

Production and characterization of biochar based on a local agricultural biomass

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Abstract

The growing world population is leading to an intensification of agricultural practices. The consequence of this practice is the production of agricultural waste in large quantities. The aim of this study is to characterize the biochar produced from agricultural biomass. Biochar based on cassava peels was elaborated by slow pyrolysis using a muffle furnace for 4 hours at 400°C and then characterized. The respective values of pH, ash content, moisture content, dry matter, total organic carbon (TOC), total nitrogen, carbon-nitrogen ratio(C/N), iodine value, potassium, calcium, magnesium, and silicon are 10.75; 18.26%; 4.9%; 95.09%; 47.3%; 1.74%; 666.225 mg/g; 9.33%; 2.7%; 0.51%; 0.52% respectively. Principal component analysis (PCA) showed very strong positive and significant correlations between the determined parameters. Thus, the potential toxic elements (Cd, Co, Cr, Cu, Ni, Pb, Zn, Ti, Mn) in the produced biochar are almost at trace level as desired by International Biochar Initiative (IBI) and European Biochar Certificate (EBC) for a biochar for agricultural purposes. These results show that the biochar produced could be beneficial for soil amendment.

Keywords: Biochar; Cassava Peelings; Pyrolysis; Valorization; Characterization

1. Introduction

Biochar is a product of the thermochemical degradation of organic matter in the absence of oxygen [1]. This process, called pyrolysis, can contribute to waste management by using residual biomass (currently poorly managed or unsuitable for conventional disposal) as feedstock. In addition to the solid biochar fraction, pyrolysis also generates gaseous and liquid fractions that are potential sources of energy [2]. Biochar production has received increasing attention due to its potential as a soil amendment, for soil carbon sequestration and for improving soil quality [3]. The potential of biochar to improve soil fertility could increase crop yields on previously degraded soils of smallholder farmers and, therefore, increase food production capacity. This could reduce the need to deforest land for agriculture; deforestation is a major contributor to greenhouse gases in the atmosphere [4]. Simultaneously, biochar offers an alternative for waste management and energy production. Biochar systems are therefore particularly relevant in developing countries and could be leveraged to address global challenges associated with food security and climate

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change mitigation. Biochar characteristics are highly dependent on the type of feedstock and pyrolysis conditions [5,6]. Therefore, the challenge for biochar science is to predict and ensure the product quality, agronomic benefits, and environmental effects of a specific biochar produced from a given feedstock under specific pyrolysis technology and process conditions [7]. In developing countries, research progress on biochar and pyrolysis systems has been limited, in part by a lack of facilities for controlled slow pyrolysis of biomass at a scale suitable for agronomic field trials [1]. Biochar can be produced with a variety of technologies suitable for household, medium, or large industrial scales. Traditional stove technologies that do not recycle pyrolysis gases dominate in developing countries. This traditional charcoal industry is considered both inefficient and polluting, emitting harmful off-gases containing methane, carbon monoxide and particulates [1]. The muffle furnace, which recirculates and burns pyrolysis gases internally, could overcome this problem. Our objectives were to produce biochar using a muffle furnace, and then to characterize the biochar in terms of its suitability for agronomic use or soil carbon sequestration with reference to the standardized definitions set by the European Biochar Certificate (EBC) and the International Biochar Initiative (IBI). Côte d'Ivoire has a strong cassava-based diet (attiéké, placali, attoukou, gari and many others) [9]. This generates 1,250,000 tons of cassava peelings per year [9]. These cassava peelings are hardly used in animal feed, hence they can be used in biochar for soil improvement. Pyrolysis and anaerobic digestion of cassava peel waste have been variously reported, with the application of its carbon-based derivatives in condensers [10], biogas [11], adsorbents [12] and electrical [13]. Cassava peel waste is considered a viable agro-waste for energy recovery [13,14] and agricultural [15]. It has been reported that the biochar mineral contents of cassava peel waste in satisfactory proportions, with a carbon content of 48.7% by weight and a significant percentage of sodium, calcium, potassium and nitrogen [16]. Nowadays, the use of biochar is becoming more and more widespread and is growing rapidly, as it has several beneficial effects on the quality and yields of agricultural crops as well as on soil properties [17,18].

2. Materials and Methods

2.1. Raw material

Cassava peels were used for biochar production. The peels were purchased from female attiéké producers in Yamoussoukro, central Côte d'Ivoire. The peels were washed to remove cassava residues and then sun-dried for 7 days.

2.2. Biochar preparation method

For biochar production, slow pyrolysis has been used. This method slowly heats dry biomass in the absence of oxygen and with a residence time in the system ranging from hours to days [19]. Dried cassava peels were carbonized in an oven at 400°C for 4 hours, with a temperature rise rate of 13.33°C/min. After cooling in the oven, the biochar was extracted, weighed and then packaged in a hermetically sealed vial for analysis. The mass yield of biochar production (r_{biochar}) is determined according to the following equation:

$$r_{\text{biochar}}(\%) = \frac{M_{\text{biochar}}}{M_S} * 100 \quad (\text{Eq 1})$$

M_{biochar} and M_S correspond to the mass of biochar produced and the initial mass of biomass, respectively.

The resulting biochar was ground using a porcelain mortar and pestle, then sieved to obtain seeds of 250 µm or less. The sieved biochar was stored in plastic bottles.

2.3. Biochar characterization

Several methods were used to characterize the biochar obtained.

2.3.1. Determination of the physical parameters of the biochar

The pH was determined according to the method described by Abderahim, (2019). Two grams (2 g) of cassava peel biochar was added to 40 mL of distilled water and stirred with a magnetic stirrer for 30 min. The suspension was left to stand for 10 min before pH measurement using a HANNA pH meter. As ash is an impurity in biochar, its content was determined using a muffle furnace by burning 5 g of biochar at 800 °C for 6 h in the presence of air [21]. The ash content of the biochar is obtained from equation 2:

$$\% AC = \frac{(m_3 - m_1)}{m_2 - m_1} \times 100 \quad (\text{Eq 2})$$

With,

- AC = Ash content (%);
- m_1 = mass of empty crucible (g);
- m_2 = mass of crucible with sample before thermal oxidation (g);
- m_3 = mass of crucible with sample after thermal oxidation (g).

Moisture and dry matter contents were determined by heating the biochar to 115°C in the oven for 24 hours. Equations 3 and 4 were used for the calculations.

$$\%TH = \frac{(m_1 - m_2)}{(m_1 - m_0)} * 100 \quad (Eq\ 3)$$

$$\%DM = \frac{(m_2 - m_0)}{(m_1 - m_0)} * 100 \quad (Eq\ 4)$$

With,

- TH = Moisture content (%);
- DM = Dry matter content (%);
- m_0 = mass of empty crucible (g);
- m_1 = mass of crucible with sample before heating in oven (g);
- m_2 = mass of crucible with sample after oven heating (g).

2.3.2. Determination of biochar chemical parameters

The concentrations of some metallic trace elements in the biochar were determined by X-ray fluorescence spectrometry (XRF). The total organic carbon (C_{OT}) and total nitrogen (TN) contents of the biochar were determined using the method described by Walkley and Black, (1934) and the Kjeldahl method (1954) respectively.

The iodine value is an important characteristic in the evaluation of the micropores of a material. It was determined according to the method applied by [22,23]. Thus, a volume of 15 mL of a 0.2 mol/L iodine solution was brought into contact with 0.05 g of biochar and then stirred for 30 min. The treated solution was filtered and then 10 mL of filtrate was assayed with a 0.1 N sodium thiosulfate solution in the presence of a few drops of a 0.1 N starch solution. A blank test was performed under the same conditions in the absence of activated carbon. Finally, the iodine value (I_d) expressed in mg/g was calculated by applying equation (5).

$$I_d = \frac{(V_b - V_s) \times N \times 126,9 \times \left(\frac{15}{10}\right)}{m_{sample}} \quad (Eq\ 5)$$

Where, V_b and V_s , the volumes (mL) of sodium thiosulfate poured in the blank test and the biochar test, respectively; N, the normality of the sodium thiosulfate solution; and m, the mass of biochar (g).

2.4. Statistical analyses of the data

The analysis results were entered and coded, using Microsoft Excel 365 spreadsheet. They were subjected to statistical analyses on IBM SPSS Statistics 21R software for principal component analysis (PCA), based on the relationship that exists between the physicochemical parameter of biochar.

3. Results and discussion

3.1. Characteristics of the obtained biochar

The physico-chemical analyses performed on the biochar allow to justify its quality. Table 1 presents some characteristics of the elaborated biochar.

Table 1 Physicochemical characteristics of the elaborated biochar

Parameters	pH	TC (%)	TH (%)	DM (%)	Id (mg/g)	TOC (%)	NT (%)	C/N	Mg (%)	Si (%)	K (%)	Ca (%)
Biochar produced at 400 °C for 4H	10.75	18.3	4.9	94.09	666.225	47.3	1.74	18	0.51	0.52	9.33	2.7

The biochar produced is alkaline in nature with a pH of 10.75. This alkalinity could be explained probably by the presence of ash produced during the pyrolysis process [24]. According to Zhou *et al.*, [25], the pH of biochar from agricultural biomass varies between 8.8 and 10.8 depending on the pyrolysis conditions and depending on the biomass used. The result obtained is in agreement with those found by Abderahim [20]. Nitrogen is present in very low concentration in the biochar produced in our study. The low percentage obtained of total nitrogen (NT) could be explained by a lower stability of this element during the pyrolysis phase [6]. Indeed, the conservation of nitrogen during pyrolysis is highly dependent on the chemical form in which it is found and the type of bond it forms in the biomass [6,26–28].

X-ray fluorescence spectrometry (XRF) analysis identified the elements present in the biochar as shown in Table 1. It was found that the biochar produced consisted of potassium (9.33%), calcium (2.7%), magnesium (0.51%) and silicon (0.52%). The presence of these nutrient resources in the elaborated biochar could promote plant growth and increase the fertility of the cultivated soil.

The value of iodine index (Id) found (666.225 mg/g) confirms the presence of microporous pores in the elaborated biochar. This result found is in agreement with those found by Kiari *et al.*, [29].

The potential toxic elements (Cd, Co, Cr, Cu, Ni, Pb, Zn, Ti, Mn) in the produced biochar are almost at trace levels as desired by International Biochar Initiative (IBI) and European Biochar Certificate (EBC). Table 2 shows the percentages of these trace metals.

Table 2 Percentage of trace metal elements in processed biochar

Trace metal elements	Cr	Cu	Ni	Pb	Zn	Ti	Mn
Values (%)	0.006	0.002	0.003	0.002	0.01	0.011	0.006

3.2. Statistical study of physical and chemical parameters

3.2.1. Principal Component Analysis (PCA)

Correlations between the parameters measured in the biochar are established using a principal component analysis (PCA) and the Bravais - Pearson correlation matrix. The eigenvalues of the two components F1 and F2 and their contribution to the total inertia are given in Table 1. The two axes taken into consideration to describe the correlations between the measured parameters alone hold the total information, i.e. 100% with 71.220% for axis 1 and 28.780% for axis 2.

Table 3 Eigenvalues and percentages expressed for the two components F1 and F2

	F1	F2
Proper value	5.698	2.302
(%) Total variance	71.220	28.780
(%) cumulative variance	70.120	100.000

Figure 1 represents the influence of the physico-chemical parameters of biochar on each other. Variables such as pH, ash content (TC), moisture content (TH), dry matter content (DM), iodine index (Id), carbon-nitrogen ratio(C/N) are well represented in the correlation square with positive coordinates on axis 1 which they are most similar to. In addition, variables such as total organic carbon (TOC) and total nitrogen (TN) are also well represented in the

correlation square with positive coordinates on axis 2 which they are most similar to. These results indicate a correlation between the different parameters and could reflect an influence of one on the other [30].

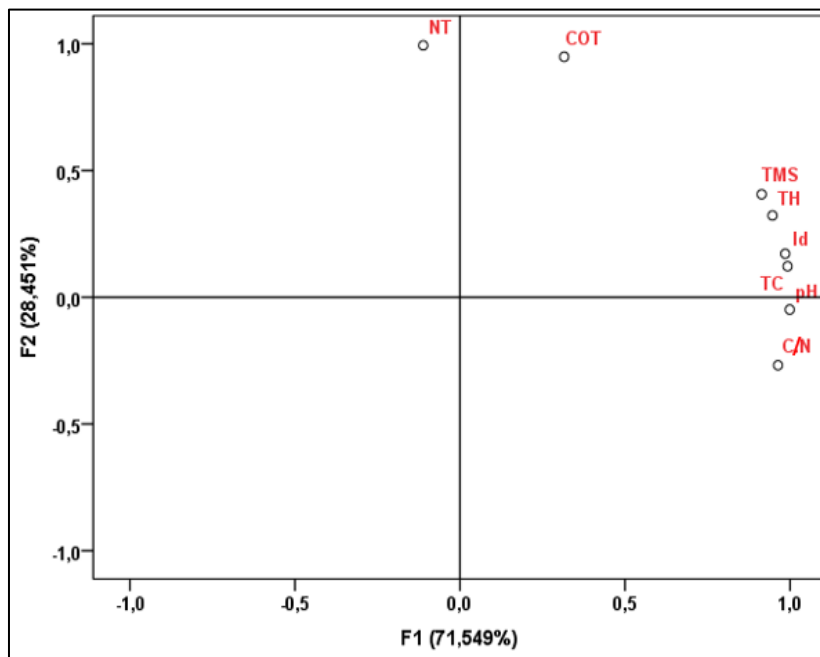


Figure 1 Influence of the physico-chemical parameters on each other

3.2.2. Correlation matrix

The Pearson correlation matrix was performed to elucidate the relationships between the variables measured in the different samples. The correlation coefficients are presented in Table 4.

Table 4 Correlation matrix of physical and chemical parameters

	pH	TC	TH	TMS	Id	TOC	NT	C/N
pH	1.000							
TC	0.993	1.000						
TH	0.947	0.979	1.000					
TMS	0.914	0.956	0.996	1.000				
Id	0.985	0.999	0.988	0.970	1.000			
TOC	0.317	0.429	0.605	0.674	0.474	1.000		
NT	-0.110	0.011	0.215	0.302	0.061	0.908	1.000	
C/N	0.829	0.755	0.605	0.531	0.721	-0.268	-0.647	1.000

Values marked in bold are significant ($r < 0.05$)

The examination of the matrix indicates the existence of positive and significant correlations between the variables. Very strong and significant correlations between Id and TC, pH and TC and also between TH and TMS and many others (with respectively $r = 0.999$, $r = 0.993$ and $r = 0.996$) were obtained. These significantly positive correlations observed between these variables indicate the mutual dependence of the parameters on each other [31]. On the other hand, a significantly negative correlation was found between C/N and NT with ($r = 0.647$). This result shows an inverse dependence between these variables and thus reflecting a decrease in one of the parameters with an increase in the other [32]. Non-significant correlations ($r < 0.5$) were observed between some variables. These weak correlations indicate that the presence or absence of one of these parameters has little effect on the content of the other [33].

4. Conclusion

The objective of this study was to valorize local agricultural biomass into biochar. The analysis carried out revealed that biochar contains necessary nutrient resources (potassium, calcium, magnesium, silico and total nitrogen) that could boost soil fertility and increase agricultural yield. The value of iodine index found (666.225mg/g) confirms the presence of microporous pores in the biochar. In addition, the significantly positive, negative and non-significant correlations were observed between the variables. The developed biochar could be beneficial in improving soil fertility.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding the publication of this paper.

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