar yield may relate to losing the weight of volatile organic compounds, as reported by several authors (Chen et al. 2018; Fan et al. 2019).

pH and Electrical conductivity (EC)

Figs 3 and 4 show the results of biochar pH and EC, respectively. The biochar pH generally increased with increased temperature from 500 °C to 700 °C (statistically significant at $p < 0.05$). The pH values of biodegradable domestic solid waste and sugarcane bagasse biochar ranged from 10.41±0.01 to 10.85±0.02; from 7.77±0.06 to 9.98±0.02, respectively. These pH values are in line with those mentioned in the literature (Hossain et al. 2020). In addition, the pH values increased with raising pyrolysis temperature similar to other studies (Tomczyk et al. 2020; Dhar et al. 2020), as acidic functional groups, including quinone, chromene, and diketone groups, are abolished at higher temperatures (Tomczyk et al. 2020).

The results in Fig 4 show that the EC value has greater influence on either feedstock type or pyrolysis temperature. Evaluating for the effect of pyrolysis temperature, the EC value of biochar produced at high temperature of 700 °C (1766.33±19.76 µS/cm for biodegradable domestic solid waste biochar, 126.17±1.96 µS/cm for sugarcane bagasse biochar) were significantly (at $p < 0.01$) higher than those produced at low temperature of 500 °C (946.67±6.66 µS/cm for biodegradable domestic solid waste biochar, 118.93 ±7.23 µS/cm for sugarcane bagasse biochar). The results obtained here are similar to the previous works (Nguyen et al. 2018; Mandal et al. 2018).

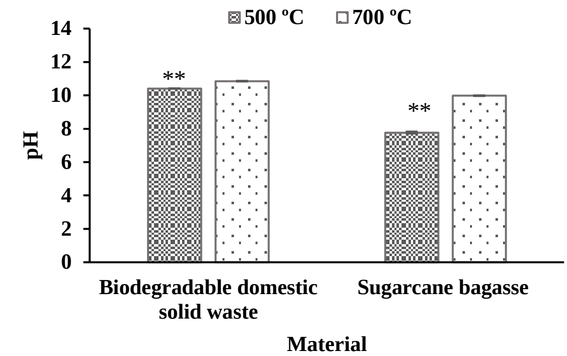

Fig. 3 pH of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse pyrolyzed at 500 °C and at 700 °C

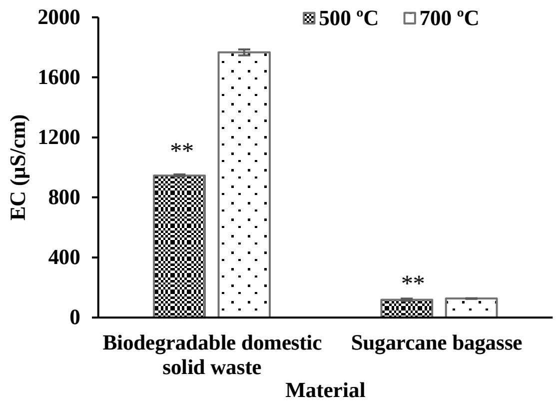

Fig. 4 Electrical conductivity of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse pyrolyzed at 500 °C and at 700 °C

Evaluating for the effect of feedstock type, the biodegradable domestic solid waste biochar significantly contained higher EC values (at $p < 0.01$). According to Nguyen et al. (2018), the biochar EC was reasonably correlated with the ash contents and has a strong linear correlation with the soluble salt in biochar (primarily K^+, Ca^{2+}, Mg^{2+}, and Na^+). Therefore, differences in the biochar EC might be due to differences in the ash content and soluble salts concentration in the biochar (Wang et al. 2020). The high EC value makes biodegradable domestic solid waste biochar seem unsuitable for soil with high soluble salt concentration, also, high pH value makes biodegradable domestic solid waste biochar inapplicable for sandy soil with low buffering capacity.

Cation exchange capacity (CEC)

The CEC values of the two biochar, shown in Fig 5, were higher at 700 °C compared to 500 °C, this finding is consistent with that of Das et al. (2021), who discovered that the CEC of biochar augmented with a rise in pyrolysis temperature (Das et al. 2021). In the case of biodegradable domestic solid waste, biochar CEC increased from 6.5±0.01 cmol/kg to 7.82±0.06 cmol/kg; while with the sugarcane bagasse, biochar CEC increased from 18.62±0.29 cmol/kg to 20.12±0.41 cmol/kg when temperature increased from 500 °C to 700 °C (all comparisons were statistically significant at $p < 0.01$).

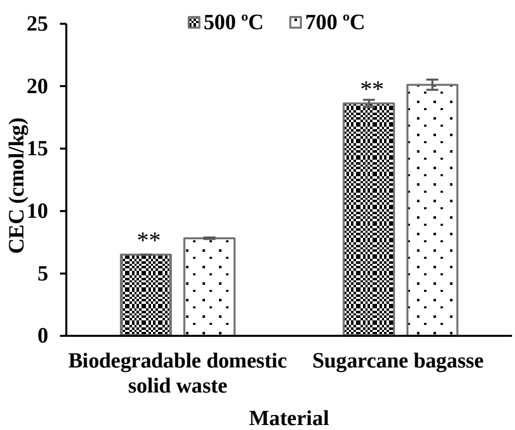

Fig. 5 CEC of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse pyrolyzed at 500 °C and at 700 °C

Compared with biodegradable domestic solid waste biochar, at the same pyrolysis temperature, the sugarcane bagasse biochar obviously possessed the higher CEC value. Higher CEC in the sugarcane bagasse biochar indicated that they may have a greater ability to hold quantities of cations, which can act as a reservoir of several essential nutrients (NH_4^+, Ca^{2+}, Mg^{2+}, and K^+) in soils with a low CEC (Nguyen et al. 2018). Therefore, they have the greater potential for maintaining soil available nutrient levels, compared to biodegradable domestic solid waste biochar.

Iodine number

The iodine number, a relative indicator of porosity or the surface area in a material, can be considered as an indication of the biochar's adsorption capacity to small-sized contaminants. The iodine value is generally expressed as the number of mg of iodine absorbed per g of biochar under specific conditions. The higher the iodine number, the higher the level of activation. The results in Fig 6 showed that the iodine number of biochar varied with feedstock types and pyrolysis temperature.

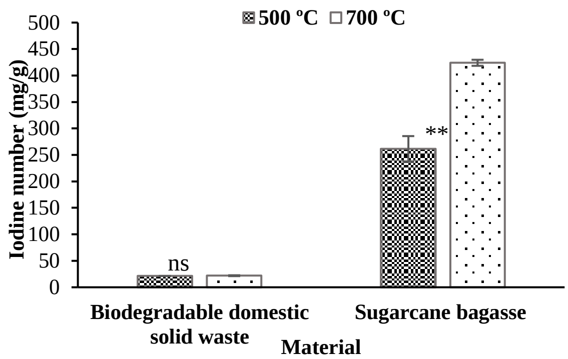

Fig. 6 Iodine number of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse pyrolyzed at 500 °C and at 700 °C

It was easily observed from Fig 6 that in sugarcane bagasse biochar, higher pyrolysis temperature resulted in the higher iodine number. The iodine number of sugarcane bagasse biochar at 700 °C (424.04±5.72 mg/g) nearly doubled as compared to that at 500 °C (261.34±24.22 mg/g). However, the iodine number value of biodegradable domestic solid waste biochar remained almost unchanged (roughly 20.12±0.41 mg /g) with increasing pyrolysis temperature. The iodine number, especially sugarcane bagasse biochar, was found to be increased with the raising of pyrolysis temperature as observed in other studies (Itodo et al. 2010). At the same temperature of 500 °C or 700 °C, the iodine number of sugarcane bagasse biochar was statistically significantly (at $p < 0.01$) higher than that of the biodegradable domestic solid waste biochar. These results show that sugarcane bagasse biochar may possess a higher porous structure than biodegradable domestic solid waste biochar, thus displaying a higher adsorption capability toward contaminants.

pH point of zero charge

The point of zero charge (pH_{pzc}) is essential for understanding the effect of pH on adsorption of a particular contaminant, and pH_{pzc} is the pH at which the net charge on biochar's surface is zero. Basically, when pH< pH_{pzc}, the biochar surface will have a net positive surface charge due to H^+ ion adsorption, and the adsorption process taking place by ion exchange mechanism will prevail. In this case, biochar will well adsorb negative ions (such as Cl^-, NO_2^-, NO_3^-, SO_4^{2-}, PO_4^{3-}...). Conversely, with pH> pH_{pzc}, the biochar surface will be negatively charged due to H^+ ion desorption and biochar will well adsorb cation ions (such as Na^+, K^+, Ca^{2+}, NH_4^+...).

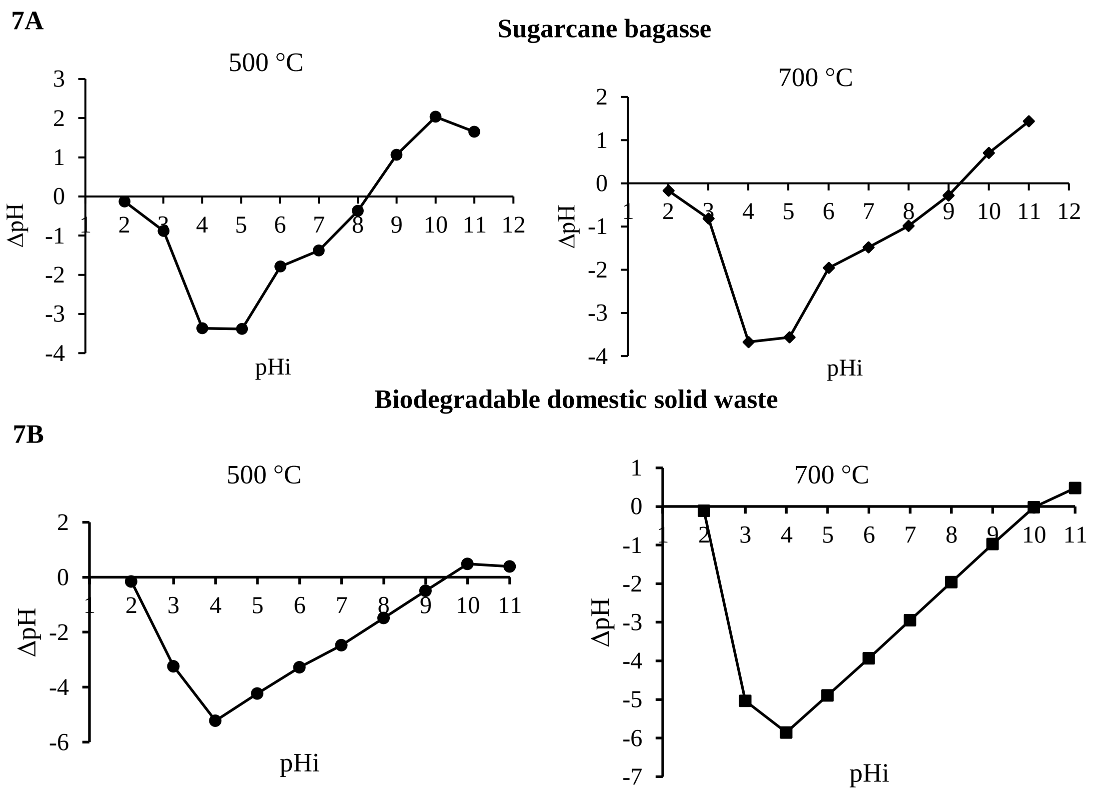

Fig. 7 pH_{pzc} of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse pyrolyzed at 500 °C and at 700 °C

The pH_{pzc} of sugarcane bagasse biochar pyrolyzed at 500 °C and at 700 °C were 8.3 and 9.3, respectively (Fig 7A). Whereas, the pH_{pzc} of the biochar derived from biodegradable domestic solid waste pyrolyzed at 500 °C and 700 °C were slightly higher, at 9.50 and 9.99, respectively (Fig 7B). These results demonstrate that at higher pyrolysis temperature, the pH_{pzc} values increased with the increase in the basicity of the surface of biochar (Usman et al. 2015). In addition, the pH_{pzc} of sugarcane bagasse biochar is around alkaline values (8.3 – 9.3), which is not so much different from those of biodegradable domestic solid waste biochar (9.50 – 9.99). According to Usman et al. (2015), the pH_{pzc} values is generally related to the acidic functional groups (e.g., carbonyl, carboxylic, lactonyl, hydroxyl and phenolic groups) and basic functional groups (e.g., ketone, pyrone, pyridine, other heterocyclic N, basic O and N donor groups) on the surface of biochar. Table 2 summarizes the results of physicochemical properties of biodegradable domestic solid waste and sugarcane bagasse biochar, at two pyrolysis temperature 500 and 700 °C.

Surface morphology

Scanning electron micrographs (SEM) were used to visualize the porous structure of biochar before and after pyrolysis. The SEM results showed that there was a significant difference in the surface morphology between the biodegradable domestic solid waste and sugarcane bagasse biochar. The SEM image of sugarcane bagasse biochar possessed a cylindrical shape, with a rough surface and highly porous structure in both biochar produced at 500 °C and 700 °C (Figs 8b and 8c). On the contrary, the domestic solid waste biochar at both pyrolysis temperatures (shown in Figs 8B and 8C) consisted of irregularly shaped particles with poorly porous structures. These SEM observations were consistent with the iodine number values analyzed previously, where the sugarcane bagasse biochar was found to possess the better porous structure due to the higher in their iodine number values.

Sugarcane bagasse

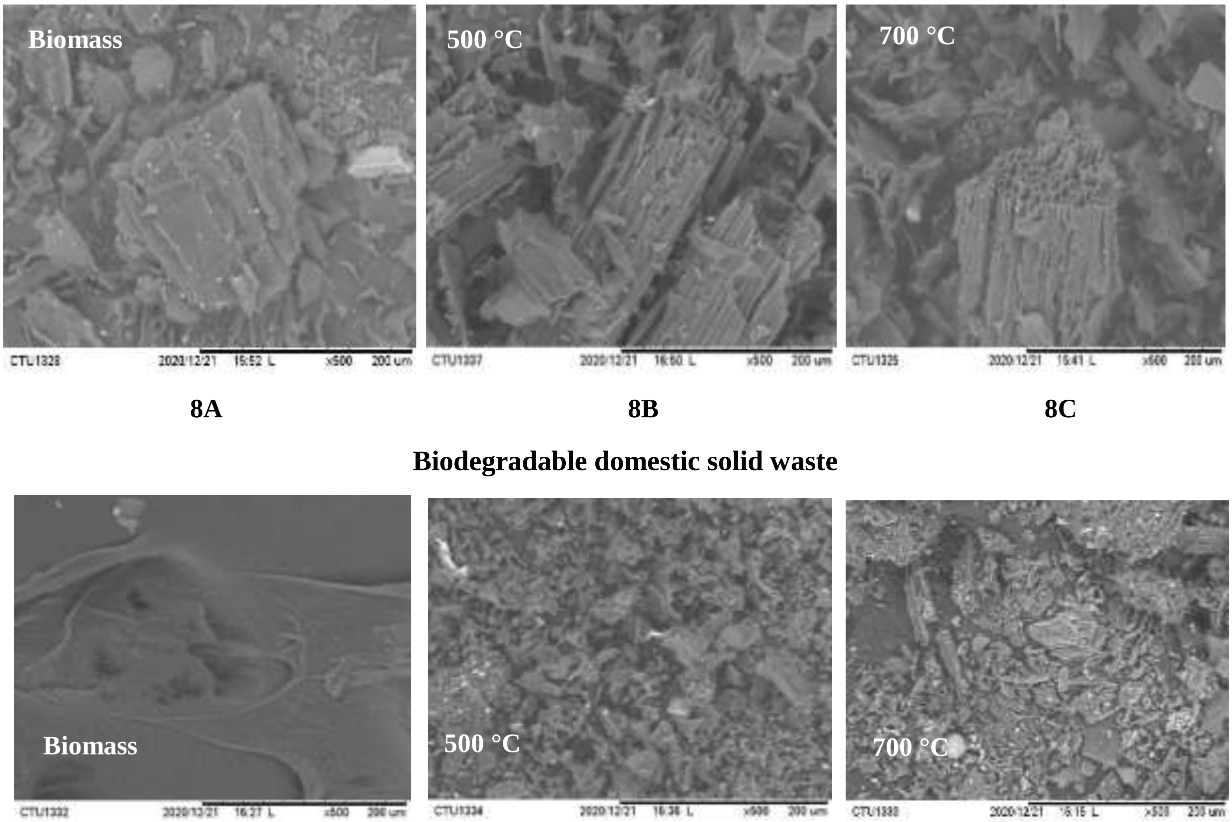

Fig. 8 SEM images of the biochar derived from biodegradable domestic solid waste and sugarcane bagasse pyrolyzed at 500 °C and at 700 °C

Table 2 Physicochemical properties of studied biochar

Parameters	Biodegradable domestic solid waste		Sugarcane bagasse	
	500 °C	700 °C	500 °C	700 °C
Yield (%)	28.33 (2.89)**	24.7 (0.18)**	28.45 (5.54)**	21.19 (0.24)**
pH	10.41 (0.01)**	10.85 (0.02)**	7.77 (0.06)**	9.98 (0.02)**
EC (µS/cm)	946.67 (6.66)**	1766.33 (19.76)**	118.93 (7.23)**	126.17 (1.96)**
CEC (cmol/kg)	6.5 (0.01)**	7.82 (0.06)**	18.62 (0.29)**	20.12 (0.41)**
Carbon content (%)	47.9 (0.41)*	48.97 (0.25)*	37.42 (0.4)*	38.8 (0.59)*
I_2 number (mg/g)	21.28 (0.13)ns	21.87 (0.81)ns	261.34 (24.22)**	424.04 (5.72)**
pH_{pzc}	9.50	9.99	8.3	9.3

*Indicates statistical significance $p < 0.05$; **indicates statistical significance $p < 0.01$; ns indicates non significance

Comparison with other studies

Table 3 compares the findings of this study with those of other studies involving the properties of biochar derived from sugarcane bagasse and biodegradable domestic solid waste. It can be seen that the percentages of yield and carbon content, the values of EC and CEC of sugarcane bagasse biochar (produced at 500 °C) from this study were lower than the majority of the others. For biodegradable domestic solid waste biochar, CEC value, the yield and carbon content percentages obtained also were lower than the study conducted by Pradhan et al. (2020), while EC was slightly higher. However, it is true that no safe comparisons can be made here because the feedstock origin and pyrolysis conditions (such as heating rate, holding time and preparation of feedstock for biochar production) were different.

Table 3 Physicochemical properties of sugarcane bagasse and biodegradable domestic solid waste biochar from this study and previous works (at 500 °C)

Feedstock	Characteristics	Raul et al. (2021)	Saleh and Hedia (2018)	Vimal et al. (2019)	This study
Sugarcane bagasse	Yield (%)	-	25.58	25	21.29
	pH	7.1	7.09	6.82	7.77
	EC (µS/cm)	620	950	33.3	118.93
	CEC (cmol/kg)	52.7	34.74	-	18.62
	Carbon content (%)	56.6	67.61	74.9	37.42
	I_2 number (mg/g)	-	-	-	261.34
	pH_{pzc}	-	-	5.9	8.3
Biodegradable domestic solid waste	**Characteristics**	Pradhan et al. (2020)		This study	
	Yield (%)	26.5		24.7	
	pH	11.8		10.41	
	EC (µS/cm)	880		946.67	
	CEC (cmol/kg)	46.2		6.5	
	C content (%)	70.2		47.89	
	I_2 number	-		20.12	
	pH_{pzc}	-		9.50	

It is possible that the two studied biochar works well in terms of the mentioned factors, but in real scale they are affected by many other factors and thus, they do not have high efficiency.

In fact, there were certain limitations of the present analysis that should be noted. Firstly, there was a lack of analysis on the chemical compositions (i.e., mineral composition and metal composition) of the two feedstock materials. Conducting the analysis for the chemical characteristics of the feedstock materials would further aid researchers gather a more in-depth understanding of the research on pH, EC, CEC and for the selection of suitable applications towards improving soil fertility and treating different contaminants. Secondly, the efficiency of the biochar produced for specific application is proven when they are examined at lab scale batches, pilot-scale systems, or real matrices. Therefore, the potential application of each biochar for either agronomic or environmental purposes should be considered in the future research.

Conclusion

The physicochemical properties of biodegradable domestic solid waste and sugarcane bagasse derived biochar, which were produced at 500 °C and 700 °C, were intensively studied. The pH, EC, CEC, pH_{pzc}, iodine number and carbon content generally increased with rising temperature from 500 °C to 700 °C. Whilst the opposite trend was found for biochar yield. Between the two biochar, at the same temperature of 500 °C or 700 °C, the sugarcane bagasse biochar possessed lower EC values (118.93±7.23 - 126.17±1.96 µS/cm) and carbon content (37.42±0.40 - 38.8±0.59%), but higher CEC values (18.62±0.29 - 20.12±0.41 cmol/kg) and iodine number (424.04±5.72 - 261.34±24.22 mg/g) than the biodegradable domestic solid waste biochar. Its SEM images also exhibited greater porosity as well as open-cell pore structure than the biodegradable domestic solid waste biochar. The sugarcane bagasse biochar therefore can be a desirable product for applications in (1) soils with low soluble salt concentrations, (2) sandy soils with low buffering capacity, (3) soils having low cation exchange capacity, and (4) soils contaminated with organic or inorganic compounds. Meanwhile, biodegradable domestic solid waste biochar can be a suitable substrate for carbon sequestration. However, the potential effects of biochar in the specific application should be conducted in a particular site to study changes in physicochemical properties of soils through biochar application.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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