IJETST- Vol.||05||Issue||02||Pages 6517-6525||February||ISSN 2348-9480 2018

Open access Journal International Journal of Emerging Trends in Science and Technology

IC Value: 76.89 (Index Copernicus) Impact Factor: 4.849 DOI: https://dx.doi.org/10.18535/ijetst/v5i2.01

Characterization of Fuelwood Species in the Guinea Savanna Ecological Zone of Ghana

Authors

Joseph Asomani*[1], Martin Amoah[2]

[1*]College of Technology Education, University of Education, Winneba PO Box 1277 Kumasi Ghana

Tel.+233263266430, Email: *joeasomani13@gmail.com*

[2]College of Technology Education, University of Education, Winneba P O Box 1277 Kumasi Ghana

Tel. +233209755968, Email: *akwasiamponsah07@gmail.com*

Abstract

Indigenous plant species from the guinea savanna ecological zone are an important biomass source. However, their fuel characteristics and the mineral concentrations are less studied. The present study investigated the fuel characteristics and the mineral concentrations of 3 tree and 10 shrub species from the guinea savanna ecological zone of Ghana. The aim was to explore their potential for biomass production. Moisture content (MC), basic density (BD) and the net calorific value (NCV) as well as the C, N, ash content and minerals (Na, Fe, Zn, Cu, Cd, Pb, As, Mg, K, Ca, P) were determined in triplicate. NCV ranged between 16.02 ± 0.11 and 18.75 ± 0.40 $MJ.kg^{-1}$. Ten of the 13 species showed high ash contents in excess of 3%.All the species exhibited sufficient heating values to warrant their usage as biomass feedstock. However, higher slagging, fouling and corrosion potentials would be exhibited by the species due to their higher ash contents

Keywords: *Guinea savanna; tree and shrub species; calorific value; ash content; biomass/ash content ratio; minerals composition; fuel value index.*

Background

Ghana is one of the fastest growing economies in West Africa. It attained the lower-middle-income status in 2012 and in 2014 recorded a real GDP growth of 6.9 %. The 2010 census recorded a population of 24.7 million which represents an increase of about 34 % over the 2000 figure[1]. With the expanding economy coupled with the growing population and urbanization, energy demand in the country has increased significantly and providing clean, reliable and affordable energy to meet the growing energy demand for both domestic and industrial consumption remains a top priority of the Government of Ghana (GoG). Moreover, in order for Ghana to achieve macro-economic stability and grow the economy to a full middle income status by 2020, its total energy supply has to grow significantly[2].

The northern part of Ghana lies within the rather fragile guinea savanna agro-ecological zone and over 80% of the population depends on small-scale agriculture for their livelihoods[3]. The indigenous tree and shrub species in this zone play a vital role in the socio-economic development of the country as fuelwood species in this zone are mostly preferred by most Ghanaian homes[4] and about 90% of charcoal produced in Ghana comes from these species[5]. However, on account of factors such as strong demand for the species in this zone and other anthropogenic activities including agricultural expansion (permanent cultivation, cattle ranching, shifting cultivation/traditional slash and burn) and annual wild fires, the woody biomass stock in this zone is rapidly dwindling. The Government of Ghana is committed to addressing this problem by increasing the biomass stock through afforestation, re-forestation and the adoption of agro forestry systems in the degraded lands [4,6]. About 300,000 hahas been identified in the guinea savanna ecological zone as potential land area for the establishment of forest plantation. Under the project, the following activities are to be undertaken:

enrichment planting (agro forestry systems), using both indigenous and exotic tree species; maintenance of 100,000 ha of enrichment planting sites within under stocked /convalescence forest reserves; and establishment and maintenance of 50,000 ha of fuelwood (energy plantation) [6].

To embark on such a project, there is the need to know which of the indigenous or exotic plant species have the best fuelwood characteristics so that they could be considered as candidates for the plantation. Again, the choice of a particular plant species for biomass or biofuel production should not only be based on their energetic content but more importantly the concentration levels of minerals are crucial considerations[7]. As information on fuel characteristics as well as the mineral concentrations of the various indigenous and exotic plant species in the guinea savanna zone of Ghana is not available, the present study is aimed at evaluating the calorific values as well as the fuelwood value index of thirteen important plant species in the guinea savanna ecological zone of Ghana. Additionally, in order to understand the health implications for using the indigenous plant species as fuel, we also aim at evaluating the concentration levels of some selected minerals. These plant species were selected on the basis of their preference for fuelwood by the local communities and therefore have the potential to be selected as candidates for the plantation project. The afforestation and reforestation project is expected to improve the socio-economic situation of the rural communities in that ecological zone.

Materials and Methods

Samples

Tree and shrub species (diameter range: 14-20 cm) of *D. microcarpum, A. leiocarpus D. oliveri, T. glaucescens, P. thonningii, A. africana P. clappertonia, M. discoidea, M. inermis F. ovata, C. febrifuga, V. paradoxa*and *E. senegalensis* were felled from the guinea savanna ecological zone of Ghana during September, 2014. Five discs of 60cm long were cut from the bottom, middle, top and the branches from each tree and shrub species. They were immediately labeled and packed in air-tight plastic bags to prevent loss of moisture. Two centimeter discs were randomly cut from each of the 60 cm long discs and oven-dried at 103 ± 2°C. The oven-dried discs were pulverized to fine powder using a high energy Ball Mill RETSCH SM 100. The powder was then sieved to obtain a fineness of 80nm. The powder was again oven-dried for the determination of ash content and calorific values.

Moisture content

The moisture content of the wood samples was determined according to the method described by [8] and [9]. Prior to pulverization of the 2cm discs, their green weight (W_g) and oven-dried weight (W_{OD}) were determined using an electronic balance with accuracy of 0.01g. Moisture content (MC) of the wood samples was determined using Eq. 1.

$$\text{MC} = \left(\frac{W_g - W_{OD}}{WOD}\right) \times 100 \qquad \text{Eq.1}$$

Basic Density

The discs were measured in green condition using electronic vernier caliper of 0.1 mm accuracy and they were then placed in an oven (at 103 ± 2℃) until their weight loss became constant. Basic density (BD) was determined using Eq. 2.

$$\text{BD} = \frac{W_{OD}}{V_g} \qquad \text{Eq. 2}$$

where, W_{OD} is the oven-dry weight and V_g is the wet volume of the sampled discs.

Ash content

The ash content was determined according to TAPPI standard T 2II. Oven-dried wood pellets were weighed before placing in a muffle furnace and ignited at 525°C for 4 hours. The percentage ash was estimated according to Eq. 5.

$$\text{Ash content(\%)} = \frac{\text{Weight of ash} \times 100}{\text{Weight of oven-dried pellet samples}} \qquad \text{Eq. 5}$$

Calorific value and fuel value index

The calorific value of oven-dried powdered wood samples was determined with Parr 6100 Compensated Jacket Bomb Calorimeter. About 10g of powdered wood samples were pelleted and oven-dried and was completely combusted using oxygen charging pressure of about 40 atm. The fuel value index (FVI) was estimated using the formula described by [10] and [11] with inclusion of MC (Eq. 3) and the formula by [12] and [13] where MC was not considered (Eq. 4).

$$FVI = \frac{NCV \times BD}{A_c \times MC} \qquad \text{Eq. 3}$$

Where *NCV* is the calorific value ($MJkg^{-1}$), *BD* is basic density, A_c is the ash content and MC, the moisture content.

$$FVI = \frac{NCV \times BD}{A_c} \qquad \text{Eq. 4}$$

Determination of Carbon, Nitrogen and minerals

Carbon (%) was determined using the loss of weight on ignition method and nitrogen (%) was determined by the Kjeldahl method. The following minerals: Na, Fe, Zn, Cu, Cd, Pb, As, Mg, K, Ca, P were determined using Atomic Absorption Spectroscopy (AAS).

Data Analysis

Data were processed and analyzed using Microsoft Excel and Statistical Package for Social Sciences (SPSS) software (IBM SPSS Statistics 21). Pearson's correlation coefficients were used to assess the significance of correlation among the minerals. All statistical tests were two-tailed and $p < 0.05$ was considered statistically significant.

Results and Discussion

Fuel properties of the tree and shrub species

The lowest and the highest basic density was found in *M. inermis* (0.38 ± 0.03 $g.cm^{-3}$) and *A. leiocarpus* (0.61 ± 0.06 $g.cm^{-3}$), respectively (Table 1). Plant species with higher density are preferred as biomass feedstock because they are more densified and therefore have higher energy content per unit volume and also burn more slowly than those with lower density [14,15,16]. In this study, however, no significant correlation was found between the basic density and the calorific value of the indigenous plant species (Table 2). Similar observation was made by [12] in their study of ten fast-growth species in Costa Rica. These findings thus suggest that the heating values of the plant species depend on other factors such as the ash content, the biomass/ash content ratio, the moisture content and the chemical composition.

The ash content was relatively high among the studied species: 6.81% in *P. thonningii*, 5.88% in *A. leiocarpus*, 5.73% in *T. glaucescens* and 5.22% in *M. discoidea*. Hardwoods are known to contain a higher percentage of ash than softwoods [7,8] and in this study, 10 of the 13 plant species showed a higher than the recommended ash content by the European Pellet Council [17,18,19]. Plant species whose ash contents were within the range recommended by the European Pellet Council are *C. febrifuga* (1.34%), *D. microcarpum* (1.41%) and *E. senegalensis* (2.73%) (Table 1). The result of the present study is in agreement with earlier findings that the calorific value of plant biomass decreases with increasing ash content [12,20,21]. The relationship between the calorific values and the ash contents of the species found in the present study is strong and negative (Pearson r = - 0.754; Table 2) implicating that plant species with high ash content may be less desirable as fuel.

Table 1 Calorific value and other fuel characteristics of thirteen plant species in the Guinea savanna ecological zone of Ghana

Plant species	Calorific value ($MJ.kg^{-1}$)	Basic density ($g.cm^{-3}$)	Ash (%)	Biomass/ash ratio	Moisture (%)
D. microcarpum	18.41 ±1.30	0.45 ± 0.03	1.41 ± 0.29	35.66 ± 5.62	109.82 ± 11.10
A. leiocarpus	16.47 ± 1.91	0.61 ± 0.06	5.88 ± 3.59	15.59 ± 4.46	43.95 ± 32.67
D. oliveri	17.14 ± 0.23	0.49 ± 0.03	3.89 ± 1.28	15.27 ± 3.57	99.00 ± 7.51
T. glaucescens	16.02 ± 0.11	0.44 ± 0.03	5.73 ± 2.61	10.10 ± 2.63	99.03 ± 7.84
P. thonningii	17.04 ± 0.71	0.49 ± 0.06	6.81 ± 2.37	8.66 ± 0.74	96.40 ± 10.53
A. Africana	16.78 ± 0.51	0.56 ± 0.03	3.84 ± 1.93	19.90 ± 4.45	80.96 ± 5.18
P. clappertonia	17.54 ± 0.65	0.51 ± 0.06	4.19 ± 0.92	13.84 ± 3.84	89.18 ± 4.20
M. discoidea	16.26 ± 0.60	0.57 ± 0.06	5.22 ± 3.11	16.00 ± 4.13	95.64 ± 5.55
E. senegalensis	18.75 ± 0.40	0.49 ± 0.03	2.73 ± 0.52	19.63 ± 1.85	97.91 ± 12.05
M. inermis	16.83 ± 0.78	0.38 ± 0.03	3.87 ± 1.27	11.60 ± 1.06	147.71 ± 13.18
F. ovata	17.00 ± 0.47	0.40 ± 0.03	4.76 ± 1.25	9.64 ± 1.43	163.03 ± 7.37
C. febrifuga	17.89 ± 0.40	0.47 ± 0.06	1.34 ± 0.51	43.99 ± 12.85	112.04 ± 19.24
V. paradoxa	17.23 ± 0.42	0.47 ± 0.04	3.13 ± 0.65	16.71 ± 1.41	102.33 ± 18.85

Another important quality characteristic of plant species for biomass is the biomass/ash content ratio. Plant species with higher biomass/ash content ratios are more desirable as biomass than those with lower ratios. Biomass/ash content ratio was highest in *C. febrifuga*, followed by *D. microcarpum*, *A. Africana* while the lowest was found in *P. thonningii*. The correlation between the calorific value and the biomass/ash content ratio was positive and significant (Pearson r = 0.587, $p < 0.01$, Table 2) suggesting that biomass/ash content ratio may be a good predictor of the heating value of the species. From the perspective of biomass/ash content ratio, the four most desirable candidates for plantation or agro forestry are *D. microcarpum*, *C. febrifuga*, *A. africana*, and *E. senegalensis*.

Moisture content (MC) is another important quality characteristic of wood fuel. Plant species with higher MC is less desirable for biomass for two reasons. First, energy is needed to expel the moisture; the higher the MC, the less efficient is the wood as fuel since the net calorific value for heating is reduced [22]. Second, woods with higher MC have transportation cost implications. The MC of the studied species ranged from 44% for *A. leiocarpus* to 163% for *F. ovata*. Woody biomass with high MC has more voids per unit volume and therefore becomes less dense when the moisture is removed. As expected, a negative correlation was found between the basic density and the MC (Pearson r = -0.903, $p < 0.01$; Table 2). This trend was also found in the study by [20]. The relatively lower basic density of the plant species may be due to their exceptionally higher MC.

Calorific values of tree and shrub species

The calorific values of the thirteen plant species varied between 16.02MJkg^{-1} for *T. glaucescens* and 18.75MJkg^{-1} for *E. senegalensis* (Table 1). According to EN-14961-2, wood pellets for non-industrial use should have calorific values in the range 16.0-19.0 MJkg^{-1} [17,18,19]. On the basis of the calorific values, three groups of plant species were identified. The first group with the highest values is made up of the following plant species in decreasing order of magnitude: *E. senegalensis* and *D. microcarpum*. The next group with intermediate values comprises *C. febrifuga*, *P. clappertonia*, *V. paradoxa*, *D. oliveri*, *P. thonningii* and *F. ovata*. The third group with the lowest calorific values, also in decreasing order of magnitude, is made up of *M. inermis*, *Aafricana*, *A. leiocarpus*, *M. discoidea*and *T. glaucescens*.

Fuelwood value index

Fuel value index (FVI) is an important fuel characteristic that has been used to screen desirable fuelwood species [12,14,20]. Opinions are divided regarding the inclusion of MC in the evaluation of fuelwood value index (FVI). Researchers who exclude MC in the evaluation of FVI [12, 13] argue that MC cannot be considered as an intrinsic value of plant species for fuel because of the variations that exist among the various plant organs (stem, branches, bark). Moreover, there is seasonal variation of MC. Other researchers[10,11] consider MC in the evaluation of the FVI.

In this study, the FVI has been estimated using the two scenarios and found the following: (a) the FVI ranges 873-5592 when MC is considered and 1228-6264 when MC is not considered; (b) a strong, positive and significant relationship exists between the two scenarios (Pearson r = 0.900, $p < 0.01$) suggesting that both approaches are identical; (c) both FVIs are positively and significantly related to biomass/ash content ratio confirming the positive influence of biomass/ash content ratio on fuel quality; (d) ash content was negatively and significantly associated with both FVIs, also suggesting that fuel quality is negatively influenced by the ash content; (e) the association between the MC and the FVI was negative and significant at $p < 0.1$, implicating that MC may be an important fuelwood property (Table 2); (f) *C. febrifuga*a nd *D. microcarpum* had the highest FVI in both scenarios. Other plant species with relatively high FVI values are *A. leiocarpus*, *E. senegalensis*, *A. africana*, and *V. paradoxa*(if MC is considered as an important fuelwood characteristic; Fig. 1a) and *E. senegalensis*, *V. paradoxa*, *A. africana* and *D. oliveri* (if MC is not considered as an important characteristic; Fig 1b).

Table 2 Pearson correlation between FVI and other wood properties

		1	2	3	4	5	6	7
1	Density ($g.cm^{-3}$)	1						
2	Biomass-ash ratio	0.032	1					
3	Calorific value ($MJ.kg^{-1}$)	-0.210	0.587**	1				
4	Ash content (%)	0.272	-0.824***	-0.754***	1			
5	MC (%)	-0.903***	-0.010	0.163	-0.285	1		
6	FVI^{+}	0.212	0.519**	0.273	-0.336*	-0.259	1	
7	FVI^{++}	0.133	0.562**	0.053	-0.342*	-0.148	0.900***	1

***Significant at $p < 0.01$ (two-tailed); **Significant at $p < 0.05$ (two-tailed). *Significant at $p < 0.1$ (two-tailed)
FVI^{+} means estimated with MC; FVI^{++} means estimated without MC

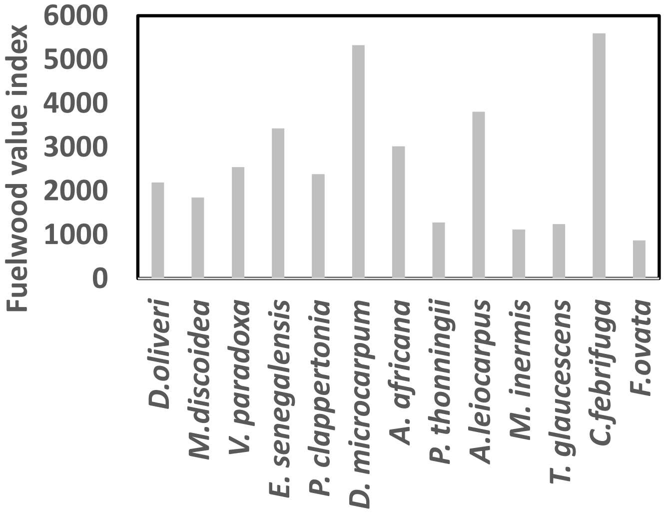

Fig 1a Fuelwood value index of thirteen plant species in the Guinea savanna ecological zone of Ghana with the moisture content

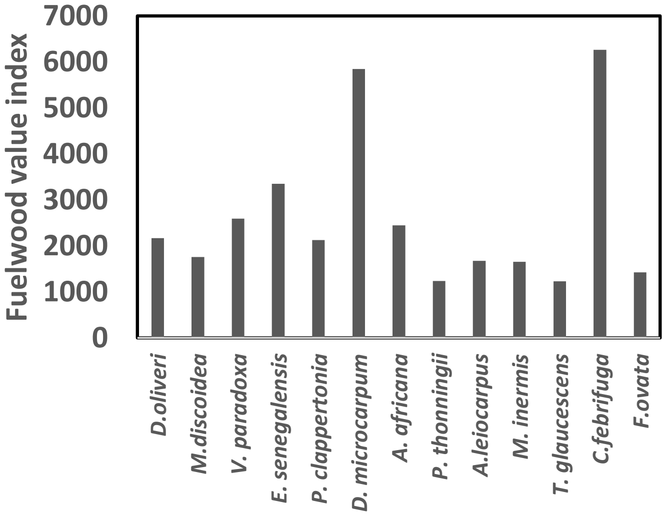

Fig 1b Fuelwood value index of thirteen plant species in the Guinea savanna ecological zone of Ghana without the moisture content

Ash forming elements in the tree and shrub species

The principal ash-forming mineral elements in wood are Ca, K and Mg[9]. As the ash forms the incombustible component of woody biomass, its presence is not desirable. Again, as the ash softening temperature is raised by Ca and Mg and lowered by Na and K [21], higher concentrations of Ca and Mg in the woody biomass is desirable. Ca concentration was highest in *P. thonningii* (1.57 ± 0.75 $mgkg^{-1}$) and lowest in *D. microcarpum* (0.22 ± 0.07 $mgkg^{-1}$)

(Table 3). In the same way, the concentration level of Mg was highest and lowest in *P. thonningii* (0.27 ± 0.06 mgkg^{-1}) and *C. febrifuga* (0.07 ± 0.03 mgkg^{-1}), respectively. The highest concentrations of Na and K were found in *M. inermis* (0.41 ± 0.06 mgkg^{-1}) and *T. glaucescens* (0.37 ± 0.07 mgkg^{-1}), respectively, whereas the lowest were in *T. glaucescens* (0.14 ± 0.04mgkg^{-1}) and *E. senegalensis* (0.10 ± 0.02mgkg^{-1}).

As the ash that is not emitted as fly ash is deposited in the combustion chamber and may corrode the metals, the melting point of the deposited ash is an important fuel characteristic[23]. During combustion, the alkaline earth metals (Mg and Ca) are known to increase the ash melting point whereas the alkali metals (Na and K) decrease the melting point of the ash [21]. Therefore, higher Ca/K, Ca/Na, Mg/K, and Mg/Na ratios are desirable characteristics of plant species for biofuel production. On the basis of this, *P. thonningii*, *M. discoidea*, and *A. Africana* are more desirable as biomass feedstock whereas *D. microcarpum* tend to be less desirable (Table 3). For the Ca/Na ratio, the highest was in *T. glaucescens*, followed by *M. discoidea*, *P. thonningii* and the lowest was found in *M. inermis*. *A. leiocarpus*, *D. microcarpum*, and *C. febrifuga* were highest in Mg/K ratio while the lowest was in *V. paradoxa*. As for Mg/Na ratio, *P. clappertonia*, *T. glaucescens*, *P. thonningii* and *D. oliveri* had the highest and the lowest was found in *D. microcarpum*. It is worthy of note that because of its high melting point, the presence of Si in biomass feedstock does not in itself pose a problem; however, in the presence of K and Ca, Si easily reacts with them forming alkali silicates that soften at low temperatures [21].

Mineral concentrations in different tree and shrub species

A. africana showed the highest concentration in N (0.53 ± 0.09mgkg^{-1}) and As (0.04 ± 0.01mgkg^{-1}). The highest concentrations of P (0.14 ± 0.04mgkg^{-1}) and Pb (4.50 ± 1.79mgkg^{-1}) were found in *T. glaucescens* whereas Cu and Cd concentrations were highest in *A. leiocarpus* (5.78 ± 0.99mgkg^{-1} and 1.96 ± 0.40 mgkg^{-1}, respectively). Zn was highest in *D. microcarpum* (26.25 ± 12.45mgkg^{-1}) and lowest in *P. clappertonia* (2.19 ± 0.35 mgkg^{-1}). Overall, the mineral concentrations in the plant species were lower than the recommended threshold values. The only exception is Cd whose concentration levels were above the recommended threshold of 0.5mgkg^{-1} [16]. Among the plant species studied, only *F. ovata* (0.45± 0.27 mgkg^{-1}) and *P. clappertonia* (0.48 ±0.23 mgkg^{-1}) showed the concentration levels of Cd lower than the recommended threshold (Table 4). Overall, the concentrations of the minerals were in the order: Fe > Zn > Cu >Pb> Cd >As

Table 3 Composition of ash-forming mineral elements (mgkg^{-1}) in the 13 tree and shrub species

Plant species	Na	Ca	Mg	K	Ca/K	Ca/Na	Mg/K	Mg/Na
D. microcarpum	0.21 ± 0.05	0.22 ± 0.07	0.09 ± 0.02	0.28 ± 0.04	0.81 ± 0.25	1.08 ±0.31	0.40 ± 0.07	0.43 ± 0.14
A. leiocarpus	0.32 ± 0.08	0.57 ± 0.13	0.23 ± 0.04	0.35 ± 0.03	1.64 ± 0.44	1.82 ±0.55	0.42 ± 0.10	0.74 ± 0.16
D. oliveri	0.17 ± 0.09	0.78 ± 0.39	0.18 ± 0.03	0.27 ± 0.04	3.07 ± 1.64	4.94 ±2.44	0.28 ± 0.12	1.20 ± 0.35
T. glaucescens	0.14 ± 0.04	1.42 ± 0.77	0.22 ± 0.14	0.37 ± 0.07	3.69 ± 1.46	11.14 ± 7.65	0.16 ± 0.06	1.70 ±1.39
P. thonningii	0.19 ± 0.05	1.57 ± 0.75	0.27 ± 0.06	0.20 ± 0.12	10.88 ± 7.89	8.19 ± 2.87	0.19 ± 0.05	1.47 ±0.48
A. africana	0.26 ± 0.06	0.85 ± 0.35	0.14 ± 0.04	0.16 ± 0.05	5.29 ± 1.67	3.48 ±1.84	0.19 ± 0.07	0.56 ± 0.09
P. clappertonia	0.16 ± 0.05	0.87 ± 0.21	0.26 ± 0.11	0.25 ± 0.05	3.57 ± 1.14	6.33 ± 0.87	0.29 ± 0.05	2.00 ±1.51
M. discoidea	0.16 ± 0.04	1.34 ± 0.92	0.13 ± 0.02	0.19 ± 0.08	7.26 ± 3.51	9.12 ± 6.90	0.13± 0.06	0.88 ± 0.33
E. senegalensis	0.31 ± 0.10	0.41 ± 0.05	0.13 ± 0.03	0.10 ± 0.02	4.33 ± 0.90	1.47 ± 0.44	0.32 ± 0.10	0.47 ± 0.19
M. inermis	0.41 ± 0.06	0.42 ± 0.22	0.18 ± 0.02	0.23 ± 0.04	1.82 ± 1.00	1.00 ± 0.48	0.54 ± 0.23	0.45 ± 0.06
F. ovata	0.30 ± 0.03	0.78 ± 0.34	0.16 ± 0.03	0.30 ± 0.03	2.57 ± 0.91	2.60 ± 1.07	0.22± 0.08	0.53 ± 0.13
C. febrifuga	0.16 ± 0.03	0.31 ± 0.16	0.07 ± 0.03	0.19 ± 0.04	1.69 ± 0.98	1.90 ± 0.82	0.32± 0.21	0.48 ± 0.18
V. paradoxa	0.37 ± 0.07	1.38 ± 0.68	0.18 ± 0.11	0.33 ± 0.05	4.26 ± 2.18	3.67 ± 1.49	0.15± 0.08	0.48 ± 0.21

Table 4 Mineral concentration in the 13 tree and shrub species

Plant species	N	P	Fe	Pb	Zn	Cu	Cd	As
D. microcarpum	0.31 ± 0.02	0.05 ± 0.03	0.95 ± 0.24	0.86 ± 0.28	26.25 ± 12.45	3.58 ± 0.46	1.79 ± 0.18	0.02 ± 0.01
A. leiocarpus	0.39 ± 0.12	0.08 ± 0.02	2.67 ± 1.69	2.67 ± 1.77	7.52 ± 3.57	5.78 ± 0.99	1.96 ± 0.40	0.01± 0.00
D. oliveri	0.35 ± 0.02	0.08 ± 0.02	12.14 ± 3.35	2.78 ± 1.84	6.11 ± 0.80	1.66 ± 0.75	1.14 ± 0.33	0.03 ± 0.007
T. glaucescens	0.46 ± 0.04	0.14 ± 0.04	13.99 ± 3.59	4.50 ± 1.79	7.02 ± 0.49	2.02 ± 0.89	0.85 ± 0.17	0.01 ± 0.004
P. thonningii	0.52 ± 0.04	0.07 ± 0.02	17.15 ± 4.80	3.03 ± 1.38	13.11 ± 6.13	3.14 ± 0.31	0.98 ± 0.16	0.03 ± 0.010
A. africana	0.53 ± 0.09	0.06 ± 0.01	12.64 ± 2.90	1.99 ± 0.77	2.72 ± 0.61	4.16 ± 1.12	1.29 ± 0.29	0.04 ± 0.010
P. clappertonia	0.52 ± 0.08	0.04 ± 0.01	11.84 ± 4.87	3.93 ± 2.03	2.19 ± 0.35	2.63 ± 1.36	0.48 ± 0.23	0.01± 0.002
M. discoidea	0.41 ± 0.04	0.06 ± 0.02	13.90 ± 6.51	4.47 ± 2.15	6.68 ± 0.78	4.33 ± 0.92	0.87 ± 0.21	0.02 ± 0.009
E. senegalensis	0.50 ± 0.05	0.03 ± 0.01	18.83 ± 5.02	2.38 ± 1.80	3.73 ± 0.34	3.18 ± 0.55	0.68 ± 0.22	0.01± 0.007
M. inermis	0.46 ± 0.04	0.09 ± 0.02	17.38 ± 4.35	3.15 ± 1.21	3.32 ± 0.58	4.57 ± 1.04	0.81± 0.16	0.03 ± 0.009
F. ovata	0.43 ± 0.04	0.04 ± 0.01	13.81 ± 4.06	3.80 ± 1.46	6.01 ± 1.95	3.01 ± 1.41	0.45 ± 0.27	0.01 ± 0.004
C. febrifuga	0.45 ± 0.04	0.03 ± 0.01	11.97± 3.99	1.87 ± 0.46	4.63 ± 1.08	1.05 ± 0.38	0.76 ± 0.13	0.02 ± 0.004
V. paradoxa	0.26 ± 0.02	0.11 ± 0.05	2.10 ± 1.10	0.84 ± 0.34	11.70 ± 13.96	3.78 ± 1.32	1.54 ± 0.44	0.02 ± 0.003

Table 5 Correlation matrix between mineral concentrations in the whole tree and shrub species

	Ash	N	P	Na	Ca	Mg	K	C	Fe	Pb	Zn	Cu	Cd	As	Ca/K	Ca/Na	Ma/K	Mg/Na
Ash	1																	
N	0.17	1																
P	0.41**	-0.15	1															
Na	0.14	-0.26	0.15	1														
Ca	0.91**	0.11	0.28	0.01	1													
Mg	0.51**	0.01	0.37*	0.24	0.46**	1												
K	0.11	-0.50**	0.46**	0.07	0.11	0.15	1											
C	-1.00**	-0.16	-0.41**	-0.14	-0.91**	-0.51**	-0.11	1										
Fe	0.34*	0.58**	-0.01	-0.03	0.18	0.12	-0.49**	-0.34*	1									
Pb	0.63**	0.22	0.32*	-0.20	0.49**	0.20	0.15	-0.63**	0.43**	1								
Zn	0.02	0.17	-0.11	-0.09	-0.06	0.10	0.11	-0.02	0.07	0.14	1							
Cu	0.27	-0.07	0.16	0.39*	0.25	0.01	0.13	-0.27	-0.19	0.02	0.05	1						
Cd	0.01	-0.36*	0.15	0.23	0.12	-0.11	0.29	-0.01	-0.58**	-0.44**	-0.15	0.50**	1					
As	0.36*	0.26	-0.04	0.05	0.32*	0.10	-0.26	-0.36*	0.34*	0.16	-0.07	0.14	0.18	1				
Ca/K	0.73**	0.31	0.02	-0.02	0.82**	0.41*	-0.35*	-0.73**	0.38*	0.26	-0.09	0.14	0.01	0.43**	**1**			
Ca/Na	0.72**	0.22	0.16	-0.44**	0.83**	0.22	0.09	-0.72**	0.21	0.60**	-0.04	0.08	-0.04	0.26	0.63**	1		
Mg/K	-0.59**	-0.16	-0.06	0.14	-0.69**	-0.03	-0.01	0.59**	-0.17	-0.34*	0.07	-0.11	-0..13	-0.13	-0.53**	-0.61**	1	
Mg/Na	0.24	0.21	0.16	-0.56**	0.30	0.60**	0.09	-0.24	0.17	0.36*	0.11	-0.26	-0.30	-0.03	0.24	0.52**	-0.09	1

**p < 0.01
*p < 0.05

Relationships among minerals Understanding the relationships among minerals is important because the negative effects of some minerals will depend on the presence of others [24]. In this study, a number of significant associations has been found among minerals at the whole plant level (Table 5). Ash content was highly and negatively associated with C (-1.00**) but positively and strongly correlated with Ca (0.91**); positively and moderately related to P, Mg, and Pb (0.41**, 0.51** and 0.63**, respectively) and positively and weakly to Fe and As (0.34* and 0.36*, respectively). Again, ash was highly and positively related to Ca/K and Ca/Na ratios (0.73** and 0.72**, in this order) and to a lesser extent negatively to Mg/K ratio (-0.59**). N was positively and moderately related to Fe (0.58**) but negatively and moderately to K (-0.58**) and weakly to Cd (-0.36*). A higher concentration of P also increases the concentration levels of Mg (0.37*), Pb (0.46**), and K (0.32*) significantly but reduces C content significantly (-0.46**). Na was positively and significantly related to Cu only (0.39*) whereas Ca was highly and negatively related to C (-0.91**) but positively to Mg, Pb, and As (0.46**, 0.49**, and 0.32*, in this order). The negative and significant associations between Na and Ca/Na ratio (-0.44**) and Na and Mg/Na ratio (-0.56**) are also worthy of note. Mg and K were, respectively, negatively and significantly correlated with C (-0.51**) and Fe (-0.49**) while Fe associated positively and significantly with Pb (0.43**) and As (0.34*) but negatively with Cd (-0.58**). Pb and Cu were, respectively, negatively and positively related to Cd significantly (-0.44** and 0.50**, in this order).

In summary, higher concentrations of ash, Ca and Fe in the studied species are likely to increase the concentration levels of As in the feedstock whereas the presence of Cu can potentially increase the concentration levels of Cd. The association of ash with its forming minerals are in the order: Ca> PB > Mg > P > As > Fe.

Conclusion

The calorific values of the studied plant species (16.02-18.75 $MJkg^{-1}$) are within the range recommended by the European Pellet Council, suggesting that these species have sufficient heating values to warrant their usage as biomass feedstock. Ten of the 13 species showed high ash content in excess of 3%; thus they could pose slagging, fouling and corrosion problems when used as feedstock. However, plant species, namely, *A. leiocarpus*, *A. africana*, *D. clappertonia*, *V. paradoxa*, and *D. oliveri*can be considered as good fuelwood due to their relatively high fuel value index. Overall, *C. febrifuga*, *D. microcarpum* and *D. senegalensis* exhibited high quality fuel characteristics and therefore promise to be a suitable feedstock as they showed the highest fuel value index mainly due to low ash contents, high calorific values and high biomass/ash content ratios. However, the major drawback of these species is their relatively high concentration levels of Cd. Cd, a by-product of zinc production, has been classified by the International Agency for Research on cancer as human carcinogen[25]. Once absorbed by organism, Cd remains resident for many years and its chronic accumulation in the kidneys can lead to kidney dysfunction [25,26]. Considering the health threat of high concentration of Cd, *D. clappertonia* and *F. ovate* appear to be the two species that have proved suitable for biomass production and therefore are recommended for the agro forestry and or the enrichment planting programme in the guinea savanna of Ghana. It is, however, necessary to conduct studies on the growth and yield of the species as well as their rotation period before they are included in the enrichment planting programme.

The project was funded from the resources of the authors

References

1. Ghana Statistical Service (2012) National Population and Housing Census. Summary of Final Results. Available at: http://www.statsghana.gov.gh. Accessed 13 April 2014
2. Ministry of Energy (2010) Energy sector strategy and development plan for Ghana. Accra, Ghana. pp.32.
3. Songsore J (1996). Population growth and ecological degradation in northern Ghana: Myths and realities. *Research Review (NS)*, 12(1&2): 51-66.
4. Ghana NatComm (2011) Ghana's second National Communication to the UNFCCC. Accra, Ghana. pp. 168.
5. Ministry of Lands and natural Resources (2012) Ghana's Forest Investment Plan: Presentation to FIP Sub-Committee. May, 2012. Accra, Ghana.
6. Ghana Forestry Commission (2013) Draft Ghana Forest Plantation Strategy: 2015-2040. Ministry of Land and natural Resources. Accra, Ghana. pp. 71.
7. Amoah M, Cremer T (2017) Net calorific values and mineral concentrations of thirteen tree and shrub species in Ghana. *Journal of Sustainable Forestry*, 36: 7, 703-716
8. Shmulsky R, Jones PD (2011) Forest Products and Wood Science. 6th Edition. Wiley-Blackwell. p.670.
9. Tsoumis G (1991) Science and Technology of Wood: *Structure, Properties, Utilization*. Verlag- Kessel. p. 34-55.
10. Purohit AN, Nautiyal AR (1987) Fuelwood value index of Indian mountain tree species. *Int Tree Crop J*, 4:177-182.
11. Jain R (1993) Fuel characteristics of tropical trees of India. *Biomass and Bioenergy*, 4:454-461.
12. Moya R, Tenorio C (2013) Fuelwood characteristics and its relation with extractives and chemical properties of ten fast-growth species in Costa Rica. *Biomass and Bioenergy*, 56:14-21.
13. Kumar JIN, Patel K, Kumar N, Kumar R (2011) An evaluation of fuelwood properties of some Aravally mountain tree and shrub species of Western India. *Biomass and Bioenergy*, 35:411-414.
14. Kumar R, Chandrashekar N (2014) Fuel properties and combustion characteristics of some promising bamboo species in India. *Journal of Forestry Research*, 25(2): 471-476.

15. Singh B, Khanduja SD (1984) Wood properties of some fuelwood shrubs of northern India. *Biomass*, 4: 235-238.
16. Goel VL, Behl HN (1996) Fuelwood quality of promising tree species for alkaline soil sites in relation to tree age. *Biomass Bioenergy*, 10(1): 57-61.
17. European Pellet Council (2011) Handbook for the Certification of Wood Pellet for Heating Purposes.
18. Melin S (2011) Quality Certification and Standards for solid Biofuels. Wood Pellet Association of Canada.
19. Alakangas E (2010). New European Pellets Standards. European Pellet Conference, 3-4 March, 2010, Wels.
20. Sahoo UK, Lalremmata J, Lalraminghinglova H (2014) Assessment of fuelwood based on community preference and wood constituent properties of tree species in Mizoram, north-east India. *Forest, Trees and Livelihoods*, 23(4): 280-288.
21. Döring (2013) Power from Pellets: *Technology and Applications*, Springer-Verlag Berlin Heidelberg, pp. 30-47.
22. Senelwa K, Sims REH (1999) Fuel characteristics of short rotation forest biomass. Biomass *Bioenerg*, 17: 127-140.
23. Hiegl W, Janssen R, Pichler W (2009) Development and promotion of a transparent European Pellets Market Creation of a European real-time Pellet Atlas: *Advancement of pellets-related European Standards.* Available at www.pelletsatlas.info Accessed 14 February 2015.
24. Monti A, Di Virgilio N, Venturi G (2008) Mineral composition and ash content of six major energy crops. *Biomass and Bioenergy*, 32:216-223.
25. Järup L, Berglund M, Elinder CG, Nordberg G, Vahter M (1998) Health effects of cadmium exposure- a review of the literature and a risk estimate. *Scand J Work Environ Health*, 24: suppl. 1-52p.
26. Bernard A (2008) Cadmium and its adverse effects on human health. In: *The Indian Journal of Medical Research*,28(4): 557-564.