CSIR-Forestry Research Institute of Ghana

Rehabilitation of degraded forests for sustainable wood fuel production and climate change mitigation in the forest-savanna transition zone of Ghana.

Carbonization, Yield and Calorific Values of Wood Fuel Species in the Kintampo Forest District, Ghana

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ABSTRACT

The biomass and energy of six (6) tree species use for wood fuel production were studied. The tree species are among the most common species employed in wood fuel production in the forest transition zone of Ghana. The wood fuel products, fuel wood and charcoal were characterized for their suitability as fuel based on moisture content, volatile matter, ash content and fixed carbon. Among the species investigated Afzelia africana, *Khaya senegalensis*, *Pterocarpus erinaceus*, *Azadrachta indica* etc have the highest in green moisture content (mc), volatile matter (vm), ash content and fixed carbon content respectively. *Pterocarpus erinaceus* gave the highest gravimetric yield for charbonization, which correlated very well with green density of the tree species. Of the 6 tree species studied *Afzelia africana* has the highest calorific value of 5.17 kcal/g for fuel wood and *Azadrachta indica* the highest value of 6.79 kcal/g for charcoal. The indigenous tree species performed very well comparable to the exotic species based on the above properties, the indigenous species will be good species to be combined with the exotic species for use in agroforestry or wood fuel plantation to advance environment and improve biodiversity.

BACKGROUND

For the last decade, energy production has been one of the most important topics worldwide. Bioenergy is one of the most common and easily accessible energy (Phonphuak et al. 2006, Rabier et al. 2006, and Mckendry et al. 2002). In the developing countries, wood fuel is an important source of bioenergy (Okello et al, 2011). Commonly, wood fuels contribute between 50 to 90% of all energy consumed in these countries (Kemausuor et al. 2011) and at the same time represent about 60 to 80% of all wood consumed. Although wood fuels are perceived as cheap energy, provide a source of income for the rural and urban poor. Wood fuel, however, has been reported as the cause of forest degradation and eventually deforestation in some countries.

The overexploitation of the forest for charcoal production, firewood and furniture making has resulted in the depletion of forest reserves at a faster rate-estimated at 3% per year (Trossero et al. 2002). Emerhi, reported in 2011 that in sub-Saharan countries the overexploitation has resulted in shortage of preferred tree species for wood fuel (Emerhi, 2011) and due that the wood fuel producers have to travel longer distance to obtain prefer species (Marfo et al. 2014). It has led to the depletion of over 75% of the total forest cover and thus leading to environmental crises. The demand for bioenergy especially wood fuel is estimated to double between 2010 and 2030, a shift to sustainable production of biomass for wood fuel is urgently needed for the developing countries (Stout et al. 2001). The sustainability of biomass for wood fuel will gain even more importance including environmental, economic and societal aspects in the coming decades.

Switching from fuel wood to charcoal has proven to be more conducive for most urban lifestyles as charcoal is more convenient to use, produces less noxious fumes when burnt and is easier to transport. Even those households who have switched to fossil fuels (mainly LPG) continue to use wood fuel occasionally, often for specific traditional preparations such as tea, BBQ. According to the Ghana Living Standards Survey of 2008, about 52.9% households uses charcoal compare to 27.2% for fuel wood (GLSS5, 2008). Unlike fuel wood where dead wood, branches of trees are collected, for charcoal production wood is harvested from the forest through clear felling and selective.

Charcoal is a wood fuel made from burning wood in a low-oxygen environment (pyrolysis). The yield of charcoal is related to tree species (Santos et al. 2012, Briseno-Uribe et al. 2015), Marfo et al. (2014) listed the preferred wood species for wood fuel in Ghana. The declining of the preferred tree species in charcoal producing area may be as a result of the shift to charcoal in the urban areas (Obiri and Nutakor, 2011). The production of charcoal increased by 28% from 2001 to 2007 (FAO, 2012). The utilization of wood as a source of energy has significantly increased during the past decade.

The chemical composition of biomass changes between tree species (Nielsen et al., 2009; Brand et al., 2011, Zanuncio et al, 2014, Obuor et al., 2013) and affects the energy properties of wood fuel. High lignin and extractives content tree species are very good candidate for wood fuel (Zanuncio et al, 2013, Shebani *et al*. 2008; Silva *et al*. 2012). Volatile matter and fixed carbon content are the properties use to represent the combustible chemical composition of wood fuel. These components undergo combustion to release energy during use. Tree species with very high volatile matter and fixed component couples with low moisture and ash content are favorable for good wood fuel.

The sustainable biomass production for wood fuel will be very important going into the future. Thus, the objective of this study was to evaluate energy characteristics of indigenous tree species for in agroforestry and wood fuel plantation.

OBJECTIVE

The objectives of the study were:

1. Energy characterization of wood fuel tree species
2. Carbonization and charcoal yield potential of wood fuel species

METHOD AND MATERIALS

Collection of wood species

About six (6) tree species comprises of two (2) exotic tree species *Azadrachta indica* and *Senna siamea* and four (4) indigenous tree species of *Anogeissus leiocarpus*, *Afzelia africana*, *Pterocarpus erinaceus* and *Khaya senegalensis*. Small size log samples were collected from the Kintampo North district of Ghana. The study area falls under the forest transition zone of Ghana. The area produces large quality of wood fuel for the commercial capitals of Ghana i.e. Kumasi and Accra.

Density

Basic density and moisture content of the wood were determined based on the ASTM D2395-07a (R08). Dimensions of density and moisture content samples were 2 x 2 x 2 cm (width x thickness x length). Each cube was soaked in water until it sunk under water or swollen by means of vacuum impregnation with water. The basic density, based on the swollen volume and oven-dry mass of the wood sample, was determined by the hydrostatic or immersion method. The weight of a container and the water it contained were determined. The wood specimen was submerged in the water, and the mass of container plus water plus specimen was again determined. The increase in mass of the container and its contents was equal to the mass of water displaced by the specimen in grams and that was numerically equal to the volume of water in cm^3 displaced by the wood sample. The wood blocks were then oven-dried at 101 ± 3^oC to constant mass and the oven dry mass determined. The Green Moisture Content (GMC%) and the Basic Density (GD), Swollen Density (SD) and Green Density were estimated.

Physico-chemical properties of wood fuel

The wood and the charcoal cubes were milled and sieved to determine their quality by proximate analysis, including moisture content, volatile matter, ash content and fixed carbon content according to the international standard ASTM D 1762-84 (ASTM 2001a).

Moisture content

The moisture content (MC) was found by weighing 1.00 g of the sample into a crucible. The sample was placed in oven at 100±3°C until the mass of the sample was constant. The sample was cooled in a desiccator and reweigh.

$$Moisture\ Content\ (MC\%) = \frac{Initial\ weight\ of sample - weight\ of\ ovendry\ sample}{Initial\ weight\ of\ sample}$$

Volatile matter

The volatile matter (VM) was determined by weighing 1.00 g of the oven-dry sample into a crucible. The sample was then kept in a furnace at a temperature of 550°C for 5 min. The sample was cool in a desiccator and re-weigh.

$$Volatile\ matter\ (VM\%) = \frac{Weight\ of\ ovendry\ sample - weight\ of\ residue}{Weight\ of\ ovendry\ sample}$$

Ash content

The ash content was determined by returning the crucible into the furnace at 550°C for 30 min. The sample after combustion is removes and cools in a desiccator and re-weighs to obtain the weight of ash.

$$Ash\ Content\ (Ash\ \%) = \frac{(Weight\ of\ Ash)}{(Weight\ of\ oven-dry\ sample}$$

Fixed carbon content

The fixed carbon (FC) was computed using the formula below.

$$Fixed\ Carbon = 100\% - (Volatile\ matter + Ash\ Content)$$

Determination of Calorific values

The calorific value was determined with a bomb calorimeter using the milled and sieved wood and charcoal products; about 0.50 g of oven-dried sample: was completely combusted under a pressurized (3000kPa) oxygen atmosphere. The change in temperature of the system was use to calculate the calorific value**.**

Carbonization of the wood species

The carbonization was carried out in an electric furnace. The charcoal was produced from wood cubes (2 x 2 x 2 cm). The sample was heated until 450^{o}C for 30 min in the electric furnace at controlled presence of oxygen. The gravimetric yield was determined according to the following equation

$$G\ (\%) = \frac{Mchar}{Mbio} \times 100\%$$

Where,
G (%) = Gravimetric yield
Mchar = Mass of charcoal (g), and
Mbio = Mass of wood (g)

RESULTS AND DISCUSSION

The Table 1 shows the physical properties (MC% and density). The moisture content (MC) values of the 6 wood species measured ranged from 45.03% (*Azadrachta indica*) to 80.62% (*Afzelia africana*). The highest wood density was observed for *Anogeissus leiocarpus* of 1.10 gcm^{-3}, where the lowest value was recorded for *Khaya senegalensis* of 0.89 gcm^{-3}.

Table 1: Physical properties of six (4) indigenous and two (2) exotic wood fuel tree species

	Scientific names	Local Names	Green MC (%)	GD (g/cm^3)	SD (g/cm^3)	BD (g/cm^3)
Exotic Species	*Azadrachta indica*	Cassia	45.03	0.98	1.09	0.67
	Senna siamea	Neem	74.18	1.02	1.09	0.59
Indigenous Species	*Anogeissus leiocarpus*	Krayie (Rosewood)	61.98	1.10	1.13	0.68
	Afzelia africana	Papao	80.62	1.03	1.12	0.57
	Pterocarpus erinaceus	*Kane*	48.20	1.08	1.16	0.73
	Khaya senegalensis	Mahogany	59.10	0.89	1.09	0.56

The quality of the wood and charcoal as wood fuel was determined as described above. The result of the proximate analysis is reported in Table 2 and Table 3 for wood and charcoal respectively. The samples were stored under shed for eight (8) weeks and the moisture content before quality assessment shows *Khaya snegalensis* with the highest value at 11.24 and *Afzelia africana* with 9.25% as the lowest. High moisture content lowers the effective heating value of wood fuel since a portion of the heat of combustion is utilized in evaporating the contained moisture. It is highly desirable, therefore, that the moisture content, except for certain purposes, be kept as low as possible for a wood fuel. The high moisture content for Khaya senegalensis even after drying will affect the gross calorific value.

The assessments show volatile matter ranges from 33.52 to 69.68% with *Azadrachta indica* having the lowest and *Khaya senegalensis* the highest. The volatile matter was very high in wood fuel and after carbonization the volatile matter reduced considerably. The high volatile matter content indicates that during burning almost all the components will burn to produce more energy.

The fixed carbon content is the percentage solid fuel available after volatile matter is removed. The fixed carbon was higher for charcoal compared to fuel wood as expected for the same species. The fixed carbon gives an estimate of the gross calorific value and is the main component that burns to produce energy. The fixed carbon content ranged from 29.64 to 66.29% in fuel wood and 66.8 to 76.8% for charcoal. This may indicate the charcoal will have more carbonous material to burn to generate energy during combustion compared to the fuel wood.

The ash content is the total inorganic component of the wood fuel. The Ash content is an important factor for determining the quality of wood fuel since ash is non-combustible and wood fuels with low ash content are preferred to fuel with high ash content. The higher the ash content of wood fuel, the lower the calorific value (Loo et al. 2008). The wood fuel with low ash content is preferred, this work found *Azadrachta indica* as the fuel wood with the lowest ash content of 0.20% and *Anogeissus leiocarpus* with 2.60% as the highest. The preference for wood fuel with low ash content is also important health wise, the ash so produced after combustion may contain other heavy metals that will be harmful when inhaled.

The carbonization of wood to charcoal is an age long technique. The process known as pyrolysis convert wood under low oxygen into carbonous product that reduces the size of wood fuel and concentrate its energy. The average gravimetric yield of charcoal was about 30.93% with *Pterocarpus erinaceus* having the highest with *Khaya senegalensis* with the lowest of 29.20%.

Gross calorific value (GCV) is the most important fuel property (Oladeji et al. 2010). It depends on the chemical composition and moisture content. The GCV of the both fuel wood and charcoal were very high for the species investigated. The gross calorific value of the six (6) wood species studied ranged from 3.39 to 5.17 kcal/g for fuel wood and from 6.07 to 6.79 kcal/g. The GCV is similar to those reported for charcoal from other tree species (Zanuncio et al. 2013). As expected the GCV for charcoal was higher compared to fuel wood and hence the switch from fuel wood to charcoal in urban areas.

Table 2: Moisture content, volatile matter (VM), ash, fixed carbon (FC) and gross calorific value (GCV) of fuel wood from the species studied.

Scientific names	Local Names	MC (%)	VM (%)	Ash (%)	FC (%)	GCV (kcal/g)
Azadrachta indica	Neem	11.24	33.52	0.20	66.29	3.39
Senna siamea	Cassia	10.55	62.41	1.08	36.51	4.47
Anogeissus leiocarpus	Krayie (Rosewood)	7.58	35.25	2.60	62.15	5.09
Afzelia africana	Papao	9.25	58.66	1.32	40.02	5.17
Pterocarpus erinaceus	Kane	10.74	59.12	2.67	38.21	4.47
Khaya senegalensis	Mahogany	9.96	69.68	0.69	29.64	4.94

Table 3: Moisture content, volatile matter (VM), ash, fixed carbon (FC), Gravimetric yield, and gross calorific value (GCV) of charcoal from the species studied.

Scientific names	Local Names	MC (%)	VM (%)	Ash (%)	FC (%)	Gravimetric Yield (%)	GCV (kcal/g)
Azadrachta indica	Neem	3.56	22.6	0.600	76.8	29.90	6.79
Senna siamea	Cassia	1.61	30.2	2.75	67.0	29.20	6.48
Anogeissus leiocarpus	Krayie (Rosewood)	2.26	26.2	6.78	67.0	34.10	6.38
Afzelia africana	Papao	1.71	26.7	6.44	66.8	29.90	6.07
Pterocarpus erinaceus	Kane	8.00	24.1	5.63	70.2	33.30	6.69
Khaya senegalensis	Mahogany	0.970	19.3	6.05	74.6	29.20	6.53

Table 4: Correlation coefficient between Volatile matter (VM), Ash content, Fixed carbon (FC) and, Gravimetric yield and Gross calorific value (GCV) of charcoal.

	Basic Density		Fixed carbon		Volatile matter		Ash Content	
GY	0.8005		0.3271		0.0797		0.4544	
GCV	0.5608	0.3903*	0.7205	0.4728*	0.4270	0.4385*	0.6161	0.4894*

Note: *indicate data for fuel wood.

The gravimetric yield correlated very well with the basic density Table 4 but not so well with swollen and green density. The wood with high basic density will produce more charcoal and this support the use of denser wood for charcoal production. There was also positive correlation between density and gross calorific value.

CONCLUSION

The introduction of exotic tree species with faster growth rate into developing countries to produce wood fuel was a laudable ideal, it have the disadvantage of changing the ecosystem and biodiversity. The results here emphasize that a single basic property is not sufficient to justify selection of the most suitable wood fuel species. However, it confirms the view of most charcoal producers that density and moisture are good indicators for the gravimetric yield of charcoal from a species. This study therefore lays an important premise for selection of these indigenous tree species for possible inclusion into reforestation, afforestation, and agroforestry initiatives in Ghana to address wood fuel shortage. The indigenous tree species performed very well comparable to the exotic species based on the above properties, the indigenous species will be good species to be combined with the exotic species for use in agroforestry or wood fuel plantation to advance environment and improve biodiversity.

REFERENCE

1. Phonphuak, N, Thiansem, S., *Constr. Build. Mater.* 29, 612–618 (2012)
2. Rabier, F, Temmerman, M, Bohm, T, Hartmann, H, Jensen, P. D, Rathbauer, J, Carrasco, J, Fernandez, M., *Biomass Bioenergy*, 30, 954–963 (2006)
3. McKendry, P., *Resource Technol.* 83, 37–46 (2002)
4. Okello, B. D., O'connor, T. G., Young, T. P., *Forest Ecology and Management,* 142, 143–53, 2001.
5. Kemausuor, F., Obeng, G.Y., Brew-Hammond, A., Duker, A., *Renew. Sustain. Energy Rev.* 15, 5143–5154, 2011.
6. Trossero, M. A., *Unasylva Newsletter 211*, vol. 53. FAO, Rome, 2002.
7. Emerhi, E. A., *Adv. Appl. Sci. Res.* 2(6), 236–246 (2011)
8. Obiri, D. B., Nunoo, I., Obeng, E., Owusu, W. F., Marfo, E., 2014, *Technical Report TROPENBOS International*, 2014.
9. Stout, B.A and Best, G., *Journal of scientific research and development*, Vol. III, 19p, 2001.
10. GLSS5 (2008) published by Ghana Statistical Service.
11. Briseno-Uribe, K., Carrillo-Parra, A., Bustamante-garcia, V., Gonzalez-Rodeiguez, H., Foroughbac, R., *International Journal Of Green Energy*,12, 961-969, 2015
12. Santos, L. C., Carvalho, A. M. M. L., Pereira, B. L. C., Oliveira, A. C., Carneiro, A. C. O., and Trugilho, P. F., Revista *Árvore* 36(5), 971-980, 2012.
13. Obiri, D. B. and Nutaor, E., *Technical Report INBAR*, China.
14. FAO 2012. *Forestatistic*. Website: http://faostat3.fao.org/browse/F/FO/S.
15. Ye *et al*. 2007
16. Nielsen, N. P. K. et al., 2009, Wood Fiber Science, v.41, n.4, p.414-425.
17. Brand, M. A., Muñiz, G. I. B., Quirino, W. F., and Brito, J. O., 2011, *Biomass and Bioenergy,* 35(7), 2581-2588.
18. Zanuncio, A. J., Carvalho, G. A., Trugilho, F. P., and Monteiro, C. T., 2014, *Revista Árvore*, 38(2), 369-374, 2014.
19. Zanuncio, A. J, Monteiro, C. T, Lima, T. J, Andrade and carvalho, G. A., *BioResources,* 8(4), 5159-5168, 5159, 2013.
20. Obuor, M. N. and Githiomi, J., *Africa Journal of Agricultural Research*, 8(21), 2476-2481, 2013.
21. Shebani, A. N., Van Reenen, A. N., and Meincken, M., *Thermochimica Acta*, 471(1), 43-50, 2008.
22. Silva, L. S., González, D. G., Villaseñor, J., Sánchez, P., and Valverde J. L., *Bioresource Technology,* 109, 163-172, 2012.
23. Loo, S. V, Koppejan, J., *Earthscan*, London, 2008.
24. American Society for Testing and Materials (ASTM). 2001a. *D 1762*- 84 *standard test method for chemical analysis of wood charcoal.* West Conshohocken, PA: ASTM.
25. Oladeji, J. T., *Pac. J. Sci. Technol.* 11(1), 101–106 (2010).