Effect of Fuel Material Compositions on Combustion Properties of Wood Chips from Smallhold Farm Plots in a Sudano-Sahelian Environment of Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author OAS designed the study, performed literature search, prepared the manuscript, wrote the protocol. Authors AMD, MU and SMI carried out the reconnaissance survey, harvesting and preparation of tree samples and laboratory studies and author BDZ the statistical analysis and also take active part in the preparation of concept note for the study. All authors read and approved the final manuscript.

Article Information

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ABSTRACT

Aims: The study explored the combustion properties of woods and barks of some selected trees and the mixtures of the two in order to map out how fuel material composition affect the combustion properties of biomass materials.
Study Design: The study is a two-factor factorial experiment in a completely randomized design. The main factors are the tree species and fuel material types.
Place and Duration of Study: Tree samples used for this study were coppiced stems harvested from smallhold farm plots along the Damaturu - Gujba fuelwood corridors in Yobe State. The analytical study was carried out in Wood and Fibre Science Laboratory of the Department of Forestry and Wildlife, University of Maiduguri, Nigeria between April 2018 and December 2019.

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Methodology: Ten tree species were used for this study. Each species was replicated 3-times, making a total of 30 stems with their dbh between 10 and 15 cm. A sample billet of 20 cm log was cut from each stem at 10 cm below and above dbh. Each billet was debarked, chipped separately and dried to approximately 12% moisture content. From the chips, 100% wood, 95%W-5%B, 90%W-10%B and 100% bark fuel material samples were created, grinded with mechanical grinder and sieved to approximately 0.4 mm particle size based on ASTM D2013-86. The sieved samples obtained were then analyzed for their percentage moisture content, volatile matter, fixed carbon, ash and gross calorific values using ASTM standard methods. The data obtained were subjected to Analysis of variance from which % variance component and LSD were computed $\alpha = 0.05$ and 0.01 level of significance.

Results: All the measured parameters varied significantly among the tree species and the compositions of the fuel materials obtained from them. Majority of the variation in the fuelwood properties were attributed to the composition of the fuel materials obtained from the trees rather than the species they were made of. On the average, moisture content of the samples ranged from 27.66 to 40.44%, volatile matter (61.38 to 75.11%), ash (0.52 to 2.42%), fixed carbon (24.19 to 36.20%) and gross calorific value (32.99 to 33.02 MJ.kg^{-1}). The moisture and ash contents of the fuel materials obtained from all the tree species increased with the level of bark inclusion whereas, volatile matter content and gross calorific values decreased significantly with level of bark inclusion ($P < 0.05$). Also, gross calorific value of the fuel materials correlates positively with volatile matter and fixed carbon contents. But, correlate negatively with moisture and ash contents. Among the studied tree species, chips obtained from *A. leiocarpus* had the highest energy value, followed by *C. arereh* and *B. aegyptiaca* while *P. reticulatum*, *A. sieberiana* and *C. lamprocarpum* had the least energy value in that order.

Conclusion: Based on their energy value and ash content, minimizing the bark content in wood chips is important from energy and environment point of view. Therefore, chips with 100% wood and those with 5% bark inclusions are recommended for heat generation.

1. INTRODUCTION

The calls to address climate change and associated environmental problems has generated age-long debate on the need to reduce the rate of using wood as a means of energy generation for domestic and industrial applications. Instead, policy makers are canvassing for the need to make energy sources from fossil fuel affordable particularly for the low income earners and the rural people [1]. As good as this may seem, this is not without its own associated problem, particularly in relation to emission of gasses during production and the fact that the purchasing power of the poor cannot sustain energy procurement from fossil fuel [2]. At present, the cheapest, most accessible and widely distributed energy source is wood. It is a resource with virtually no international trade regulation despite being a dominant source of energy for about 2.7 billion people globally [3]. Fuelwood, with its energy rich store of carbon and volatiles, account for about 10 percent of the world energy supply, about two-third of which is consumed in developing countries for cooking and heating purposes [4]. In sub-Sahara Africa, more than 80 percent of primary energy supply is derived from wood, where the per capita consumption of wood for energy is almost 0.7 m^3/person/year compared to the global average of about 0.28 m^3/person/ year [5]. The high demand for wood, for fuel energy has been attributed to be the major factor for the fuelwood crisis in Sub-Sahara Africa [6].

To enhance sustainability of tree-based energy production, integration of trees with short rotation coppices on agricultural farm or pasture lands and efficient utilisation of wood biomass needs to be encouraged [7]. Integration of trees on farm plots can also help in environmental protection and improve the management of productive landscapes. Apart from the sustainability of wood biomass supply, a thorough understanding of the properties of the tree component parts will also enhance the efficient energy production from the wood biomass. This is because, combustion properties vary among the component of a tree, particularly between the wood and the bark portion [8].

Several studies had reported variations in combustion properties within and between tree species and between the component parts of same trees [8-10]. Few studies had also reported the influence of bark and wood fraction combinations on the combustion properties of the resulting fuel materials [11-13]. However, knowledge of the properties of coppice stems on continuous farm plots, particularly, in sudano-Sahelian environment of Nigeria is still quite limited. The on-farm trees could be affected by agro chemicals and fertilizers which can directly influence the chemical composition of the trees and distribution of biomass in bark and wood components and thus affecting their combustion properties. Majority of the stem mass is made of wood, which makes it the single most important component to consider in proximate analysis [14]. However, in small-diameter stems, the bark percentage is quite high, especially in coppice shoots. Understanding the properties of each component is crucial for the analysis and design of their conversion route [15]. Based on numerous studies, combustion of wood bark produce more ash than wood. The amount of ash from combusted wood bark is about 1.0-1.5% while that of wood is approximately less than one [16]. On the basis of higher ash content and its associated emission of dangerous particulate matter that are injurious to human health and increase cost of maintenance of burner, Radačovská, et al. [17], suggested the need to deal with content of wood bark during combustion process. One way through which this can be achieved is by formulating appropriate biomass material composition from combinations of bark and wood fractions.

This study therefore centered on the combustion properties of ten selected tree species from smallhold farms in a Sudano-Sahelian environment of Nigeria. The aim is to investigate the combustion properties of the chips obtained from the wood and bark of the selected trees and the mixture of the two in order to map out how fuel material composition affect combustion properties of biomass materials.

2. MATERIALS AND METHODS

2.1 Selection of Tree Species

The tree species used for this study were coppiced stems harvested from smallhold farm plots along Damaturu - Gujba fuelwood corridors in Yobe State, Nigeria. The area lies between latitudes 11º44′55″ N and longitudes 11º57′50″ E with average annual temperature of 25.2ºC and rainfall of 649 mm [18]. Ten tree species listed in Table 1 and commonly used for fuelwood in the study area (Dadile AM, University of Maiduguri, Nigeria. Unpublished M.Sc Dissertation) were selected for this study. For each species, three stems of diameter at breast height (Dbh) between 10 cm and 15 cm were randomly selected and harvested for this study. A sample billet of 20 cm long was thereafter cut at 10 cm below and above Dbh of each tree. The samples were then labelled, bagged separately in a black polyethylene bag and transported fresh to laboratory for analysis.

2.1.1 Sample preparation

Each sample billet was debarked, chipped separately and dried to approximately 12% moisture content. From each chipped sample, 100% wood, 95%W-5%B, 90%W-10%B and 100% bark fuel material samples were created, following the method adopted by Filbakk, et al. [11] and Nosek, et al. [13]. The fuel material samples from each tree were then grinded separately with mechanical grinder and sieved to approximately 0.4 mm particle size based on ASTM D2013-86 [19]. The milled samples were analyzed for their percentage moisture content, volatile matter, fixed carbon, ash and gross calorific values using standard methods.

2.2 Moisture Content Determination

The moisture contents of the fuel material samples were determined using ASTM designation E 871-82 [20]. For each fuel material, 2 g of the sample was placed in porcelain crucibles of known weight and heated in the oven at 105±3ºC until constant weight was obtained. The difference in weight before and after constant weight of each sample was obtained indicated the moisture content of each sample. The percentage moisture content was calculated using the formula expressed in equation 1.

$$M.C = \frac{W_{0sc} - W_{1sc}}{W_{0s}} \times 100 \qquad (1)$$

Where, M.C is the percentage moisture content of the sample, W_{0sc} is the initial weight of the sample and crucible, W_{1sc} is the final weight of the sample and crucible and, W_{0s} is the initial weight of the sample.

2.3 Volatile Matter Content Determination

The volatile matter contents of the fuel materials were determined based on ASTM D3174-89 [21]. From each fuel material type, 1 g of the sample was placed in porcelain crucible of known weight and dried in the oven at a temperature of 105ºC to constant weight after which it was heated in the furnace at 600ºC for 10 min. The sample was then cooled in a desiccator and weighed. The volatile matter content of the sample material was calculated as the percentage loss in weight to the oven dried weight of the sample using the formula expressed in equation 2.

$$V.M\ (\%) = \frac{W_{0sc} - W_{1sc}}{W_{0s}} \times 100 - \%M.C \qquad (2)$$

Where, V.M is the volatile matter content of the sample in percentage, W_{0sc} is the initial weight of the sample plus crucible, W_{1sc} is the final weight of the sample plus crucible after heating in the furnace for 10 minutes and, W_{0s} is the initial weight of the sample.

2.4 Ash Content Determination

The determination of ash content of the fuel materials was determined using ASTM Designation D1102-50 [22]. The procedure is similar to volatile matter content determination. But, in this case, each fuel material sample was heated in the furnace for 4 hours at a temperature of 600ºC. The crucible content after dry ashing was then cooled in a desiccator and weighed. The ash content of each sample was calculated using the formula expressed in equation 3.

$$Ash\ content\ (\%) = \frac{W_{dsc} - W_c}{W_{1ds}} \times 100 \qquad (3)$$

Where, W_{dsc} is the final weight of the sample plus crucible after dry ashing for 4 hours, W_c is the weight of the crucible and, W_{1ds} is the initial dry weight of the sample after moisture content determination.

2.5 Fixed Carbon Content Determination

The percentage fixed carbon of the fuel materials from each tree species were evaluated using empirical formula, by subtracting the aggregate moisture, ash and volatile matter contents of each sample material from 100 similar to the method adopted by Solar, et al. [23] and Álvarez-Álvarez, et al. [24]. This is expressed as shown in equation 4.

$$FC\ (\%) = 100 - (\%MC + \%VM + \%AC) \qquad (4)$$

Where, FC is the percentage fixed carbon, MC is the moisture content (%), VM is the volatile matter content (%) and AC is the ash content (%) of the sample.

2.6 Calorific Value Determination

The Calorific values of the fuel materials were estimated based on ASTM E-711-87 [25] using Gallenkamp autobomb calorimeter. This is based on the principle of measuring the heat released from complete combustion of the fuel material in the presence of oxygen. About 1 g oven dried fuel material sample was combusted in an adiabatic bomb containing 3.4 MPa of pure oxygen under pressure. This was done by carefully placing the sample in a capsule and pressed to compact the material. The sample was then placed in the crucible in a pressure vessel containing known amount of water and electrode attached with ignition wire. The ignition wire was also firmly attached to the capsule containing the fuel material with the aid of a cotton thread. Thereafter, the calorimeter was fired by pressing the ignition button. The difference between the initial temperature and the temperature of the calorimeter fluid after combustion is calculated as the energy released from the sample material as well as its calorific value. The formula used is as expressed in equation 5.

$$Calorific\ value = \frac{[(T_1 - T_0)\ x\ 10.82] - 0.086}{W_{ds}} \qquad (5)$$

Where, T_1 is the final temperature, T_0 is the initial temperature, 10.82 is the heat capacity of the ignition wire, 0.086 is the combined energy value of the ignition wire and the cotton thread and, W_{ds} is the dry weight of the fuel material sample.

2.7 Statistical Analysis

The Effects of two factors were investigated in this study. The effect due to variations among tree species and the effect due to fuel material composition, namely; 100% wood, 95%W-5%B, 90%W-10%B and 100% bark on their combustion properties. The data obtained were subjected to analysis of variance from which % variance component and LSD were computed. Also, correlation analysis was carried out to investigate the relationships between the gross calorific value and proximate properties of the chips obtained from the selected tree species at α = 0.05 and 0.01 level of significance. All analysis was carried out using Minitab 16.

Table 1. List of selected tree species with their name description

Scientific name	Family name	Common name	Local name (Hausa)
Anogeisus leiocarpus (DC.) Guil. and Perr.	Combretaceae	African birch	Marke
Cassia arereh (Del.)	Leguminosae-Caesalpinioidae	Sorcerer's rod	Gama fada
Balanites aegyptiaca (Del.)	Balanitaceae	Desert date	Aduwa
Combretum molle R. Br. ex G. Don	Combretaceae	Velvet bushwillow	Gooda jiki
Terminalia mollis M.A.Lawson	Combretaceae	Large-leaved terminalia	Baushin giiwaa
Tamarindus indica Linn.	Fabaceae	Tamarind	Tsamiya
Sclerocarya birrea (A.Rich.) Hochst.	Anacardiaceae	Marula	Danya
Combretum lamprocarpum (Diels.)	Combretaceae	Bushwillows	Bauli
Piliostigma reticulatum (DC.) Hochst.	Leguminosae-Caesalpinioidae	Camel's foot	Kalgoo
Acacia sieberiana (DC.)	Leguminosae-Mimosoideae	Paperbark acacia	Farar kaya

3. RESULTS AND DISCUSSION

3.1 Moisture Content (MC)

The moisture content of the chips varied among the selected tree species and the compositions of the chips obtained from them. About 91.0% of the variation was accounted for by the differences in fuel material compositions while variation among the trees accounted for 5.32% (Table 2). Among the tree species, the M.C. ranged from 27.66 % in *A. leiocarpus* to 40.44% in *A. sieberiana* (Table 3).

Chips obtained from isolated barks contained approximately two times higher moisture content than wood without bark. Similarly, addition of bark fraction to the tune of 5 and 10% alternately increased the M.C. of the fuel materials from all the tree species. The trend in the reduction of M.C with inclusion of bark fractions to the wood chips however, differs among the tree species (Table 3). This is in conformity with what was reported on woods and barks of some biomass by Deka, et al. [9] and Nosek, et al. [13]. Different studies have demonstrated the influence of moisture content on the combustion properties of fuelwood materials [24-28] and concluded that moisture had negative effect on fuel value of the wood. Thus, bio fuel materials with low moisture content are always preferred because of the high energy content per unit volume, durability and slow burning rate.

3.2 Volatile Matter Content

As shown in Table 2, volatile matter content of varied significantly among species and the composition of fuel materials obtained from them. The effect due to variations in fuel material obtained from the trees accounted for 88.61% of the variation in volatile matter, while variation among species accounted for 8.38%.

The average volatile matter contents of the fuel materials were quite high. Also, the volatile matter contents of the wood chips were significantly higher than those of their respective barks (P < 0.05). In *A. leocarpus* and *C. arereh*, it was approximately 19.0% and 23% higher in their respective wood than their barks. Similarly, the inclusion of bark fraction to the tune of 5 and 10% of the wood fuel material, lowered the volatile matter content of *A. leocarpus* by 11.17 and 15.73%, respectively. The extent of the effect of bark inclusion on volatile matter content of the resulting fuel material varied across tree species (Table 4). This is similar to the results obtained by Senelwa and Sims [8] on the volatile matter content of the wood and bark of some short rotation forest biomass. It also, agrees with the finding of Deka, et al. [9] on some indigenous tree species in north-east India. The higher volatile matter in wood is an indication of its better thermal decomposition during combustion process which also reflects that the bulk volume of wood chip is consumed in gaseous state during combustion compared to the bark. According to Sotannde, et al. [29,30], volatile matter content determines largely the ease of ignition and to some extent production of smoke during biomass combustion and is mainly the waxes, oils, resins, fats, tannins and aromatic compounds in wood.

3.3 Ash Content

Ash is an inert and noncombustible component of a biomass material that is used in evaluating the desirability of biomass material for energy purpose. The ash content varied significantly among the trees ($P < 0.05$) and compositions of fuel materials obtained from them ($P < 0.001$). As evident from the variance component analysis computed, more than 90% of the variations was due to differences in fuel material compositions while approximately 4% was as a result of variations among the tree species (Table 2). The mean ash content ranged from less than 1% in *A. leocarpus* and *C. arereh* to more than 2% in *P. reticulatum* and *A. sieberana* (Table 5). This value is within the range of 0.19 and 3.11% reported by Chettri and Sharma [31] on some fuelwood species in west Sikkim, India and some selected tropical hard woods by Telmo, et al. [32] but lower than those recorded for some indigenous fuelwood species in north-east India [9]. The low ash contents reported for the trees under study implied that a considerable portion of the wood volume can be converted into energy.

On the average, the bark of Sudano-Sahelian tree species selected for this study contained approximately nineteen times the ash content of their wood without bark. Also, inclusion of bark fraction in wood-fuel up to the tune 10% results in increased ash generation to about four times that of wood without bark (Table 5). The increase in ash content with the percentage of bark inclusion in the fuel feedstock can negatively affect the combustion process due to difference in melting temperature of ash during combustion of wood and bark. A higher content of ash in the bark compared to wood without bark of same tree has also been reported by many authors [9,11,13,33,34]. This could be traced to the presence of some trace elements and heavy metals in the bark which does not support combustion. High presence of dirt or sand on the bark of a felled tree can also increase the total ash of the bark fuel.

3.4 Percentage Fixed Carbon

Determination of fixed carbon (FC) is essential for evaluating the energy value of a biomass material since it represent the portion of biomass that must be burnt in solid state. In a combustion process, it is the combustible residue containing carbon and minor quantity of hydrogen, oxygen, nitrogen and, sulfur left after volatile matter is distilled off. The knowledge of FC is important in the selection of combustible equipment, since its form and hardness are indicative of caking properties of fuel. The results of the variance components and effect of back inclusion on FC of the selected fuelwood species are presented in Tables 2 and 6. Tree species showed little variation in FC. However, the compositions of the fuel materials obtained from them accounted for 89.0% of the variation in FC (Table 2).

Among the trees, FC content ranged from 24.19% in *C. arereh* to 36.20% in *P. reticulatum* (Table 6). This is similar to those recorded for some indigenous tree species by Deka, et al. [9] but higher than the range of 13.50 to 23.02% obtained in some tree species by Álvarez-Álvarez, et al. [24] and 5.1 to 7.6% obtained in the stump of some trees from short rotation forest by Senelwa and Sims [8]. On the average, FC content is approximately 15% higher in tree bark compared to their respective wood without bark. Similarly, inclusion of bark fractions to the tune of 5 and 10% alternately, increased the fixed carbon to 33.28 and 46.22% in *P. reticulatum*, respectively and to 10.95 and 15.51% in fuel materials obtained from *A. leocarpus*. Similar trend were also observed in fuel materials obtained from other species (Table 6). The lower fixed carbon in wood as compared to bark of the same species could be attributed to the high volatile matter content of wood which further buttressed that the bulk volume of the wood is consumed in gaseous state during combustions.

Table 2. Variance component of measured proximate composition of the selected tree species

Source of variation	Df	Variance component (%)				
		Moisture content	Volatile matter	Ash content	Fixed carbon	Gross calorific value
Tree species (A)	9	5.32**	8.38**	3.62*	9.64**	3.28*
Fuel material composition (B)	3	91.00***	88.61***	94.25***	88.84***	94.23***
A x B	27	3.68**	3.01*	2.13*	4.52**	2.49*
Error	80					

*Df = Degrees of freedom; * = P < 0.05; ** = P < 0.01; *** = P < 0.001*

Table 3. Effect of bark inclusion on the moisture content of selected tree species

Tree species	Fuel material composition				Mean
	100% wood	95W-5B	90W-10B	100% bark	
A. leiocarpus	22.53[c]	27.15[b]	28.76b	32.19[a]	27.66[D]
C. arereh	20.46[d]	27.20[c]	34.53[b]	41.29[a]	30.87[BCD]
B. aegyptiaca	19.15[c]	25.03[c]	33.62[ab]	39.94[a]	29.43[CD]
C. mole	13.09[c]	31.17[b]	40.66[a]	41.19[a]	31.53[BCD]
T. mollis	17.11[c]	22.06[b]	42.87[a]	44.78[a]	31.71[BCD]
T. indica	19.55[c]	27.24[b]	44.12[a]	36.69[a]	31.90[BCD]
S. birrea	19.59[c]	31.57[b]	38.02[ab]	44.71[a]	33.47[BCD]
C. lamprocarpum	22.78[c]	32.57[b]	31.04[b]	50.32[a]	34.17[BC]
P. reticulatum	22.90[d]	29.20[c]	38.37[b]	51.99[a]	35.61[AB]
A. sieberiana	29.57[c]	35.04[bc]	45.14[ab]	52.03[a]	40.44[A]
Mean	20.67[A]	30.42[B]	37.78[AB]	41.85[B]	

95W-5B = chips with 95% wood and 5% bark; 90W-10B = chips with 90% wood and 10% bark. Values with the same alphabets within the same tree and among trees in mean column and among fuel materials in the same row are not significantly different using LSD at α 0.05. Each value is an average of three replicates

Table 4. Effect of bark inclusion on the volatile matter content of the selected tree species

Tree species	Fuel material composition				Mean
	100% wood	95W-5B	90W-10B	100% bark	
A. leiocarpus	86.48[a]	75.31[b]	70.75[bc]	67.90[d]	75.11[A]
C. arereh	85.94[a]	78.11[b]	72.89[c]	63.48[d]	75.10[A]
B. aegyptiaca	78.65[a]	71.61[ab]	69.00[b]	67.29[b]	71.64[B]
C. mole	86.17[a]	77.69[b]	65.75[c]	56.87[d]	71.62[B]
T. mollis	78.07[a]	73.06[ab]	69.90[ab]	64.50[b]	71.38[B]
T. indica	73.43[a]	67.87[b]	64.99[b]	63.62[b]	67.48[C]
S. birrea	83.03[a]	74.71[b]	68.48[c]	54.34[d]	70.14[BC]
C. lamprocarpum	75.19[a]	72.21[a]	68.66[a]	65.69[a]	70.44[BC]
P. reticulatum	81.89[a]	66.19[b]	52.76[c]	44.69[d]	61.38[D]
A. sieberiana	74.02[a]	73.14[a]	68.12[ab]	63.71[b]	69.75[C]
Mean	80.29[A]	72.99[B]	67.13[BC]	61.21[C]	

95W-5B = chips with 95% wood and 5%bark; 90W-10B = chips with 90% wood and 10% bark. Values with the same alphabets within the same tree and among trees in mean column and among fuel materials in the same row are not significantly different using LSD at α 0.05. Each value is an average of three replicates

Table 5. Effect of bark inclusion on the ash content of the selected tree species

Tree species	Fuel material composition				Mean
	100% wood	95W-5B	90W-10B	100% bark	
A. leiocarpus	0.03[c]	0.24[b]	0.26[b]	1.54[a]	0.52[D]
C. arereh	0.12[c]	0.21[c]	0.57[b]	1.92[a]	0.71[CD]
B. aegyptiaca	0.07[c]	0.24[bc]	2.14[a]	3.23[a]	1.42[BC]
C. mole	0.13[c]	0.47[b]	0.77[b]	3.81[a]	1.29[BCD]
T. mollis	0.35[c]	0.60[bc]	0.81[b]	5.55[a]	1.83[AB]
T. indica	0.31[c]	0.79[b]	1.38[b]	5.36[a]	1.96[AB]
S. birrea	0.46[c]	0.74[bc]	1.09[b]	5.38[a]	1.92[AB]
C. lamprocarpum	0.41[c]	0.70[bc]	1.72[b]	4.55[a]	1.85[AB]
P. reticulatum	0.31[c]	0.53[bc]	1.02[b]	7.83[a]	2.42[A]
A. sieberiana	0.16[c]	0.94[bc]	1.28[b]	6.15[a]	2.13[AB]
Mean	0.24[C]	0.55[BC]	1.11[B]	4.53[A]	

95W-5B = chips with 95% wood and 5%bark; 90W-10B = chips with 90% wood and 10% bark. Values with the same alphabets within the same tree and among trees in mean column and among fuel materials in the same row are not significantly different using LSD at α 0.05. Each value is an average of three replicates

Table 6. Effect of bark inclusion on the fixed carbon content of selected tree species

Tree species	Fuel material composition				Mean
	100% wood	95W-5B	90W-10B	100% bark	
A. leiocarpus	13.49[c]	24.44[b]	29.00[a]	30.61[a]	24.37[C]
C. arereh	13.86[c]	21.58[b]	26.35[b]	34.60[a]	24.19[C]
B. aegyptiaca	21.28[b]	28.15[a]	28.85[a]	29.48[a]	26.94[B]
C. molle	13.70[b]	21.77[b]	33.49[a]	39.32[a]	27.09[B]
T. mollis	21.58[b]	26.35[ab]	29.29[a]	29.95[a]	26.79[B]
T. indica	26.26[b]	31.02[ab]	31.34[ab]	33.62[a]	30.56[AB]
S. birrea	16.51[c]	24.55[b]	30.14[b]	40.28[a]	27.94[B]
C. lamprocarpum	24.11[b]	27.38[a]	29.62[a]	29.76[a]	27.72[B]
P. reticulatum	17.79[c]	33.28[b]	46.22[a]	47.49[a]	36.20[A]
A. sieberiana	25.82[b]	25.92[b]	30.14[a]	30.60[a]	28.12[B]
Mean	19.77[B]	26.17[B]	31.77[A]	34.26[A]	

95W-5B = chips with 95% wood and 5%bark; 90W-10B = chips with 90% wood and 10% bark. Values with the same alphabets within the same tree and among trees in mean column and among fuel materials in the same row are not significantly different using LSD at α 0.05. Each value is an average of three replicates

Table 7. Effect of bark inclusion on the gross calorific value of selected tree species

Tree species	Fuel material composition				Mean
	100% wood	95W-5B	90W-10B	100% bark	
A. leiocarpus	33.60[a]	33.61[a]	33.66[a]	33.23[b]	33.53[A]
C. arereh	33.54[ab]	33.63[a]	33.52[ab]	33.14[b]	33.46[A]
B. aegyptiaca	33.65[a]	33.65[a]	33.02[ab]	32.66[b]	33.25[AB]
C. molle	33.57[a]	33.52[a]	33.52[a]	32.55[a]	33.29[AB]
T. mollis	33.56[a]	33.52[a]	33.47[a]	31.89[b]	33.11[B]
T. indica	33.61[a]	33.49[a]	33.31[ab]	31.96[b]	33.09[B]
S. birrea	33.48[a]	33.45[a]	33.38[a]	32.03[b]	33.08[B]
C. lamprocarpum	33.59[a]	33.46[a]	33.17[ab]	32.22[b]	33.11[B]
P. reticulatum	33.59[a]	33.54[a]	33.54[a]	31.27[b]	32.99[B]
A. sieberiana	33.65[a]	33.40[a]	33.32[a]	31.69[b]	33.02[B]
Mean	33.58[A]	33.53[A]	33.39[B]	32.26[B]	

95W-5B = chips with 95% wood and 5%bark; 90W-10B = chips with 90% wood and 10% bark. Values with the same alphabets within the same tree and among trees in mean column and among fuel materials in the same row are not significantly different using LSD at α 0.05. Each value is an average of three replicates

Table 8. Correlation coefficients between the gross calorific value and proximate properties of the ten-tree species at varying levels of bark inclusion

Proximate Properties	Gross calorific value			
	100% wood	95W-5B	90W-10B	100% bark
Moisture content (%)	-0.201[ns]	-0.328[ns]	-0.412[*]	-0.571[**]
Volatile matter (%)	0.677[**]	0. 645[**]	0.532[**]	0. 417*
Ash content (%)	-0.248[ns]	-0.307[ns]	-0.349[ns]	-0.423[*]
Fixed carbon (%)	0.531[**]	0.786[**]	0.866[**]	0.897[**]

*95W-5B = chips with 95% wood and 5%bark; 90W-10B = chips with 90% wood and 10% bark. *= significant ($P < 0.05$), ** = significant ($P < 0.001$), ns = not significant*

3.5 Gross Calorific Value (GCV)

The gross calorific value gives an indication of the quantity of wood required to generate a specific amount of heat energy and it is a reflection of the previous tests (volatile matter, ash and fixed carbon contents). As presented in Table 7, the average GCV obtained in all the selected trees was quite high. It ranged from 32.99 MJ.kg^{-1} and 33.02 MJ.kg^{-1} in *P. reticulatum* and *A. sieberana*, respectively to 33.53 MJ.kg^{-1} in *A. leocarpus* (Table 7). The values obtained were in the range of 32.94 and 33.68 MJ.kg^{-1} reported for some fuelwood tree species by

Chavan, et al. [35], but higher than between 19.6 and 20.2 MJ.kg^{-1} recorded for some short rotation forest biomass [8] and, 13.78 and 22.22 MJ.kg^{-1} of some ash and extractive free biomass [36].

Meanwhile, the impact of bark inclusion on GCV of the wood fuel varied among the tree species understudy. For example, while addition of bark fractions to the wood from *A. leiocarpus* and *C. arereh* increased their GCV, it lowered the GCV of wood from other tree trees. This inconsistency in the trend of GCV between bark and wood without bark of different trees had been reported by some authors [9]. Senelwa and Sims [8] worked on fuel characteristics of some short rotation forest biomass and reported higher heating value in the bark of *A. dealbata* and *P. eridiano* compared to their wood without bark. Similarly, Deka, et al. [9], worked on six different indigenous tree species and reported higher heating values in the bark of 5 out of the 6 trees studied. In another study, Álvarez-Álvarez, et al. [24], recorded higher heating value in the bark of maritime pine compared to its wood without bark. However, as obtained in this study, wood of most tree species had higher heating value compared to their bark.

3.6 Relationship between the Gross Calorific Value and Proximate Properties of the Selected Tree Species

Since, GCV is a major criteria for rating the energy value of a fuel material, attempt was made to find the relationship between it and proximate properties of the fuel materials understudy. The results, presented in Table 8, showed that there is negative correlation between moisture content of the fuel materials and the GCV. The correlation though, not significant with wood chips without bark (r = -0.201) and wood chips with 5% bark inclusion (r = -0.328), the relationship became significant with wood chips with 10% bark inclusion (r = -0.412) and 100% bark (r = -0.571). The implication of this is that the amount of fuel material required to generate a particular amount of energy is inversely proportional to the moisture content in the fuel material. In line with this, Lyons, et al. [37], stated that high moisture content makes the fuel material less efficient since it reduce the net calorific values as well as the usable heat content in it. Therefore, fuel materials with low moisture content are

preferable based on their high energy content per unit volume.

As observed with MC, negative correlation exists between GCV and ash content at all levels of bark inclusion. Also, the coefficient of correlations increases with increase in in the share of bark in the wood chips. The implication of this is that the non-combustible ash-rich content of the biofuel is higher in the bark. It also implies that majority of the variations in the ash contents of the fuel materials is attributable to the extent of bark inclusions in the bio fuels. Thus, to increase the competitiveness of energy generation from wood chips, it is necessary to control the extent of bark inclusion in the wood chip. In line with this, Sheng and Azevedo [38], reported that, for every 1% increase in ash-rich content of the fuel material, there is 1.39% increase in wood and wood residue consumption. Meanwhile, the relationship between GCV, volatile matter and fixed carbon content was very strong and positive at all the levels of bark inclusions. This is an indication that an increase in volatile matter and fixed carbon contents of a fuel material will result in increase in its net calorific value. In line with this, Chung [39], reported that about 80% of wood energy originates from the combustion of volatile matter while the remaining 20% originates from fixed carbon. Jimenez and Gonzales [40], in their own work reported that 53% of the variability in gross calorific value of biomass material was largely explained by the presence of volatile matter and free carbon content of the biomass material.

4. CONCLUSION

The species of the tree used and composition of the fuel materials obtained from them had significant influence on all the measured fuel properties. Majority of the variability in the proximate and gross calorific value was as a result of variations in the composition of the biomass materials obtained from the trees. Moisture, ash and fixed carbon contents showed an increasing trend with the level of bark contents included in the wood fuel material. Whereas, volatile matter content and gross calorific values decreased with level of bark inclusion. On the average, the bark of the studied species contains higher ash and fixed carbon contents than wood without bark. The wood without bark on the other hand had higher volatile matter content and gross calorific value. Therefore, moisture and ash contents of the fuel materials had negative correlation with gross

calorific value while volatile matter and fixed carbon content contributed positively to gross calorific value. Among the selected species, *A. leiocarpus* had the highest energy value, followed by *C. arereh* and *B. aegyptiaca* while *P. reticulatum, A. sieberiana* and *C. lamprocarpum* had the least energy value in that order. Based on their energy value and ash content, minimizing the bark content in wood chips is important from energy and environment point of view. Therefore, chips with 100% wood and those with 5% bark inclusions are recommended for heat generation.

CONSENT

This study was conceived and carried out by the authors involved. No consent is required from other party.

ETHICAL APPROVAL

The study did not violate any human or animal rights.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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