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Evaluation of Some Combustion Characteristics of Biochar produced from Coconut Husks, Corn Cobs and Palm Kernel Shells

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ABSTRACT: In developing countries such as Togo, biomass and fuel wood are essentially utilized by households for cooking, mainly in rural and peri-urban area, whereas charcoal and sometimes butane gas are used in urban area.

The present study aims to investigate the energy potential of some biomasses, produced in Togo, as coconut husks, corn cobs and palm kernel shells in order to reduce charcoal utilization by making them as competitive as charcoal. To achieve this aim, raw biomass samples were carbonized and some of the obtained biochar combustion characteristics such as lower calorific value, energy per unit volume associated to bulk density, ash content and ash mineral content were explored.

The results showed that palm kernel shells biochar has the highest lower calorific value (25095 kj/kg), followed by corn cobs biochar (24760 kj/kg) when, with 16560 kj/kg, coconuts husks biochar has the lowest lower calorific value. On another note, with the highest bulk density of 0.670 g/cm^3 palm kernel shells biochar has the highest energy per unit volume (16813.65 j/cm^3), whereas with the lowest bulk density of 0.148 g/cm^3, corn cobs biochar had the lowest energy per unit volume. The ash content shows that coconut husks had the highest ash content (15.2 %), followed by corn cobs biochar (10.4 %) and finally palm kernel shells biochar (6.8 %). Among the three biochars, only palm kernel shells biochar ash does not contain chloride and sulfur.

In view of these results, palm kernel shells biochar seems to be the best candidate as alternative fuel in replacement of charcoal.

KEYWORDS: Biomass, Carbonization, Biochar, Lower Calorific Value, Ash Content.

1 INTRODUCTION

Since few decades, the energy demand grows exponentially as world population increases [1]. With the announced exhaustion of fossil energy associated to the world warm caused by their consummation, it is essential to turn towards renewable and sustainable sources of energy. Among these sources, wood and its derivatives are the most utilized in the world, especially in Africa and South Asia [1], [2], [3] in households mainly to cook food or keep warm [4], in less advanced combustion technologies, inducing poor efficiency [5].

This, amplified by other uses of wood, leads to the overexploitation of tropical forests, threatening their existence. For example, through a survey carried out by the International Tropical Timber Organization (ITTO) in 65 countries, Togo, Nigeria and Ghana are the three countries which have the strongest deforestation index. Togo, on its one, looses 5.75 % of his forest from 2005 to 2010 (http://www.republicoftogo.com) [6]. Therefore, it is indispensable to look for an alternative fuel, as biomass in the aim to minimize the pressure on tropical forests. According to A. Demibras, ''biomass includes wood and lagging residues, agriculture crops and their waste byproducts, the organic portion of municipal solid waste, animal wastes, municipal biosolids (sewage), waste from food processing and aquatic plants and algae. … Energy can be obtained from direct combustion of biomass, by burning dry organic matter'' [4]. In sub-Africa countries, biomass covers a large part of the energy needs. Due to irritation provoked by smoke and burning gas when it burn, associated to storage space it need, firewood, logging residues, tree bark, animal and agriculture wastes are more utilized in peri urban and rural areas. Charcoal is preferred in towns, as the biochar obtained from biomass has not the same characteristics as charcoal, obtained from tree trunks; independent of elaboration conditions [7]. As a matter of fact, with the lowest lower calorific value compared to charcoal, the produced biochar takes different shapes and sizes, dependent of feedstock. Also, very light and crumbly, it blocks stoves air intake leading thus to the reduction of combustion performances. Then, biochar, as it is, cannot be used in replacement of charcoal by households in cooking stoves (Xing Y. 2017). One of the ways to allow their utilization in households, is to press them in order to increase their energy per unit volume.

Furthermore it should be noted that many studies are done in order to use biochar as soil amendment and carbone sequestration [9], [10], [11]. That explains the reason that it is also called agrichar [12], 13].

According to Gino et al. [8], the mixture of various biochars may result in fuel combustible lower calorific value greater than fuel combustible took separately. In order to allow biochar utilization as alternative fuel by households in cooking stoves, in replacement of charcoal, we need to increase energy per unit volume of biochars by finding the mixture proportion which increases lower calorific value before pressing them into briquettes at the adequate pressure.

The objective of this study is the determination of some combustion characteristics of the available biomasses (palm kernel shells, corn cobs and coconut husks) in Togo, as they depend on their background. We use simple carbonizer made in Laboratory with local materials, cheap and easily realizable, to produce biochar of raw samples. The lower calorific value of each samples, their ash content and some mineral presented in ash are been determined.

2 Material And Methods

2.1 Sample Collection

All tested samples were collected in Lomé (Republic of Togo, West Africa) and its surroundings. Shells of palm kernel were collected in a small traditional oil mill, coconut husks were provided by coconut water sellers and corn cobs were obtained from a farmer.

2.2 Biochar Preparation

The collected palm kernel shells were covered by a thin clay layer. Thus, they were cleaned in two steps. At the first step, they were washed by tap water for several minutes and in the second step, in distilled water for about five minutes. They were then sun dried for nine hours per day during four days. As regard to coconut husks and corn cobs, they were collected already dried and sorting is made following their cleanness.

2.3 Biochar Stove System

These biomasses were carbonized separately in a metallic biochar stove made in Laboratory, which is shown in Fig. 1. It is consisted of a metallic cylinder tank containing another metallic colon as shown in figure 1(b). For each carbonization, about 6.0 kg of palm kernel shells, 200 g of corn cobs and 200 g of coconut husks can be introduced.

During the carbonization, the temperature is determined in the biochar stove by introducing at 10 cm from its bottom a K-type thermocouple. In Fig. 1(b), T indicates the position where the thermocouple is installed.

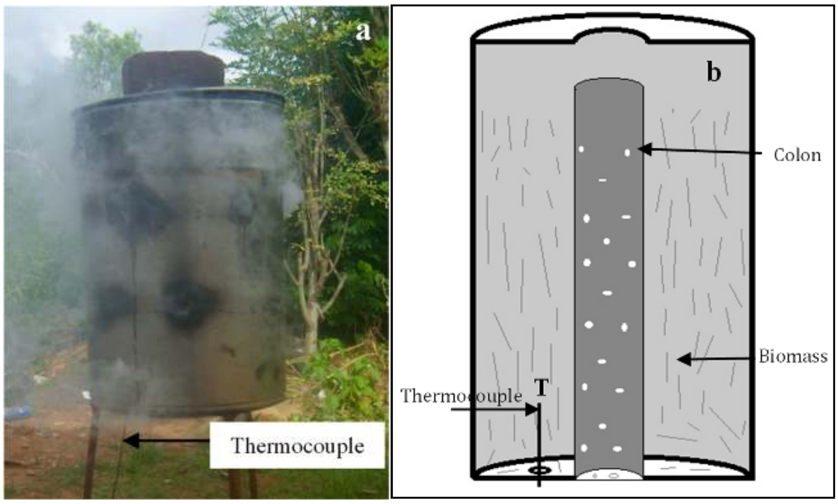

Fig. 1. (a) The photographic image of the biochar stove and (b) its schematic sectional

2.4 Biochar Characterization

2.4.1 Biochar Yield

The yields of biochar, BY, were determined as the ratio of the produced biochar to the biomass subjected to carbonization as shown in equation 1 :

$$BY = (W_2/W_1) \times 100 \quad (1)$$

Where :

- W_1 is the air dried weight of each biomass prior to carbonization,
- W_2 is the biochar weight.

2.4.2 Quantification Of Lower Calorific Value

The Lower Calorific Value (LCV) of the samples was determined using adiabatic oxygen bomb calorimeter, PARR Calorimeter, model 1241 with the Standard Test Method for calorific value.

2.4.3 Ash Content Determination

Biochar of each biomass was ground into powder in aluminum mortar, poured in a porcelain crucible and introduced into a desiccator, at 105°C, for 12 hours. For each dry sample, 2 g were taken off and placed in pre-weighed porcelain before being introduced into a preheated muffle furnace set at 600°C for 1 hour, for calcination [3], [14]. After calcination, the crucible and its content were took out of the furnace at 105°C and reweighed. The new weight was recorded and the Ash Content AC (%) was estimated using the following formula :

$$AC = (W_a/W_0) \times 100 \quad (2)$$

Where :

- W_a is the weight of ash after cooling,
- W_0 is the original weight of dry powder of each biochar.

2.4.4 Bulk Density Measurement

10 g of each biochar powder were put in an uncovered porcelain crucible and introduced into a desiccator at 105°C, for 12 hours and; after drying, they were immediately poured into a 200 mL graduated cylinder. Once their volume V_0 known, the biochar powder density was determined with this formula :

$$BD = W/V_0 \quad (3)$$

Where :

- W is the weight of the sample.
- V_0 is the Volume of the sample

2.4.5 Quantification Of Ash Electrical Conductivity And Mineral Content

Samples ash solution electrical conductivity was determined with WTW cond.730, with a concentration of 5g/L of each sample. Using the same concentration, the acidity was measured with WTW/PH 330i/SET pH-meter. Certain minerals salts content for 100 g of each sample solution were determined by volumetric titration (Chloride, Sulfur) and others (Sodium, Potassium) by flame photometric detector, Jenway, model PFP7.

3 Results And Discussion

Fig. 2 presents the temperature profile at the bottom of the biochar stove, during carbonization of each sample. Under the same condition the temperature is plotted as a function of time.

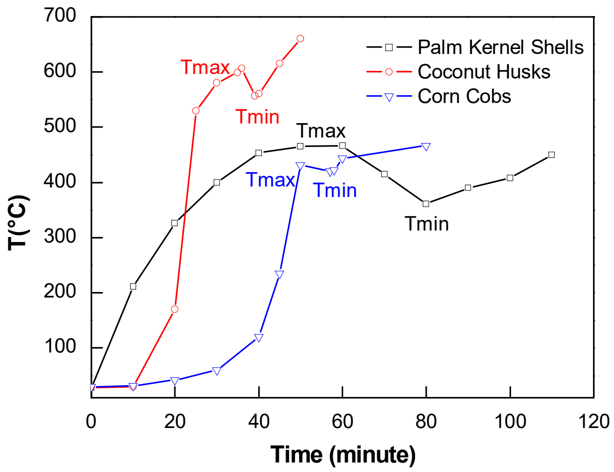

Fig. 2. Temperature measured at the bottom of the biochar stove for the three biomasses.

Minutes after firing samples, we observe that, for the three biomasses, temperature increases with time to reach a maximum value, noted Tmax. But, their growth rates are not similar. For the palm kernel shells, temperature increases almost linearly but for the coconut husks and corn cobs, it increases very slowly, respectively within the first 20 and 40 minutes, before reaching the maximum value. Then, it suddenly drops sharply for coconut husks and corn cobs, but slowly for palm kernel shells to a minimum value, noted Tmin. From this minimum, the temperature increases slightly at the carbonization end. Thermal increase to Tmax may be consistent to the emission of combustion gases such as H_2, CH_4, CO, CO_2 and volatile material, related to combustion zone progress which increases heat locally, as the thermo-chemical pyrolysis and gasification reactions took place. These observations have been made by Hiroki and Hussein [3], [15]. After this combustion, temperature drops from Tmax to Tmin. The slight increase from Tmin may arise due to the obtained char combustion. Thus, few minutes after Tmin reached, the char obtained must be transferred into a closed container to prevent its combustion.

Table 1. presents the maximum and minimum temperatures (Tmax, Tmin), the residence time (RT) and the biochar yield (BY).

Table 1. Values of Tmax, Tmin and RT the residence time of feedstock associated to the time at which Tmin is reached.

Bio char	Tmax (°C)	Tmin (°C)	RT (mn)	BY (%)
Palm Kernel Shells	467	432	80	43
Corn Cobs	445	420	57	38
Coconut husks	600	557	40	25

As shown in Table 1., palm kernel shells, corn cobs and coconut husks biochar are produced during slow pyrolysis; their residence time (RT) is longer and the temperature lower than 700°C [15]. Palm kernel shells present the highest residence time, followed by corn cobs and the lowest time is recorded for coconut husks.

Due to the actively metabolizing role played by the coconut husks (green as the leaf) [16], it may contains the highest volatile components which escape and burn very quickly, leading to the higher temperature Tmax, shortening the residence time and reducing the biochar yield [17]. Corn cobs have relatively the similar behaviour but palm kernel shells behave differently. Apart for coconut husks (25 %), the yield of the biochar produced, is more than 35 % [15] proving the efficiency of our biochar stove and the method used to produce the biochar.

Table 2. summarizes the measurement results of pH and electrical conductivity of the ashes of the three biochars.

The extracted ash pH values ranged from 9.30 to 10.30, similar to rice husks [15] and to some trees were found to be alkaline in nature [16], which suggests that they can be used to reduce soil acidity. Indeed, according to their chemical and physical characteristics, biochar could be used either as combustible fuel or soil amendment [17]. The palm kernel shells biochar ash is less alkaline than the others.

Table 2. pH and Electrical conductivity of each biomass ash

Biochar	pH	Elect. Conduct. (µS/cm)
Palm Kernel Shells	9.30	149.5
Corn Cobs	10.30	2390
Coconut husks	10.05	3800

Concerning the samples ash mineral content, summarized in Table 3., especially the concentration of potassium, corn cobs and coconut husks, as an actively metabolizing part of the plant, mainly for coconut husks, have the highest mineral content and consequently the highest electrical conductivity (Table 2.) than the palm kernel shells [16]. Palm kernel shells biochar shows no chloride and sulfur content indicating that they are not harmful for the cooker.

Table 3. Mineral content of the three biomass ash

Biochar	Cl (g/100g)	S	Na (g/100g)	K (g/100g)
Palm Kernel Shells			0.5	2.3
Corn Cobs	4	1.2	1.05	15.4
Coconut Husks	15.7	5.0	5.6	20.4

We summarize in Table 4. the Lower Calorific Value (LCV), Bulk Density (BD), Ash Content (AC) and Heat Per Volume Unit (HPVU) of the analysed samples.

Table 4. Lower Calorific Value, Ash Content, Biochar Yield, Bulk Density and Heat Per Volume Unit of different samples

Biochar	LCV (kJ/kg)	AC (%)	BD (g/cm^3)	HPVU (J/cm^3)
Palm Kernel Shells	25095	6.8	0.670	16813.65
Corn Cobs	24760	10.4	0.148	3664.48
Coconut Husks	16560	15.2	0.246	4073.60

The LCV of palm kernel shells biochar is the highest (25095 kJ/kg), medium for corn cobs (24760 kJ/kg) and lower for the coconut husks (16560 kJ/kg). The observed calorific value of palm kernel shells and corn cobs biochars are greater than most of those of fuel wood, found to vary from 19,747.74 kJ/kg in *Tectonia grandis* to 33,983.4 kJ/kg in *Terminalia bellirica* [2], [18]. This is because carbonization increases the carbon concentration of organic material and thus calorific value. For example, raw corn cobs biomass calorific value has found to be 20 890 kj/kg [20] smallest compared to that of its biochar we found. It is the same with palm kernel shells found to be 22 970 kj/kg [21] compared to our result. Coconut husks biochar has the smallest calorific value and was similar to that obtained by Koteswararao B. [22].

Concerning AC, palm kernel shells biochar has the lowest ash content (6.8 %), corn cobs (10.4 %) is medium and highest for coconut husks (15.2 %).

These results are consistent with the fact that, the lower AC, the higher LCV. In fact, many studies prove that high mineral content in biomass has a negative impact on its calorific value by lowering it [1], [2], 16]. The lowest heat value recorded for coconuts husks can then be explained by its highest ash content.

According to some studies, BD could be a contributing parameter but not a major factor in the energy content of the biochar [2]. It is an important parameter for determining energy per volume unit a fuel likely to contain and the longer time it burns [23]. Palm kernel shells biochar has the highest BD (0.670 g/cm^3), followed by the coconut husks (0.246 g/cm^3) and the lowest value is recorded for corn cobs (0.148 g/cm^3). As a result, the palm kernel shells and the coconut husks biochars have the highest energy per unit volume, respectively 16813.650 J/cm^3 and 4073.60 J/cm^3. With 3664.480 J/cm^{3,} corn cobs have the smallest energy by unit volume content. This raises the issue of this alternative fuels acceptance in households, as more volume of fuel is necessary to cook the same meals. It can be seen that biochar from palm kernel shells energy per volume unit is at least 4 times higher than those of coconut husks and corn cobs.

4 Conclusion

This study investigated the calorific values of char made from three biomasses and some parameters related to their combustion phenomenon. It aimed to evaluate the energy potential of these biochars in order to allow their utilization as alternative fuels in households located in cities. From the obtained results, it may be concluded that the carbonization of palm kernel shells present the highest biochar yield (43 %), with the highest Lower Calorific Value (25095 kJ/kg), the highest energy per volume unit (16813.65 J/cm^3) and the lowest ash content (6.8 %) without harmful mineral elements as chloride and sulfur. The biochar of corn cobs had the lowest Lower Calorific Value close to that of palm kernel shells one's (24760 kJ/kg) but the minimum energy per volume unit (3664.480 J/cm^3) with high ash content (more than 6%). Coconuts husks char had the lowest Lower Calorific Value (16560 kJ/kg) but an intermediate energy per volume unit (4073.60 J/cm^3) and the highest ash content well above the standards (15.2 %).

This work has showed the energy potential of three biochars from palm kernel shells, corn cobs and coconut husks. Among them, biochar from palm kernel shells seem to be the best alternative fuel.

References

[1] A. Demirbas, '' Biodiesel : A Realistic Fuel Alternative for Diesel Engines'', *Springer, London*, pp. 21-22, 2008.

[2] J. I. Duruaku, V.I.E. Ajiwe, N.H. Okoye and R.U. Arinze, ''An Evaluation of the Calorific Values of the Branches and Stems of 11 Tropical Trees'', *Journal of Sustainable Bioenergy Systems*, no. 6, pp. 44-54, 2016.

[3] H. Hiroki, H. Hirroomi and M. I. Yusrizal, ''Wood Pyrolysis in Pre-Vacuum Chamber'', *Journal of Sustainable Bioenergy Systems,* no. 3, pp. 243-249, 2013.

[4] A. Demirbas ''Biofuels from Agricultural Biomass'', *Energy sources Part A*, no. 31, pp. 1573-1582, 2009.

[5] M. M. Lesego, O. B. Michael, A. A. Ayotunde, O. D. Michael, P. C. Nonhlanhla and A. O. Peter, ''Beneficiation of corncob and sugarcane bagasse for energy generation and materials development in Nigeria and South Africa: A short overview'', *Alexandria Engineering Journal,* no.55, pp. 3025–3036, 2016.

[6] http://www.republicoftogo.com [Online] (16 may, 2018)

[7] L. Mathilde, 2017. [Online] Available : https://mediatheque.agencemicroprojets.org/etude-evaluation-capitalisation-charbon-vert/ (29 august, 2017)

[8] M. T. A. Gino, S. K. Yuji and T. B. Florinda, ''Evaluation of Fuel Properties of Charcoal Briquettes Derived From Combinations of Coconut Shell, Corn Cob and Sugarcane Bagasse'', *Proceedings of the DLSU Research Congress,* Vol. 3, 2015.

[9] S. Hardy, D. Gerald and G. Bruno,''Positive effects of composted biochar on plant growth and soil fertility'', *Agron. Sustain. Dev. n*o. 33, pp. 817–827, 2013.
doi 10.1007/s13593-013-0150-0

[10] K. Jindo, H. Mizumoto, Y. Sawada, M. A. Sanchez-Monedero and T. Sonoki, ''Physical and chemical characterization of biochars derived from different agricultural residues'', *Biogeosciences,* no.11, pp. 6613–6621, 2014.

[11] H. Amine, M. Donato, F. Saverio, P. F. Francesco, C. Ziad Al and D. Stefano,'' Production and characterization of biochar from three-phase olive mill waste through slow pyrolysis'', *Biomass and Bioenergy,* 2014. http://dx.doi.org/10.1016/j.biombioe.2014.09.024

[12] H. B. Jehangir, P. J. Stephen and K. Raju,'' Phosphorus Sorption Behavior of Torrefied Agriculture Byproducts under Sonicated Versus Non-Sonicated Conditions'', *Sustainable Agriculture Research,* vol. 6, no. 4, 2017.

[13] L. Jorge L.,''Perspective of the preparation of agrichars using fossil hydrocarbon coke'', *Renewable and Sustainable Energy Reviews,* vol. 16, no. 8, pp. 5597 – 5602, 2012.

[14] S. S. Dara, ''Experiments and Calculations in Engineering Chemistry. S. Chand and Co. Ltd.''*, New Delhi*, pp. 185-191, 1991.

[15] K. N. Hussein, E. H. Sarah, C. Gerard and T. B. Robert,'' Sustainable Technologies for Small-Scale Biochar Production – A Review'' *Journal of Sustainable Bioenergy Systems*, no. 5, pp. 10-31, 2015.

[16] A. Hanisom, A. M. Kun and W. Hongwei,'' Biochar as fuel : 2. Significant Differences in Fuel Quality and Ash Properties of Biochars from Various Biomass Components of Mallee Trees'', *Energy Fuels,* no. 24, pp. 1972-1979, 2010.

[17] E. Agrafioti, G. Bouras, D. Kalderis and E. Diamadopoulos, '' Biochar production by sewage sludge pyrolysis'', *Journal of Analytical and Applied Pyrolysis*, no. 101, 72-78, 2013.

[18] S. Chakradhari and K. S. Patel, '' Combustion Characteristics of Tree Woods'', *Journal of Sustainable Bioenergy Systems*, no. 6, 31-43, 2016

[19] Y. Xing, W. Hailong,J. S. Peter, X. Song, L. Shujuan, L. Kouping, S. Kuichuan, G. Jia, C. Lei, H. Lizhi, S. O. Yong, Y. Guodong, S.Ying and C. Xin '' Thermal Properties of Biochars Derived from Waste Biomass Generated by Agricultural and Forestry Sectors'', *Energies,no.* 10, pp. 469, 2017 doi:10.3390/en10040469

[20] M. T. A. Gino, S. K. Yuji and T. B. Florinda T, '' Evaluation of Fuel Properties of Charcoal Briquettes Derived From Combinations of Coconut Shell, Corn Cob and Sugarcane Bagasse,'' *Proceedings of the DLSU Research Congress,* vol. 3*,* 2015

[21] W. A. Wan Ab Karim Ghani, M.S.F. Abdullah, K. A. Matori, A. B. Alias and da S. Gabriel, '' Physical and Thermochemical Characterisation of Malaysian Biomass Ashes'', *Journal - The Institution of Engineers, Malaysia*, vol. 71, no. 3, 2010.

[22] B. Koteswararao, L. Ranganath and K. K. Radha, '' Fuel from Green Tender Coconut'', *2nd International Seminar On "Utilization of Non-Conventional Energy Sources for Sustainable Development of Rural Areas* ISNCESR'16 17th & 18th March, 2016.

[23] S. J. Mitchual, K. Frimpong-Mensah and N. A. Darkwa,'' Evaluation of Fuel Properties of Six Tropical Hard-wood Timber Species for Briquettes'', *Journal of Sustainable Bioenergy Systems*, no. 4, pp. 1-9, 2014.