Analysis of the Calorific and Fuel Value Index of Bamboo as a Source of Renewable Biomass Feedstock for Enegry Generation in Nigeria

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Fuel quality of *Bambusa vulgaris* was investigated, with the main focus on its use as an alternative source of biomass feedstock for energy generation in Nigeria. *Bambusa vulgaris* from age 2, 3 and 4 years were harvested. Proximate and chemical analysis were carried out according to ASTM and TAPPI standards. The density of *B. vulgari*s varies significantly from 709.63 kg/m^3 to 937.95 kg/m^3 among ages. Age 3 had the highest density. The ash content increase from age 2 through age 4 and along the culm length from base to top. The volatile matter content ranged from 93% to 95.30% with the middle portion of age 3 having the highest. The fixed carbon ranged from 23.80% to 54.80% with the top portion of age 2 having the highest value of 54.80%. The gross calorific value ranges from 1810.90 cal/kg - 4160.60 cal/kg with an average of 3157.80 while the fuel value index varies from 609.27 to 3383.40. No significant difference existed in the volatile matter, fixed carbon, ash content, calorific value, fuel value index, cold water, hot water and alcohol-benzene soluble extractives of *B. vulgaris* among ages and along the sampling height. Age seems to have influence on the cellulose and lignin content with no significant difference along the culm length. The calorific value and the fuel value index had a very weak correlation with the age and position along the culm length, density, hot water, cold water and alcohol-benzene soluble extractive content, cellulose, and lignin content. However, the calorific value and fuel value index was highly negatively correlated with volatile matter but strongly positively correlated with fixed carbon. Ash content of *B. vulgaris* was less or equal to 4%, the level beyond which slagging of ash usually occur with biomass fuels. Although, the gross calorific value is lower to the minimum standards values suggested for fuel pellets and briquettes, *B. vulgaris* will make an important source of energy considering its sustainability, renewable nature, and environmental benefits.

Keywords: Bamboo; Biomass; Extractives; Lignin content; Gross heat value; Fuel Value Index

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INTRODUCTION

Woody biomass is the major source of energy in the developing countries of the world. FAO (1986) reported that about 13% of the world's primary energy was derived from woody biomass. Nadia *et al*. (2011) project that total fuelwood use in Africa will increase by 34 %, that is about 850 million cubic meters, by 2020.

Over 76% of the Nigerian populace depends on fuelwood as source of energy (Babanyara and Saleh 2010) mainly due to its accessibility, affordability, convenience, tradition, and vegetation distribution, as other energy sources are costly (Akut 2008). Fuelwood is gaining more popularity among the medium and high-income earners in urban centres due to scarcity and hike in prices of other fuel sources. The unpleasant hike in prices of petroleum products has necessitated an ever-increasing reliance on firewood by both urban and rural dwellers. Between 1991 and 1994, kerosene and cooking gas rose by about 900% (Momah and Soaga 1999), and between 1995 and 2009 it rose by 1000% (Babanyara and Saleh 2010). Presently, kerosene, which used to be sold for N50 a litre, had risen to N160 per litre. A 12 kg cylinder of cooking gas now costs between N3,300 and N3,500 in most gas plants. Nadia *et al.* (2011) stated that many households could no longer afford to buy kerosene and cooking gas, thereby resorting to the use of fuelwood, which contributed to an increase in the extraction of wood for fuel.

The available wood supply will continue to decrease due to biomass demand for energy generation. A search for alternative fuel material is of utmost priority. Bamboo could be such alternative. Bamboo is an efficient way to reduce the ever-increasing pressure on the traditional fuelwood species (Kokutse *et al*. 2013). The potential of bamboo as a suitable alternative to wood in the face of dwindling wood resources has never been explored in Nigeria. Bamboo could easily be planted to supply a constant source of fuelwood in place of wood for energy generation. According to Anderson *et al*. (1984), specific gravity, chemical composition, fuel value, and size are the indices of woody biomass quality that influence its suitability for efficient conversion with respect to energy. Davidson (1987) also reported that suitable species to be selected for bio-energy plantation should have high wood calorific value, ability to produce wood of high specific gravity, and capacity for rapid growth on a wide range of sites. Bamboo meets most of these qualities of rapid growth rates, high annual re-growth after harvesting, and high biomass production (Sadiku and Oyerinde 2015).

Energetic properties of bamboo have been reviewed by several studies (Benjamin *et al.* 2012; Engler *et al*. 2012; Gielis 2000; Nagano *et al.* 2009; Lan *et al*. 1999). These sources report that bamboos are potentially suitable to be used as fuel in biomass-fed combustion plants. Bamboo is said to have some desirable fuel characteristics such as low ash content and low alkali index with a lower heating value higher than most agricultural residues, grasses, and straw but also lower than many woody biomass (Scurlock *et al*. 2000). The productivity of bamboo, in terms of the generation of biomass is not different from that of woody biomass (Hunter and Jungi 2002). The average biomass of bamboo per hectare was given as 241.7 Mg/ha (Kumar *et al.* 2005). Bamboo is highly resilient, and its rapid establishment and growth rates allow frequent harvesting that limits exposure to risks such as fire and extreme weather. Bamboos are believed to perform roughly equivalent to fast-growing plantation species (Lobovikov *et al.* 2009).

A bamboo forest requires approximately seven years to grow to maturity, which is significantly faster than tree species. Although, bamboo stands require more frequent management practices compared with other kinds of forestry stands, due to its rapid growth and regeneration, bamboo can be harvested by annual selective cutting (Lou *et al.* 2010). To ensure the long-term sustainability of forest resources in Nigeria, the fuel quality of *Bambusa vulgaris* the most dominant Bamboo species in Nigeria was investigated with the main focus on its use as an alternative source of biomass feedstock for energy generation.

EXPERIMENTAL

Materials

The bamboo species for this study, *Bambusa vulgaris*, was obtained from bamboo grooves on the Federal University of Technology, Akure Campus. The Federal University of Technology at Akure lies between longitude 50 8'East and 50 10' East of the Greenwich Meridian and between latitude 70 16' North and 70 19' North of the Equator. All the reagents used were of analytical grade.

Methods

Culms of age 2, 3, and 4 years were harvested. Three (3) representative culms from each age group were harvested, making a total of nine (9) culms. The culms were carefully marked and labelled for easy identification according to ages and position along the culm length. After this, the culms were divided into three equal parts, i.e. the base, middle, and top, for proximate and chemical properties analysis. The samples were milled in their fresh state to pass BS 40 – mesh sieve (425 μm) but retained on BS 60 – mesh (250 μm sieve). After that, they were shade dried until they had attained constant moisture content. The specific gravity of *B. vulgaris* was determined according to ASTM D 2395-93, volatile matter was determined in accordance with ASTM D3175-11, ash content determined according to TAPPI standard T211om-9, organic carbon content determined using FAO Guide to Laboratory Test, and gross calorific value determined with a bomb calorimeter in accordance with ASTM Standard E711-87. Fuel value index was calculated based on the gross heat value, wood density, and ash content. Alcohol-benzene solubility of *B. vulgaris* was determined according to TAPPI standard T 204 cm-97, hot and cold water solubility was done according to TAPPI standard T 207 cm-99, alpha (α) cellulose content according to TAPPI standard T 203 cm, and lignin content according to TAPPI standard T222 cm-88.

Statistical Analysis

The effects of age and position along the culm length on the fuel properties were evaluated by analysis of variance at $p \leq 0.05$. Duncan Multiple Range Test was used to compare mean values for the different ages and positions along the culm length. Correlation analysis was used to determine the relationship between the age, position along the culm length, and the fuel properties of bamboo

RESULTS AND DISCUSSION

The Gross calorific value, fixed carbon content, volatile substances, ash, and cellulose/lignin contents are the most essential properties to be considered for potential energy analyses of lignocellulosic wastes (Erol *et al.* 2010; Akkaya 2009; Majumder *et* *al.* 2008; Moghtaderi *et al.* 2006). Table 1 to 4 shows the result of the proximate, chemical analysis, analysis of variance and Duncan multiple Range Test for the specific gravity, fixed carbon, volatile matter, extractive contents, cellulose content, lignin content, gross heat value, fuel value index and ash content of *B. vulgaris* from three age classes

Density

The densities of *B. vulgaris* specimens were found to vary with age and along the culm length; density values ranged from 709.63 kg/m^3 to 937.95 kg/m^3, and they increased from the basal portion of the culm to the top (Table 1). These values are in the same range with that of *S. siamea* with specific gravity of 0.60 to 0.80 but a bit higher than that of *Gliricidia sepium* (0.45 to 0.72) and *L. leucocephala* (0.48 to 0.72) reported by NAS (1980), *Gmelina arborea* (0.45), *Eucalyptus tereticornis* (0.59), *Cassia siamea* (0.67), *Tectona grandis* (0.62), and *Gliricidia sepium* (0.7) (Chow and Lucas 1988), *L. leucocephala* (0.69), *G. sepium* (0.67), and *S. siamea* (0.64) (Mainoo and Appiah 1996), *Acacia mellifera* (703 g/m^3), *Acasia senegal* (728 Kg/m^3), *Eucalyptus tereticornis* (673 g/m^3) and *Moringa oleifera* (226.3 kg/m^3) (Khider and Elsaki 2012), and *Melia dubia* (463.26 g/m^3) (Saravanan *et al.* 2013).

Table 1. Mean Value of the Proximate Composition of *B. vulgaris*

Properties	Age	Position		
		Base	Middle	Top
Density (kg/m^3)	2	709.63 ± 26.29	797.20 ± 2.84	758.83 ± 106.38
	3	813.64 ± 86.76	880.10 ± 3.79	937.95 ± 31.62
	4	794.93 ± 66.83	758.16 ± 7.15	793.53 ± 122.87
Volatile Matter (%)	2	93.00 ± 6.06	95.10 ± 5.24	93.20 ± 5.21
	3	94.53 ± 2.49	95.30 ± 4.61	93.90 ± 4.42
	4	93.77 ± 7.26	93.25 ± 7.34	93.55 ± 1.24
Fixed Carbon (%)	2	4.08 ± 5.88	4.51 ± 5.01	5.48 ± 4.51
	3	3.60 ± 2.45	4.10 ± 2.75	4.18 ± 2.89
	4	5.12 ± 7.40	5.02 ± 7.05	2.38 ± 1.35
Ash (%)	2	2.92 ± 0.99	2.83 ± 3.33	1.32 ± 0.70
	3	1.88 ± 0.04	3.10 ± 1.66	2.60 ± 1.11
	4	2.27 ± 1.42	2.24 ± 0.64	4.08 ± 0.52
Calorific Value	2	1810.90 ± 891.54	3253.00 ± 3435.50	4160.60 ± 3293.89
	3	2406.60 ± 851.21	2980.00 ± 2372.68	3478.30 ± 2438.00
	4	3844.50 ± 4964.28	3984.30 ± 4860.32	2501.10 ± 365.70
Fuel Value Index	2	2609.20 ± 230.38	2950.50 ± 4429.67	2899.10 ± 845.70
	3	1277.30 ± 435.18	940.59 ± 568.31	1411.40 ± 1207.37
	4	3383.40 ± 5271.38	1983.90 ± 2629.35	612.90 ± 25.89

The data are average values of at least 3 samples.

The pattern of variation in the bamboo density showed an increase from base to the top along the bamboo culm length. Also, among the three age classes, the density increased from age 2 to 3 and later decreased at age 4 (Table 1). The density of *B. vulgaris* differed significantly among ages, with age 3 having the highest density. The density at 2 years was significantly lower compared to that of age 3 and 4. The density was slightly different between age 3 and 4 but significantly different from that of age 2. The density at the base, middle and top along the culm length were not significantly different (Table 1).

High density is expected to influence the fuel value index of biomass for energy generation, as density has a positive correlation with fuel value index. High-density materials present a higher mass per volume and have an advantage of resulting in a higher combustion yield. Denser wood contains more heat per unit volume, such that they tend to burn for longer periods of time (Mitchual *et al.* 2014). The density of *B. vulgaris* shows that it is more likely to have a higher energy per unit volume and will burn for a longer period of time. Due to higher density of *B. vulagris*, it is likely to produce briquettes with higher densities when the biomass material is pressed at room temperature and low compacting pressure (Mitchual 2013).

Ash Content

The ash content of *B. vulgaris* increased with increase in age from age 2 through age 4 and along the culm length from base to top. The highest ash content (4.08%) was from age 4 at the top portion, where the lowest (1.32%) was from top portion of age 2. The ash content of *B. vulgaris* is higher than some bamboo species used as fuel such as *P. bissetti* (1.0%), *P. bambusoides* (0.7%), *P. nigra* (0.5%) (Scurlock *et al.* 2000), *P. heterocycla* (1.3%), *P. reticulata* (1.9%) and *P. nigra* (2.0%) (Higuchi 1957). When compared to some fuelwood species such as G. arborea (4.5%), *Eucalyptus tereticornis* (6.0%), *Cassia siamea* (4.0%), and *Tectona grandis* (8.7%) (Chow and Lucas 1988), but extremely higher than that of *Gliricidia sepium* (1.5) (Chow and Lucas 1988) and *Melia dubia* (Saravanan *et al.* 2013) and in the same range with those of Sudanese fuelwood species (Khider and Elsaki 2012). The trend of the ash content of *B. vulgaris* showed an increase from the base to the middle portion of the culm, and latter decreased at the top. Among the three age classes, the ash content increased from age 2 all through age 4 (Table 1). The ash content of *B. vulgaris* were not significantly different at the base, middle and top along the length of bamboo as well as among the three age classes at $p \leq 0.05$ (Table 2). Ash content and its chemistry affect the efficiency of the boiler, thereby increasing its maintenance cost (Grover and Mishra, 1996). Ash is deposited on the boiler surfaces during combustion and this give boilers a major setback; ash causes slagging and fouling of boilers, the extent of which is determined by the elements present in the ash and their levels. High ash content is known to be less desirable for fuel as it is non-combustible and hence reduces the heat of combustion. *B. vulgaris* may be considered as good fuelwood on account of comparatively low ash content (Bhatt and Tomar 2002). Moreover, low ash content of *B. vulgaris* indicates that it has low mineral matter. *B. vulgaris* had ash content less than or approximately equal to 4%, the level beyond which slagging of ash usually would occur with biomass fuels (Grover and Mishra, 1996). Thus, it is likely that when *B. vulgaris* is used as fuel no slagging would occur.

Table 2. Variation in the Proximate Composition of *B. vulgaris*

Source of Variation		Density Kg/m^3	Volatile Matter (%)	Fixed Carbon (%)	Ash (%)	Calorific Value	Fuel Value Index
Age	2	755.22c	93.77a	4.69a	2.36a	3075.00a	2153.00a
	3	877.23a	94.58a	3.96a	2.52a	2954.90a	1209.80a
	4	782.21ab	93.52a	4.17a	2.86a	3443.30a	1993.40a
Position	Base	772.70a	93.77a	4.27a	2.35a	2687.30a	1756.70a
	Middle	811.82a	94.55a	4.54a	2.72a	3405.90a	1958.30a
	Top	830.11a	93.55a	4.01a	2.67a	3380.00a	1641.10a

Means with the same letter vertically are not significantly different at ($p \leq 0.05$)

Volatile Matter (VM)

The volatile matter (VM) content ranged from 93% to 95.30% with the middle portion of age 3 having the highest, whereas the basal portion of age 2 had the lowest (Table 1). The trend in the VM showed an increase at age 2 up to age 3 and later slightly decreased at age 4. There were no significant difference in the VM of *B. vulgaris* among all the 3 ages as well as along the culm length (Tabe 2). Stephen *et al*. (2014) and Mitchual *et al*. (2014) stated that volatile matter refers to the part of a biomass material that is released as volatile gases when it is heated up to 400 °C to 500 °C. Heating of biomass fuels liberates volatile matter (flammable gas and smoke) as visible flame on supply of sufficient air, time, temperature, and turbulence. Patel and Gami (2012) stated that if volatile matter in the fuel is higher, then a large amount of secondary air with high pressure need to be supplied at a strategic location for effective combustion. However, incomplete combustion of volatile matter leads to dark smoke, heat loss, pollution hazard, and soot deposition on boiler surfaces (Patel and Gami 2012). Biomass materials with volatile contents up to 78% indicated ignition temperatures between 236 °C and 270 °C, while the lignite with volatile content 53% ignited at 274 °C (Vamvuka *et al*. 2011). Moreover, high volatile matter content of a biomass material means that during combustion, most of it will volatilize and burn as gas in cook stove applications (Akowuah 2012). There were no significant difference in the VM of *B. vulgaris* among all the 3 ages as well as along the culm length any portion of the culm, *B. vulgaris* from any age or portion is suitable as biomass material for energy generation.

Fixed Carbon (FC)

The fixed carbon (FC) ranged from 23.80% to 54.80%, with the top portion of age 2 having the highest (54.80%) and top portion of age 4 having the lowest (23.80%). The FC increased from age 2 with slight decrease at age 3 and later increased at age 4. Along the culm, it increased from the base to the middle before declining at the top (Table 1). The range of values of fixed carbon in *B. vulgaris* is very high compared to what was reported for 2 year old *P. nigra* (16.68%), *P. bisetti* (16.32%), *P. bambusoides* (15.73%), and 4.5 year old, *P. nigra* (13.7%), *P. bisetti* (12.14%), and *P. bambusoides* (14.38) (Sculock *et al.* 2000). From the Duncan Multiple Range Test results, there were no differences in the fixed carbon among the three ages of *B. vulgaris* and along the culm length (Table 2). It was expected that the fixed carbon content would be positively correlated with bamboo density among ages and along the culm length. The age with the highest density had the least fixed carbon content. Also, the portion with the highest density had the least fixed carbon. Carbon is the major constituent of biomass, and its combustion increases the heating value; therefore, high carbon content is desirable in biofuels. The fixed carbon of any material gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning (Akowuah *et al.* 2012). Thus, the higher the carbon content of a biomass fuel, the more likely it is that the species would have higher heating value. The value recorded for *B. vulgaris* is an indication of higher heating value.

Gross Calorific Value (GCV)

The GCV of *B. vulgaris* ranged from 1810.90 cal/kg to 4160.60 cal/kg with an average of 3157.80 cal/g. The GCV of *B. vulgaris* increased from age 2 with slight decrease at age 3 and later increased at age 4. Along the culm length, the trend was similar; the GCV increased from the base with slight decrease at middle and later increased at the top (Table 1). The highest GCV was at the top portion of age 2 (4160.60 cal/kg), whereas the lowest was from basal portion of age 2 (1810.90 cal/g) (Table 1). From the DMR Test result, there were no differences in the GCV among the three ages of B. vulgaris and along the culm length (Table 2). This result is similar to the findings of Engler *et al*. (2012). The mean GCV of *B. vulgaris* (3157.80 cal/g) was lower compared to the range 18.3 to 19.7 MJ/kg reported for some bamboo species (Gielis 2000) and also low compared to the range 19.3 to 20 MJ/Kg for *P. pubescens*, which was used for district heating (Nagano *et al*. 2009) and 20.1 MJ/Kg for *P. pubescens* reported by Ian *et al*. (1999), 19.62 MJ/kg reported for *P. pubescens* (Scurlock *et al*. 2000), and also comparably lower than most fuelwood species such as *Leuceana leucocephala* (4703cal/g), *Gliricidia sepium* (4569 cal/g), *Senna siamea* (4480 cal/g) (Mainoo and Appiah 1996), *Tectona grandis* (4580 cal/g), *Gmelina arborea* (4290 cal/g), *Eucalyptus tereticornis* (4050 cal/g), *Cassia siamea* (4210 cal/g), and *Gliricidia sepium* (4250 cal/g) (Chow and Lucas 1988). The standard measure of the energy content of a fuel is its heating value or calorific value (Stephen *et al*. 2014). The gross calorific value gives an indication of the amount of heat and the potential value of electricity that can be produced by the biomass. An ideal fuel wood should have high calorific value, high density, and low ash content (Kumar *et al.* 2011). The GCV of *B. vulgaris* is lower compared to the minimum values suggested by the Austria and German standards of 17.5 to 19.5 MJ/kg for fuel pellets and briquettes. Generally, the GCV of *B. vulgaris* is lower than those of fuelwood species but *B. vulgaris* from any age could be used. Considering the lower heating values of *B. vulgaris* compared to that of wood species and fossil fuels, in terms of sustainability, renewability nature and environmental benefits, *B. vulgaris* will continue to be an important source of energy.

Fuel Value Index (FVI)

The selection of ideal fuel wood species is based on its FVI calculated using calorific value, wood density, and ash content (Bhatt and Todaria 1992). The FVI for *B. vulgaris* ranged from 609.27 to 3383.40 with a mean of 1785.40. The highest value

(3383.40) was from the basal portion of age 4, and the lowest (609.27) from the basal portion of age 2. The FVI of *B. vulgaris* increased from age 2 with slight decrease at age 3 and later increased at age 4. Along the culm length, the FVI increased from the base to the middle and with a slight decrease at the top (Table 1). There were no significant differences in the FVI among ages and along the culm length from base to top (Table 2). Similar to the findings of Engler *et al.* (2012), this shows that any portion of the culm at any age may be used for fuel. The FVI of *B. vulgaris* is comparably lower than some of fuelwood species such as *Leuceana leucocephala* (2488) and in the same range as *Gliricidia sepium* (1255) and *Senna siamea* (1327) (Chow and Lucas 1988) and *Melia dubia* (1540.15 to 4125.60) (Saravanan *et al*. 2013). The increase in FVI may be attributed to increase in calorific value, density, age of the bamboo, as well as reduced ash content. A combination of three factors; CV, density, and ash content, is most appropriate in determining the suitability of a woody species as fuel material. In addition, FVI is an important characteristics for screening desirable fuel wood species (Puronit and Nautiyal 1987; Jain 1994). From the value of the FVI, *B. vulgaris* can serve as a replace for wood as biomass feed stock for energy generation.

Extractive Content

The solubility of *B. vulgaris* in different solvents can serve as an indication of the extractive contents, which are not cell wall components. The cold and hot water soluble extractives of *B. vulgaris* varied from 1.76% to 6.63% and 4.05% to 11.96%, respectively. The average was 4.44% for cold and 8.73% for hot water. Cold and hot water solubility of *B. vulgaris* was almost similar to that of sweet bamboo, 5.91% to 8.04% for cold and 5.91% to 7.03% for hot water soluble extractives, respectively. The cold water soluble extractives of *B. vulgaris* increased at age 2, decreased at age 3, and later increased at age 4 but increased from base to top along the culm length. For hot water soluble extractives, it increased from age 2 to 3 and later declined at age 4 but decreased from base to top along the culm length in contrast to the cold water soluble extractives (Table 3). The cold-water removes a part of extraneous components, such as inorganic compounds, tannins, gums, sugars, and coloring matter, while the hot-water removes, in addition, starches (TAPPI, 2002). The high extractive content of *B. vulgaris* may probably be due to large lumen diameter of the fibre, as almost all of the extractives fill up the cell lumen. Cold and Hot water solubles are important in the evaluation of water soluble extractives such as tannis, starch, sugar, pectin, and phenolic compounds within woody materials (Janes 1969).

The average alcohol-benzene solubility of *B. vulgaris* ranged from 3.98% to 7.14%, which is higher compared to 3.1%, 1.9% and 2.2% reported for 2 year old *P. bisetti*, *P. bambusoides*, and *P. nigra* and 2.2%, 1.1% and 1.9% recorded for 4.5 year old *P. bisetti*, *P. bambusoides*, and *P. nigra* (Sculock *et al*. 2000) and *P. nigra* (3.4%) and *P. reticulata* (3.4%) reported by Higuchi (1957), but in the same range with *P. heterocycla* (4.6%) (Higuchi 1957) and some wood species such as *Acacia mellifera* (3.0%), *Acacia senegal* (2.9%), *Eucalyptus tereticornis* (2.2%), and *Moringa oleifera* (3.0%) (Khider and Elsaki 2012).

The alcohol-benzene soluble extractives of *B. vulgaris* increases with increasing age from 2 through to age 4, but increased from base, decreased at the middle and later increased at the top along the culm length with no significant difference among age and along the culm length (Table 4).

Alcohol-benzene extractive contents of *B. vulgaris* (5.56%) were higher than those in wood (2.14%) (Gong *et al*. 2007). This shows that the *B. vulgaris* contained more substances like waxes, fats, resins, phytosterols, non-volatile hydrocarbons, low-molecular weight carbohydrates, salts, and other water-soluble substances (Cao *et al.* 2014). Extractive content is a parameter that directly affects the heating value of a biomass (Demibras 2002). According to Nemestothy (2008), the higher heating value of resins, oils, and the other extractives in wood is around 38 MJ/kg. Therefore, heating values increase with an increase in extractive content.

Table 3. Mean Values of the Chemical Content of *B. vulgaris*

Properties	Age (years)	Position		
		Base	Middle	Top
Cold water solubility (%)	2	5.48 ± 1.54	4.60 ± 1.24	5.54 ± 1.61
	3	1.76 ± 0.89	4.10 ± 5.75	5.66 ± 1.43
	4	2.41 ± 1.78	3.78 ± 4.33	6.63 ± 3.21
Hot water solubility (%)	2	6.44 ± 3.03	10.50 ± 0.82	10.15 ± 5.24
	3	11.96 ± 1.25	11.83 ± 1.83	4.05 ± 5.5
	4	8.46 ± 4.45	4.50 ± 1.65	10.71 ± 6.25
Alcohol-benzene solubility (%)	2	6.85 ± 0.77	3.98 ± 1.45	5.08 ± 0.64
	3	4.45 ± 0.76	4.84 ± 1.15	7.13 ± 3.92
	4	4.22 ± 0.63	6.34 ± 2.32	7.14 ± 3.02
Cellulose	2	78.23 ± 0.88	75.00 ± 2.93	73.81 ± 4.33
	3	61.30 ± 4.69	70.11 ± 6.40	69.81 ± 9.00
	4	65.62 ± 2.94	67.31 ± 3.05	69.93 ± 6.41
Klason Lignin	2	34.72 ± 14.60	55.42 ± 10.68	47.55 ± 13.41
	3	37.76 ± 2.32	33.20 ± 2.46	38.23 ± 12.99
	4	29.01 ± 7.84	27.28 ± 9.35	31.44 ± 2.74

The data are average values of at least 3 samples.

Table 4. Variation in the Chemical Content of *B. vulgaris*

Source of Variation		Cold Water	Hot Water	Alcoho-benzene	α - Cellulose	Klason Lignin
Age	2	5.21a	9.03a	5.30a	75.68a	45.90a
	3	3.83a	9.28a	5.47a	67.07b	36.40ab
	4	4.27a	7.89a	5.90a	67.62b	29.24c
Position						
	Base	3.22a	8.95a	5.17a	68.38a	33.83a
	Middle	4.16a	8.94a	5.05a	70.81a	38.63a
	Top	5.94a	8.30a	6.45a	71.18a	39.07a

Means with the same letter vertically are not significantly different at ($p \leq 0.05$)

Cellulose Content

The cellulose content of *B. vulgaris* ranged from 61.30% to 78.23%, with the basal portion of age 3 having the lowest and the basal portion of age 2 having the highest. Age seemed to influence the cellulose content (Table 4), with no significant difference along the culm length. The cellulose content of *B. vulgaris* under study was significantly higher than what was reported for *G. brang* (51.58%), *G. scortechinii* (46.87%), *G. wrayi* (37.60%), and *G. levi* (33.80%) (Wahab *et al.* 2013). Mahanim *et al*. (2008) also got 46.14% to 46.53% for *G. scortechinii* and 48.4% to 56.45% for *G. lagulata*, 58.72% for *B. blumeana* (Ireana 2010); 41.71% to 49.02% for *P. pubescens* (Li *et al*. 2007), but a bit similar to *G. scortechinii* (63.30% to 64.60%) (Hisham *et al.* 2006). The result of this study show that the cellulose content of *B. vulgaris* is significantly higher than most other bamboo species, softwood (42%), and hardwood (45%) (Thomas 1977). For any species to be viable as an energy crop, the cellulose content must be high. Cellulose is the major combustible and principal compound in biomass.

Cellulose in wood has a high heating value of approximately 19.5 MJ/kg, although lower than those of lignin and extractives (Nemesthoty 2008). Heating values for cellulose may differ based on the feedstock. However because of its higher percentage in terms of its composition, the overall calorific value of biomass tends to hinge on the cellulose content. For biomass with higher cellulose content, the pyrolysis rate will be faster, while the biomass with higher lignin content gave slower pyrolysis rate (Gani and Naruse 2007).

Lignin Content

The result of Klason lignin or acid insoluble lignin value for *B. vulgaris* shows that age had an influence on lignin content, whereas position along the culm length did not (Table 4). The lignin content was in the range of 27.28% to 55.42%. The basal portion of age 4 had the lowest, while the middle portion of age 2 had the highest lignin content. Among ages, lignin content decreased from age 2 through age 4. This could be due to the fact that the full lignification of bamboo culm is completed within one growing season with no further significant aging effects (Abd. Latif *et al.* 1994). However, the lignin content increased from the base to the top along the culm length, which contradicts the findings of Abd. Latif *et al.* (1994). This was attributed to the individual characteristics of the bamboo.

The lignin content of *B. vulgaris* under study is in a similar range to that of *P. bisettii* 27.7%, and higher than 26.2% and 27.1% for *P. bambusoides* and *P. nigra* respectively (Scurlock *et al.* 2000). Compared to some fuel wood species such as *Acacia mellifera* (23.3%), *Acacia senegal* (22.2%), *Eucalyptus tereticornis* (21.8%) and *Moringa oleifera* (24.9)% (Khider and Elsaki 2013), *G. arborea* (26.1%), *Eucalyptus tereticornis* (30.4%), *Cassia siamea* (28.3%), *Tectona grandis* (19.8%) and *Gliricidia sepium* (23.1). *B. vulgaris* is extremely high in lignin content, and this makes it a desirable species as an energy crop. For thermochemical conversion of biomass to energy, high lignin content is desirable although the extent of its effect is not well known (Boateng *et al*. 2008; Cassida *et al*. 2005).

Correlation between Calorific Value and Age and Position along the Culm Length of Bamboo, Density and Chemical Properties

The calorific value (CV) had a very weak correlation with the age (r = 0.058), position (r = 0.108) along the culm length, and density (r= -0.162) of *B. vulgaris*. The relationships were not significant at $p \leq 0.05$ (Table 5). The CV may not be predicted from the age, position along the culm length, and density of bamboo. Likewise, there were very weak correlation between the CV and hot water, cold water, and alcohol-benzene soluble extractive content, cellulose, and lignin content. This result is contrary to those of Shafizadeh and Degroot (1976) and Demirbas (1998), where significant correlation was found between Higher Heating Value (HHV) and holocellulose, lignin, and extractives on dry basis. On the other hand, significant correlations existed among the CV and fixed carbon (FC) and volatile matter (VM) contents. This supports the findings of Susott *et al.* (1975) and Tillman (1978) where linear relationship was found between the HHV and the carbon content of natural fuels, chars and volatiles. They also concluded that the higher heating values for extractives, lignin, and holocellulose are consistent with their carbon content. The correlation of CV and VM was strong negative correlation (-0.882) while that of FC was strong positive correlation (0.903) (Table 5). This indicated that as the FC increases, the CV increases. Also, as the VM increases, the CV decreases and vice versa. This result is also similar to the findings of Avelin *et al.* (2014), who reported that higher heating value did not correlate with the lignin content, but contradict the report of Tilman (1978), who found a linear relationship between the higher heating value and the lignin content.

Table 5. Correlation between Fuel Properties and Age and Position along the Culm and Chemical of *B. Vulgaris.*

Properties	Gross Calorific value	Fuel value index
Age	0.058 ns	-0.028 ns
Position along the culm	0.108 ns	-0.021 ns
Density (kg/m^3)	-0.162ns	-0.030ns
Volatile matter (%)	-0.882**	-0.689**
Fixed Carbon (%)	0.903**	0.781**
Cold water solubility (%)	-0.176 ns	-0.054 ns
Hot water solubility (%)	-0.016 ns	0.073 ns
Alcoho-benzene solubility (%)	0.236 ns	0.017 ns
Cellulose	0.149 ns	0.077 ns
Lignin	0.112 ns	0.183 ns
Ash content	-0.192 ns	-0.467 ns

ns = not significant; ** = significant at $p \leq 0.01$

Correlation between Fuel Value Index and Age and Position along the Culm Length of Bamboo, Density and Chemical Properties

The fuel value index (FVI) followed similar trend as the GCV. FVI had a very weak negative correlation with culm age (r = -0.028), position (r = -0.021) along the culm length, and density (r= -0.030) of *B. vulgaris*. The relationships were not significant at the 0.01 level (Table 5). The FVI may not be predicted from the age, position along the culm length, and density of bamboo. Likewise, there were no significant correlations between the FVI and the hot water, cold water and alcohol-benzene soluble extractive content, cellulose, and lignin content, but significant correlations existed between the FVI and fixed carbon and volatile matter content. The FVI was highly and negatively correlated with volatile matter, having a correlation coefficient of -0.689, while fixed carbon was strongly and positively correlated with FVI, with a correlation coefficient of 0.781 (Table 5). Therefore as the FVI increases, the fixed carbon increases but decreases with increasing the volatile matter.

CONCLUSION

The density of *B. vulgaris* was found to vary with age and along the culm length, and it increased from the basal portion of the culm to the top. The density of *B. vulgaris* shows that it is more likely to have a higher energy per unit volume and will burn for a longer period of time. The trend of the ash content of *B. vulgaris* showed an increase from the base to the middle portion of the culm, but it decreased at the top portion of the culm. Among the three age classes, the ash content increased from age 2 all through age 4 and were not significantly different along the length of bamboo as well as among the three age classes. Low ash content of *B. vulgaris* indicates that if used as biomass fuel, no slagging would occur. The fixed carbon value recorded is an indication of higher heating value. Although the gross calorific value is lower compared to the minimum standards values suggested for fuel pellets and briquettes, as well as for those of fuelwood species, *B. vulgaris* from any age could be used. The FVI is comparably lower than some fuelwood species, but due to its sustainability, renewability, and environmental benefits *B. vulgaris* can serve as a replace for wood as biomass feed stock for energy generation. *B. vulgaris* is extremely high in lignin content, and this makes it a desirable species as an energy crop.

REFERENCES CITED

Abd. Latif, M., Khoo, K. C., Jamaludin, K., and Abd. Jalil, H. A. (1994). "Fibre morphology and chemical properties of *Gigantochloa scortechinii*," *Journal of Tropical Forest Science* 6, 397-407.

Akkaya, A. V. (2009). "Proximate analysis based multiple regression models for higher heating value estimation of low rank coals," *Fuel Processing Technology* 90(2), 165-170, 2009.

Akowuah, J. O., Kemausuor, F., and Mitchual, S. J. (2012). "Physico-chemical characteristics and market potential of sawdust charcoal briquettes," *International Journal of Energy and Environmental Engineering* 3, p. 6.

http://dx.doi.org/10.13031/2013.32359
Akut, Y. B. (2008). "Some determinants of house-hold energy consumption in Jimeta," Mammam, A. B, Chup, C. D., and Mashi, S. A. (eds.), *Book of Proceedings of the 49th Annual Conference of the Association of Nigerian Geographers (ANG)*, Joyce Graphics Printers & Publishers, pp. 535 & 537.

American Society of Testing Materials (ASTM) (1997). "Standard test methods for specific gravity of wood and wood-based materials," *Annual Book of ASTM Standards Des. D 2395-93 (Reapproved 1997)* Vol. 4.10. Philadelphia, PA.

ASTM International (2008). "ASTM D3175-11, "Standard test method for volatile matter in the analysis sample of coal and coke," *Annual Book of ASTM Standards*, 153-154.

ASTM International (2012). "ASTM Standard E711-87, "Standard test method for gross calorific value of refuse-derived fuel by the bomb calorimeter," http://ia600806.us.archive.org/23/items/gov.law.astm.e711.1987/astm

Anderson, H. W., Balatinez, J. J., Chen, C. P., and Roy, D. N. (1984). "Internal biomass characteristics for efficient energy conversion," Morgan, D. J. *et al*. (eds.), *IENENOR Joint Workshop Proc.* March, 1985 Uppsala Sweden, p. 31-86.

Arnold, M., Kohlin, G., Persson, R., and Shepherd, G. (2003). "Fuelwood revisited: What has changed in the last decade?," *CIFOR Occasional Paper* (39), CIFOR, Jakarta, Indonesia.

Avelin, A., Skvaril, J., Aulin, R., Odlare, M., and Dahlquist, E. (2014). "Forest biomass for bioenergy production – comparison of different forest species," in: Yan, J. (ed.), *Proceedings of The 6th International Conference on Applied Energy* – ICAE2014, Taipei May 30-June 2 2014.

Babanyara, Y. Y., and Saleh, U. F. (2010). "Urbanisation and the choice of fuel wood as a source of energy in Nigeria," *J. Hum. Ecol.* 31(1), 19-26.

Engler, B., Schoenherr, S., Zhong, Z., and Becker, G. (2012). "Suitability of bamboo as an energy resource: Analysis of bamboo combustion values dependent on the culm's age," *International Journal of Forest Engineering* 23.

Boateng, A. A., Weimer, P. J., Jung, H. G., and Lamb, J. F. (2008). "Response of thermochemical and biochemical conversion processes to lignin concentration in alfalfa stems," *Energy and Fuels* 22, 2810-2815.

Bhatt, B. P., and Todaria, N. P. (1992). "Fuelwood characteristics of some Indian mountain tree species," *Forest Ecology and Management* 47, 363-366.

Bhatt B. P., and Tomar, J. M. S. (2002). "Firewood properties of some Indian mountain tree and shrubs species," *Biomass and Bioenergy* 23, 257-260

Cao, S., Ma, X., Lin, L., Huang, F., Huang, L., and Chen, L. (2014). "Morphological and chemical characterisation of Green bamboo (*Dendrocalamopsis oldhami* (Munro) Keng F.) for dissolving pulp production," *BioResources* 9(3), 4528-4539.

Cassida, K. A., Muir, J. P., Hussey, M. A., Read, J. C., Venuto, B. C., and Ocumpaugh, W. R. (2005). "biofuel component concentrations and yields of switchgrass in south central U.S. environments," *Crop Sci.* 45, 682-692.

Chow, P., and E. B. Lucas (1988). "Fuel characteristics of selected four years old tree(s) in Nigeria," *Wood and Fibre Sci.* 20(41), 431- 437.

Davidson, J. (1987). "Bioenergy tree plantation in the tropics. Their ecological implications and impacts," *Commission of Ecology Paper* No. 12 UCN. Dorset, Switzerland, p. 47.

Demirbas, A. (1998). "Fuel properties and calculation of higher heating values of vegetable oils," *Fuel* 77, 1117.

Demibras, A. (2002). "Relationships between heating value and lignin, moisture, ash and extractive contents of biomass fuels," *Energy Exploration and Exploitation* 20(1).

Engler, B., Schoenherr, S., Zhong, Z., and Becker, G. (2012). "Suitability of bamboo as an energy resources: Analysis of bamboo combustion values dependent on the culm's age," *Int. J. of Forest Engineering* 23.

Erol, M., Haykiri-Acma, H., and Kuçukbayrak, S. (2010). "Calorific value estimation of biomass from their proximate analyses data," *Renewable Energy* 35(1), 170-173.

Food and Agriculture Organization (1986). "Tropical forestry action plan," *Fuelwood Energy* FAO, Rome, Italy. p. 159.

FAO (2003). "African forests: A view to 2020," *Forestry Outlook Study for Africa*, FAO, Rome, Italy.

Gani, A., and Naruse, I. (2007). "Effect of cellulose and lignin content on pyrolysis and combustion characteristics for several types biomass," *Renewable Energy* 32(4), 649-661.

Gielis, J. (2000). "Future possibilities for bamboo in European agriculture," Rijkevorsel, Oprins Plant, Retrieved January 8, 2013, www.bamboonetwork.org/downloads/gielis01.pdf.

Gong, H. R. (2007). "Wood characteristics and storage methods of poplar residue," *China. Wood-based Panels* 14(3), 29-30.

Grover, P. D., and Mishra, S. K. (1996). "Biomass briquetting: Technology and practice," *Regional Wood Energy Development Programme in Asia*, Field Document, No. 46.

Higuchi, H. (1957). "Biochemical studies of lignin formation," *III. Physiologia Plantarum* 10, 633-648.

Hisham, N. H., Othman, S., Rokiah, H., Abd Latif, M., Ani, S., and Mohd Tamizi, M. (2006). "Characterisation of bamboo *Gigantochloa scortechinii* at different ages," *Journal of Tropical Forest Science* 18, 236-242.

Hunter, I. R., and Jungi, W. (2002). *Bamboo Biomass*, International Network for Bamboo and Rattan (INBAR).

Ireana, Y. (2010). "Cell wall architecture, properties and characteristics of bamboo," M.Sc. Thesis, Kenaf and Rice Straw Fibers, USM.

Jain, R. K. (1994). "Fuelwood characteristics of medium tree and shrub species of India," *Bioresource Technology* 47, 81-84.

Khider, T. O., and Elsaki, O. T. (2012). "Heat value of four hardwood species from Sudan," *Journal of Forest Products and Industries* 1(2), 5-9.

Kokutse, A. D., Niyaou, G., and Kokuu, K. (2013). "Anatomical, physical and mechanical properties variability of bamboos in Togo," *Rev. Cames*-Vol. 01.

Kumar, B. M., Rajesh, G., and Sudheesh, K. G. (2005). "Above ground biomass production and nutrient uptake of thorny bamboo [*Bambusa bambos* (L) Voss] in the home gardens of Thrissur, Kerala," *Journal of Tropical Agriculture* 43(1-2), 51-56.

Kumar, N. J. I., Patel, K., Rita, N. K., and Rohit, K. B. (2011). "An evaluation of fuelwood properties of some aravally mountain tree and shrubs species of Western India," *Biomass and Bioenergy* 35, 411-414.
Lan, B., Hong, W., Wu, C. Z., Xu, W. B., and Zeng, S. T. (1999). "A study on the energy structure of *Phyllostachys pubescens* stand," *Journal of Fujian College of Forestry* 19, 20-22.
Li, X. B., Shape, T. F., Peter, G. F., Hse, C. Y., and Eberhardt, T. L. (2007). "Chemical changes with maturation of the bamboo species *Phyllostachys pubescens*," *J. Trop. Forest Sci.* 19(1), 6-12.
Lobovikov, M., and Lou Y. P. (2009). "The poor man's carbon sink. Bamboo in climate change and poverty alleviation," *Non-Wood Forest Products Working Document (FA O)*, no. 8, FAO, Rome (Italy). http://www.fao.org/forestry/58865/en
Yiping, L., Yanxia, L., Buckingham, K., Henley, G., and Guomo, Z. (2010). "Bamboo and climate change mitigation," *Technical Report* No. 32, INBAR.
Mahanim, S. M. A., Puad, E., Rafidah, J., Wan Asma, I., and Shaharuddin, H. (2008). "A study on physical and chemical properties of *Gigantochloa scortechinii* and *Gigantochloa ligulata*. Utilisation of oil palm tree: Strategizing for commercial exploitation," *Forest Products Journal*, Forest Research Institute Malaysia.
Mainoo, A. A., and Appiah, F. U. (1996). "Growth, wood yield and energy characteristics of *Leucaena Leucocephala*, *Gliricidia Sepium* and *Senna Siamea* at age four years," *Ghana Journal of Forestry* Vol. 3.
Majumder, A. K., Jain, R., Banerjee, P., and Barnwal, J. P. (2008). "Development of a new proximate analysis based correlation to predict calorific value of coal," *Fuel* 87(13-14), 3077-3081.
Mitchual, S. J. (2013). "Densification of sawdust of tropical hardwoods and maize cobs at room temperature using low compacting pressure without a binder," Ph.D. Thesis, School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi.
Mitchual, S. J., Frimpong-Mensah K., and Darkwa N. A. (2014). "Evaluation of fuel properties of six tropical hardwood timber species for briquettes," *Journal of Sustainable Bioenergy Systems* 4, 1-9.
Moghtaderi, B., Sheng, C., and Wall, T. F. (2006). "An overview of the Australian biomass resources and utilization technologies," *BioResources* 1(1), 93-115.
Bystriakova, N., Brown, S., Gonzalez, P., Irland, L. C., Kauppi, P., Sedjo, R., and Thompson, I. D. (2011). "Ecosystems and human well-being: Volume 1: Current state and trends," *Timber, Fuel, and Fiber Ecosystem Services*, Retrieved from: http://www.eoearth.org/view/article/152276.
Nagano, M., Nagano, M., and Mabuchi, Y. (2009). "Utilization of bamboo forest for a district energy resource: An example of *Phyllostachys pubescens*," *Social Society for Social Management* 9(125), 1-7.
National Academy of Sciences (1980). "Firewood crops - Shrubs and tree species for energy production," *Report* No. 27, National Academy Press, Washington D.C., p. 237.
Nemestothy, K .P. (2008). "Wood fuels: Characteristics, standards, production technology," E.V.A-The Austrian Energy Agency.

Nordin, A. (1994). "Chemical elemental characteristics of biomass fuels," *Biomass and Bioenergy* 6, 339-347.

Olanrewaju, R. M., and Ogunleye-Adetona, C. I. (2000). *Contemporary Issues in Environmental Studies*, H. I. Jimoh, and I. P. Ifabiyi (eds.), Haytee Press and Publishing Co. LTD, Nigeria, p. 149.

Puronit, A. N., and Nautiyal, A. R. (1987). "Fuelwood value index of Indian mountain tree species," *The International Tree Crop Journal* 4, 177-182.

Sadiku, N. A., and Oyerinde, O. V. (2015). "Carbon storage potential of bamboo and harvested bamboo products: A review," *Proceedings of Nigeria Tropical Biology Association (NTBA) 5th Annual Biodiversity Conference*, Federal University of Technology, Akure. 19-20 May.

Saravanan, V., Parthiban, K. T., Kumar, P., Anbu, P. V., and Ganesh, P. P. (2013). "Evaluation of fuel wood properties of *Melia dubia* at different age gradation," *Research Journal of Agriculture and Forestry Sciences* 1(6), 8-11.

Scurlock, J. M. O., Dayton, D. C., and Hames, B. (2000). "Bamboo: An overlooked biomass resource?," *Bio. Bio. Energ.* 19, 229-244.

Shajizadeh, F., and Degroot, W. G. (1976). "Thermal uses and properties of carbohydrates and lignins," *Academic Press*, New York.

Mitchual, J. S., Frimpong-Mensah, K., and Darkwa, A. N. (2014). "Evaluation of fuel properties of six tropical hardwood timber species for briquettes," *Journal of Sustainable Bioenergy Systems* 4(1), DOI:10.4236/jsbs.2014.41001.

Susott, R. A., DeGroot, W. F., and Shafizadeh, F. (1975). "Heat content of natural fuels," *J. Fire Flammabil.* 6, 311-325.

TAPPI Test Methods. (2002). TAPPI Press, Atlanta.

TAPPI (1997). "Solvent extractives of wood and pulp T204cm," 97:1-5.

TAPPI (1999). "Water solubility of wood and pulp- T207cm," Atlanta, USA, 99: 1-3.

TAPPI (2002b). "Ash in wood, pulp, paper and paperboard: combustion at 525 °C. T 211cm," 02: 1-5.

TAPPI (2006). "Acid-insoluble lignin in wood and pulp T222 cm,"Atlanta, USA, 06: 1-6.

TAPPI (1999). "Alpha-, beta- and gamma-cellulose in pulp T 203 cm-99," TAPPI Standard Test Method.

Thomas, R. J. (1977). "Wood: Structure and chemical composition in wood technology chemical aspects," *American Chemical Society (ACS) Symposium Series* 43, p. 1-23.

Tillman, D. A. (1978). "Wood as an energy resource,"*Academic Press*, New York.

Vamvuka, D., Chatib, N. E., and Sfakiotakis, S. (2011). *Proceedings of the European Combustion Meeting*, Cardiff, 28 June-1 July.

Wahab, R., Mohd Tamizi, M., Mahmud, S., Aminuddin, M., Shafiqur, R., Hashim W. S., and Izyan K. (2013). "Extractives, holocellulose, α-cellulose, lignin and ash contents in cultivated tropical bamboo *Gigantochloa brang, G. levis, G. scortechinii and G. wrayi*," *Current Research Journal of Biological Sciences* 5(6), 266-272.

White, R. H. (1987). "Effect of lignin content and extractives on the higher heating value of wood," *Wood Fiber Sci.* 19, 446-452.

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