



Characterization of Charcoal Lighters Produced from Selected Lignocellulosic Materials

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Abstract

This study was undertaken to determine the combustion properties of some selected lignocellulosic materials with the aim of producing a low risk and sustainable solid charcoal lighter. *Citrus sinensis* peels (A), *Pinus caribaea* needles (B), *Thaumatococcus daniellii* leaves (C), *Hildegardia barteri* leaves (D), *Monodora myristica* seeds (E) and *Khaya grandifoliola* wood sawdust were used. Materials were milled, air-dried, sieved and stored. Materials A, B, C, D, and E were blended in equal proportions and compounded with Wood Sawdust (WS) at two ratios (10% and 15%). Data were collected on the following: bulk density, calorific value (CV), lignin content, proximate analysis [%Ash, %Fixed Carbon (FC), %Volatile Matter (VM)] and combustion properties (Combustion rate and ignition time) of the tinder samples as well as the compounded lighters using standard test procedures. Data obtained were analyzed using descriptive statistics and Analysis of Variance (ANOVA) at $\alpha_{0.05}$. Average bulk density of the lighter was $10.45 \pm 0.55 \text{ g/m}^3$. Significant differences were observed in the CV of the selected tinders with highest and lowest values being $22,405.7 \pm 6.28 \text{ kJ/kg}$ and $1,815.36 \pm 6.28 \text{ kJ/kg}$ obtained for *M. myristica* seeds and *C. sinensis* peels, respectively. The highest and lowest CV were $30,299.42 \pm 6.28 \text{ kJ/kg}$ and $25,634 \pm 10.65 \text{ kJ/kg}$ obtained for AB10%WS and ABCD10%WS, respectively. The needles of *P. caribaea* had the highest lignin content of $44.16 \pm 0.13\%$ while *T. daniellii* leaves had the lowest ($12.32 \pm 0.17\%$). The AB10%WS was found to be the best formulation and compounding ratio as it exhibited the least ignition time ($13.33 \pm 0.33 \text{ s}$) and highest combustion rate ($8 \times 10^{-3} \text{ g min}^{-1}$) with low ash ($4.085 \pm 0.85\%$).

Keywords: Bioenergy, Calorific value, Charcoal lighter, *Pinus caribaea*, Proximate analysis, *Thaumatococcus daniellii*

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INTRODUCTION

In the present-day world, massive quantities of energy are being consumed, with much of that energy accounted for by GHG-emitting fossil fuels (Bernstein *et al.*, 2007). As projected by FAO (2003), the global consumption of fossil fuels will continue to be on the rise through 2040 with the exclusion of coal which is believed to have leveled off around 2020. Energy is very essential in

meeting the basic needs of humans such as heating, lighting and cooking. It plays a pivotal role in cooking and processing of food materials for consumption which promotes healthy living (Eva, 2006).

Biomass has the potential to be an increasingly cost-competitive renewable energy source in Australia and to make a valuable contribution to the overall energy supply system mainly because of its very low cost and the fact that it is renewable. Lignocellulosic biomass has proven its potential to be an increasingly cost-

competitive renewable source of energy which could make a valuable contribution to global energy supply system mainly because of its renewability and very low cost (James and Behdad, 2007). As widely reported, use of lignocellulosic biomass constitutes an important material in current world energy scenario and has been recognized as a major renewable energy which could serve as an alternative to the declining conventional sources of energy (McKendry, 2002; Lemm *et al.*, 2014). Utilization of lignocellulosic biomass also presents some environmental benefits, which include neutral gaseous CO₂ emissions as well as low NO₂ and SO₂ emissions (Gil *et al.*, 2010). In light of this, biomass materials have shown considerable properties for use as combustion materials and bioenergy application. For example, the leaves of *Thaumatococcus daniellii* are moderately low in ash (8.95g/100g) compared to its fruit and seed with ash contents of 21.08g/100g and 11.30g/100g, respectively, which makes it suitable for combustion (Shalom *et al.*, 2014). The phytochemical screening of the *T. daniellii* leaves confirm the presence of tannins, terpenoids, flavonoids, alkaloids and cardiac glycosides all making essential compound which support biomass combustion. In the same vein, gasification and pyrolysis of wastes of citrus peel as well as other fruit seeds were recently studied in order to evaluate their potentials for use as bio-fuel in thermal and electrical energy production (Tamelova *et al.*, 2018).

Charcoal combustion has long been a popular activity, to facilitate its starting and combustion for outdoor cooking or barbecue fires, several ignition lighter compositions have been developed. Charcoal lighter exists in different forms from solid to liquid. Liquid lighters are basically made up of flammable hydrocarbon mixtures such as terpene, surfactant, water, alcohol and a thickening agent. All these materials are aggregated to produce a lighter fluid which has so many deficiencies such as unclean burning, introduction of hydrocarbon odour into grilled food and emission of Volatile Organic Compounds (VOC). According to Emmanouil and Panagiotis (2015), VOC emission contributes immensely to low air quality;

approximately 14,500 metric tonnes VOC/year are emitted from the combined combustion of charcoal lighter fluid. The combined combustion of charcoal lighter fluid and a bed of coal contribute to household air pollution which has often recorded a huge number of deaths per year (Mitchual *et al.*, 2014). Reports showed that indoor air pollution accounts for more than 1.5 million deaths/year of mostly of young children and their mothers, with about 400-610 Indoor Air Pollution (IAP) deaths/million recorded in 2000 (Mitchual *et al.*, 2014). For risks associated with the combustion and ignition of charcoal through the use of liquid charcoal lighters as well as the high production cost, it is necessary to shift focus from the use of heavy and non-biodegradable compounds in the production of these lighters and turn to the use of materials of biological origin that will present a level of resource sustainability and development with low risks of combustion.

The overall aim of this study was to formulate, compound and produce a solid charcoal lighter from lignocellulosic tinders. Based on this objective, the effect of formulation and compounding on the bioenergy properties of the solid charcoal lighter were hypothetically assessed in a bid to select the best tinder combination which expresses low ignition time, high intensity and rate of combustion with low ash content. This was achieved through energy and lignin content determination of the selected lignocellulosic tinders while formulating, compounding, and producing charcoal lighter. The energy content, rate of ignition, and proximate analysis (percentage volatile matter, ash content and fixed carbon) of the lighter were also carried out.

MATERIALS AND METHOD

Citrus sinensis (Sweet Orange) fruits and *Monodora myristica* seeds were sourced from Bodija market in Ibadan. Needles of *Pinus caribaea*, *Khaya grandifoliola* wood sawdust and *Hildegardia barteri* leaves were collected within the premises of Faculty of Renewable Natural Resources, University of Ibadan. *Thaumatococcus daniellii* leaves were obtained from the Forestry Research Institute

of Nigeria (FRIN), Jericho Hill, Ibadan. These samples were air-dried to constant weight, milled with an electric milling machine and stored in separate polythene bags (Plate 1) in accordance with procedures of Onuegbu *et al.*, (2011). Materials for production were combined at equal proportion and compounded with sawdust from *K.*

grandifoliola at 10% and 15% by mass of the material combination as shown in Table 1. For example, AB10%WS is a combination of 500 g each of *C. sinensis* and *P. caribaea* compounded with 100 g of *K. grandifoliola* Wood Sawdust (WS).

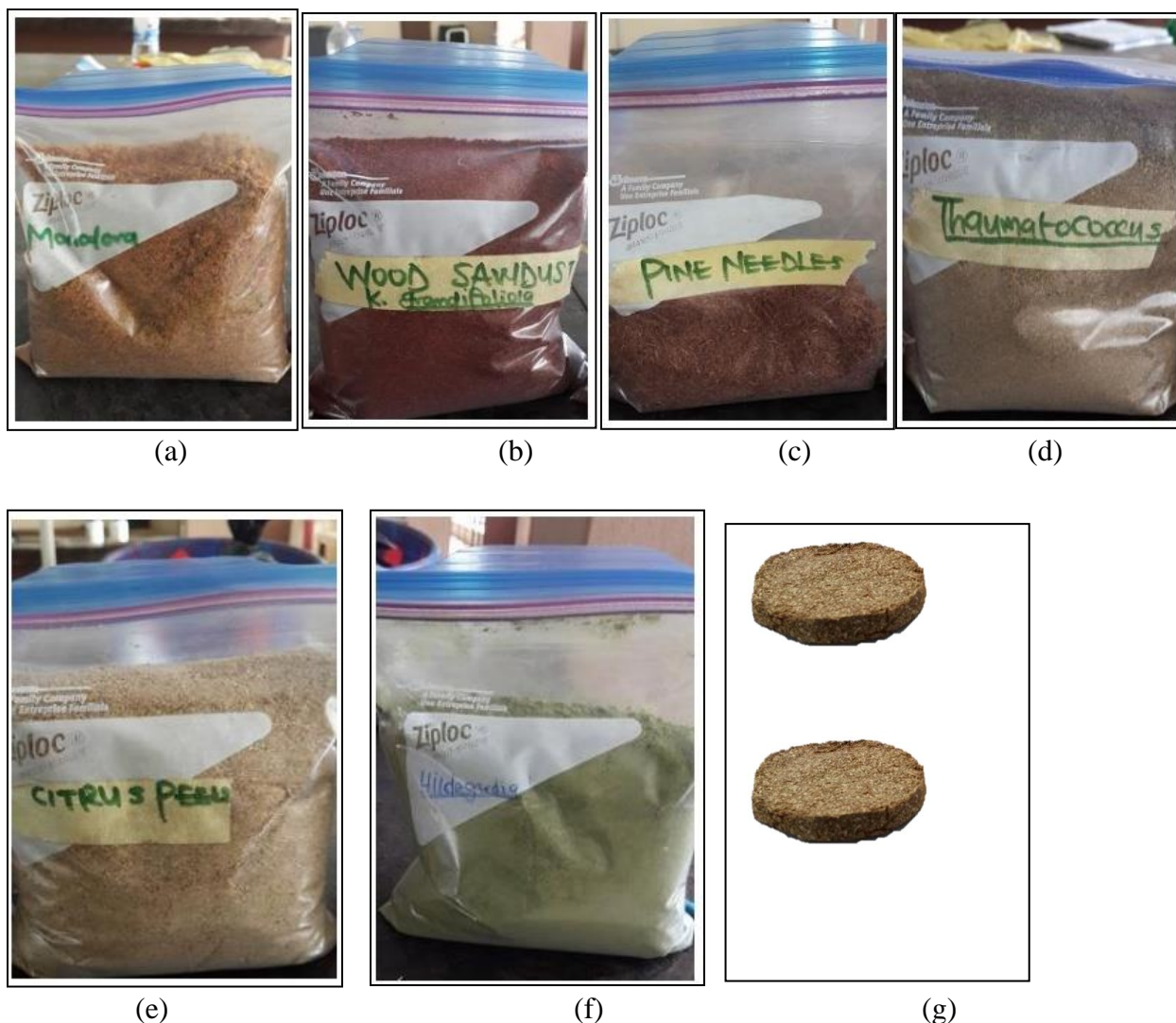


Plate 1: Pulverised tinder samples used for the lighter production: (a) *Monodora myristica* seeds, (b) *Khaya grandifoliola* sawdust, (c) *Pinus caribaea* needles, (d) *Thaumatococcus daniellii* leaves, (e) *Citrus sinensis* peels, (f) *Hildegardia barteri* leaves, (g) solid charcoal lighter produced

Table 1: Lignocellulosic material combinations and formulations

Materials	Material Combination (1 kg)	Compounding with Wood Sawdust (WS)	
		10%* (100 g)	15%** (150 g)
<i>Citrus sinensis</i> peels (A)			
<i>Pinus caribaea</i> needles (B)	AB	AB+10%WS	AB + 15%WS
<i>Thaumatococcus daniellii</i> leaves (C)	ABC	ABC + 10%WS	ABC + 15%WS
<i>Hildegardia barteri</i> leaves (D)	ABCD	ABCD + 10%WS	ABCD + 15%WS
<i>Monodora myristica</i> seeds (E)	ABCDE	ABCDE + 10%WS	ABCDE + 15%WS

* = 10% by mass of the material combination; ** = 15% by mass of the material combination

Each of the treatment combinations were replicated three (3) times. The mixture of the substrate and the wood flour were then bonded together using a synthetic resin adhesive. The ratio of the overall substrate to that of the binder by mass was 6:1. The only two varied factors are material combinations and compounding ratio with wood sawdust (10% and 15%). After biomass collection, data on the weight (wet weight was determined using a digital weighing scale), density (bulk density), moisture content, calorific value and lignin content of each material were obtained by following standard procedures before drying them out to a moisture content of 12% using the oven-drying method.

Calorific Value

The gross calorific value of each lignocellulosic materials used was obtained using the Gallenkamp Ballistic bomb Calorimeter following the ASTM E711-87 standard as reported by Klasnja *et al.*, (2002). A measure of 0.25g of each biomass sample (depending on bulkiness) was weighed into the steel capsule. A 10cm thread of cotton was attached to the thermocouple touching the capsule. The bomb was closed followed by oxygen charge at 30atm. Thereafter, the bomb was ignited, burning the sample in an excess oxygen condition. The thermocouple and galvanometer system were used to measure the maximum temperature in the bomb. The temperature rise was compared with that obtained for 0.25g of Benzoic value of each sample which was then determined by calculation.

Lignin Content

Lignin content of each lignocellulosic material was determined using Klason method, where the carbohydrates in the biomass materials were hydrolyzed and solubilized with 72% sulfuric acid. The acid-insoluble lignin was filtered off, dried, and weighed (Daniel *et al.*, 2014).

Ignition Time

This is basically the time taken for the lighter to catch fire after ignition. For the material combination and compounding ratio, each lighter sample was ignited at the base in a drought free area (Harada, 2001). The time required for the flare from an ignition source (match) to ignite the lighter was then recorded as the ignition time with the aid of a stop watch.

Rate of Combustion

The rate of combustion was assessed with full combustion in a furnace. Approximately 2g of the solid charcoal lighter produced was combusted in a furnace at 600°C for 4 hours to attain full combustion. The weight of ash after combustion was subtracted from the initial weight of the lighter to determine the fuel loss (Jenkins *et al.*, 1998)

Percentage Content of Ash

The percentage contents of ash of both the lighter and various lignocellulosic materials used were determined. A measure of 2g of each sample was put in a porcelain crucible and placed in the furnace to burn at 600°C for 4 hours to attain full combustion (ASTM D 1102-84). After full combustion, the samples were allowed to cool in a desiccator. A crucible containing the sample was weighed and subtracted from the initial weight of the crucible to obtain the weight of the ash.

The content of ash was determined using equation 1 below:

$$\text{Ash Content} = \frac{\text{Weight of ash after full combustion}}{\text{Weight of lighter sample before combustion}} \times 100 \quad (1)$$

Percentage Volatile Matter and Percentage Fixed Carbon

The content of volatiles of each compounded lighter was determined following the ASTM D3175-11 (equations 2 & 3) procedure as reported by Mohan *et al.*, (2006). Approximately 2g of each compounded lighter as well as the various lignocellulosic materials were placed in porcelain crucible, kept in a furnace at 550°C for 10 mins, weighed after allowing to cool in a desiccator.

$$\%VM = \frac{A-B}{A} \times 100 \quad (2)$$

A = weight of oven-dried sample

B = weight of sample after 10 mins in the furnace at 550°C

$$\%FC = 100 - (\%Ash + \%VM) \quad (3)$$

Data Analysis

The experiment was arranged in a 4x2 factorial experiment in completely

randomized design. Full Factorial Analysis was used to study the effect of material combination, compounding ratio and their possible interaction on the various properties examined. Descriptive statistics and Analysis of Variance (ANOVA) were used to analyze the data obtained. Pair of means found to differ significantly were separated using Duncan Multiple Range Test (DMRT).

RESULTS

Energy Value of the Selected Tinders

Table 2 shows the energy or heat value of the selected tinders. *M. myristica* seeds had the highest calorific value (22405.78 kJ/kg) which was significantly different from other selected tinders. *C. sinensis* peels had the lowest calorific value (18155.36 kJ/kg). The energy values of *K. grandifoliola* wood sawdust and *P. caribaea* needles (20797.94 kJ/kg and 20772.61 kJ/kg respectively) were not significantly different.

Table 2: Energy Characteristics of the Selected Tinders

Tinder Type	Calorific Value (kJ/kg)			
	Minimum	Maximum	Mean	C.V (%)*
<i>Citrus sinensis</i> (Peels)	18149.08	18161.64	18155.36 ±6.28 ^a	0.05
<i>Hildegardia barteri</i> (Leaves)	18932.16	18944.72	18938.44±6.28 ^b	0.05
<i>Khaya grandifoliola</i> (Wood Sawdust)	20791.46	20804.02	20797.74±6.28 ^c	0.04
<i>Monodora myristica</i> (Seed)	22399.50	22412.06	22405.78±6.28 ^d	0.04
<i>Pinus caribaea</i> (Needles)	20762.14	20783.08	20772.61±10.47 ^c	0.07
<i>Thaumatococcus daniellii</i> (Leaves)	18438.02	18454.77	189446.40±8.38 ^e	0.06

Mean values with the same alphabet are not significantly different using Duncan's Multiple Range

Test at p<0.05, *C.V = Coefficient of Variation

Proximate analysis of selected tinder

Among all the selected tinder, the peels of *Citrus sinensis* had the highest percentage of volatile matter (71.25%) though not significantly different from the volatile matter of *H. barteri* leaves (70.05) as shown on Table 3. Also, the equivalent percentage fixed carbon and percentage ash content were 21.51% and

7.25%, respectively. For all the selected tinders, percentage fixed carbon were not significantly different with p>0.05 except for leaves of *H. barteri* (15.25%) and needles of *P. caribaea* (28.75%). The peels of *C. sinensis* had the lowest ash content, which was significantly different from other selected tinders while *H. barteri* (14.25%) had the highest ash content, which was not significantly different from that

of *T. daniellii* (13.50%). The needles of *P. caribaea* had the highest percentage lignin content (44.16 %) while *T. daniellii* leaves had the lowest percentage lignin content (12.32 %). There was no significant differences in the lignin content of *C. sinensis* peels and *H. barteri* leaves while other tinder samples (*K. grandifoliola*, *M. myristica*, *P. caribaea* and *T. daniellii*) were significantly different ($p<0.05$)

Energy Value of the Compounded Lighter

Table 4 shows the energy value of the compounded lighter, AB10%WS (a combination of *C. sinensis* peels and *P. caribaea* needles) had the highest energy value (30,299.42 kJ/kg) while ABCD10%WS had the lowest energy value (25,634.42 kJ/kg). Energy values of all the material combinations were statistically different.

Table 3: Proximate Analysis of Selected Tinder Samples

Tinder Type	Proximate Analysis				
	Moisture Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Ash Content (%)	Lignin Content (%)
<i>Citrus sinensis</i> (Peels)	11.00	71.25±0.75 ^a	21.51±1.00 ^a	7.25±0.25 ^a	18.20±0.05 ^a
<i>Hildegardia barteri</i> (Leaves)	12.10	70.05±0.5 ^a	15.25±0.75 ^b	14.25±0.25 ^c	18.40±0.02 ^a
<i>Khaya grandifoliola</i> (Wood Sawdust)	12.60	66.13±0.23 ^b	23.63±0.48 ^a	10.25±0.25 ^b	16.20±0.02 ^b
<i>Monodora myristica</i> (Seed)	12.40	67.75±0.75 ^b	23.25±0.25 ^a	9.00±0.25 ^b	39.72±0.14 ^c
<i>Pinus caribaea</i> (Needles)	12.04	61.00±0.5 ^c	28.75±0.75 ^c	10.25±0.25 ^b	44.16±0.13 ^d
<i>Thaumatococcus daniellii</i> (Leaves)	12.34	62.75±0.25 ^c	23.75±0.75 ^a	13.50±1.00 ^c	12.32±0.17 ^e

Mean values with the same alphabet (along the column) are not significantly different ($p<0.05$)

Table 4: Energy Value of the formulated charcoal lighters

Material Combination	Calorific Value (kJ/kg)		
	Minimum	Maximum	Mean ± S.E*
AB10%WS	30,293.13	30,305.70	30,299.42±6.28 ^a
ABC10%WS	26,310.72	26,323.28	26,317.00±6.28 ^b
ABCD10%WS	25,623.95	25,644.89	25,634.42±10.65 ^c
ABCDE10%WS	26,779.73	26,792.29	26,786.01±6.28 ^d
AB15%WS	29,807.37	29,819.93	29,813.65±6.28 ^e
ABC15%WS	29,752.93	29,765.49	29,759.21±6.25 ^f
ABCD15%WS	26,712.73	26,725.29	26,719.01±6.28 ^g
ABCDE15%WS	25,665.83	25,678.39	25,672.11±6.28 ^h

*S.E = Standard Error. Mean values with the same alphabet are not significantly different ($p<0.05$)

Proximate analysis of the compounded lighter materials

The percentage volatile matter reduced with increase in the material combination, though values were not significantly different (Table 5). Unlike the percentage volatile matter, percentage ash content of all the material combinations were significantly different. Table 6 shows the effect of material

combination and compounding ratio on the proximate analysis of the compounded lighter. The material combination, compounding ratio and the interaction between them had a significant effect on the percentage fixed carbon and percentage ash ($p<0.05$). Conversely, there was no significant effect of compounding on volatile matter of the compounded lighter ($p=0.378$).

Table 5: Proximate Analysis of the formulated charcoal lighters

Proximate Analysis	% Volatile Matter	% Fixed Carbon	% Ash
Material Combination	Mean*	Mean	Mean
AB10%WS	69.00±0.50 ^a	26.92±0.59 ^a	4.09±0.09 ^a
ABC10%WS	64.50±0.50 ^d	31.06±0.56 ^{b,c}	4.45±0.06 ^b
ABCD10%WS	64.68±0.33 ^d	29.84±0.34 ^b	5.49±0.02 ^c
ABCDE10%WS	63.43±0.08 ^{c,d}	31.52±0.02 ^c	5.06±0.06 ^d
AB15%WS	68.90±0.40 ^a	17.60±0.40 ^d	13.50±0.00 ^e
ABC15%WS	67.45±0.04 ^a	24.07±0.07 ^c	8.49±0.02 ^f
ABCD15%WS	63.68±0.68 ^{c,d}	28.27±0.73 ^a	8.06±0.06 ^g
ABCDE15%WS	62.70±0.20 ^c	27.79±0.22 ^a	9.52±0.02 ^h

*Mean ± Standard Error. Mean values with the same alphabet along the columns are not significantly different (p<0.05).

Table 6: Analysis of Variance (ANOVA) showing effect of compounding and material combination on proximate properties of the charcoal lighters

		Sum of Squares	Df	Mean Square	F	Sig.
Fixed Carbon (%)	Material Combination	135.979	3	45.326	120.102	0.000*
	Compounding	116.748	1	116.748	309.348	0.000*
	Interaction	35.296	3	11.765	31.175	0.000*
	Error	3.019	8	0.377		
	Total	291.043	15			
Volatile Matter (%)	Material Combination	78.535	3	26.178	82.859	0.000*
	Compounding	0.276	1	0.276	0.872	0.378 ^{ns}
	Interaction	10.077	3	3.359	10.632	0.004*
	Error	2.527	8	0.316		
	Total	91.415	15			
Ash Content (%)	Material Combination	12.809	3	4.270	1.020E3	0.000*
	Compounding	105.062	1	105.062	2.509E4	0.000*
	Interaction	26.532	3	8.844	2.112E3	0.000*
	Error	0.033	8	0.004		
	Total	144.436	15			

* = significant; ns = not significant

Effect of compounding and material combination on the combustion properties of the solid charcoal lighter

Table 7 shows the combustion properties of the compounded lighter. AB10%WS had the least ignition time (13.33 s) with the highest rate of combustion ($8 \times 10^{-3} \text{gmin}^{-1}$) while ABC10%WS combusted with high ignition time (35.33s). AB15%WS had the lowest rate

of combustion ($7.2 \times 10^{-3} \text{gmin}^{-1}$). From the factorial ANOVA (Table 8), material combination, compounding ratio and the interaction between them had a significant effect on the ignition and burning time (s) of the compounded lighter (p<0.05). Conversely, the material combination (p=0.412) and factors interaction (p=0.442) do not have significant effect on the combustion rate (gmin^{-1}) of the compounded lighter.

Table 7: Combustion properties of the charcoal lighters

Material Combination	Density (g/m ³)	Ignition Time (s)	Burning Time (s)	Combustion Rate (gmin ⁻¹)
AB10%WS	39.56±4.21	13.33±0.33	117.33±2.91	8.00x10 ⁻³
ABC10%WS	20.52±1.98	35.33±1.20	157.00±3.46	7.96x10 ⁻³
ABCD10%WS	22.25±0.77	28.00±2.31	127.00±2.65	7.88x10 ⁻³
ABCDE10%WS	19.02±0.51	21.33±0.88	85.67±2.03	7.92x10 ⁻³
AB15%WS	20.20±0.48	30.33±2.33	129.33±2.40	7.20x10 ⁻³
ABC15%WS	18.76±0.80	21.00±0.58	74.33±1.00	7.63x10 ⁻³
ABCD15%WS	19.66±0.54	25.00±2.58	197.50±3.50	7.67x10 ⁻³
ABCDE15%WS	22.32±1.33	27.67±6.28	70.67±4.26	7.54x10 ⁻³

Table 8: Analysis of Variance (ANOVA) showing effect of compounding and material combination on combustion properties of the charcoal lighters

		Sum of Squares	Df	Mean Square	F	Sig.
Ignition Time (s)	Material Combination	62.188	3	20.729	4.198	0.046*
	Compounding	27.562	1	27.562	5.582	0.046*
	Interaction	672.688	3	224.229	45.414	0.000*
	Error	39.500	8	4.938		
	Total	801.937	15			
Burning Time (s)	Material Combination	123116.750	3	41038.917	887.328	0.000*
	Compounding	17556.250	1	17556.250	379.595	0.000*
	Interaction	113878.750	3	37959.583	820.748	0.000*
	Error	370.000	8	46.250		
	Total	254921.750	15			
Combustion Rate (gmin ⁻¹)	Material Combination	0.048	3	0.016	1.076	0.412 ^{ns}
	Compounding	0.628	1	0.628	42.098	0.000*
	Interaction	0.045	3	0.015	0.998	0.442 ^{ns}
	Error	0.119	8	0.015		
	Total	0.840	15			

* = significant; ns = not significant

DISCUSSION

With a view to selecting the best material combination and compounding ratio of the solid charcoal, the major fuel properties (low ignition time, high combustion rate and low percentage ash content) of the lighter were considered. The formulation and compounding of the solid charcoal lighter was assessed to select the best tinder combination which expresses good ignition (as low as possible), high intensity and rate of combustion with low ash content. The high

energy content found in *Monodora myristica* seed could be attributed to inherent volatile essential oils in the seed which is believed to have high energy values. Owokotomo and Ekundayo (2012) noted that the essential oil of *M. myristica* seeds had tricyol (13.35%), germacrene (25.48%), cadinene (11.09%) and linalool (17.98%). The selected tinder samples had calorific values higher than some other biomass materials such as groundnut shell (13,785-17,428 kJ/kg) and black walnut hull (17,719-21,193 kJ/kg) as reported by Jekayinfa and Omisakin (2005). According to

Austrian standard for fuel pellets and briquettes, all the tinder samples selected are considered adequate since they had gross calorific values of between 18,000 and 22,400 kJ/kg, mostly within the range of the prescribed minimum value (18,000 kJ/kg), (Austria ÖNORM M7135, 2000) and 17,500-19,500 kJ/kg reported by Germany DIN 51731 (1996) standard (Stephen *et al.*, 2014).

The sawdust of *Khaya grandifoliola* had average lignin content outside the range reported by Maha (2015) for hardwood stems (18% -25%); which could be attributed to the difference in ecological region. The inherent volatile essential oils of *M. myristica* may also have accounted for its high lignin content and which resulted in its high energy value. According to Demirbas (2010), Higher Heating Value (HHV) is highly positively correlated with percentage lignin content, which means that the higher the lignin content, the higher the energy value. From a general overview of nut shells, the lignin content of *M. myristica* seeds falls within the range reported by Maha (2015) for nut shells. By comparison, the leaves of *T. daniellii* had a lignin content slightly lower than that obtained for the stalk of the same species (13.04%) as reported by Oluwadare and Sotande (2014) and also lower than other Non-Wood Fibres (NWFs) such as kenaf and hemp (Dutt *et al.*, 2009). In a report by Shalom *et al.*, (2014), the phytochemical screening of *T. daniellii* leaf confirmed the presence of tannins, terpenoids, alkaloids, flavonoids and cardiac glycosides, all of which are essential compound that support biomass combustion.

C. Sinensis, among other materials studied, had the highest content of volatiles, which may imply that it loses most of its gases and essential oils during combustion which could practicably leave a good scent on foods cooked on the grill. Results of proximate analysis obtained for the selected tinders are in consonance with the report of Emmanouil and Panagiotis (2015) that most biomass have higher volatile content than coal, while herbaceous biomass tend to have volatile content slightly higher than that of woody biomass or certain agro-industrial residues. By practical implication, solid fuels with high volatile-matter content will have a good

ignition property and will be highly reactive in combustion applications though it could cause some problems to internal combustion engines (Li *et al.*, 2009). Fixed carbon which is the combustible residue remaining after heating a particle and the volatile matter is discharged. With the exception of *Hildegardia barteri* leaves, all the materials studied had percentage fixed carbon higher than most biomass fuels reported by Miles *et al.* (1995) and Joshua *et al.* (2016). This could imply that the tinder samples are appropriate for combustion applications.

As compared to the energy values of the tinders, the compounded lighter had a higher energy value. This higher value could be attributed to compounding and/or densification which is believed to enhance volumetric energy value of biomass materials and produce a consistent, stable and clean fuel, or an feedstock for further processes (Shaw, 2008). All the material combination and compounding ratio could be considered adequate because their respective calorific values were higher than the recommended minimum standard for fuel pellets (Austria ÖNORM M7135, 2000).

The compounded lighter in this study had a volatile matter and fixed carbon higher than some other fuels produced from materials such as rice straw, wheat straw and rice hull (Muthuraman *et al.*, 2010). The observed difference could be as a result of material combination which had a significant effect on proximate properties of the lighter. Conversely, ash content of the compounded lighter is lower than some other fuels reported by Jenkins *et al.*, (1998). The proximate analysis result implies that the charcoal lighter could ignite easily, combust freely and burn with low ash.

From results obtained, it could be inferred that any of the material combinations and compounding ratio can be selected as they do not have significant effect on the combustion rate of the solid charcoal lighter even though the compounding ratio had a singular effect on the combustion rate. According to Haugen *et al.*, (2016), combustion properties and gasification of biomass is chiefly influenced by important factors such as heating value, moisture, ash residue and volatile contents.

AB10%WS had the highest volatile content, which was statistically different from other material combinations. This could be a probable reason why it exhibits good combustion properties (low ignition time, high rate of combustion and low ash residue). Hence, among other material combination, ABCDE15%WS had the lowest volatile content, a high ignition time, lowest burning time, low combustion rate and highest ash content; this in a way seem less appropriate for the desired end use.

CONCLUSIONS

The outcome of this study has shown that there was an increase in the heating value of the lighter which revealed the effect of various

REFERENCES

- American Standard for Testing Materials International (2008). ASTM D1102-84, Test Method for Ash in Wood. Annual Book of ASTM Standards, pp. 153-154
- American Standard for Testing Materials International (2012). ASTM Standard E711-87, Standard Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter.
- Austria ÖNORM M7135 (2000). Compressed wood and compressed bark in natural state – Pellets and briquettes. Requirements and test specifications, Energy from solid biofuels. 1-10
- Bernstein, L., Roy, J., Delhotal, K. C., Harnisch, J., Matsushashi, R., Price, L., Tanaka, K., Worrell, E., Yamba, F., Fengqi, Z. (2007). Industry. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Daniel, J. N., Aaron, T. L. and Raymond, C. F. (2014). A Three-Stage Klason Method for more Accurate Determinations of Hardwood Lignin Content. *Cellulose Chem. Technol.*, 48 (1-2):53-59
- formulations on the energy value of lignocellulosic biomass. From the results, it could be concluded that the charcoal lighters produced from lignocellulosic tinders could be a better substitute to existing liquid charcoal lighters because it could burn and combust easily with less ignition hazard and less volatile emission. Out of the various formulations, AB10%WS was found to be the most preferred formulation as it exhibited the lowest ignition time, better combustion rate and low ash content. This formulation consisted of *Citrus sinensis* peels with the needles of *Pinus caribaea* and compounded with 10% (by mass) of wood sawdust from *Khaya grandifoliola*.
- Demirbas, A. (2010). Fuels from Biomass. A publication of Springer (IX):3-73. <http://www.springer.com/978-1-84882-720-2> ISBN: 978-1-84882-720-2. Retrieved: 9-11-2018.
- DIN 51731 (1996). Testing of solid fuels - Compressed untreated wood - Requirements and testing. STANDARD by Deutsches Institut Fur Normung E.V. (German National Standard), 10/01/1996
- Dutt, T.D., Upadhyay, J.S., Singh, B., and Tyagi, C.H. (2009). Studies on *Hibiscus connabinus* and *Hibiscus sabdariffa* as an alternative pulp blend for softwood: An optimization of kraft delignification process. *Industrial Crops and Products*, 29(1):16-26.
- Emmanouil, K., and Panagiotis, G. (2015). "Descriptions of the biomass fuel composition" A Fuel Analysis BISOPLAN Handbook. http://bisoplan.bioenarea.eu/fuel_appendix.pdf Retrieved: 20-11-2015. 1-6
- Eva, R. (2006). Fuel for life: household energy and health. I. Rehfuess, Eva. II. World Health Organization. ISBN 92 4 156316 8.1-23.
- FAO (2003). Medium-term prospects for agricultural commodities. A publication of FAO Commodities and Trade Division. 1-89p
- Gil, M.V., Oulego, P., Casal, M. D., Pevida, C., Pis, J. J., and Rubiera, F. (2010). Mechanical durability and combustion

- characteristics of pellets from biomass blends. *Bioresource Technology*, 101: 8859-8867
- Harada, T. (2001). Time to Ignition, heat release rate and fire endurance time of wood in cone calorimetry test. *Fire and Materials* 25:161-167.
- Haugen, H.H., Furuvik, N.C.I., and Moldestad, B.M.E. (2016). Characterization of biomass wood. Conference Proceedings of the 2nd International Conference on Energy Production and Management. WIT Transactions on Ecology and The Environment, 205: 257-269; doi:10.2495/EQ160241..
- James, N. and Behdad, M. (2007). Biomass and Bioenergy: Coal-Biomass Cofiring Handbook, Chapter 1, Publisher: Cooperative Research Centre for Coal in Sustainable Development, 1-36.
- Jekayinfa, S., and Omisakin, O. (2005). The Energy Potentials of some Agricultural Wastes as Local Fuel Materials in Nigeria. *Agricultural Engineering International: the CIGR Ejournal*. 7: 1-9
- Jenkins, B. M., Baxter, L. L., Miles Jr. T. R., Miles, T.R. (1998). Combustion properties of biomass. *Fuel Processing Technology* 54:17-46.
- Joshua, J.A., Julius, C. A., and Ayoade, K. (2016). "Nigerian Hardwood (*Nesogordonia papaverifera*) Sawdust Characterization: Proximate Analysis, Cellulose and Lignin Contents" *Lignocellulose*. 5(1): 50-58.
- Klasnja, B., Kopitovic, S., and Orlovic, S., (2002). Wood and bark of some poplar and willow clones as fuelwood. *Biomass and Energy* 23:427-432.
- Lemm, O., Erni, R., and Ballmer, M. I. (2014): Potenziale, Chancen und Risiken der Energieholznutzung. Zur Rolle des Holzesim Schweizer Energie system. WSL Berichte Reports. 21: 29-42.
- Li, Z., Zhao, W., Li, R., Wang, Z., Li, Y., and Zhao, G. (2009). Combustion characteristics and NO formation for biomass blends in a 35-ton-per-hour travelling grate utility boiler. *Bioresource Technology*, 100: 2278-2283
- Maha, D. (2015). Challenges of ethanol production from lignocellulosic biomass. A publication of Katzen International Inc. pp. 1-45
- McKendry, P. (2002). Energy production from biomass (part 1): overview of biomass. *Bioresource Technology*. 83 (2002): 37-46.
- Miles, I., Kastrinos, N., Bilderbeek, R., Hertog, P. D., Flanagan, K., Huntink, W., and Bouman, M. (1995). *Knowledge-intensive business services: users, carriers and sources of innovation*. (European Innovation Monitoring System (EIMS) Reports). European Commission
- Mitchual, S.J., Frimpong-Mensah, K., and Darkwa, N. A. (2014). Evaluation of Fuel Properties of Six Tropical Hardwood Timber Species for Briquettes. World Academy of Science, Engineering and Technology. *International Journal of Environmental and Ecological Engineering*, 8:531-537.
- Mohan, D., Pittman, Jr., U.C., and Steele, H. P. (2006). "Pyrolysis of wood/biomass for bio-oil: A critical review," *Energy and Fuels* 20:848-889.
- Muthuraman, M., Namioka, T., and Yoshikawa, K. (2010). A comparison of co-combustion characteristics of coal with wood and hydrothermally treated municipal solid waste. *Bioresource Technology*. 101:2477-2482
- Oluwadare, A.O., and Sotande, O.A., (2014). Fibre and elemental contents of *Thaumatococcus daniellii* stalk and its implications as a non-wood fibre source. *International Journal of Applied Science and Technology*. 4(1):178-185
- Onuegbu, T.U., Ekpunobi U.E., Ogbu, I.M., Ekeoma, M. O. and Obumselu, F.O. (2011). Coal and biomass briquette blend. *International Journal of Recent Research and Applied Sciences*. 8:153-159
- Owokotomo, I.A., and Ekundayo, O. (2012). "Comparative study of the essential oils of *Monodora myristica* from Nigeria". *European Chemical Bulletin*. 1(7):263-265.
- Shalom, N., Adetayo, Y.O, Samuel, T.P, Bolaji, J.D., and Tamunotonyesia, E. (2014). Analyses of the leaf, fruit and seed of

- Thaumatococcus daniellii* (Benth.): exploring potential uses. *Pakistan Journal of Biological Sciences*. 17 (6):849-854.
- Shaw, M.D. (2008). "Feedstock and Process Variables Influencing Biomass Densification, Agricultural and Bioresource Engineering", Master of Science, University of Saskatchewan, Canada. 147p.
- Stephen, J. M., Kwasi, F. M., and Nicholas, A.D. (2014). "Evaluation of fuel properties of six tropical hardwood timber species for briquettes. *Journal of Sustainable Bioenergy Systems*.4:1-9
- Tamelova, B., Malat'ak, J., and Velebil, J. (2018). Energy volarisation of citrus peel waste by torrefaction treatment. *Agronomy Research*. 16(1):276-285. <https://doi.org/10.15159/AR.18.029>
- US Energy Information Administration (2017). International Energy Outlook. <https://www.eia.gov/todayinenergy/detail.php?id=32912>. Retrieved: 3rd March, 2019.