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Original article

Diagnostic analysis of the techniques of carbonization in Togo (West Africa)

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ABSTRACT

The annual average quantity of the produced charcoal in Togo is 419 963 tons. But the wood densities of species used for charcoal production as well as the optimal yield of the production techniques are badly known. The objectives of this study are i) to determine the wood densities of the used species (priorities and alternatives) in carbonization in Togo, ii) to compare the yield of the traditional mound kiln and casamance improved mound kiln in the context of Togo and iii) to determine the optimal distance between the blowholes of the casamance improved mound kiln for the carbonization of heavy and very heavy species. Wood densities of used species in carbonization in Togo are determined by the AFNOR method. The comparison of the yield of carbonization techniques and the determination of the optimal distance between the blowholes of the casamance improved mound kiln for the carbonization of heavy and very heavy woods are achieved by the trial of carbonization. The results show that the priority species belong to two classes of wood density (semi-heavy wood and very heavy wood) and the alternative species belong to the class of lightweight wood density. Moreover the yield of the casamance improved mound kiln is significantly superior to the one of the traditional mound kiln (p= 0, 000). At last, the distances of 1.5 meters, 2 meters, 2.5 meters and 3 meters between the blowholes of the casamance improved mound kiln give all the good mass yield. But it is 2 meters distances that give fewer unburnt wood.

1. Introduction

Woodfuel is used at 90% in developing countries (Coomes et Burt, 2001; Dovie et al., 2004; Okello et al., 2001; Parikka, 2004). This reliance is more obvious in sub-Saharan Africa where firewood and charcoal are the main energy for a large number of households (Amous, 1999; Ballis et al., 2005). Evaluated to 19.8 million tons in 2000, the charcoal consumption in Africa reached 21.7 million tons in 2002, an increase of about 1 million per year (FAO, 2003). These figures show that households of the African countries have to depend for decades on this form of energy to meet their daily needs (Aguilar et al., 2012; Arnold et al., 2006). The International Energy Agency estimates that, although shifts to other sources of energy could be expected to substantially reduce the share of these fuel by 2030, the biomass energy will still account for an estimated three quarter of total residential energy in Africa in that year, and that the number of people using fuel wood and other biomass fuel in that region will rise by more than 40% during 2000-2030 (IEA 2002).

In Togo, firewood and charcoal contribute more than 80% to the total domestic energy requirements (Kokou et al., 2009). The annual average production of charcoal between 2004 and 2008 is 419 963.8±47 896.5 tons in national level, with per capita consumption estimated at 75 kg per year (Fontodji et al., 2011). For many years, the need for wood fuel continues to increase and the total needs are provided by the national production. The production increase entails a direct incidence on the potentialities of the country in terms of vegetal resources. In effect, the activity of charcoal production has brought about a rate of deforestation which is 5000 hectare per year (MEMEPT, 2002). In these days, the increase of the deforestation rates in Togo caused by the charcoal production that becomes more and more worrying especially for Plateaux and Centrale regions (Fontodji, 2007). Biomass destroyed by this activity is estimated over 2 799 759 tons per year between 2004 and 2008 at the national level (Fontodji et al., 2011). This is dangerous for Togo which is not a forest country like Ghana, Ivory Cost or Nigeria. The availability of biomass energy in the coming decades will be severely compromised if the adequate measures are not taken right now to rationalize its exploitation. Already, most of the villages are experiencing more and more difficulties for the supply of wood fuel (Fontodji, 2007; Kokou et al., 2009; Kokou and Nuto, 2009). The real bottleneck in the charcoal production is inefficient production techniques (Aguilar et al., 2012). The production yield is about 8 to 20% (only 80 to 200 kg of charcoal per 1000 kg of woody material used) (Chidumayo, 1991; Girard, 2002).

Considering the extent of the impact of charcoal production on the environment in Togo, the non governmental organizations (NGO) have imported the technique of casamance improved mound kiln in 2011. Casamance mound kiln is the best known improved mound kiln (Schenkel et al., 1997). This method, of course allows neat improvement of the mass yield from 25 to 35% (Lusadisu, 1989, Sawadogo, 2007) which can help reduce deforestation. The casamance improved mound kiln has other advantages such as the reduction of the duration of the carbonization cycle and the recuperation of tars and pyrolignous acid by the chimney. However, its yield depends on several factors such as the wood density, the rates of wood humidity, the distance between the blowholes and the wood stacking, etc. (Schenkel et al., 1997). This makes it difficult to define a procedure to follow to optimize the performance of this new technique. In 2010, Benin proposed the optimization procedure of the yield of this technique; the trials of carbonization achieved in the context of its “Projet Bois de Feu Phase 2” have shown that there should be 2 and 3 meters distance between the blowholes respectively for the heavy and lightweight woods (PBF 2, 2010). But the appreciation of the heavy and light weight woods remains subjective and has no scientific basis because it is only based on the opinions of the producers.

Several studies were carried out on the charcoal in Togo (Fontodji et al, 2009; Fontodji et al, 2011; Kokou et al, 2009; Kokou et Nuto, 2009; Tagba, 2013) and on the casamance improved mound kiln (Ducenne, 2001; Gbozo, 2010; PBF 2, 2010; PERACOD, 2010; Schenkel et al., 1997). However, a little attention had been given to the performance of the casamance improved mound kiln compared to the traditional mound kiln in the context of Togo, to the classes of wood density to which belong the preferred woods (priority species) by the charcoal producers in carbonization, and the optimal distance to respect between the blowholes for the carbonization of heavy and vey heavy species with casamance improved mound kiln newly imported in Togo. The purpose of this study is to contribute to the sustainable management of forest resources through the improvement of the present production techniques of charcoal in Togo. In a specific way, it is i) to determine the classes of wood density of species (priorities and alternatives) used in carbonization in Togo, ii) to compare the performance of the traditional mound kiln and casamance improved mound kiln in the context of Togo and iii) to determine the optimal distance between the blowholes of casamance improved mound kiln for carbonization of heavy and very heavy species.

2. Materials and methods

2.1. The study area

The study is conducted on the region of Plateaux in Togo and precisely the districts of Haho and Amou (Figure 1). The region of Plateaux is made up of twelve districts. But the choice of these two districts is justified by the concentration of the charcoal production (Fontodji, 2007).

The area of Haho is 3,185 km² and comprises 247 817 inhabitants (DGCSN, 2011). It is limited in the north by the districts of Ogou and Amou, in the east by the districts of Kpele-Akata and Agou, in the west by the district of Moyen-Mono and in the south by the districts of Zio and Yoto. It is situated in the southern part of the ecological zone III and the northern part of the ecological zone V. Its relief is characterized by the Beninese- Togolese plain. Annual rainfall varies between 1150 mm and 1450 mm. The predominant vegetation are guinean savannas wooded (Brunel, 1981). There is also a forest of Togodo North, clear forests and gallery forests along the main streams.

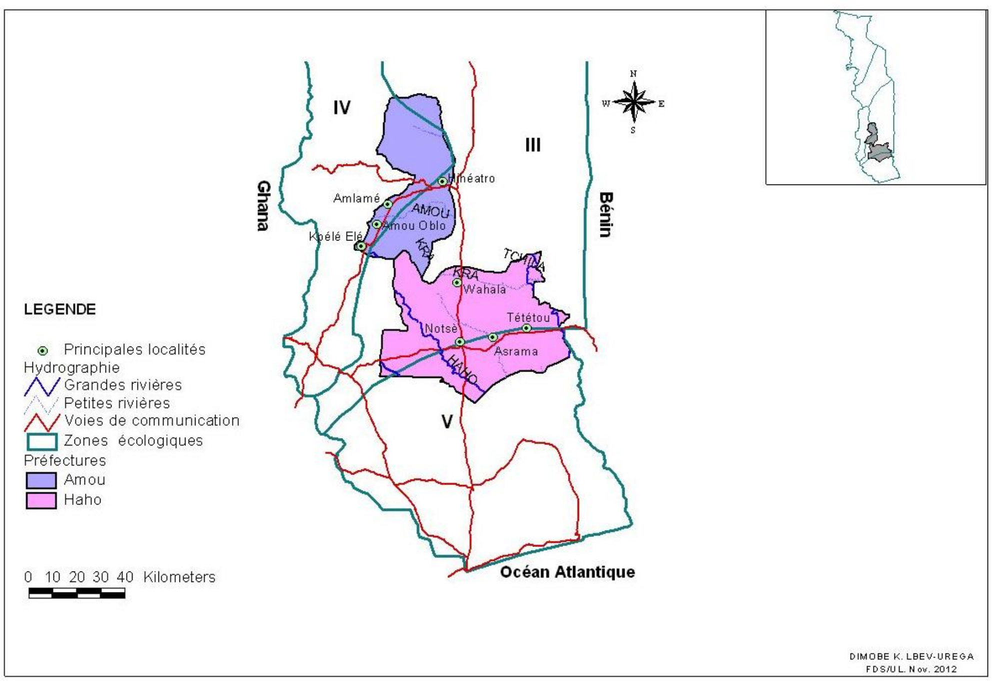


Fig. 1. Localization of the study area.

2.2. Classification of species by category and determination of their class of wood density

As far as the district of Amou is concerned, its area is 1759 km² and comprises 105 091 inhabitants (DGCSN, 2011). It is limited in the north by the district of Akebou, in the west by the districts of Wawa and Danyi, in the east by the district of Ogou and in the south by the districts of Kpele-Akata and Haho. The western part of this district is situated in the ecological zone IV that corresponds to the southern part of Mounts-Togo also called the Structural

Unity of Atakora (Sylvain et al., 1986), dominated by the Akposso plateau. Its eastern part is found in the ecological zone III characterized by the Beninese-Togolese plain. This district has the subequatorial climate of transition (Papadakis, 1966; Trochain, 1980), influenced by the altitude and principally marked by precipitations varying between 1300 and 1500 mm. It contains heavy-wet forests and semi-deciduous forest (Akpagana, 1989). These forests coexist with edaphic or anthropophile savannas (Guelly, 1994).

In Togo, charcoal producers aim primarily 15 native plant species classified as the species of the first choice or species of category 1 and when these are not available, they move toward alternative species or species of category 2 which are 19 in number (Kokou et al., 2009). Among the priority species, 12 are presented in the study area. There are, *Afzelia africana, Anogeissus leiocarpus, Burkea africana, Combretum micranthum, Crossopteryx febrifuga, Detarium microcarpum, Erythrophleum suaveolens, Lophira lanceolata, Prosopis africana, Pterocarpus erinaceus, Terminalia glaucescens, Vitellaria paradoxa* (Tagba, 2013). Wood density of 6 species out of the 12 exist already in the database of Cirad-Forêt (Gérard et al., 1998). There are, *Afzelia africana, Anogeissus leiocarpus, Burkea africana, Prosopis africana, Pterocarpus erinaceus, Vitellaria paradoxa*. This study is focused on 6 other species the wood density of which has not been known yet. There are, *Crossopteryx febrifuga, Combretum micranthum, Erythrophleum suaveolens, Detarium microcarpum, Lophira lanceolata and Terminalia glaucescens*. Moreover, 13 alternative species over 19 used in Togo are presented in the study area. Over the 13, the wood density of 6 species namely *Albizia adianthifolia, Daniellia oliveri, Diospiros mespiliformis, Khaya senegalensis, Parkia biglobosa and Tectona grandis*, exist in the database of Cirad-Forêt (Gérard et al., 1998). Because of the available means, 2 species over the 7 remaining are chosen randomly for the determination of their wood density. There are *Cola gigantea and Vitex doniana*. The wood density of the 5 other species presented in the study area (*Bridelia ferruginea, Hexallobus monopertalus, Hymenocardia acida, Isoberlinia doka and Pseudocedrela kotschyii*) was not determined. On the whole, the wood densities of 8 species (6 priority and 2 alternative) were determined.

The wood density is determined at 12% of humidity from basic density, radial and tangential withdrawals. For this reason, a section of 20 cm of each of these species is taken at 1.3 meters high of the tree. These sections of the wood are marked and brought back to the laboratory. They were stabilized at 12% of humidity in a conditioned room (20°C and 65% of humidity within 3 months) until the obtaining of a constant mass. To determine the withdrawals and the basic density, the sections of the wood were cut into specimen of dimensions 20 mm x 20 mm x 10 mm according to the radial (R), tangential (T) and longitudinal (L) directions (Figure 2).

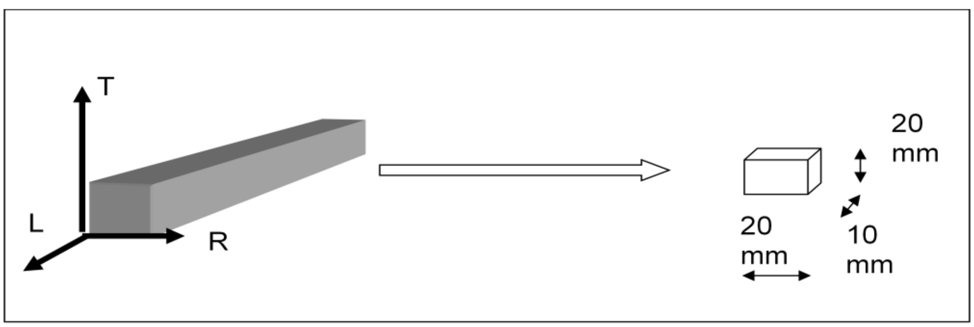


Fig. 2. Direction cutting of the specimens.

Withdrawals are determined according to the French norm, NF B 51-006 (sept 1985) (AFNOR NF B 51-006, 1985). The water content (X%), radial withdrawal (Rr) and tangential withdrawal (Rt) have permitted to calculate the coefficient of the volume withdrawal. Besides, the basic density is determined from the dry mass of each specimen (obtained after drying of the wood at 103°C) and its saturated volume measured according to the Archimedes principle. The density is finally calculated to the saturation point of fibers (PSF) from the basic density and from the coefficient of the volume withdrawal. The wood densities obtained are ordered in the 5 classes of density defined by Cirad-Forêt (Gérard et al., 1998). It is classes of very lightweight wood (volume mass (MV) < 500 kg/m^3), lightweight woods (500 kg/m^3 < MV < 650 kg/m^3), semi-heavy woods (650 kg/m^3 < MV < 800 kg/m^3), heavy woods (800 kg/m^3 < MV < 950 kg/m^3) and very heavy woods (MV > 950 kg/m^3).

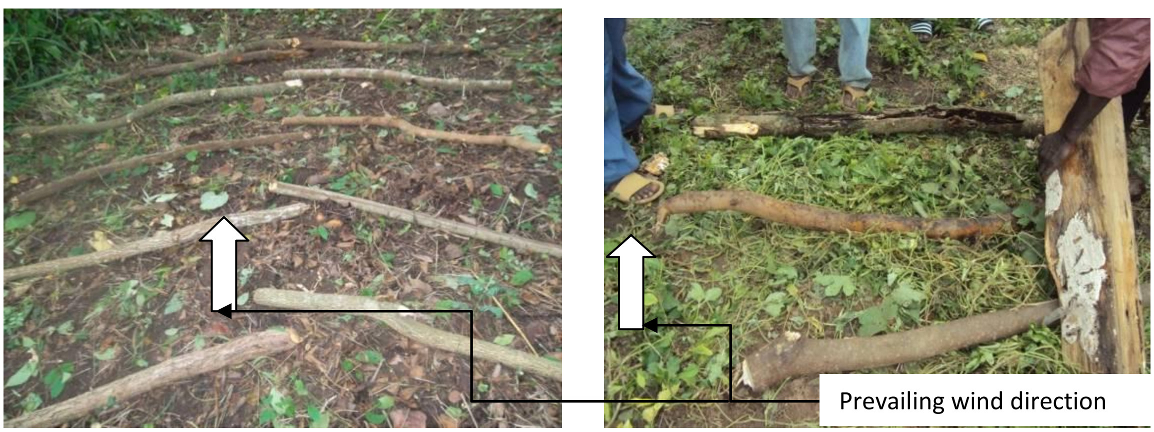
2.3. Determination of yield of charcoal production techniques used in Togo

The traditional mound kiln is the only technique of carbonization in use in Togo before the introduction of casamance improved mound kiln in 2011. Trials of carbonization are then achieved in order to compare the yield of these two techniques of carbonization. The experimental protocol is constituted by two factors, the type of the mound kiln and the class of wood density. The first factor (type of mound kiln) has two modalities such as the traditional mound kiln and the casamance improved mound kiln. The second factor (class of wood density) has also two modalities that are, one species of heavy wood (*Pterocarpus erinaceus*) and one species of very heavy woods (*Anogeissus leiocarpus*) (Gérard et al., 1998). The choice of these species is based on their availability in the area of trial and on their preference by the charcoal producers (Kokou et al., 2009). The number of repetitions of the treatments is 6, or 6 experimental units.

The casamance improved mound kiln follows almost the same technical procedure as the traditional mound kiln. But its uniqueness lies at five basic levels. These are,

Realization of the basic, the woods of the base of the casamance improved mound kiln are arranged in the form of fish bone in the prevailing wind direction while those of the base of the traditional mound kiln are arranged parallel to each other and perpendicular to the prevailing wind direction (Photo1);

The arrangement of woods, the woods of the casamance improved mound kiln are arranged from the smallest to the largest starting from the base whereas those of the traditional mound kiln are arranged from the largest to the smallest starting from the base;



a) The base of the casamance mound kiln. b) The base of the traditional mound kiln.

Photo 1. Realization of the base of casamance and traditional mound kilns.

a) A traditional mound kiln at work. b) A casamance improved mound kiln at work.

Photo 2. Comparison of traditional mound kiln and casamance improved mound kiln.

The introduction of the chimney, a chimney by which the smoke goes out is introduced in the width of the casamance improved mound kiln at the opposite side to where the prevailing wind comes from (Photo 2b); this is not the case of the traditional mound kiln;

The introduction of the blowholes pipes (2 meters distanced in this experience) (Photo 2b) at the level of the casamance improved mound kiln; the number of the pipes depends on the height of the mound kiln whereas at the level of traditional mound kiln, the opening of the blowholes does not follow any principle, the most important thing is that the mound kiln works;

The introduction of a barrel of recuperation, a barrel is put in a hole situated at the base of the chimney of the casamance improved mound kiln for the recuparation of pyrolignous liquid, whereas this liquid percolates the soil in the case of the traditional mound kiln.

2.4. Determination of the optimal distance between the blowholes of the casamance improved mound kiln

Only one factor was tested here. It is the distance between the blowholes of casamance improved mound kiln. It is constituted by four modalities such as 1.5 meters; 2 meters; 2.5 meters and 3 meters. The *Terminalia glaucescens* was used to complement of *Pterocarpus erinaceus* and *Anogeissus leiocarpus* as vegetal material. The species had been used in a mixed way. The number of the repetitions of the treatments is 2, or 2 experimental units.

2.5. Analysis of the data

The water content (X%), the radial withdrawal (Rr) and tangential withdrawal (Rt) of specimens are calculated as follows ,

$$X_{\%} = \frac{Ps - Pa}{Pa} * 100 \quad \text{(Formula 1)}$$

$$R_r = \frac{Drs - Dra}{Drs} * 100 \quad \text{(Formula 2)}$$

$$R_t = \frac{Dts - Dta}{Dts} * 100 \quad \text{(Formula 3)}$$

With,

Ps = weight of the specimen at the saturated state ; Pa=weight of the specimen at the dry state ;

Drs = radial Dimension of the specimen at the saturated state ; Dra =radial Dimension of the specimen at the dry state; Dts = tangential dimension of specimen at the saturated state ;

Dta = tangential dimension of the specimen at the dry state.

The density at 12% of humidity (D_{12}) is calculated to PSF (30%) according to the following formula ,

$$D_{12} = \text{basic density} * \frac{1.12}{1-(PSF-12)} * \frac{coefRvol}{100} \quad \text{(Formula 4)}$$

With , coefRvol = coefficient of volume withdrawal ; PSF = 30%

The dry yield (R) of the carbonization is calculated with the following formula ,

$$R = \frac{Mc}{Mb} * 100 \quad \text{(Formula 5)}$$

With , Mc , the mass of the charcoal taken out of the mound kiln and Mb , the dry mass of the wood put in the mound kiln.

The yield of the two techniques and the types of the species (heavy and very heavy species for the same technique) are compared by the Student's t-test with the software R (R Development Core Team, 2012). The difference between the averages of the yield is significant if the probability $p \leq 0.05$.

The ANOVA allowed comparing the results of the different distances between the blowholes of the casamance improved mound kiln (Chambers et al., 1992). The significant differences had been considered at $p \leq 0.05$.

3. Results

3.1. Density of the species used in carbonization in Togo

The 6 priority species studied have wood density which is situated between 776±0.010 kg/m^3 and 1059±0.077 kg/m^3 (Table 1). They belong to 2 classes of density, the class of the semi-heavy species (650 kg/m^3 < MV < 800 kg/m^3) and those of very heavy species (MV > 950 kg/m^3). The species of the class of the semi-heavy density are, *Crossopteryx febrifuga* (density =776±0.010 kg/m^3), *Detarium microcarpum* (density = 781±0.026 kg/m^3) and *Combretum micranthum* (density =794±0.016 kg/m^3). The others belong to the class of very heavy density. It is *Lophira lanceolata* (density =957±0.021 kg/m^3), *Terminalia glaucescens* (density =987±0.046 kg/m^3) and *Erythrophleum suaveolens* (density =1059±0.077 kg/m^3) (Table 1).

But the two alternatives species studied have a density which is situated between 510±190 and 513±220 kg/m3 (Table 1). It is *Cola gigantea* (510±190 kg/m^3) and *Vitex doniana* (513±220 kg/m^3). So they all belong to the class of lightweight species (MV < 650 kg/m3).

Table 1
Classes of wood density of the species used in carbonization

Category of species	Species	Density (kg/m3)	Class of density
Priority species	*Crossopteryx febrifuga*	776 ± 0.010	Semi-heavy
	Detarium microcarpum	781 ± 0.026	
	Combretum micranthum	794 ± 0.016	
	Lophira lanceolata	957 ± 0.021	Very heavy
	Terminalia glaucescens	987 ± 0.046	
	Erythrophleum suaveolens	1059 ± 0.077	
Alternative species	*Cola gigantean*	510 ± 190	Lightweight
	Vitex doniana	513 ± 220	

3.2. The yield of the techniques of carbonization presently in use in Togo.

The amount of charcoal obtained for the casamance improved mound kiln is on average 154.23±24.65 kg for a quantity of wood put in the kiln of 573.87±53.61 kg, or an average yield of 26.70±2.11%. On the contrary, the quantity of the charcoal obtained for the traditional mound kiln is 56.82±12.07 kg for a quantity of wood put in the kiln which is 503.6±3.37 kg, or an average yield of 11.24±2.33%. The Student's t-test that is achieved on the average of the yields of the two techniques shows that this difference is significant (p = 0.000) (Table 2).

Table 2
Compared yield of traditional mound kiln and casamance improved mound kiln.

Types of mound kiln	Quantity of wood put in the mound kiln (Kg)	Quantity of charcoal obtained (Kg)	Yield (%)	Duration of carbonization (days)
Casamance improved mound kiln	573.87±53.61	154.23±24.65	26.70±2.11	1.5±0.3
Traditional mound kiln	503.6±3.37	56.82±12.07	11.24±2.33	4±0.0

Student's t-test, tc=12.027; df=10; p=0.000.

In addition, the carbonization time used by the casamance improved mound kiln is relatively shorter than that used by the traditional mound kiln to carbonize almost the same amount of wood. This time is on average 1.5±0.3 days for the casamance improved mound kiln and 4±0.0 days for the traditional mound kiln, or more than the double of the time used by the first technique. The casamance improved mound kiln allows also recuperating the pyrolignous liquid that percolates the soil and pollutes the environment in the case of the traditional mound kiln.

Moreover, the heavy and the very heavy woods give the same yield with the same technique of carbonization. This yield is 27.49±1.87% and 26±2.46% respectively for the heavy and the very heavy woods with the casamance improved mound kiln and of 12.89±1.42% and 9.66±2% respectively for the same woods with the traditional mound kiln (Table 3). The Student's t-test achieved on these averages shows that within the same technique, the yield of the heavy and the very heavy woods are not significantly different (p=0.4531 for the casamance improved mound kiln and p=0.0926 for the traditional mound kiln). Species of heavy and very heavy densities can be considered similar and therefore can be used as a mixture with the same carbonization technical procedure to give good performance.

Table 3
The compared yields of the heavy and the very heavy woods with the two techniques of carbonization.

Types of mound kiln	Class of wood density	Quantity of woods put in the mound kiln (Kg)	Quantity of charcoal obtained (Kg)	Yield (%)	Duration of carbonization (days)
Casamance improved mound kiln	Heavy wood	607.73±2.34	167.07±11.16	27.49±1.87	1.67±0.29
	Very heavy wood	540±61.14	141.4+-30	26±2.46	1.33±0.29
	Student's t-test, tc=0.84; df=3.73; p=0.4531				
Traditional mound kiln	Heavy wood	505±4.23	65.13±7.71	12.89±1.42	4±0
	Very heavy wood	502.2±2.15	48.5±9.86	9.66±2	4±0
	Student's t-test, tc=2.27; df=3.61; p=0.0926.				

3.3. The influence of the distance between the blowholes on the performance of the casamance improved mound kiln

For the considered distances between the blowholes, the yield varies between 24.57% and 27.36% (Figure 3). The lowest yield is obtained with the space of 1.5 meters between the blowholes. But the highest one (27.36%) is obtained with the space of 3 meters between the blowholes. The test of ANOVA shows that these values are not significantly different from each other at 5% (p=0.343). All the studied distances can then be considered optimal with regard to the mass yield. However, the distances of 1.5 meters, of 2.5 meters and of 3 meters give a lot of unburnt woods with the casamance improved mound kiln (Table 4).

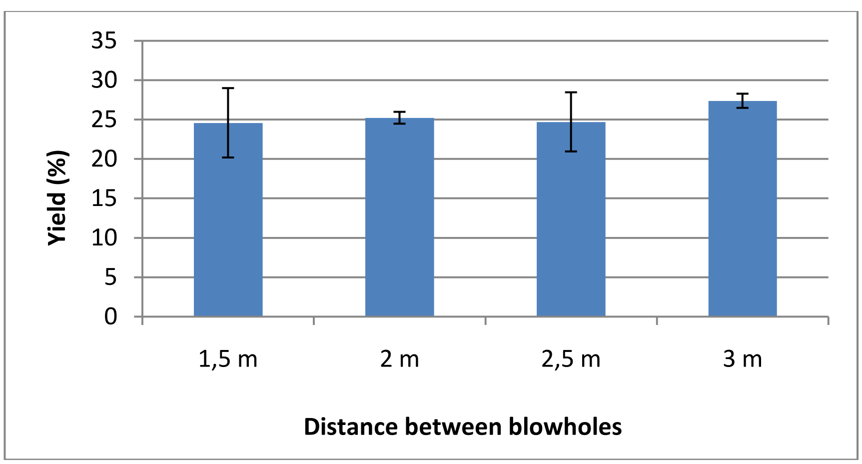


Fig. 3. Yield variation with the distance between the blowholes of the Casamance improved mound kiln.

The minimum unburnt wood is obtained with the distance of 2 meters between the blowholes. This difference noted in the quantity of the unburnt woods is linked to the quantity of the air that enters the mound kiln. More or less there is air in the mound kiln (eg spacing of 1.5 m, 2.5 m and 3 m between the blowholes), less wood have time to burn completely. The result is the high quantity of unburnt wood in all cases and the transformation of part of the charcoal into ash (in the case of excess air).

Table 4
Quantity of unburnt woods with regard to the distances between the blowholes.

N° trial	Distance between the blowholes (m)	Quantity of unburnt woods (%)
1	1.5	11.78
2	2	5.55
3	2.5	10.70
4	3	10.26

4. Discussion

In this study, the 6 priority species studied belong to the classes of density of semi-heavy woods (*Crossopteryx febrifuga, Detarium microcarpum and Combretum micranthum*) and very heavy wood (*Lophira lanceolata, Terminalia glaucescens and Erythrophleum suaveolens*). Among the priority species used in carbonization in Togo, 2 other ones belong to the class of densisty of heavy wood (*Afzelia africana and Pterocarpus erinaceus*), 3 other ones to the class of density of very heavy woods (*Anogeissus leiocarpus, Prosopis africana, Vitellaria paradoxa*) (Gérard et al., 1998). Only *Burkea africana* belong to the class of density of lightweight wood. Most of the priority species used in the carbonization in Togo belong then to the classes of wood density of semi-heavy to very heavy. On the contrary, the 2 alternative species (*Cola gigantea* and *Vitex doniana*) belong to the class of density of lightweight wood. Other alternative species also belong to this class of wood density. It is *Albizia adianthifolia , Daniellia oliveri* and *Parkia biglobosa* (Gérard et al., 1998). However, it should be noted that some rare alternative species get a density of semi-heavy wood (*Khaya senegalensis, Tectona grandis*) and heavy wood (*Diospiros mespiliformis*) (Gérard et al., 1998). The density of wood intervenes then in the choice of the species to be carbonized (or the preference made) by the charcoal producers (Chidumayo, 1991; Girard, 2002). A heavy wood produces a heavy charcoal, less brittle and meets better the expectations of the consumers (Chidumayo, 1991). These are therefore the wood of medium to heavy density that allow to get a charcoal of optimal qualities and which are recommended.

Moreover, the tests of carbonization achieved in the context of this study show that the traditional mound kiln give an average yield of 11.24±2.33% (Table 2). Walubengo et al. (1993), have achieved the similar results (10 to 13%) in Kenya. These results are also comparable with the yields of 10-15% reported by Mama and Ogouvidé (2005) in Benin. But PBF 2 (2010) has achieved the results of 18% with this technique in Benin. This high value is explained by rigorous follow up observed in the course of the carbonization cycle according to the author. In addition, Chidumayo (1991) and Hibajene et al*.* (2003) reported a yield of 8 to 23% in Zambia, and Girard (2002) reported a yield of 15 to 20% with the same technique. Contrary to the traditional mound kiln, the yield of the casamance improved mound kiln in this study is on the average 26.70±2.11%. PBF 2 (2010) has achieved the same results in Benin (26 à 28%) whereas Ducenne (2001) in Tchad has got a result of 25 to 30% and Lusadisu (1989) has got a yield of 29 to 33% in Zaire with same mound kiln. It is the same for Burkina Faso where Sawadogo (2007) reported the mass yield from 30 to 35%.

The average yield of the casamance improved mound kiln (26.70±2.11%) is two times superior to that of the traditional mound kiln (11.24±2.33%). This difference is very significant at 1% (Table 2). These results are similar to those of PBF 2 (2010) that also reported a significant difference between the two mound kilns. This confirms the performance of the casamance improved mound kiln with regard to the traditional mound kiln. This performance can save the wood to increase carbon sinks. In effect, it is reported that the carbon content of wood and charcoal is respectively 50% and 90% (Girard, 2002). On this basis, for one ton of carbonized wood with the traditional mound kiln (11% of yield), it is rejected in the atmosphere, 401 kg of carbon, or 1.47 tons of CO2. On the contrary, with the casamance improved mound kiln (26% of yield), for one ton of carbonized wood, 266 kg of carbon are rejected, or 975 kg of CO2. This corresponds to 135 kg of carbon avoided, or 495 kg of CO2. Thus, for the country of Togo which consumes 419 963.8 tons of charcoal per year (Fontodji et al., 2011), if the casamance improved mound kiln is expanded in all the country, 218 058.13 tons of carbon, or 799 546.47 tons of CO2 would be avoided in the atmosphere every year. At the same time, 2.2 million tons of unconsumed wood would be saved as a result of increased yield and constitute carbon sinks.

Apart from these ecological and environmental impacts, the casamance improved technique allows the charcoal producers to gain the time. Trials of carbonization made on the field have shown that this technique reduces more half the time of carbonization (Table 2). Schenkel et al. (1997) reported the same facts. This will enable the charcoal producers to have enough time for other activities which bring about money. This technique can be considered as a development tool and deserves to be vulgarized throughout the country. Good mass yields it provides are due to better ventilation ensured by a good mastery of the air (Schenkel et al., 1997, Stassen, 2002). However, the amount of air entering the mound kiln is function of the distance between the blowholes. This distance is one of the parameters which determine obtaining a good yield of carbonization with the casamance improved mound kiln. In this study, the distances of 1.5 m, 2 m, 2.5 m and 3 m between the blowholes provide all good yields for heavy and very heavy species. But this is the distance of 2 m between the blowholes that provides the least amount of unburnt wood. These results corroborate those of PBF 2 (2010) which performed the best yield with a distance of 2 m between the blowholes of the casamance improved mound kiln using the wood of *Anogeissus leiocarpus* (heavy wood).

5. Conclusion

In this study, the densities of 6 priority species and 2 alternative species used in the production of charcoal in Togo are known. The wood of the priority species belong to class of density semi heavy and very heavy and those of alternative species belong to the class of density of lightweight wood. It is then the wood density that determines the preference of certain species by the charcoal producers.

Both carbonization techniques tested in this study give significantly different yields, 11.24 ± 2.33% for traditional mound kiln against 26.70 ± 2.11% for the casamance improved mound kiln. The casamance mound kiln not only improves the charcoal yields, but also reduces the duration of carbonization cycle and pollutes fewer environments. These considerations constitute then advantages to the popularization and adoption of this new technique in Togo. The generalization of the casamance improved mound kiln will enables Togo to avoid 799 546.47 tons of CO2 into the atmosphere and preserve 2.2 million tons of wood every year. It is therefore a real tool for fighting against the global warming.

However, it should be noted that the good yield of the casamance improved mound kiln owe partly to a mastery of the circulation of the air in the mound kiln, then to the definition of the optimal distance between the blowholes for the different categories of wood (lightweight wood, semi-heavy wood, heavy wood and very heavy wood). For the heavy woods and very heavy woods, the study has revealed that there should be 2 meters distance between the blowholes in order to optimize the yield with this technique and have less unburnt wood. The definition and a mastery of the optimal distances between the blowholes for the other categories of wood remain a challenge to the popularization of the casamance improved mound kiln.

References

AFNOR, N.F.B., 1985. Bois- Caractéristiques Physiques et Mécaniques des Bois, Association française de Normalisation. Paris., pp 192-195.

Aguilar, R., Chilardi, A., Vega, E., Skutsch, M., Oyama, K., 2012. Sprouting productivity and Allometric Relationship of Two Oak Species Managed for Traditional Charcoal Making in Central Mexico. Biomass and Bioenergy., 36 , 192-207.

Akpagana, K., 1989. Recherche sur les forêts denses humides du Togo. Th. Doct. Sc. Nat., Univ. Bordeaux III., 195 p.

Amous, S., 1999. Le rôle de l'énergie ligneuse en Afrique. Energie ligneuse aujourd'hui pour demain. WETT/FAO, 90 p.

Arnold, J.E.M., Kohlin, G. et Persson, R., 2006. Woodfuels, livelihoods, and Policy Interventions, Changing Perspectives. In World Dev. Vol. ,34 (3) , 596-611.

Ballis, R., Ezzati, M., Kammen, D., 2005. Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. Sci., 308, 98-103.

Brunel, J.F., Scholz, H., Hiekpo, P., 1984. Flore analytique du Togo , Phanérogames. Eschborn., GTZ, 751 p.
Chambers, J.M., Freeny, A., Heiberger, R.M., 1992. Analysis of variance; designed experiments. Chapter 5 of Statistical Models in Chambers, J. M. Hastie T. J., Wadsworth & Brooks/Cole.
Chidumayo, E.N., 1991. Woody biomass structure and utilisation for charcoal production in a Zambian Miombo woodland. Bioressource Technol., 37 , 43-52.
Coomes, O.T., Burt, G.J., 2001. Peasant charcoal production in the Peruvian Amazon , rainforest use and economic reliance. For. Ecol. Manage., 140 , 39-50.
Direction Générale de la Comptabilité et de la Statistique Nationale (DGCSN)., 2011. Recensement général de la population et de l'habitat, République Togolaise. Rapport., 57 p.
Dovie, D., Witkowski, E.T.F., Shackleton, C.M., 2004. The fuelwood crisis in southern Africa relating fuelwood use to livelihoods in rural village. GeoJ., 60, 123-133.
Ducenne, H., 2001. Rapport première mission visant l'amélioration de la carbonisation dans les zones d'interventions de l'Agence Energie Domestique Environnement (AEDE) en périphérie de N'Djamena. Tchad., 21 p + Annexes.
Food and Agriculture of the United Nations (FAO)., 2003. (http,//apps.fao.org/).
Fontodji, K.J., 2007. Impact de la production du charbon de bois sur les propriétés du sol et la biodiversité au Togo. Mémoire de DEA, Univ. de Lomé-Togo, 70 p.
Fontodji, K.J., Mawussi, G., Nuto, Y., Kokou, K., 2009. Effects of charcoal production on soil biodiversity and soil physical and chemical properties in Togo, West Africa. Int. J. Biolol. Chem. Sci., Vol. 3 (5), 870-879.
Fontodji, K.J., Atsri, H., Adjonou, K., Radji, A.R., Kokutse, A.D., Nuto, Y., Kokou, K., 2011. Impact of Charcoal Production on Biodiversity in Togo (West Africa). In López-Pujol J. (Ed), The Importance of Biological Interactions in the Study of Biodiversity., ISBN, 978-953-307-751-2, InTech, DOI, 10.5772/22969.
Gbozo, E., 2010. Techniques de carbonisation au benin et influence des caracteristiques du bois sur le rendement en charbon de bois. Mémoire d'Ingénieur, Univ. Parakou, Bénin, 72 p.
Gérard, J., Kouassi, A.E., Daigremont, C., Détienne, P., Fouquet, D., Vernay, M., 1998. Synthèse sur les caractéstiques technologiques des principaux bois commerciaux africains. Série FORAFRI, document 11, CNRA ABIDJAN, CIRAD-Forêt, Campus International de Baillarguet, Montpellier. France., 186 p.
Girard, P., 2002. Quel futur pour la production et l'utilisation du charbon de bois en Afrique. Unasylva., 211, Vol 53 , 30-34.
Guelly, K.A., 1994. Les savanes de la zone forestière subhumide du Togo. Thèse de Doctorat. Univ. Pierre et Marie CURIE. Paris VI., 163 p.
Hibajene, S.H., Kalumiana, O.S., 2003. Manual for Charcoal Production in Earth Kiln in Zambia. Stockholm Institute of Energy / Dep. Ener.
International Energy Agency (IEA)., 2002. Energy and poverty. Chapter 13. In World Energy Outlook 2002, Paris. OECD.
Kokou, K., Nuto, Y., Atsri, H., 2009. Impact of charcoal production on woody plant species in West Africa, A case study in Togo. Sci. Res. Essay., 4(9), 881-893.
Kokou, K., Nuto, Y., 2009. Assessment of Charcoal Production and Impact of Environmental Policies in Limited Forest Resources Countries, The case of Togo, West Africa. Discov. Innov., Vol 21 (1&2).
Lusadisu, L., 1989. Etude comparative des performances des meules traditionnelles zaïroises et casamançaises. CATEB. Zaire., 1989, 29 p.
Mama, V.J. et Ogouvidé, T.F., 2005. Typologie et analyse technico-financière de la production du charbon de bois dans la région centre et sud du Bénin. Rapport d'étude., 56 p.
Ministère de l'Equipement, des Mines de l'Energie, et des Postes et Télécommunications (MEMEPT)., 2002. Analyse, stratégie et programme d'action du sous-secteur des énergies traditionnelles. Rapport national, République Togolaise.
Projet Bois de Feu Phase 2 (PBF 2), 2010. Mise au point d'une meule à cheminée de type casamançaise « Casa GV » adaptée aux zones de production du charbon de bois au Bénin. Rapport d'étude. République du Bénin., 21 p.
Okello, B.D., O'Connor, T.G., Young, T.P., 2001. Growth, biomass estimates, and charcoal production of Acacia drepanolobium in Laikipia, Kenya. Forest Ecol. Managem., 142, 143-153.
Papadakis, J., 1966. Enquête agro-écologique en Afrique occidentale (Liberia, C. I., Ghana, Togo, Dahomey, Nigeria). FAO., Rome.
Parikka, M., 2004. Global biomass fuel resources. Biomass and Bioenergy., 27, 613-620.

PERACOD (Programme pour la promotion des énergies renouvelables, de l'électrification rurale et de l'approvisionnement durable en combustibles domestiques)., 2010. Comparaison des rendements de production de charbon de bois entre la meule traditionnelle et la meule Casamance dans la forêt communautaire de Sambandé. Ministère en charge de l'énergie, Sénégal. Rapport., 20 p.

R Development Core Team., 2012. R , A language and environment for statistical computing. R foundatin for statistical computing, Vienna, Austria. ISBN3-900051-07-0, URL http,//www.R- project.org/.

Sawadogo, Y., 2007. Les stratégies d'exploitation forestière à vocation énergétique au Burkina Faso pour un développement durable, cas de la filière de carbonisation. Mémoire de DESS, Université de Dschang, CRESA, 85 p + Annexes.

Schenkel, Y., Bertaux, P., Vanwijnsberghe, S., et Carré, J., 1997. Une évaluation de la technique de la carbonisation en meule. Biotechnol. Agron. Soc. Environ., vol 1 (2) , 113-124.

Stassen, H.E., 2002. Faits nouveaux concernant la technologie de production du charbon de bois. Unasylva 211, Vol 53 , 34-35.

Sylvain, J-P., Collart, J., Aregba, A., Godonou, S., 1986. Notice explicative de la carte géologique au 500 000e du Togo. Lomé , Dir. Gén. Min. Géol. / Bur. Nat. Rech. Min., (Mem. N° 6).

Tagba, M.S., 2013. Comparaison des rendements des meules de carbonisation utilisées au Togo, et amélioration de la performance de la meule casamançaise. Mémoire de DEA, UL, Togo, 51 p + Annexes.

Thiam, A.T., 1991. Etude de marché des produits forestiers ligneux au Togo. Rapport. Projet., PNUD/FAO.

Trochain, J-L., 1980. Ecologie végétale de la zone intertropicale non désertique. UPS, Toulouse (France), 468 p.

Walubengo, D., Kimani, M.J., 1993. Dissemination of RETs in Africa. In Walubengo, D., Kimani, M.J., Whose technologies? The development and dissemination of renewable energy technologies (RETs) in sub-Saharan Africa. Nairobi, Kenya, KENGORWEPA.

White, H., 1986. La végétation de l'Afrique. Mémoire accompagnant la carte de végétation d'Afrique. UNESCO / AETFA / UNSO.