INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Christopher T Warburg et al., Vol.4, No.4, 2014

Energy Characteristics of Five Indigenous Tree Species at Kitulangalo Forest Reserve in Morogoro, Tanzania

Christopher T Warburg*‡, Cecil K. King'ondu*

*Nelson Mandela African Institution of Science and Technology, P.O. Box 447 Arusha, Tanzania.
(warburgc@nm-aist.ac.tz;kithongo.king'ondu@nm-aist.ac.tz)

‡Corresponding Author: Christopher T Warburg, Tel: +255 27 2970 002, e-mail: warburgc@nm-aist.ac.tz

Received: 14.10.2014 Accepted: 29.11.2014

Abstract- This study presents the investigation of material composition and energy characteristics of *B. spiciformis, B. boehmii, C. molle, P. maprouneifolia, and S. birrea* indigenous tree species at kitulangalo forest reserve in Tanzania. Energy content of each species mostly depends on its chemical content (C, H and O) and it is reduced by inorganic elements and moisture. Biomass chemical composition was done by proximate and ultimate analyses. Regarding the elemental composition, *P. maprouneifolia* and *C. molle* had high energy content of 18.62 and 18.30 MJ/Kg, respectively because of their higher H:C ratio and relatively low O:C ratio. Carbon, oxygen, and hydrogen were found to be highest in *P. maprouneifolia* with 46.71, 41.96, and 5.7%, respectively. In contrast, *P. maprouneifolia* had the lowest N:C ratio of 0.014, implying good efficiency for nitrogen use to fix carbon. On the other hand, ash, moisture, and volatiles were highest at 4, 55, and 85% for *S. birrea, B. spiciformis,* and *S. birrea,* correspondingly. The ratio of macronutrients to carbon for each species was also calculated. Results show that all species have high demand for nitrogen followed by potassium and calcium, in that order. Finally, heating values have been shown to decrease with increasing moisture content. These experimental results were used for ranking these biomass materials for energy generation. They also furnish vital biomass information for equipments and process designers.

Keywords—Biomass, Elemental Composition, Indigenous Species, Energy Characteristics.

1. Introduction

Currently, renewable energy contributes a greater proportion of the total energy supply in developing countries than in industrialized countries. Over 75% of renewable energy is consumed in developing countries in the form of hydropower and biomass. It is estimated that 2.5 billion people, especially in developing countries rely on traditional biomass fuels for cooking. In the Eastern African countries, it is estimated that an annual per capita energy consumption is 29,300 MJ (0.7 toe) out of which, about 80% is from biomass which is used mostly for cooking. In the case of Africa, the energy is generated mostly from biomass (47%), fossil fuel (24.8%), coal (16.5%), and gas (10.4%) [1]. These studies justify biomass prominence as a source of fuel in Africa and the whole world in general, based on the fact that, it is abundant and readily available.

Tanzania is enriched with sufficient biomass energy from plantation forest, natural forest and agricultural residues. These biomass materials together or isolated create potential and renewable resources of variable forms of renewable energy. Tanzania's energy demand is distinguished by a low per capita usage of commercial energy (petroleum and electricity) and high usage of non-commercial energies like biomass fuels in the form of charcoal, firewood and bio-waste. Biomass energy will still remain as the main energy sources in the foreseeable future. Other potential renewable energy resources are geothermal, micro-hydro, solar, and wind energy. Since 85% of Tanzanian population lives in the rural areas that have limited access to commercial energy forms, large amount of biomass energy is used at household level in the form of wood and charcoal. Regarding this, 92% of Tanzania's primary energy come from wood and charcoal [2]. Firewood is a preferred form of energy in rural areas due to the fact that it is a free resource that can be collected in the surrounding woodlands and farms. On the other hand, charcoal is preferred in urban areas because it is cheap, light in weight compared to firewood, easy to transport, distribute, and store. It is almost smoke free and has higher calorific value (30 MJ/kg) than firewood (15 MJ/kg) [3].

Characterization of biomass is necessary and important to ensure complete combustion, pyrolysis, liquefaction, or gasification of biomass materials. These processes are governed by the materials composition and heating values. For correlating the respective content to the energy behaviour of biomass samples under investigation, standard test methods known as ultimate and proximate analysis are used. This is essential because the biomass energy value is strongly associated with the contents of organic and inorganic components such as ash, volatiles, including the elemental content of carbon, hydrogen, and oxygen [4]. Two important aspects governing biomass usage as fuel are: (1) extension and improvement of the basic understanding on content and properties; and (2) to apply the knowledge for the highly advanced and environmentally safe biomass usage [5]. It is common practice that the complete description of biomass used (as samples or feedstock), where they came from and how they were collected, as well as storage and processing conditions is avoided or not given in complete details. For example, the use of biomass specification such as fuelwood, wood, firewood, forest or agricultural residue, straw, bark, manure, grass, coppicing or dedicated energy crop and short rotation coppice or crop, do not provide enough details for actual characterisation and identification of a specific type of biomass. Moreover, the exact fuel condition of the samples under study, for example, as collected (harvested from field), as received, air-dried (at ambient temperature) or oven-dried (at specific temperature up to 105°C) is usually not reported, which is a serious omission [5]. Moreover, data on specific biomass materials, for example, a certain forest tree species from natural woodlands, targeted for the design of boilers, gasifier or other biomass processing equipments is unavailable. Comprehensive study on Miombo woodlands indigenous trees energy characteristics and their correlation with the biomass composition obtained by complementing ultimate, proximate, and ash analyses as well as phase, mineral, and trace elements analyses are missing or they are very scarce. In this study therefore, chemical composition, carbon fixing efficiency, and energy characteristics of five indigenous tree species at Kitulangalo forest reserve and their correlation with energy characteristics were investigated.

2. Materials and Methods

Site Description

The geology of Kitulangalo is Precambrian Usagaran, Meta sedimentary rock made of ganel- biotite gneiss with some kyanite bearings bands. In lower lying area, a mixture of alluvial, and colluvial deposits obtained from these rocks are present while at highland limestone and dolomite rocks are found [6]. The soil at Kitulangalo forest reserve is blackish, sandy soil sensitive to drying [7]. The more developed soil, that is, Alfisols soil is present on the undulating to rolling convex slopes on the piedmont of the Kitulangalo hill, while mollisol and inceptsols are found on the gentle undulating concave valley bottoms [6]. The textures of the top soils in the woodland structure are mainly sandy loam and sandy clay loam. These soils are well drained and aerated especially those found on the convex slopes and linear slopes. The sandy texture and relatively low subsoil organic matter content makes this soil to have poor nutrient retention. Generally, these soils have poor supply of major nutrients such as Nitrogen and Phosphorous [8]. The annual minimum and maximum temperature are 18 and 30^{0}C respectively while the mean annual temperature is 24.3^{0}C. Wet season is occurs from mid February to early June. June, July, and August are typically dry and cool. The remainder of the year remains dry up to mid February [9].

Historically, the government have used the reserve as a 'productive reserve' meaning that it has been controlled by mandatory possession of license for wood production since 1955. Harvesting was forbidden in 1985 even though illegal utilisation still occurs and in 1995 the reserve was divided into two parts. One part stayed under the central government's management and the other one under Sokoine University of Agriculture's management (SUA). The areas under the central government and SUA's management are 1200 and 500 ha, respectively [10]. Most of the forest reserve is covered with regrowth open Miombo woodlands. Scattered within the forest reserve are species of *Julbenadia globiflora*, *Brachystegia spp.* and *Pterocarpus rotundifolius* reaching a height of 15-20 m. It is common for trees to occur understory, at 5-10 m height consisting of *Combretum zeyheri*, *Diplorhynchus candylocarpon*, *C.apiculatum* and others.

There is a herbaceous layer which consist of dense *Themeda triandra* grass reaching a height of 1.5 m. Grass fires are common in Miombo areas and substantial woodland areas are burnt annually [9]

Elemental Composition

Inventory procedures employed [10] while studying the same forest; that is, Kitulangalo Sokoine University of Agriculture (SUA) Training Forest Reserve were used. This was done by dividing the forest into five transects which were laid perpendicular to the highway. 30 plots were laid in the transects. The rationale behind the dividing the forest into five transects lying perpendicular to the highway was to estimate the standing biomass for the five species under study. Within these plots; two trees from each species of diameter class between 18 and 23 cm were randomly selected for elemental composition and moisture contents analysis. The reason for selecting this diameter class is that these trees are matured enough to provide services such as firewood and charcoal.

Five samples from representative trees were taken for each of the plant components (leaves, branches, and stem) from ten trees of different sizes and dried at 103ºC to a constant weight. The mass of water content results from the weight difference before and after the drying process.Samples were then ground in a mill to pass through 0.1mm mesh sieve and then processed further for nutrient analysis. Nitrogen content in the plant components was determined by the Kjeldahl method [11]. Sulphur analysis was done by the di-acid (HNO3–HClO4) digestion method [11] and carbon content was determined by volumetric method [11]. Total Ca, K, and Mg were determined by dry ashing [11]. Phosphorous content was determined by Spectrophotometric vanadium phosphomolybdate method [11]. Calculations for nutrient content of each biomass in percentages were done as the product of its biomass and corresponding concentration of each nutrient. Carbon efficiency was then calculated as a ratio of each nutrient percentage to carbon percentage for each species.

Volatile matter and ash were determined by heating biomass samples in a crucible in an oven at 600°C for 2 h, and monitoring sample weight constantly. The loss in weight corresponds to the amount of volatile matter in the materials, and the remaining fraction is a mixture of fixed carbon and ash. In the present study, the remaining fractions were heated in an oxidizing environment to obtain ash contents of the samples.

The following correlation equations were used to calculate hydrogen, oxygen, and fixed carbon contents of the biomass samples;

$$H = 0.005FC + 0.062VM \tag{1}$$

$$O = 0.304FC + 0.476VM \tag{2}$$

$$C = 0.637FC + 0.45VM \tag{3}$$

Where;

FC = % fixed carbon, VM = % volatile matter, H = % hydrogen, and O = % oxygen in wt % on a dry basis.

Energy Production

Energy yield for each species was determined by using two mathematical equations developed for calculating energy from carbon and nutrients content of biomass materials as follows; [12]

$$HHV = 0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.0151N - 0.0211Ash \tag{4}$$

$$HHV = 33.83C + 144.3\left(H - \frac{O}{8}\right) + 9.42S \tag{5}$$

Where;

HHV = Higher heating value (MJ/Kg); C, H, S, O, N, and ash are percentages of carbon, hydrogen, sulphur, oxygen, nitrogen, and ash contents, respectively, of biomass samples on dry basis.

The lower heating value of the samples was determined by the following mathematical equation;

$$LHV = HHV - (9 * m_h * h_{fg}) \tag{6}$$

Where;

LHV = Lower heating value (MJ/Kg), $m_{h\,=}$mass fraction of hydrogen in the solid fuel and $h_{fg=}$enthalpy of vaporization of water.

Results from equations (4) were used to extrapolate energy yield per hectare and per ton, for each species using equations (7) and (8).

$$\frac{KWh}{Kg} = \frac{HHV}{3.6} \tag{7}$$

$$\frac{GJ}{Ha} = \frac{HHV * \frac{Kg}{ha}}{1000} \tag{8}$$

Finally, energy yield at different moisture contents was calculated by equation (9) [13].

$$NCV_M = NCV_o * \frac{(100-M)-2.44M}{100} \quad (9)$$

Where; $NCV_M = Heating\ value\ at\ a\ given\ moisture, NCV_o = heating\ value\ at\ 0\%\ moisture\ and\ M = Moisture\ content\ of\ a\ biomass\ material\ (\%)$

3. Results and Discussions

Elemental Composition

From ultimate analysis of biomass materials, elemental composition results of biomass materials were obtained and summarized in Table 1. Carbon was found to range from 46.7 in *P. maprouneifolia* to 40% in *S.birrea*. Hydrogen was highest in *P. maprouneifolia* which had 5.70%, and lowest in *B. boehmii* and *S. birrea*, 5.3 and 5.38%, respectively. Oxygen ranged from 41.96 in *P. maprouneifolia* to 40.19% in *B. boehmii*. The lowest amount of nitrogen (0.63%) was obtained in *P. maprouneifolia*, while *B. boehmii* afforded the highest amount, 2.62%.

Table 1. Elemental composition of different biomass materials

Species	O.C (%)	H (%)	O (%)	N (%)	S (%)
B. spiciformis	45.35	5.57	41.06	2.01	0.14
B. boehmii	42.44	5.38	40.19	2.62	0.14
P. maprouneifolia	46.71	5.70	41.96	0.63	0.10
C. molle	45.86	5.61	41.30	0.84	0.14
S. birrea	40.00	5.38	41.09	1.01	0.15

Sulphur was highest in *S.birrea* and lowest in *P. maprouneifolia* with 0.15% in the former and 0.1% in the later. The elemental composition were within the range that has been reported by others for woody biomass materials [14; 5] . The relatively high amount of sulphur (S) in biomass as shown by *S. birrea* is not conducive for combustion purposes. Chlorine and sulphur are the major contributing elements to ash formation and problems thereof as they contribute to the movement of inorganic compounds from the fuel to surfaces where they form corrosive compounds [4]. Carbon fixing efficiency or Nutrients to carbon ratio was calculated and results are presented in Figure 1.

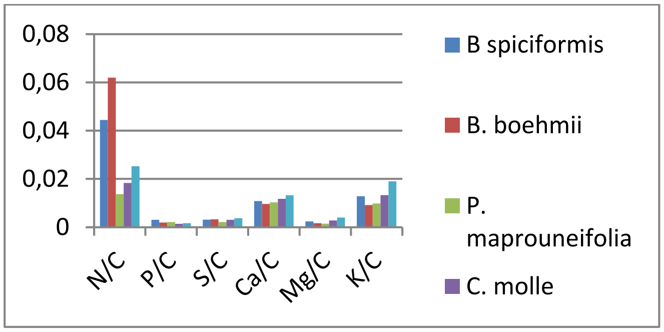

Figure 1. Carbon to nutrients ratios for the five species studied**.**

The nutrient to carbon ratio is a measure of how efficiently a particular nutrient is being utilized to fix carbon, the lower the ratio the better is the utilization of that nutrient. Generally; all five species have higher N:C ratio compared to other nutrients as shown in figure 1, indicating that nitrogen is an important nutrient and can be a limiting factor for carbon fixation if not available in sufficient quantities. *P. maprouneifolia* has the lowest N:C ratio of 0.014 and *B. boehmii* has the highest ratio of 0.062. Therefore *P. maprouneifolia* can be a good choice for planting in nitrogen poor soils. Nevertheless, all of the above species can perform better in nitrogen poor soils than the exotic species that usually requires better soils hence compete with agricultural crops for good land. Results for P:C ratio shows that ratio for *C. molle is 0.0014* which is the lowest and *B. spiciformis* has the highest ratio of 0.0013. Therefore, *C. molle* may be a good candidate for growing biomass in phosphorous deficient soils. Generally, the P:C ratio is the lowest for all species indicating their ability to produce carbon in phosphorous deficient soils. *P. maprouneifolia* had the lowest S:C ratio of 0.0021 and S. birrea is the least efficient with a ratio of 0.0038. Generally all species shows acceptable levels of sulphur hence fewer problems associated with higher levels of sulphur may be encountered during further processing or operations for any of the above species. The Ca:C ratios are the second highest for all species after the N:C ratios, calcium therefore may be a critical factor for carbon production for the above species. *B. boehmii* has the highest efficiency for calcium with a ratio of 0.0097 while *S. birrea* has the lowest efficiency with a ratio of 0.013. Generally, all species have shown good Mg:C ratios; *P. maprouneifolia* has the lowest C:Mg ratio of 0.0015 *and S. birrea* has the highest Mg:C ratio of 0.004, therefore *S. birrea* may not be a good choice for planting in magnesium poor soils. The K:C ratios for all species is also generally higher compared to other ratios except N:C and Ca:C ratios. *B. boehmii* has the lowest K:C ratio of 0.0092 *while S. birrea* has the highest K:C ratio of 0.019 therefore *S. birrea* it may not be a good choice for planting in potassium poor soils. The proximate analysis yielded the results which are presented in Table 2.

Table 2. Proximate analysis of five species at Kitulangalo forest reserve

Species	Ash (%)	Moisture (%)	Volatiles (%)	FC (%)
B. spiciformis	2	55	75	17.62
B. boehmii	2	47	77	11.62
P. maprouneifolia	3	32	76	19.04
C. molle	2.5	40	75	18.42
S. birrea	4	51	85	2.08

These non elemental compositions are also in agreement with the range for ash, moisture, and volatiles reported by [5;14], for woody biomass materials. It is generally desirable to dry biomass since processing techniques such as gasification and pyrolysis require dry biomass fuels of uniform size and moisture content below 15% by weight, for trouble free and economical operations. It was shown [4] that the presence of excessive moisture (above 20%) produced syngas with much lower LHV compared to those with less moisture content. Therefore, before further processing the above biomass species must be dried to acceptable moisture contents levels. Compared to coal, biomass has a larger amount of volatile matter, with crop residue having 63-80%, Wood, 72-78 %, Peat, 70 %, Coal, up to 40 %, and charcoal, 3-30 %. *S. birrea* has highest amount of volatiles and may cause equipment operational problems faster than the other species due to tar formation and fouling. Since slagging problems usually occurs at ash content above 5%, all of the species studied in our work are suitable for gasification since their ash content was found to be below 5%. The greater the fixed carbon content, the lower the degree of oxygenation, thus the higher the heating value of the fuel and the higher the yield of the gasification species. *S. birrea* has the lowest amount of fixed carbon content and this species may not be a good candidate for gasification process.

Energy Characteristics and Yield

Table 3 below presents the energy or calorific value of the five species at Kitulangalo forest reserve calculated from equations (4) (HHV4), (5) (HHV5), and (6) (LHV). The results are also presented in Kwh/Kg and GJ/ha.

Table 3. Energy yield for five different species at kitulangalo forest reserve

Species	HHV4 (MJ/Kg)	HHV5 (MJ/Kg)	LHV (MJ/Kg)	Kwh/ Kg	GJ/ ha
B. spiciformis	18.09	15.98	16.86	5.02	13.80
B. boehmii	16.93	14.88	15.75	4.70	6.63
P. maprouneifolia	18.62	16.47	17.37	5.17	4.22
C. molle	18.30	16.17	17.06	5.08	23.53
S. birrea	15.97	13.89	14.79	4.44	9.32

Since results from equation (4) were within the range (15-20 MJ/Kg) reported in the literature for woody biomass, [4]; further calculations were done using these results. *P. maprouneifolia* showed the highest energy value of 18.62 MJ/kg while *S. birrea* gave the lowest energy value, 15.97 MJ/Kg, probably due to its lower fixed carbon content. Energy yield per hectare was highest for *C. molle* because this species had the highest biomass yield per ha. *P maprouneifolia* had the lowest biomass yield per ha and this is also reflected in its energy yield per ha which is also lowest compared to other species. *P. maprouneifolia*, *C. molle*, and *B. spiciformis* had calorific values above 18 MJ/Kg. These energy yields are significantly higher than those of the commonly used biomass materials such as rice husk, bagasse, and sisal bole, reported to have energy yields of 13.93, 17.33 and 17.23 MJ/Kg respectively [4]. Therefore, *P. maprouneifolia*, *C. molle*, and *B. spiciformis* species are good candidates for practical energy and power generation.

A comprehensive analysis of the materials' properties was done by investigating their ''H:C" and ''O:C" ratios and the results are shown in Table 6. In a study [4], it was reported that materials with higher H:C ratio and lower O:C ratio exhibit higher heating values than materials with higher O:C ratio, similar results were found for this study as presented in Table 4.

Table 4. H:C ratio and O:C ration of five species at kitulangalo forest reserve

Species	H:C Ratio	O:C Ratio	HHV MJ/Kg
B. spiciformis	0.12	0.91	18.09
B. boehmii	0.13	0.95	16.93
P. maprouneifolia	0.12	0.90	18.62
C. molle	0.12	0.90	18.30
S. birrea	0.13	1.03	15.97

P. maprouneifolia and *C. molle* had O: C ratio of 0.90 each, the heating values were highest for *P. maprouneifolia* followed by *C. molle*. This is caused by the high correlation of hydrogen and carbon to the heating value of biomass materials as indicated in equations (4) and (5). On the other hand, *S. birrea* and *B. boehmii* had O:C ratio of 1.03, and 0.95, respectively and their heating values were 15.97 and 16.93 MJ/Kg, respectively. As such, these two species have lower heating values than the rest of the species. This is suggested to be due to their higher O:C ratios. Heating values at different moisture contents were also calculated and are presented in Figure 2.

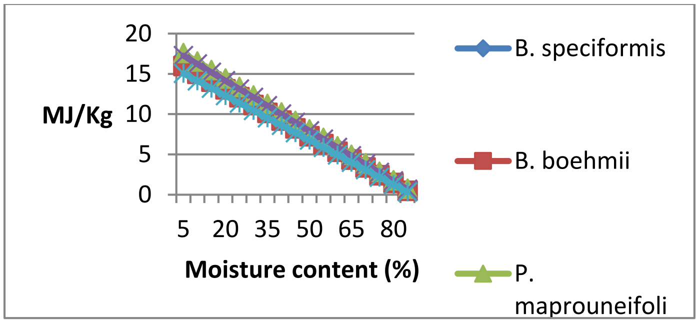

Figure 2. Heating values at different moisture content

Generally, heating values of all species decreased with increasing moisture content, at 40% M.C, only *P. maprouneifolia* had heating value above 10 MJ/Kg. Therefore, it is important to dry biomass material. In order to improve the conversion efficiency, moisture content above 20% in biomass material should be removed before conversion, since the presence of excessive moisture decreases heating values since the materials take a long time to degrade and the ignition becomes more difficult leading to lower efficiencies.

4. Conclusion

In this study, we have successfully investigated energy yield and characteristics of five Miombo woodland species and correlated the energy yield with the biomass composition. Miombo woodlands are home to more than 500 different tree species, most of these species are highly valued by the local people as a source of different products including firewood and charcoal for energy. In terms of energy yield, *P. maprouneifolia*, *C. molle* and *B. spiciformis* have shown good potential with 18.62, 18.30 and 18.09 MJ/Kg respectively. Carbon, oxygen, and hydrogen were found to be highest in *P. maprouneifolia* with 46.71, 41.96, and 5.7%, respectively. In contrast, *P. maprouneifolia* had the lowest N:C ratio of 0.014, implying good efficiency for nitrogen use to fix carbon. On the other hand, ash, moisture, and volatiles were highest at 4, 55, and 85% for *S. birrea*, *B. spiciformis*, and *S. birrea*, correspondingly. Fixed carbon was highest in *P. maprouneifolia*, 19.04%, while H:C ratio was highest for *B. Boehmii* and *S. birrea both* at 0.13 and 0.13 respectively. O:C ratio highest for *S. birrea* at 1.03, because of its high O:C ratio, *S. birrea* had the lowest heating value compared to the rest of the species studied. Heating values for all species decreased with increasing moisture levels.

Characterization of tree species within Miombo woodlands will help researchers and energy planners to isolate suitable species for use in biomass planting schemes. The information in this study will contribute to the general scientific knowledge about yield and energy characteristics of the five species under study. Further studies to determine thermal characterization of the five species in this study are recommended.

References

[1] Facts G. Scientific Facts on Forests and Energy 2010. Available from: http://www.greenfacts.org/.

[2] National-Energy-Policy. Tanzania National Energy Policy. In: Minerals MoEa, editor. Dar es salaam2003.

[3] Malimbwi R. E , Zahabu E, Kajembe G. C, Luoga E.J. Contribution of Charcoal Extraction to Deforestation: Experience from CHAPOSA Research Project. 2000.

[4] Wilson L, Yang W, Blasiak W, John GR, Mhilu CF. Thermal characterization of tropical biomass feedstocks. Energy Conversion and Management. 2011;52(1):191-8.

[5] Vassilev S.V, Baxter D, Andersen L.K, Vassileva C.G. An overview of the chemical composition of biomass. Fuel. 2010;89(5):913-33.

[6] Msanya B, Kimaro D, Shayo-Ngowi A. Soils of Kitulangalo Forest reserve area, Morogoro District, Tanzania. SUA, Department of Soil Science. 1995.

[7] Elifuraha E, Nöjd P, Mbwambo L. Short term growth of miombo tree species at Kitulangalo. Working Papers of the Finnish Forest Research Institute 98: 37–45. 2008.

[8] Nduwamungu J. Tree and shrub diversity in Miombo woodland: A case study at SUA Kitulangalo Forest Reserve, Morogoro, Tanzania. Unpublished MSc Dissertation, Sokoine University of Agriculture. 1996.

[9] Malimbwi R.E, Zahabu E, Monela G, Misana S, Jambiya G, Mchome B. Charcoal potential of Miombo woodlands at Kitulangalo, Tanzania. Journal of Tropical Forest Science. 2005:197-210.

[10] Hammarstrand L, Särnberger A. Comparative evaluation of two forest systems under different management regimes in Miombo woodlands. Unpublished MSc Dissertation: Chalmers University of Technology, Gothenburg, Sweden.; 2013.

[11] Motsara M, Roy RN. Guide to laboratory establishment for plant nutrient analysis: Food and Agriculture Organization of the United Nations Rome; 2008.

[12] U.S. Environmental Protection Agency. Methodology for Thermal Efficiency and Energy Input Calculations and Analysis of Biomass Cogeneration Unit Characteristics In: Radiation OoAa, editor.: U.S Environmental Protection Agency; 2013.

[13] Francescato V, Krajnc N. Wood fuels handbook: AIEL-Italian Agriforestry Energy Association; 2009.

[14] Neves D, Thunman H, Matos A, Tarelho L, Gómez-Barea A. Characterization and prediction of biomass pyrolysis products. Progress in Energy and Combustion Science. 2011;37(5):611-30.