Carbonization techniques and wood species influence quality attributes of charcoals produced from industrial sawmill residues in Eastern Cameroon

Joseph Zobo Mfomo[1]
Achille Bernard Biwolé[1]
Evariste Fedoung Fongzossie[1]
Gilbert Tsoh Ekassi[1]
Didier Hubert[2]
Hugues Ducenne[2]
Jean Gaston Tamba[3]
Ruben Mouangue[4]

[1] University of Douala
Advanced Teacher's Training College for
Technical Education
PO Box 1872, Douala
Cameroon

[2] German Development Cooperation
Program for the Implementation of the
Rural Development Strategy
Forest-Environment Programme
Eco-Consulting Group
PO Box 7814, Yaoundé
Cameroon

[3] University of Douala
University Institute of Technology
PO Box 8698, Douala
Cameroon

[4] University of Ngaoundéré
University Institute of Technology
PO Box 454, Ngaoundéré
Cameroon

Auteurs correspondants /
Corresponding authors:
Joseph ZOBO MFOMO
– zobo_mfomo@yahoo.fr
Ruben MOUANGUE
– r_mouangue@yahoo.fr

Improved traditional kiln commonly used by charcoal producers in the eastern region of Cameroon. Photo D. Hubert.

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J. Zobo Mfomo, A. B. Biwolé,
E. Fedoung Fongzossie, G. T. Ekassi,
D. Hubert, H. Ducenne, J. G. Tamba,
R. Mouangue

RÉSUMÉ

Influence de la technique de carbonisation et de l'essence de bois sur la qualité des charbons produits à partir des résidus de sciages industriels à l'Est du Cameroun

Le Cameroun exploite un volume considérable de bois rond chaque année, dont une infime partie est utilisée pour la fabrication de produits manufacturés. Depuis quelques décennies, des initiatives se développent autour de scieries industrielles, surtout dans la région de l'Est, pour valoriser la biomasse résiduelle. Cependant, l'utilisation non différenciée des résidus issus d'essences différentes donne souvent des produits au potentiel énergétique variable et pas toujours appréciés des consommateurs. D'autre part, les caractéristiques physico-chimiques de ces charbons de bois sont inconnues, de même que les facteurs qui influencent leur qualité. La présente étude avait pour objectif d'évaluer la variabilité des propriétés physico-chimiques du charbon de bois produit avec des résidus du sciage industriel à l'Est du Cameroun, à l'aide de différentes techniques de carbonisation. Trois essences de bois, ayous, fraké et movingui, et trois types de fours (traditionnel, traditionnel amélioré et casamançais) ont été utilisés. Pour chaque essence, trois fagots de cinq morceaux de bois chacun ont été préparés, avec un taux d'humidité initial variant de 28 % à 36 %. Les propriétés physico-chimiques déterminées étaient le taux d'humidité, la densité apparente, les teneurs en matières volatiles, en carbone fixe et en cendres, et le pouvoir calorifique supérieur (PCS). Nos résultats montrent que les propriétés du charbon de bois varient selon l'essence et les types de fours utilisés. Le charbon de bois de movingui, dont la densité est la plus élevée (0,73 g/cm³), présente le plus faible taux d'humidité (4,03 %) et la densité apparente la plus élevée (0,42 g/cm³). Les teneurs les plus faibles en matières volatiles (20,32 %) et en cendres (1,27 %) ont également été obtenues avec cette essence, ainsi que la teneur la plus élevée en carbone fixe (74,95 %). Toutes ces valeurs pour le charbon de bois de movingui ont été obtenues avec la meule casamançaise. Cependant, le PCS le plus élevé (32,51 MJ/kg) a été obtenu avec le charbon de bois d'ayous produit dans une charbonnière Casamance. La comparaison des trois types de fours utilisés montre que les meilleures propriétés physico-chimiques s'obtiennent avec la meule casamançaise. Tous les charbons de bois analysés sont conformes aux normes FAO pour la cuisson des aliments. Le PCS le plus élevé obtenu avec le charbon de bois d'ayous indique sa forte capacité à émettre une grande quantité d'énergie thermique au cours de la combustion tout comme un bois dur.

Mots-clés : charbon de bois, techniques de carbonisation, propriétés physico-chimiques, résidus de scierie industrielle, Est-Cameroun.

ABSTRACT

Carbonization techniques and wood species influence quality attributes of charcoals produced from industrial sawmill residues in Eastern Cameroon

Cameroon harvests a considerable volume of round wood each year, only a small part of which is used for manufactured products. In recent decades, various charcoal-making initiatives have emerged around industrial timber-processing units, particularly in the eastern region, in order to develop a market for residual biomass. However, the undifferentiated use of these residues obtained from different species often results in products with varying energy potential that are not always appreciated by consumers. Moreover, the physical and chemical characteristics of the charcoal produced are unknown, as are the factors that influence its quality. The aim of this study was to assess the variability of the physical and chemical properties of charcoal produced from industrial sawmill residues in the eastern region of Cameroon using different carbonization techniques. Three wood species, Ayous, Frake and Movingui, and three types of kilns (traditional, improved traditional and Casamance system) were used. For each species, three bundles of five pieces of wood each were prepared, with an initial moisture content ranging from 28% to 36%. The physical and chemical properties determined were moisture content, apparent density, volatile matter content, fixed carbon content, ash content and Higher Heating Value (HHV). Our results showed that the charcoal properties varied depending on the wood species and types of kilns used. Movingui, with the highest density (0.73 g/cm³), produced charcoal with the lowest moisture content (4.03%) and the highest apparent density (0.42 g/cm³). The lowest volatile matter content (20.32%), the lowest ash content (1.27%) and the highest fixed carbon content (74.95%) were also obtained with this species. All these values were obtained with Movingui charcoal produced with the Casamance system. However, the highest HHV (32.51 MJ/kg) was obtained with charcoal from Ayous, also produced with the Casamance system. On comparing the three charcoaling systems used, the Casamance model yielded the best physical and chemical charcoal properties. All the charcoals studied complied with FAO standards for cooking fuel. The highest HHV obtained with charcoal from Ayous hardwood shows its ability to release large amounts of thermal energy during combustion.

Keywords: charcoal, carbonization techniques, physico-chemical properties, industrial sawmill residues, Eastern Cameroon.

RESUMEN

Las técnicas de carbonización y las especies de madera influyen en las propiedades cualitativas del carbón vegetal producido por los residuos de serrerías industriales en el este del Camerún

El Camerún explota anualmente un volumen considerable de madera redonda, una pequeña parte de la cual se utiliza en productos manufacturados. En las últimas décadas se han desarrollado diferentes iniciativas de producción de carbón vegetal junto a las industrias de procesamiento de madera, especialmente en la región del este, para desarrollar un mercado para su biomasa residual. Sin embargo, el uso no diferenciado de estos residuos, obtenidos de diferentes especies, a menudo proporciona productos con potencial de energía variable, que no siempre son apreciados por los consumidores. Además, las características física y química de este carbón vegetal son desconocidas, así como los factores que influyen en su calidad. El objetivo de este estudio es evaluar la variabilidad de las propiedades físicas y químicas del carbón vegetal producido con residuos de serrería en la región este de Camerún, mediante diferentes técnicas de carbonización. Se utilizaron tres especies de madera, Ayous, Frake y Movingui, y tres tipos de hornos (tradicional, tradicional mejorado y sistema Casamance). Para cada especie, se prepararon tres haces de cinco piezas de madera cada uno, con un contenido inicial de humedad en el rango del 28 al 36 %. Las propiedades físicas y químicas determinadas eran la tasa de humedad, la densidad aparente, la cantidad de materia volátil, la cantidad de carbono fijado, la cantidad de ceniza y el poder calorífico superior (PCS). Nuestros resultados mostraron que las propiedades del carbón vegetal variaban en función de la especie de madera y de los tipos de horno utilizados. Movingui, con la densidad más elevada (0,73 g/cm³), produjo carbón vegetal con la tasa de humedad más baja (4,03 %) y la densidad aparente más elevada (0,42 g/cm³). La cantidad de materia volátil más baja (20,32 %), la cantidad de ceniza más baja (1,27 %) y la cantidad de carbono fijado más elevada (74,95 %) también se obtuvo con estas especies. Todos estos valores se consiguieron con el carbón vegetal de Movingui producido por el horno Casamance. Sin embargo, el PCS más elevado (32,51 MJ/kg) se obtuvo con carbón vegetal de Ayous producido en el horno Casamance. Comparando los tres tipos de horno utilizados, el horno Casamance proporcionó las mejores propiedades físicas y químicas del carbón. Todos los carbones vegetales estudiados cumplían los estándares FAO de combustible para cocción de alimentos. El PCS más elevado, obtenido con carbón vegetal de Ayous, muestra su capacidad para liberar grandes cantidades de energía térmica durante la combustión de madera dura.

Palabras clave: carbón vegetal, técnicas de carbonización, propiedades fisicoquímicas, residuos de serrería industrial, este de Camerún.

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Introduction

Central Africa hosts a remarkable forest potential that significantly contributes to national economies (Nasi *et al.,* 2012; Eba'a Atyi *et al.,* 2013). The wood production capacity in Cameroon is estimated at 5 million cubic metres of standing timber per year, of which 2.97 million cubic metres represents the share of round wood harvested annually. However, only a small proportion of this harvested volume is processed, most of the residual biomass is being considered as unusable residues (FRM, 2018). Nowadays, the quantity of processed round wood in Cameroon is estimated at 891,000 m³/year, representing a mass-yield (volume of products processed on the logs volume received at the factory) of only 30%. This low material yield is mainly explained by the current industrial model, based on the export of primary processing products to markets with high quality requirements (FRM, 2018).

Paradoxically, the use of wood energy remains a major concern in large urban centres in Cameroon and other Central African countries, where it represents the main form of domestic energy (Marien *et al.*, 2013). Indeed, faced with the difficulty to access the other forms of energy such as: fossil energy, hydroelectric energy, and alternative energies (solar, wind), wood consumption is increasing sharply in most countries in this region (Schure *et al.*, 2010) and this trend will certainly continue to evolve in the coming decades due to demographic expansion. In Cameroon, where nearly 83% of the population depends on woody biomass as energy source, charcoal consumption is growing at a rate of 2.67%/year (Eba'a Atyi *et al.*, 2013).

Charcoal is currently one of the most sought-after fuels in urban centres in this country. This is due to its properties and various uses (Schure *et al.*, 2012). Although several other techniques have been tested, including improved traditional kiln, Casamance kiln, metal kiln, Brazilian kiln, artisanal horn kiln, and buried industrial horn kiln (Nguenang and Ngo Badjeck, 2013; Tchouanti Nzali *et al.*, 2019; Mouangue *et al.*, 2020; Miguiri *et al.*, 2020), charcoal production remains essentially archaic in Cameroon. It is mainly based on the use of traditional kilns which are practical and economically affordable, but with low mass-yield between 12 to 20% (FAO, 2017). However, there is no information on their properties as well as the impact of the carbonization techniques used for their production in the literature (Nguenang and Ngo Badjeck, 2013). The domestic charcoal quality is determined by its physical and chemical properties. According to FAO (FAO, 1985), charcoal of excellent quality has less than 10% of moisture content, 20 to 25% of volatile matter content, 75 to 80% of fixed carbon content, and 3 to 4% of ash content. Rosa *et al.* (2012) reported higher values of apparent density (0.46 g/cm³), higher heating value (30.88 MJ/kg) and fixed carbon content (75 to 83%), lower values of moisture content (5.5%), volatile matter (15 to 23%), and ash content (0.68 to 1.65%). There are studies indicating that, the properties of charcoal are influenced by the carbonization techniques (Assis *et al.*, 2016) and the wood species used (Adegoke *et al.*, 2014). Indeed, Adegoke *et al.* (2014) in Nigeria reported good combustion properties of charcoal from the sawmill residues of two low-density African species: *Terminalia superba* (higher heating value = 32.69 MJ/kg) and *Triplochiton sclorexylon* (higher heating value = 32.79 MJ/kg). Unfortunately, until date, few studies have been focused on the tropical species that are harvested from central Africa. Hence, the properties of charcoal produced from the sawmill residues are largely unknown. Yet, such information could help to better define the conditioning of these products and improve its access to new markets. There is therefore an urgent need to determine the properties of these charcoals and to evaluate the impact of carbonization techniques on the final products. It is in this perspective that the present work was carried out with the objective of assessing the physical and chemical properties of charcoal obtained from sawmill residues in the eastern region of Cameroon, and to analyse the influence of carbonization techniques on the final products.

Materials and methods

Acquisition and preparation of charcoals

Wood materials used for the production of charcoal were industrial sawmill residues collected from a wood-processing unit of a logging company (*Société Industrielle de Mbang*) located in the eastern region of Cameroon. This company has an agreement with charcoal producers to supply them with the sawmill residues necessary to produce charcoal. Three different types of kilns were used by these charcoal producers were selected as the carbonization technologies to be analysed (photos 1). They include the traditional kiln (TK), which is the most widely used by the charcoal producers, the improved traditional kiln (ITK) and the Casamance kiln (CK). A brief description of these three carbonization technologies is given in the following section.

Three wood bundles of five pieces, each of 700 x 200 x 20 mm and initial moisture contents ranging from 28% to 36% were placed in each kiln. Each bundle that was charred was made of one of the three species used: Ayous (*Triplochiton scleroxylon*), Frake (*Terminalia superba*) and Movingui (*Distemonanthus benthamianus*). Ayous and Frake are very light, soft and porous woods, while Movingui is a Medium-heavy wood. These species were chosen based on the availability of their sawmill residues in the processing unit during the study period (February-April 2018) and the traceability of the wood species processed in the processing unit. Eight samples of each bundle were randomly selected for physicochemical properties analysis (figure 1). Five of them were used to determine the physical properties. Each of these five samples were futher divided into two parts. One part was used for moisture content analysis, while the other one was use for the determination of the apparent density. The three remaining samples of each bundle were also taken

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Photos 1.
The three types of kiln commonly used by charcoal producers in this eastern region of Cameroon. A) Traditional kiln;
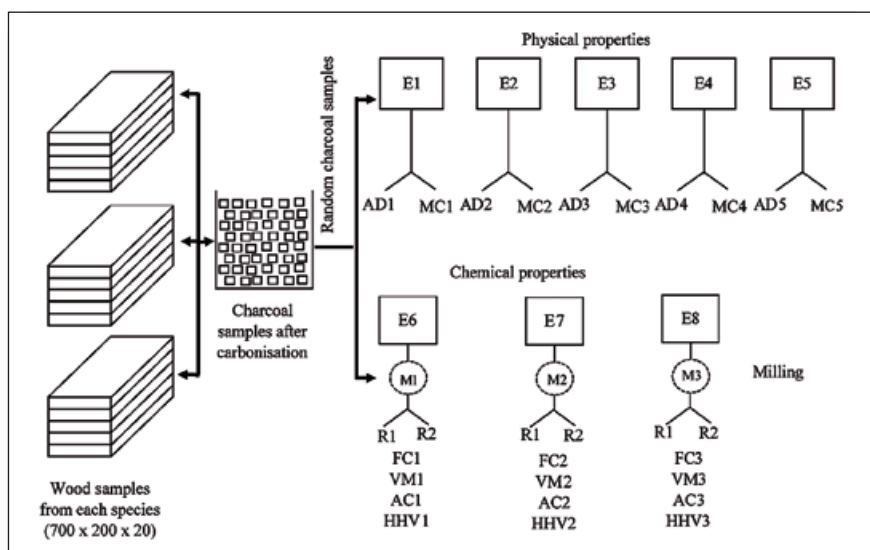B) Improved traditional kiln;
C) Casamance kiln.
Photos D. Hubert.

Figure 1.
Schematic illustration of sampling design from the wood to charcoal to laboratory. E1 to E5 are the six samples selected for the analysis of physical properties; E6 to E8 are three samples selected for chemical properties analysis. AD1 to AD5; MC1 to MC5; FC1 to FC3; VM1 to VM3, AC1 to AC3 and HHV1 to HHV3 corresponding to samples used to measure Apparent density, Moisture content, Fixed carbon, Volatile matter, Ash content and Higher heating value respectively.
M1 to M3 are the fraction of charcoal mill used for chemical analysis. R1 and R2 are the replicates of each sample used for chemical analysis.

Descriptions of the charcoal production techniques studied

Traditional Kiln (TK)

The most widely used kiln used in the eastern region of Cameroon is the traditional dome kiln. It is made from locally available materials. Wood residues collected from the wood processing units are perpendicularly arranged in the kiln. Then two successive layers of sawdust and earth respective are used to seal the kiln. A ventilation hole allows control and monitoring of the carbonization process. Depending on the size of the kiln, constant attention needs to be paid for the 3 to 15 days after firing. Once the kiln has cooled, charcoal can be collected. The main advantage of this type of kiln is that it can easily be carried out at the operating site. The disadvantages are that charring takes long time and the process requires constant attention.

Traditional Improved Kiln (TIK)

It has a horizontal shape with a triangular or elliptical base. It differs mainly from the traditional kiln with the following specifications:
▪ the wood is sorted in thicknesses;
▪ loading is based on double ventilation;
▪ the cover is made of a mixture of earth, sawdust and grass;
▪ ventilation holes are on the sides of the kiln and funnel is at the back of the kiln. For a load of 15 tons, a charcoal-making cycle takes 15 days.

Casamance Kiln (CK)

This kiln contains a funnel that can be made of metal barrels whose function is to improve the control of air flow. The heat flow does not escape completely from the kiln but is partially redirected to circulate within the kiln; hence the pyrolysis is ameliorated. Thanks to this "reintroduction" of heat, the charcoal-making is faster and more uniform than in traditional kiln. The main advantage of this type of kiln is its efficiency and the reduction in charcoal-making time due to its better heat circulation. The main disadvantage is the high cost of construction and running.

Determination of moisture content and apparent density

The determination of the moisture content was carried out in accordance with the NF EN 14774 (AFNOR, 2010a). The five samples used to determine the moisture content were weighed to an accuracy of 0.01 g, dried during 48 h to a constant mass in a drying oven at 103 °C and reweighed.

The moisture content was determined based on dry mass. Apparent density was determined in accordance with the NBR 11941 (Brazilian Association of Technical Standards, 2003). The five samples prepared for this pur-

for chemical analysis. For this purpose, each sample, which was previously grinded, was separated into two parts. All these samples were then labelled and stored in polyethylene bags for laboratory analysis.

The pyrolysis cycle lasted for 10 days in the traditional and improved traditional kilns, and 7 days in the Casamance kiln.

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pose were first immersed in water for 24 h. The volume of each sample was then determined by using the hydrostatic method (Rosário da Silva e Silva *et al.*, 2018).

Chemical composition of charcoal

The samples were crushed in the porcelain mortar using a pestle. A set of sieves from 2 to 200 µm was used for separation and classification. Charcoal fractions with diameters less than 0.2 mm were used for chemical analyses. These analyses were carried out with fives replicates of each species. A 105 °C drying oven was used to dry samples and determine their moisture content and dry mass. The volatile matter content was determined according to the NF EN 15148 (AFNOR, 2010b) in a muffle furnace at 950 °C by placing the crucibles for 2 mn on the outer edge of the furnace (300 °C) and then for 3 mn on the edge of the furnace (500 °C). The crucibles were then moved to the back of the furnace for 6 mn with the muffle door closed. The ash content was quantified in accordance with the NF EN 14775 (AFNOR, 2010c) which requires that the crucibles be placed in the muffle furnace at 750 °C for 6 h. The fixed carbon content is derived after determining the moisture content of the charcoal, the volatile matter index and the ash content. All weights were taken with an accuracy of 0.01 g. The moisture content and chemical components were calculated based on the dry mass of the charcoal (Godjo *et al.*, 2015).

Determination of the Higher Heating Value

The higher heating values (HHV) were measured according to ASTM D 5865 ASTM, 2012) using an XRY-1A+ brand electronic oxygen calorimeter bomb on 1 g of sample previously dried in the oven for 48 h to a constant mass in a oven at 103 °C.

After the firing and balancing of the assemblage, the temperature variation was measured using a thermocouple. Before the measurements, the calorimeter water value was calibrated with pure benzoic acid of known calorific value 26.463 MJ/kg. The HHV results are expressed in megajoules per kilogram of 100% dry charcoal.

Statistical analysis

The collected data were tested for normality and homogeneity of variance by Shapiro-Wilks and F tests at 5% significance, respectively. Thereafter, effects of kiln type and wood species on each property was analysed using a two-way analysis of variance. Pairwise Wilcox test was then performed at 5% for comparison between the kiln type and wood species. Average values of the properties were compared to FAO standards (1985). According to Reynaud and Maley (1994), box plots are powerful graphical representations that give an overview and numerical summary of a data set distribution. Therefore, box plots were produced to support analyses of the charcoal variability among and within kiln and wood species. All statistical analyses were carried out using the R software (R Core Team, 2018).

Results and discussion

Influence of the species and carbonization technique on the physical properties of charcoal

Variability of moisture content

The moisture content of charcoal differ significantly among species and type of kilns used (table I). Charcoal from Movingui produced in the Casamance kiln had the lowest moisture content (4.03%). Likewise, in the other kilns its moisture content was the lowest (table II, figure 2). All the values of moisture content of charcoal investigated remained below 10%, which is the maximum threshold for charcoal intended for domestic use according to the FAO standards (FAO, 1985). The differences observed between the wood species could be related by their anatomical characteristics (table III). The lower the density, the higher the moisture content. Nko'o Abuiboto (2015) showed that charcoals produced experimentally from three African species, namely Dibetou (*Lovoa trichilioides* Harms: 0.53 g/cm³), Iroko (*Milicia excelsa*: 0.64 g/cm³) and Moabi (*Baillonella toxisperma*: 0.87 g/cm³), have moisture contents of 7%, 6% and 4%, respectively. In fact, when the charring is well

Table I.
Results of the homogeneity test of the variances of average moisture contents and apparent densities of charcoals between the three wood species and the three types of kilns.
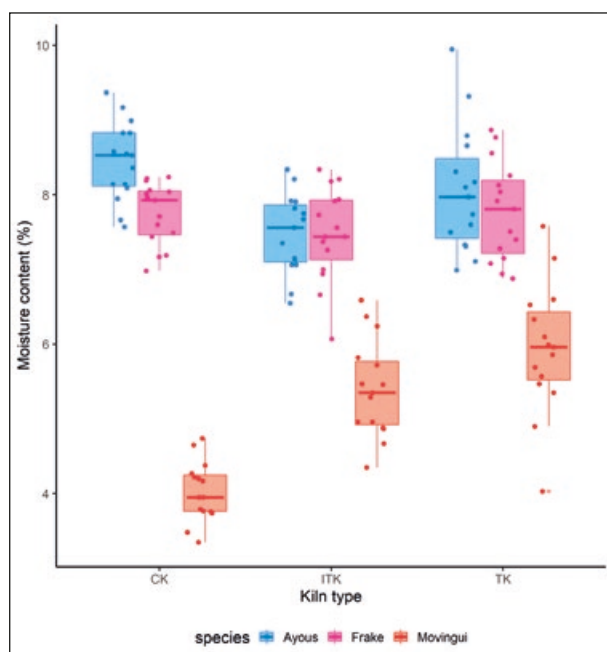
Study properties	Sources of variation	Degree of freedom	*F-value*	*P-value*
Moisture content	Kilns	2	9.17	0.000191 ***
	Species	2	276.63	‹ 2e-16 ***
	Kilns x species	4	18.57	5.1e-12 ***
	Residues	126		
Apparent density	Kilns	2	7.55	0.000798 ***
	Species	2	261.24	‹ 2e-16 ***
	Kilns x species	4	1.487	0.210073
	Residues	126		

P-value*: test significant at 5 %.

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Table II.
Physical and chemical properties of charcoal produced from three selected wood species, Ayous (*Triplochiton scleroxylon*), Frake (*Terminalia superba*) and Movingui (*Distemonanthus benthamianus*) residues in the three types of kilns (TK, ITK and CK mean: traditional kiln, improved traditional kiln and Casamance kiln).

Properties	Type of kiln	Number of samples	Wood species		
			Ayous *Triplochiton scleroxylon*	Frake *Terminalia superba*	Movingui *Distemonanthus benthamianus*
Moisture content (%)	TK	15	8.06 ± 0.84^{Aa}	7.77 ± 0.66^{Aa}	5.94 ± 0.87^{Ba}
	ITK	15	7.48 ± 0.53^{Ab}	$7.47 \pm 0,63^{Aa}$	5.40 ± 0.65^{Ba}
	CK	15	8.45 ± 0.53^{Aa}	7.75 ± 0.40^{Ba}	4.03 ± 0.40^{Cb}
Apparent density (g/cm³)	TK	15	0.25 ± 0.02^{Aa}	0.29 ± 0.02^{Ba}	0.38 ± 0.04^{Ca}
	ITK	15	0.25 ± 0.02^{Aa}	0.29 ± 0.03^{Ba}	0.42 ± 0.05^{Cb}
	CK	15	0.27 ± 0.02^{Aa}	0.31 ± 0.01^{Ba}	0.42 ± 0.05^{Cb}
Volatile Matter content (%)	TK	18	49.39 ± 1.65^{Aa}	38.31 ± 1.65^{Ba}	34.69 ± 1.62^{Ca}
	ITK	18	36.07 ± 3.23^{Aa}	30.54 ± 3.84^{Bb}	22.50 ± 3.00^{Cb}
	CK	18	29.46 ± 1.71^{Aa}	24.84 ± 2.52^{Bb}	20.32 ± 1.03^{Bc}
Fixed Carbon content (%)	TK	18	39.00 ± 1.7^{Aa}	50.30 ± 1.72^{Ba}	57.25 ± 1.65^{Ca}
	ITK	18	52.66 ± 3.09^{Ab}	58.39 ± 3.79^{Bb}	70.97 ± 2.00^{Cb}
	CK	18	59.12 ± 2.07^{Ac}	63.63 ± 3.44^{Bc}	74.95 ± 0.31^{Cc}
Ash content (%)	TK	18	3.55 ± 0.69^{Aa}	3.61 ± 0.73^{Aa}	2.12 ± 0.67^{Ba}
	ITK	18	3.46 ± 0.99^{Aa}	3.58 ± 0.93^{Aa}	2.07 ± 0.55^{Ba}
	CK	18	3.17 ± 1.04^{Aa}	3.78 ± 1.58^{Aa}	1.27 ± 0.16^{Bb}
Higher Heating Value (MJ/kg)	TK	18	27.95 ± 3.12^{Aa}	23.02 ± 4.01^{Ba}	26.20 ± 0.43^{Aa}
	ITK	18	30.03 ± 0.94^{Ab}	26.62 ± 3.52^{Bb}	28.99 ± 0.49^{Ab}
	CK	18	32.51 ± 1.25^{Ac}	28.85 ± 4.31^{Bc}	30.02 ± 0.10^{Bb}

Figure 2.
Variation of moisture content of charcoal among the three wood species and three types of kiln. TK, ITK and CK mean the following: traditional kiln, improved traditional kiln and Casamance kiln, respectively.

controlled, charcoal contains about 1% of moisture when it leaves the kiln (Avom, 2004). Due to its hydrophilic nature, it can quickly reabsorb moisture from the atmosphere, resulting in an irreversible water absorption that ranges from 5 to 10% depending on the species (FAO, 1985). In addition, the lowest moisture content obtained in the Casamance kiln could be explained by the quality of carbonization, which is faster and more uniform in this type of kiln, due to better air circulation in the combustion chamber, than in the two other types of kilns (Júnior *et al.*, 2015; GIZ-HERA, 2020).

Variability of apparent densities

As for moisture content, the apparent densities of charcoal differ significantly among species and kiln type (table I). Comparatively, charcoal from Movingui is denser (table II, figure 3). This result could be explained by its anatomical structure (Gomes *et al.*, 2007; Brand *et al.*, 2015), as Movingui is a medium-heavy wood with a density of 0.7 g/cm³ compared to the other two woods species which are light woods (table III). In addition, the highest density (0.42 g/cm³) of charcoal produced in the Casamance kiln and the improved traditional kiln, suggests a significant effect of the carbonization technique, which are faster and more uniform in these two types of kilns (GIZ-HERA, 2020). Similar differences were also found in Senegal with charcoal from Eucalyptus produced in the Casamance kiln and the metal kiln (Ndour, 1986).

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Table III.
Characteristics of the wood species used for charcoal production.

Commercial name	Scientific name	Wood density (g/cm³)	Qualification
Ayous	*Triplochiton scleroxylon*	0.38 ± 0.05	Very light wood
Frake	*Terminalia superba*	0.54 ± 0.07	Light wood
Movingui	*Distemonanthus benthamianus*	0.73 ± 0.06	Medium wood

Figure 3.
Variation of apparent density of charcoal among the wood species and the three types of kiln. TK, ITK and CK mean the following: traditional kiln, improved traditional kiln and Casamance kiln, respectively.

Influence of carbonization technique and the species on chemical properties of charcoal

Table IV shows that the volatile matter content, ash content and fixed carbon content vary significantly among wood species and types of kilns. In table II, the lowest volatile matter content (20.32%), ash content (1.27%) and the highest fixed carbon content (74.95%) are obtained with charcoal from Movingui produced in the Casamance kiln. The differences between species and kiln types can also be explained by the anatomical characteristics of the wood used (Gomes *et al.*, 2007; Brand *et al.*, 2015) and the quality of the pyrolysis in the kiln (GIZ-HERA, 2020).

Variability of volatile matter content

Among the three wood species, Movingui charcoal obtained from Casamance kiln had the lowest volatile matter content (20.32 %). The most possible explanation could be related to the chemical composition of the wood of these species, particularly their level of liquid and tarry residues. Indeed, it has been shown that the denser the wood, the lesser its volatile matter content (Nko'o Abuiboto, 2015). The differences observed between the kilns could therefore be attributed to the degree of burning, precisely the final temperatures reached during the pyrolysis reaction (Assis *et al.*, 2016). Ndour (1986) found similar results on charcoal from Eucalyptus produced from the Casamance kiln (22.9%) and the metal kiln (30.1%). In addition, for domestic use it is only the charcoal produced in the Casamance kiln that satisfy FAO's standards (FAO, 1985).

In addition, charcoals produced in the Casamance kiln are the only ones that satisfy FAO's standards (FAO, 1985), from good charcoal for domestic use.

Variability of the ash content

The results from the various ash content test show that Movingui charcoal produced in the Casamance kiln has the lowest ash content (1.27%). These differences can be explained by the proportion of inorganic compounds in each species (Badea *et al.*, 2008). This finding is supported by Mensah *et al.* (2017) who found ash contents of 2.1% to 2.9% in charcoals produced from some plantation species in Ghana. Girard (2002) also found an average ash content between 3.1 to 5.8% with charcoal from Eucalyptus produced with the traditional kiln and Nko'o Abuiboto (2015) found that the average ash contents are between 1.4% and 8.8% in three African species (Dibetou, *L. trichilioides* Harms, Iroko, *M. excelsa* and Moabi, *B. toxisperma*).

Variability of fixed carbon content

The highest fixed carbon content (74.95%) was obtained with charcoal from Movingui produced in the Casamance kiln (table II, figure 4). This result highlights the influence of the carbonization process on the residual fixed carbon content of charcoal (Ndour, 1986). Briane and Haberman (1984) also showed that the fixed carbon content of charcoals increases with the carbonization temperature. This parameter is also influenced by the species (Nko'o Abuiboto, 2015).

Variability of the Higher Heating Value

The higher heating value (HHV) of the charcoal differs significantly between woods species and kiln types (table II). On comparing the kilns, the highest HHV value (32.51 MJ/Kg) was obtained with charcoal from Ayous. In addition, this value was observed in the Casamance kiln. Although there are no standards that specify the HHVs of commercial charcoals, Girard (2002) showed that the higher heating values of Eucalyptus vary between 28.6 and 32.6 MJ/kg. Ndour (1986) obtained similar results for this species with charcoal produced in the metal and the Casamance kilns: 26.6 and 31.8 MJ/kg. The HHV obtained with charcoal from Ayous, a lightwood species, in the Casamance kiln reflects its abi-
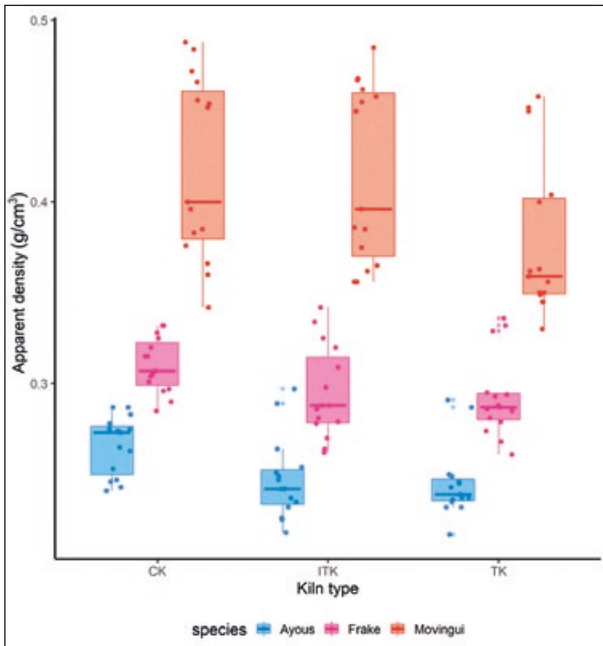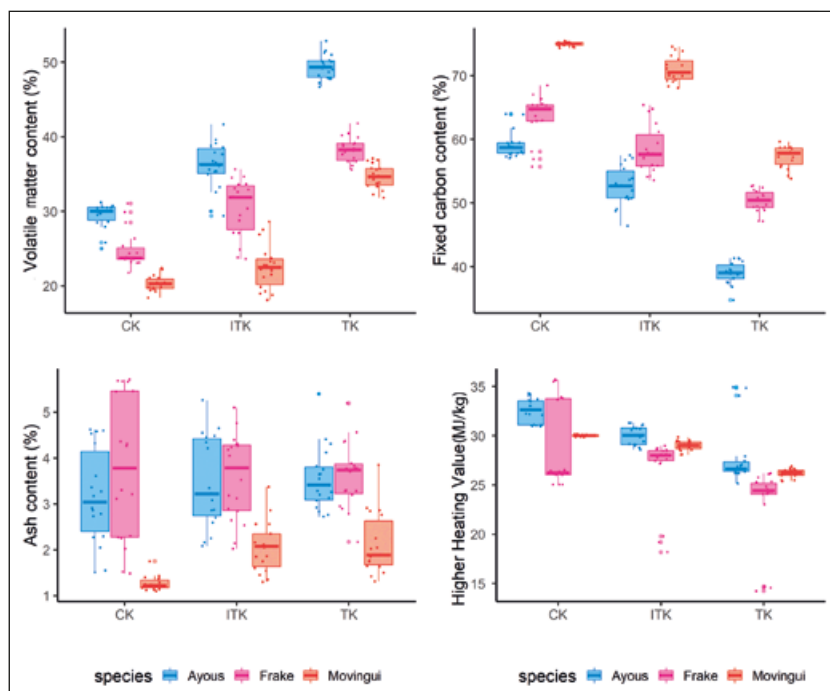
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Table IV.
Results of the ANOVA test on the chemical properties and the higher heating value of the charcoal obtained among the three types of kilns and the studied wood species.

Study properties	Sources of variation	Degree of freedom	F-value	P-value
Volatile Matter content	Kilns	2	615.2	‹ 2e-16 ***
	Species	2	361.0	‹ 2e-16 ***
	Kilns x species	4	13.5	1.9e-09 ***
	Residues	153		
Fixed Carbon content	Kilns	2	701.86	‹ 2e-16 ***
	Species	2	708.43	‹ 2e-16 ***
	Kilns x species	4	12.18	1.27e-08 ***
	Residues	126		
	Kilns	2	2.471	0.0879
Ash content	Species	2	66.966	‹ 2e-16 ***
	Kilns x species	4	1.912	0.1112
	Residues	126		
	Kilns	2	46.248	‹ 2e-16 ***
Higher Heating Value (HHV)	Species	2	32.752	1.45e-12 ***
	Kilns x species	4	0.989	0.416
	Residues	126		

P-value*: test significant at 5 %.

Figure 4.
Variation of chemical content and higher heating value (HHV) of charcoal among the three wood species and the three types of kiln. Ayo, Fra and Mov mean: Ayous, Frake and Movingui and TK, ITK and CK mean: traditional kiln, improved traditional kiln and Casamance kiln, respectively.

lity to release a large amount of thermal energy by combustion as a hardwood. Adegoke *et al.* (2014) found similar results with this species (32.79 MJ/kg) as well as for another light-wood species namely Frake (*T. superba*, 32.69 MJ/kg). These results indicate that the HHV of charcoal is mainly influenced by the type of kiln used, rather than the wood species (Ndour, 1986).

The singularity of Ayous charcoal

Charcoal from Ayous (*T. scleroxylon*) has the lowest density (0.25 g/cm³) and the highest HHV (32.51 MJ/kg). This HHV could be related to its porous structure and chemical composition. Zeng *et al.* (2015) found that large pores are associated with a high reactivity, or combustibility and thus the best combustion performance. Similarly, these authors noted that the volatile matter is a significant fraction of the higher heating value of charcoal. Tillman (2000) also showed that the ratio of the volatile matter to fixed carbon (VM/FC) is a good indicator of the charcoal reactivity. According to this author, a charcoal with good reactivity has a VM/FC ratio greater than 1. The maximum value obtained with charcoal from Ayous is 1.29, which reflects its a very good reactivity.

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Conclusion

The objective of this study was to assess the variability of the physical and chemical properties of charcoals produced from industrial sawmill residues in the eastern region of Cameroon using three different carbonization technologies (traditional kiln, improved traditional kiln and Casamance kiln) and three wood species namely: Ayous (*Triplochiton scleroxylon*), Frake (*Terminalia superba*) and Movingui (*Distemonanthus benthamianus*). Physical and chemical properties determined are moisture content, apparent density, volatile matter content, fixed carbon content, ash content and Higher Heating Value. Our results show that properties of charcoal are strongly influenced by the species and the type of kiln used. Movingui, with the highest density (0.73 g/cm³), provided charcoal with the lowest moisture content (4.03%) and a highest apparent density (0.42 g/cm³). The lowest volatile matter (20.32%), the lowest ash content (1.27%) and the highest fixed carbon content (74.95%) were also obtained with this species. All the properties of charcoals investigated are better in the Casamance kiln, certainly due to the quality of pyrolysis, which is faster and more uniform in this kiln than in the other types.

The singularity of charcoal from Ayous, which shows a highest HHV (32.5 MJ/kg), reflects its ability to release a large amount of thermal energy by combustion. This high reactivity offers good energy expectation of this species for cooking and establishes the energy efficiency of some lightwoods, which are sometimes wrongly considered inappropriate for the production of charcoal. This result is also very interesting in the current context of Cameroon because Ayous is the most exploited species in the country, with annual log volumes of more than 800,000 m³/year, representing 34.84% of national log production. As the yield material of the sawmills in Cameroon is 30%, the valorization of the large residual biomass generated by this species as biofuel could represent an enormous energy potential, which could contribute to reduce the pressure on forest ecosystems.

In addition, the results obtained in this study also support the government's position that promotes the use of sustainably produced charcoal from industrial sawmill residues instead of charcoal from felling trees, and reassure consumers about their technological characteristics. Indeed, in 2012, the Government of Cameroon took a decision (Decision No. 2032/D/MINFOF of 22 August 2012) that specifies special products of economic interest to the country whose commercial exploitation is conditional on obtaining a prior operating permit. In order to encourage the use of sustainably produced charcoal, exemption from the scope of this decision and from prior authorisation for its production and marketing is given to charcoal from sawmill residues.

Finally, the present study thus opens interesting perspectives to investigate other tropical woods that are currently exploited to promote their potentials for the production of charcoal.

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Zobo Mfomo et al. – Contribution des auteurs

Rôle du contributeur	Noms des auteurs
Conceptualisation	J. Zobo Mfomo, A. B. Biwolé, E. F. Fedoung
Gestion des données	J. Zobo Mfomo, A. B. Biwolé, E. F. Fedoung
Analyse formelle	J. Zobo Mfomo, A. B. Biwolé
Acquisition du financement	D. Hubert, H. Ducenne
Enquête et investigation	G. T. Ekassi
Méthodologie	J. Zobo Mfomo, A. B. Biwolé
Gestion de projet	J. Zobo Mfomo
Ressources	D. Hubert, H. Ducenne, R. Mouangue, A. B. Biwolé
Logiciels	A. B. Biwolé
Supervision	J. Zobo Mfomo
Validation	J. Zobo Mfomo, A. B. Biwolé, E. Fo. Fedoung
Visualisation	J. Zobo Mfomo, A. B. Biwolé
Écriture – Préparation de l'ébauche originale	J. Zobo Mfomo
Écriture – Révision et édition	J. Zobo Mfomo1, A. B. Biwolé, E. F. Fedoung, G. T. Ekassi, D. Hubert, H. Ducenne, R. Mouangue