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EXPERIMENTAL ANALYSIS OF THREE COMMON TREE SPECIES IN GHANA

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ABSTRACT

Biomass, in the form of firewood and charcoal, continue to dominate energy supply sources in Ghana. Global energy demand projections, and indeed projections in Ghana, have shown that biomass will continue to serve as a principal energy source to many developing countries for the foreseeable future. While several woody crop species may hold potential as sources for firewood and charcoal production, there is limited data on these woody crops in Ghana. This study therefore analysed the energy characteristics and other properties of wood and charcoals produced from three wood species grown in Ghana: Neem (*Senna siamea*), Cassia (*Azadirachta indica*), and Teak (*Tectona grandis*), which have been identified as potential woody biomass species by the Forestry Commission of Ghana. The calorific value, ranged from 4.62 to 4.82 kCal/g for woods and 7.20 to 7.38 kCal/g for charcoals of the three species, with no significant difference. Other properties determined were volatile matter content, fixed carbon content, ash content, and the presence of other elements such as sulphur, nitrogen and oxygen. Overall, the analysis presented in this study, coupled with their fast-growth nature, has shown that woods and charcoals of Neem, Teak and Cassia are good potential woody biomass feedstock.

KEYWORDS: Tree species, neem, cassia, teak, Ghana

INTRODUCTION

Like many countries in sub-Saharan Africa, Ghana's bulk energy supply for heating and cooking is from woodfuel, in the form of firewood and charcoal (Ghana Statistical Services, 2014). In 2015, firewood and charcoal provided 39 % of the Total Primary Energy Supply (TPES) in the country, down from 55% in 2005 (Energy Commission, 2016). Although the percentage contribution of woodfuel to the Total Primary Energy Supply has been decreasing over the years, there has been an increase in the absolute numbers, with 3.6 million toe woodfuel consumed in 2015 compared to 3.1 million toe in 2005 (Energy Commission, 2016). This is alarming, considering the fact that an estimated 90% of woodfuel is sourced from natural forests in Ghana (Mensah *et al*., 2014), adding to deforestation challenges.

Even though Ghana is striving to move up the fuel ladder with the introduction of an LPG policy, it has been forecasted by Kemausuor *et al.* (2015) and Mensah *et al.* (2014) that there would still be a significant portion of the population relying on solid biomass into the foreseeable future. Data from the Ghana Statistical Services (2014) indicates that more than 70% of the population depended on woodfuel as the main cooking fuel in 2013. A draft Renewable Energy Masterplan is calling for the cultivation of dedicated woody crops that can serve as a source of wood supply and lessen the effect of woodfuel consumption on deforestation[1] The potential of Ghana

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[1] Personal communication with Wisdom Ahiataku-Togobo, Director of Renewable and Alternative Energy at the Ghana Ministry of Power

to cultivate dedicated woody crops for solid biomass supply cannot be over emphasized, with the vast arable and degraded lands available (Kemausuor *et al*., 2015).

During the past two decades, a better understanding of wood energy systems has led to the recognition that supply sources are more diversified than was once assumed, including not only forest areas but also trees outside forests. Thus the alarmist predictions of the 1970s of a "fuelwood crisis" in which supply sources would not be capable of meeting the demand have proved unfounded (Girard, 2002). In the short and medium terms, Kituyi (2001) argues that any sustainable development solutions in the household energy sub-sector in Africa must focus on biomass energy technology development and dissemination. This includes sustainable fuelwood production and its efficient utilization through adoption of improved energy technologies, with sustained efforts to eliminate barriers that hinder access to commercial energy (Demirbas *et al*., 2009; Kammen and Lew, 2005; Antal and Grønli, 2003). FARA Secretariat (2008) has argued that the triple effect of population growth increases the demand for charcoal use, leading to deforestation and desertification. Lurimuah (2011) has stated that forest protection and sustainable livelihood are met by adopting efficient and appropriate technologies. These include: planting fast growing trees, good harvesting techniques, utilizing most parts and avoiding waste to the barest minimum, using more efficient charcoal production methods like metal ring kilns, and the use of more efficient cook stoves.

While several woody crop species may hold potential as sources for firewood and charcoal production, there is limited data on these woody crops in Ghana. Data on identified woody species would help predict the energy potential per cubic meter of sustainably managed forest at a given time (Howe, 2013). This study therefore analysed the energy characteristics of wood and charcoals produced from three wood species in Ghana: Neem (*Senna siamea*), Cassia (*Azadirachta indica*), and Teak (*Tectona grandis*), which have been identified as potential woody biomass species by the Forestry Commission of Ghana, with reference to some of their physical and chemical characteristics. Specifically, the study sought to achieve the following objectives: to determine the moisture content, volatile matter content, ash content and fixed carbon content of woods and charcoals of Neem, Cassia and Teak specimens, to determine the percentage composition of constituent elements in the woods and charcoals of these selected tree species and to determine their heating values.

MATERIALS AND METHODS

Study Location

The project was carried out at the premises of the Ghana Forestry Commission in Berekum, a town located in the Brong Ahafo Region of Ghana. Berekum is generally plain with rolling and undulating land surface in some parts. General land elevation is between 60 m and 150 m above sea level. The soils of the site belong to two main groups, the savanna ochrosols occurring in the south-western part of the district and the ground water lateral soil.

Soils in Berekum are agriculturally important and support cultivation of tubers, cereals, tobacco, cashew, vegetables and legumes. Vegetation types of the area used to be the dry semi-deciduous forest type but now comprise of grassland, wooded savanna or tree savanna. Forest trees like *Melicia excela* (Odum), *Triplochiton scleroxylon* (Wawa), *Ceiba Pentandra* (Onyina) and *Terminalia superba* (Emire) are being replaced with *Tectona grandis* (Teak), *Senna siamea* (Cassia) and *Azadirachta indica* (Neem) used as "Greenbelts" and shelter belts or avenue plantings of a sort. The vegetation is in a delicate state of imbalance with all kinds of efforts like reforestation, fire-fighting and education to restore the once luxuriant dry semi-deciduous forest.

Double maxima raining seasons with their peaks occurring normally in May-June and September-October govern Berekum. The mean annual rainfall is 1600 mm. The second wet season is reliable. The mean annual temperature ranges between 26.5 °C and 27.2 °C. There is prolonged dry season between October and April. Relative humidity ranges between 90-95% in wet season and 75-80% in the dry season.

Experimental Procedure

Selection and preparation of wood species for analysis and carbonization

Three years old *Azadirachta indica* (Neem) and *Senna siamea* (Cassia) were felled, cross-cut into billets of one meter each and stacked into piles of 1 m^3 each. Off cuts from freshly felled ten years old *Tectona grandis* (Teak) were also similarly prepared. Each pile was stacked between October 2014 and April 2015 (six months) to dry. These choice of age classes were made because they are the lowest age at which significant size and woody biomass can be obtained from these wood species for commercial charcoal production. The top of each pile was covered with polythene to prevent rain and dew falling on them. By the end of six months (end of April), the moisture contents of the wood species were measured using electronic moisture meter as follows; Neem 20%, Cassia 20% and Teak 22%. Samples of the woods of the different species (20g each) were put in polythene bags for proximate and ultimate analysis and also for calorific value determination in the laboratory.

The rest of the wood was packed into a kiln at the above moisture contents and carbonized. A billet each of Neem, Cassia and Teak were wrapped in wire meshes individually and separately so as to enable the easy identification of the charcoals of these for the study. Carbonization was completed in 48 hours and the kiln was completely sealed with soil and allowed to cool. In 72 hours the charcoal was ready. The various species of charcoals were then selected from the cold kiln and put in labelled polythene bags immediately to avoid the absorption of moisture analysis. Physical properties (density, moisture content [MC]) and chemical properties (volatile matter [VM], ash content [Ash], fixed carbon content [FC]) as well as energy value of the neem, cassia and teak woods and charcoals produced were determined by standard analytical methods prescribed by the American Society for Testing and Materials (ASTM) and Association of Official Analytical Chemists (now AOAC International). The particular methods used were: moisture content (E871), volatile matter content (E872), ash content (D1102), fixed carbon content and calorific value (E711). Tests were conducted in triplicates and the average values determined.

The fixed carbon content was obtained using the equation 1.

$$FC = 100\% - (MC + VM + Ash)\% \qquad \text{Equation 1}$$

The calorific values were determined using the bomb calorimeter. Here again, each experiment was done in triplicate and the average value determined. Carbon (C) (E777), Hydrogen (H) (E777), Oxygen (O) (E870) and Nitrogen (N) (E778) contents were detected by an elemental analyzer. 200 mg of samples of wood pellets were burned at 200 ^{o}C in an oxygen atmosphere, so that the C is converted to carbon dioxide, (CO_2), H to H_2O and N into N_2. The C and H are detected quantitatively by an infra-red detector, while N_2 was determined by a thermal conductivity detector. The same procedure was carried out for the charcoals (Moka, 2012).

The sulphur content for woods and charcoals were determined by the calorimetric combustion of the woods with the addition of diluted sodium hydroxide to convert sulphur to sulphates, which are largely precipitated with barium chloride as barium sulphate. The barium sulphate content was calculated by weight difference.

Equation 2 was used to calculate the percentage sulphur content of the sample for a one-gram sample.

$$\%\ \text{Sulphur} = \frac{\text{Weight of dry BaSO4 x 32x100}}{235} \qquad \text{Equation 2}$$

The mean time taken to light a sample of neem, cassia and teak charcoals at a given moisture content was determined by putting three hundred (300) grams of the charcoals in a coal pot. Five (5) grams of dried palm nut fiber was placed on the charcoal bed on the grate with an opening underneath to draw air upwards into the charcoal bed. Once the fiber was lighted / ignited, a stop watch was used to determine the time taken for the charcoal to ignite freely. Three replicates were carried out for each specimen. After igniting the charcoal fire as described previously, the fire is allowed to burn freely without fanning for 30 minutes. The charcoal embers were observed and how each of them burnt within the period of the burn noted. The result was coded as follows;

1 = Burns continuously, freely and faster without fanning
2 = Burns continuously, freely and slowly without fanning
3 = Burns for a long time but fire finally goes off without fanning
4 = Burns fast for a short time and the heat goes down without fanning
5 = Burns for a short time and the fire goes off.

Three hundred (300) grams of charcoals from the tree species were ignited, air drawn into the charcoal bed continuously for 5 minutes, and the embers were observed for sparks. The result was coded as follows;

1 = Spits/Sparks profusely and continuously
2 = Spits/Sparks profusely but not continuously
3 = Spits/Sparks sporadically
4 = Does not spark at all

For ash deposition, 300 g of charcoals from the tree species were again ignited and left to burn without fanning. The ash produced due to the combustion was observed[2]. The results are coded as follows. Each experiment was triplicated.

1 = Very heavy deposition of ash on embers (90 % of ember is covered with ash)
2 = Heavy deposition of ash on ember (60% of ember is covered with ash)
3 = Fair deposition of ash on ember (45% of ember is covered with ash)
4 = Less deposition of ash on ember (30% of ember is covered with ash)

For Water Boiling Test (WBT), 300 g of neem, cassia and teak charcoals were ignited with 5 g of dry palm kernel fibre to boil 1 litre of water for 30 min. Burning rate (grams of charcoal consumed per unit time) and work done (grams of water evaporated per grams of charcoal used) were determined. Each experiment was done in triplicate and the average value determined.

Microsoft Excel 2013 software package was used to perform univariate analysis of variance (ANOVA) and least significance difference (LSD) in the charcoal properties of the different wood species determined at 5% level of significance.

RESULTS AND CONCLUSION

Heating value of the woods and charcoals of Neem, Teak and Cassia

The lower heating value of woods of Neem, Teak and Cassia were in the range of 4.682 – 4.820 kCcal/g. This conforms to a study carried out by Mainoo (1996) where the calorific values of stem components of three four-years old multipurpose tree species (*Luceana leucocephala*, *Gliricidia sepium* and *Senna siamea*) from the Kwame Nkrumah University of Science and Technology – Natural Resource Management farm, were obtained as follows; *L. leucocephala*, 4.703 kCal/g; *G. sepium*, 4.569 kCal/g and *S. siamea*, 4.480 a range of 4.480 – 4.703 kCal/g. The study also conformed to studies done by Puri *et al.* (1994) who obtained 4.243 – 4.937 kCal/g for multipurpose hardwoods, 4.200 – 4.900 kCal/g reported for most multipurpose tree species (Mainoo, 1996). The heat value of the charcoals of these juvenile trees; Neem, Teak and Cassia were in the range of 7.682 – 7.82 kCal/g. This compared with high density indigenous and slow growing wood species *Cylicodiscus. gabonensis* and *Acacis nilotica* with calorific values of 7.20 and 7.38 kCal/g respectively[3].

Proximate analysis of wood and charcoal from Neem, Teak and Cassia

Proximate analysis is a good indicator for biomass quality, and a base for further thermal conversion and processing requires relatively dry biomass (normally less than 10% moisture). Wood, mostly organic, comprises cellulose, hemicellulose, lignin, organic acids and minerals components in a proportion of 90 – 95% of the plant biomass (Overend, 2004). These are held by moisture and the value of the moisture content is determined by the state and surrounding humidity. Table 1 shows the moisture, volatile matter, fixed matter and ash contents of the wood and charcoal from the trees. The moisture contents of the woods of Neem, Teak and Cassia were less than 10%, indicating good quality biomass. Even though moisture content in Teak wood was significantly higher than in Neem and Cassia, the moisture content in Teak charcoal was the least of the three, which could probably be an attribute of the species. Before carbonization, more water was held in cell walls and in higher proportions in its components than in Neem and Cassia as revealed in the study for Neem and Cassia respectively. However, these values are still far less than the 10% stated for ideal biomass resources indicative of the fact that the charcoals of these fast-growing hardwood tree species are good biomass resources.

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[2] There was no empirical way of determining or measuring the percentage of deposition of ash on charcoal embers yet the observation was important as the phenomenon was critical to the performance of the charcoal, hence the only way was to estimate the coverage of ash on the ember surface.

[3] Unpublished material prepared by Derkyi, N. S. (Utilization of Tetrapleura Waste for Energy and Climate Change Mitigation). Forestry Commission of Ghana.

It is obvious that volatile matter which is a constituent of wood comprising all those liquids, tarry residues, tannins and exudates is stuck in them until they are expelled by the process of carbonization. The range of volatile matter in the woods of these fast-growing hardwood trees species (Neem, Teak and Cassia) was between 64 - 67% because they were yet to be carbonized. This value gives them their ability to burn readily as good fuelwood resources because of the syngas production, which promotes a successful secondary combustion (Emrich, 1985). In this study, the significantly higher volatile matter in Teak wood suggests it will burn faster with more flame with probably more smoke than Neem and Cassia. After carbonization, the range of volatile matter content of Neem, Teak and Cassia charcoals dropped considerably to 20.9 – 22.1%. Comparatively, volatile matter content of the charcoals of Neem, Teak and Cassia in this study was less than was observed in *Petophorum dasylachis* and *Keteleeria davidiana* with 37.59% and 36.86% respectively in a study by Vongsaysana & Achara (2009). The values obtained fall within the FAO recommended volatile matter content of charcoals from mixed tropical hardwood of 17.1 – 23.6% (FAO, 1985). The volatile matter content make the charcoals suitable for use in updraft gasifiers (Reed, 1988).

The fixed carbon in wood is relatively low compared to that of charcoal because of the cellulose, hemi-cellulose and lignin constituents of wood. The fixed carbon in the woods of Neem, Teak and Cassia were low and in the range of 18.2 to 23.0%. Meanwhile, after the carbonization process, the fixed carbon in Neem, Teak and Cassia rose to a range of 70.4 – 71.6%.

The ash content of woods of these juvenile and logging residue; Neem, Teak and Cassia in this study yielded a range of 3.0 – 3.6 % either as present in the wood or picked up as contamination from the earth during processing. Teak recorded a significantly higher ash content probably because of the thickness of the bark which is still a big portion of the wood and a bigger sapwood to heartwood volume due to its age (because it was harvested as a pole at age 10) which was part of the wood compared to the Neem and Cassia which have relatively light barks even at age three. The ash content of the charcoals of Neem, Teak and Cassia in this study (2.1 – 2.9 %) conform to FAO standards (Emrich, 985) which state that the ash content of a good charcoal varies from 0.5 – 5% depending on the species of wood, the amount of bark included with the wood in the kiln and the amount of sand and earth contamination. They also likened size of charcoal lump to ash content such that, lump charcoal contained about 3% ash whiles fine charcoal (plus 4 mm) will have up to 5 – 10% ash. Meanwhile the size of the charcoals in this study conform to the size description by HCCG (The Hampshire Coppice Craftsmen's Group), (2014) stating that, "lump wood charcoal shall be that retained on a mesh of minimum dimensions 12.5mm by 12.5 mm.

Table 1: Proximate analysis of wood and charcoals specimens of Neem, Teak and Cassia

Proximate Analysis of Wood Specimens								
Parameters (%)	Treatments					df	P-value	*LSD* *(0.05)*
		Neem	Teak	Cassia	Total			
Moisture	**Mean**	**6.2 ^{a}**	**6.5 ^{b}**	**6.0 ^{a}**	**6.2**	8	*0.033*	*0.27*
	SD	0.11	0.19	0.13	0.14			
Volatile Matter	**Mean**	**65.2 ^{a}**	**67.3 ^{c}**	**66.4 ^{b}**	**66.3**	8	*0.001*	*0.59*
	SD	0.20	0.17	0.59	0.32			
Fixed carbon	**Mean**	**23.0**	**18.2**	**18.5**	**19.9**	8	*0.061*	-
	SD	3.75	0.17	0.20	1.37			
Ash Content	**Mean**	**3.0 ^{a}**	**3.6 ^{c}**	**3.2 ^{b}**	**3.3**	8	*0.003*	*0.20*
	SD	0.10	0.18	0.15	0.14			
Proximate Analysis of Charcoal Specimens								
Moisture	**Mean**	**5.7 ^{b}**	**5.3 ^{a}**	**5.6 ^{b}**	**5.5**	8	*0.020*	*0.13*
	SD	0.09	0.12	1.18	0.46			
Volatile Matter	**Mean**	**21.6 ^{a}**	**22.1 ^{b}**	**20.9 ^{c}**	**21.5**	8	*0.000*	*0.27*
	SD	0.26	0.10	0.10	0.15			
Fixed carbon	**Mean**	**70.9 ^{a}**	**71.6 ^{b}**	**70.4 ^{c}**	**71.0**	8	*0.000*	*0.19*

	SD	0.10	0.17	0.06	0.11			
Ash Content	**Mean**	**2.1 ᵃ**	**2.9 ᶜ**	**2.4 ᵇ**	**2.5**	8	*0.003*	*0.28*
	SD	0.26	0.12	0.10	0.16			

Mean values with similar alphabets are not significantly different by Fisher's LSD multiple comparison test

Ultimate analysis

Since the main elemental components of the above ground biomass include hydrogen, oxygen and carbon, the range of hydrogen content in the woods of Neem, Teak and Cassia in this study is 3.42 – 3.56%, and the hydrogen content of the charcoals of Neem Teak and Cassia being 4.10 – 4.56% (Table 2). Under the same circumstances, oxygen in the woods of Neem, Teak and Cassia ranged from 40.27 – 42.80% whiles the oxygen in their charcoals ranged in 22.30 – 25.20%. The carbon content of the woods range from 49.094 – 55.114% and Neem had the least in carbon content. However, in their charcoals because carbonization amount to more carbon production from wood, the carbon content rose up to 69.57 – 73.09% this time with teak charcoal having the least.

Nitrogen content in the woods of Neem, Teak and Cassia was quiet low 0.32 – 0.39% and the content in the charcoals also ranging between 0.23- 0.28%. Nitrogen in Neem was significantly higher than in Teak and Cassia because although these plants all need some amount of nitrogen in functional molecules such as porphyries (Emrich, 1985), this study shows that because Neem is a nitrogen–fixer it carries more nitrogen than Teak and Cassia. Neem's ability to fix nitrogen makes them tolerant to poor soils and makes them useful in land reclamation projects as well as good fuelwood and charcoal.

The sulphur content of woods of Neem, Teak and Cassia in this study ranged from 0.356 – 0.386 % whiles the sulphur contents of their charcoals were within 0.280 – 0.302 %. In both wood and charcoal the sulphur contents in Teak were significantly higher but in conformity with what is expected of biomass, sulphur content strongly varies between plant species and ranges between 0.1 – 6% of the plants dry weight. These figures attained in this study attest to assertions made by Emrich, (1985) that sulphur contents in biomass is quiet negligible compared to fossil fuels.

Table 2: Ultimate analysis of wood and Charcoals of Neem, Teak and Cassia

Ultimate Analysis of Wood Specimens							
Parameters (%)	Treatments				df	P-value	LSD (0.05)
		Neem	Teak	Cassia			
Hydrogen	**Mean**	**3.42 ᵇ**	**3.56 ᵇ**	**3.35 ᵃ**	8	*0.000*	0.03
	SD	0.02	0.02	0.01			
Sulphur	**Mean**	**0.356 ᵃ**	**0.386 ᶜ**	**0.362 ᵇ**	8	*0.000*	0.003
	SD	0.03	0.01	0.02			
Carbon	**Mean**	**55.114 ᵃ**	**49.094 ᵇ**	**53.168 ᶜ**	8	*0.000*	0.03
	SD	0.01	0.03	0.01			
Nitrogen	**Mean**	**0.39 c**	**0.34 ᵇ**	**0.32 ᵃ**	8	*0.000*	0.01
	SD	0.00	0.01	0.01			
Oxygen	**Mean**	**40.72 ᵃ**	**42.62 ᵇ**	**42.8 ᵇ**	8	*0.005*	0.84
	SD	0.355	0.714	0.458			
Heat value (kCal/g	**Mean**	**4.682**	**4.82**	**4.70**	8	*0.878*	-
	SD	0.60	0.078	0.086			
Ultimate Analysis of Charcoal Specimens							
Hydrogen	**Mean**	**4.10 ᵃ**	**4.65 ᵇ**	**4.22 ᵃ**	8	*0.005*	0.21

	SD	0.10	0.144	0.140			
Sulphur	**Mean**	**0.280**	**0.302**	**0.289**	8	*0.746*	-
	SD	0.002	0.049	0.010			
Carbon	**Mean**	**73.09 ^{b}**	**69.57 ^{a}**	**72.141 ^{b}**	8	*0.001*	1.01
	SD	0.212	1.056	0.211			
Nitrogen	**Mean**	**0.23 ^{a}**	**0.28 ^{c}**	**0.25 ^{b}**	8	*0.032*	0.03
	SD	0.014	0.026	0.01			
Oxygen	**Mean**	**22.3 ^{a}**	**25.2 ^{b}**	**23.1 ^{a}**	8	*0.002*	0.94
	SD	0.889	0.436	0.265			
Heat value (kCal/g)	**Mean**	**7.82**	**7.682**	**7.70**	8	*0.759*	0.01
	SD	0.288	0.228	0.20			

Mean values with similar alphabets are not significantly different by Fisher's LSD multiple comparison test.

Physical properties of charcoals of Neem, Teak and Cassia

The densities of charcoals of Neem, Teak and Cassia from this study range between 0.43 and 0.45 g/cm^3 with no significant difference at the 5 % level (see Table 3). Meanwhile this depends on the species, age and portion of wood used. However, in this study the charcoals of mid-stem portions of three years old Neem and Cassia trees compare with a top portion of a 10-year old teak logging residue in this regard. According to FAO (1985), the weight of wood fuel depends on density and the density within and between wood species is not uniform. Mature wood in old trees are denser than juvenile wood in young trees just as sapwood is less dense than heartwood. In this regard, the densities of cassia (0.44 g/cm^3) and Neem (0.450g/cm^3) at three years old are good indicators of fuelwood resource. More important is the fact that these are coppiceable and so renewable in very short term with good and outstanding results compared to the traditional tree species with long gestation periods.

More teak charcoal was burnt within 30 minutes at 3.73 g/min than that of Neem and Cassia to evaporate 2.94 g of water. This shows that charcoal from a more matured teak tree burnt up faster than juvenile Neem and Cassia tree charcoals which used up 2.33 and 2.70g/min to boil off 5.06 and 4.85g of water respectively. Significantly, these used less charcoal to boil off more water. This is apparently due to the less dense nature of teak charcoal which has an influence on the burning rate compared to a denser Neem and Cassia charcoals even though they were younger. The amount of heat conducted continuously from the charcoal embers to the aluminium pot holding the water contributed to the amount of water evaporated within the period.

In this study, it would have been expected that Teak with the lowest moisture content and higher volatile matter should have lighted earliest but that was not to be. Cassia charcoal easiest to light (0.45 min) compared to Teak and Neem in that order, contrary to assertions by HCCG (The Hampshire Coppice Craftsmen's Group, 2014).

Burning properties of the three species are shown in Table 4. Neem charcoal burned continuously, freely and faster when left without fanning compared to teak charcoal which burned fast for a short time and went off. Cassia rather burned continuously, freely and slowly without fanning. All three species conform to the method of burning shown by Emrich (1985) by stating that "Charcoal reacts with oxygen in air as a glowing red heat (primary combustion) to form colourless carbon monoxide gas which then burns with a blue flame with more oxygen from the air (secondary combustion to produce carbon dioxide gas). Due to the heat liberated by both of these reactions, the charcoal reaches a glowing red and radiates heat energy". However, Teak charcoal fire goes down in terms of heat released after a while because ash is deposited around the embers covering up to about 90 % of the total surface of the ember. This further confirms assertions made by Emrich (1985) that such ash depositions made on embers prevent oxygen from reaching the fire so it extinguishes by itself with time. This also means that when cooking with teak charcoal and left unattended, the fire may go out whiles the food is uncooked. Besides, the ash from teak charcoal can be flaky and prone to getting whipped up in the wind and onto food and even messing up the cook and the kitchen as a whole. A solution to this will be a blend with charcoals of other species such as Neem and or cassia. Nonetheless, Neem charcoal has a fair deposition of ash (45 %) whiles cassia has less deposition (30 %) making them charcoals that burn better and most freely without fanning.

Neem and cassia often drop their ashes off the embers and so may not be good to be used in downdraft gasifiers where ash deposits are likely to melt and flow under high temperatures to cause blocking of drafts. Unlike some charcoals such as those of *Magaritaria discoidea* that flur with fiery sparks, Neem sparks sporadically only upon high fanning whereas Teak and Cassia do not. This signifies that while Neem may have very little pockets of moisture, resins or gases that explode during burning cassia and teak do not and therefore are not dangerous to use.

Table 3: Some physical properties of charcoals of Neem, Teak and Cassia

PARAMETERS	**TREATMENTS**				
	NEEM	**TEAK**	**CASSIA**	**P-Value**	**LSD (0.05)**
Density (g/cm$_3$)	0.44 ± 0.009 **a**	0.43 ± 0.003 **a**	0.45 ± 0.015 **a**	0.187	
Burning Rate (g/min)	2.33 ± 0.17 **a**	3.73 ± 0.64 **b**	2.70 ± 0.17 **a**	0.016	0.84
Work done	5.06 ± 0.69 **b**	2.94 ± 0.53 **a**	4.85 ± 0.43 **b**	0.007	1.12
Easy to light	0.65 ± 0.05 **b**	0.59 ± 0.10 **b**	0.45 ± 0.05 **a**	0.033	0.14

Values bearing the same letter in a column are not significantly different at the 5% level by LSD

Table 4: Some burning properties of charcoals of Neem, Teak and Cassia

PARAMETERS	**TREATMENTS**		
	NEEM	**TEAK**	**CASSIA**
Burning freely without fanning	1	4	2
Ash deposition	3	1	4
Spitting / Sparking	3	4	4

CONCLUSION

The proximate analysis in this study shows that woods and charcoals of Neem, Teak and Cassia are good potential woody biomass feedstock. Making use of teak wastes from pole harvesting will also contribute significantly to the resource feedstock. They can be relied upon for sustainable energy and climate change mitigation. The high levels of carbons released during combustion will be compensated for by the fast regrowth of the stumps of the harvested trees in short time through sequestration.

Though there was no significant difference in the heating values of Neem, Teak and Cassia, it can be appreciated that Neem and Cassia will offer a cleaner and more sustainable burn because of their high calorific values. Meanwhile, Teak logging waste utilization will ameliorate the loss of vast amounts of biomass with good potential to sustain the woody bio-energy resource base and also mitigate climate change. Since Neem and Cassia grow fast enough in most Ghanaian localities with these excellent fuelwood characteristics, they have the potential to sustain wood fuel energy. Notwithstanding, taking advantage of the initial thinning wastes of Teak plantations will also serve the purpose of increasing the biomass feedstock and for climate change mitigation.

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