PRODUCTION AND FORMULATION OF SOLID CHARCOAL LIGHTER FROM LIGNOCELLULOSIC MATERIALS

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Abstract

This study was undertaken to determine the bioenergy 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 air-dried and stored after milling to pass through a 4mm standard sieve. Materials were combined (AB, ABC, ABCD, ABCDE) in equal proportion and compounded with Wood Sawdust (WS) at different ratios (10% and 15%). Data were taken on 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 analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$. Average bulk density of the lighter was $10.45 \pm 0.55 g/m^3$. Significant differences were observed in the CV of the selected tinders with highest and lowest value being $22405.7\pm6.28kJ/kg$ and $1815.36\pm6.28kJ/kg$ obtained for M. myristica seeds and peels of C. sinensis, respectively. The highest and lowest CV was $30299.42\pm6.28kJ/kg$ and $25634\pm10.65kJ/kg$ obtained for AB10%WS and ABCD10%WS, respectively. The needles of P. caribaea had the highest lignin content of $44.16\pm0.13\%$ and T. daniellii leaves the lowest ($12.32\pm0.17\%$). The AB10%WS was found to be the best formulation and compounding ratio as it exhibits the least ignition time ($13.33\pm0.33s$) and highest combustion rate ($8x10^{-3}gmin^{-1}$) with low ash ($4.085\pm0.85\%$).

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

Introduction

In the present day world, massive quantities of energy are being consumed, with much of that energy embodied 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 level off around 2020. Energy is very essential in meeting the basic needs of human 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).

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In the developing nations of the world, charcoal combustion constitutes a significant energy and lignocellulosic biomass has proven its potential to be an increasingly cost-competitive renewable source of energy which could make a valuable contribution to the global energy supply system mainly because of its renewability and very low cost (James and Behdad, 2007). As broadly reported, biomass constitutes an important material in the 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). Biomass also presents some environmental benefits, which include neutral gaseous CO_2 emissions as well as low NO_2 and SO_2 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 other parts of the plant (fruit and seed) having 21.08g/100g and 11.30g/100g respectively and this makes it suitable for combustion (Shalom *et al.*, 2014). The phytochemical screening of the leaf confirms the presence of tannins, terpenoids, flavonoids, alkaloids and cardiac glycosides all making an essential compound which support biomass combustion. In the same vein, several authors recently studied gasification and pyrolysis of wastes of citrus peel as well as other fruit seeds in order to evaluate their potential for use as bio-fuel in thermal and electrical energy production (Tamelova *et al.*, 2018).

Outdoor uses of energy such as charcoal combustion has long been a popular activity and 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 asterpene, 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 onto 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 1.5million deaths/year which is mostly of young children and their mothers with about 400-610 Indoor Air Pollution (IAP) deaths/million recorded in 2000 (Mitchual *et al.*, 2014). With 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 therefore 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 which will present a level of resource sustainability and development with low risks of combustion.

The overall objective 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

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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 the following specific objectives:

i. determination of calorific value of the selected lignocellulosic tinders
ii. determination of lignin content of the selected lignocellulosic tinders
iii. formulation, compounding and production of a solid charcoal lighter
iv. determination of calorific value and ignition rate of the formulated and compounded lighter
v. proximate analysis (percentage volatile matter, ash content and fixed carbon) of the formulated and compounded lighter

Materials and Methods

Citrus sinensis (Sweet Orange) fruits and *Monodora myristica* seeds were sourced from Bodija market in Ibadan. Needles of *Pinus caribaea*, wood sawdust of *Khaya grandifoliola* and *Hildegardia barteri* leaves were collected within the Faculty of Renewable Natural Resources, University of Ibadan premises. *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 millings machine and stored in separate polythene bags (Plate 1) in accordance with procedures of Onuegbu *et al.,* (2011). Major materials for production were combined at ratio 1:1 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 Wood Sawdust (WS) from *K. grandifoliola*.
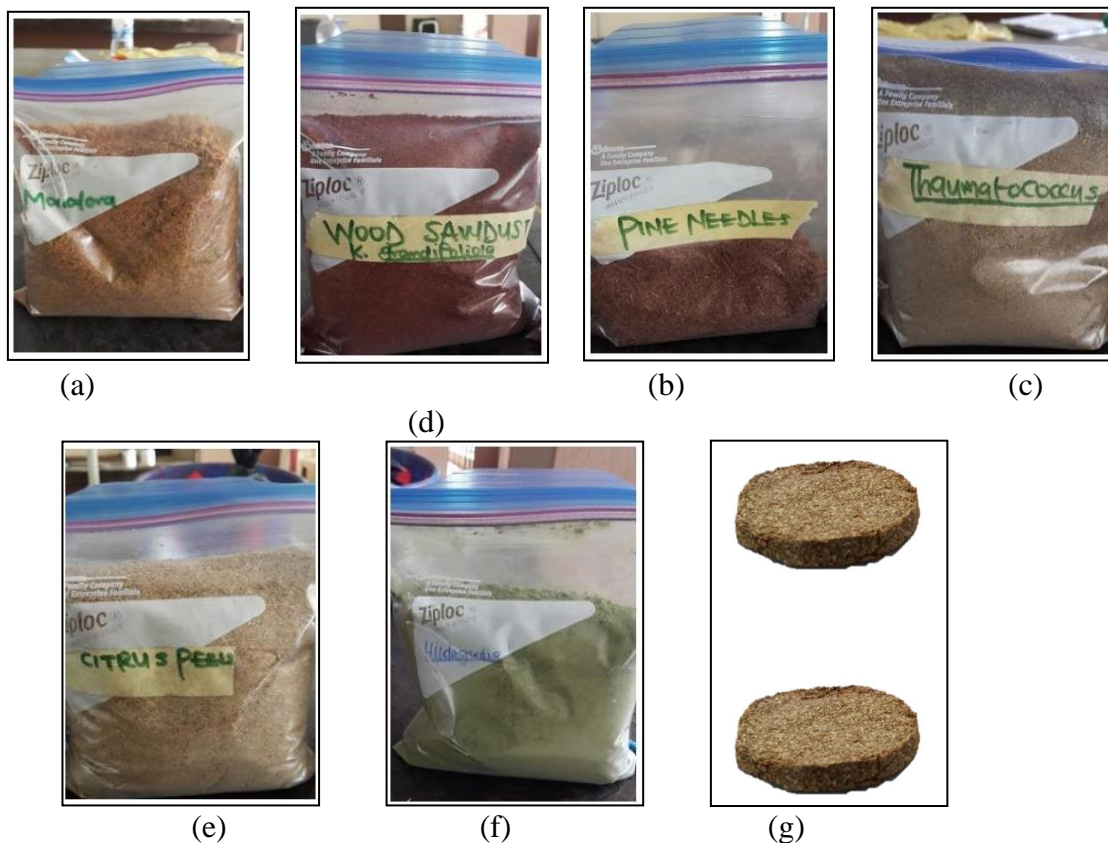

(a)   (b)   (c)

(d)

(e)   (f)   (g)

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: Material combination and compounding ratio

Materials	Material Combination (1 kg)	Compounding with Wood Sawdust (WS)	
		10%* (100 g)	15%** (150 g)
Citrus sinensis peels (A)			
Pinus caribaea needles (B)	AB	AB+10%WS	AB + 15%WS
Thaumatococcus daniellii leaves (C)	ABC	ABC + 10%WS	ABC + 15%WS
Hildegardia barteri leaves (D)	ABCD	ABCD + 10%WS	ABCD + 15%WS
Monodora myristica 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 respectively. The only two varied factors are material combinations and compounding ratio with wood sawdust (10% and 15%).

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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 was 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 4hrs 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 content of ash of both the lighter and various lignocellulosic materials used was determined. A measure of 2g of each weighed sample was put in a porcelain crucible and placed in the furnace to burn at 600°C for 4 hrs 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 the formula below:

$$Ash\ Content = \frac{Weight\ of\ ash\ after\ full\ combustion}{Weight\ of\ lighter\ sample\ before\ combustion}\ x\ 100\ \text{------------ (i)}$$

Percentage Volatile Matter and Percentage Fixed Carbon
The content of volatiles of each compounded lighter was determined following the ASTM D3175-11 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.

$$\%VM = \frac{A-B}{A}\ x\ 100\ -------------------(ii)$$

A = weight of oven-dried sample
B = weight of sample after 10 mins in the furnace at 550°C
$$\%FC = 100 - (\%Ash + \%VM)\ \text{-- (iii)}$$

Data Analysis
Data obtained were analysed descriptively, means were separated using Analysis of Variance (ANOVA) while further analysis using Duncan Multiple Range Test (DMRT) was used to measure specific differences between the pair of means. Following a 4x2 factorial design, Full Factorial Analysis was used to study the effect of material combination, compounding ratio and their possible interaction on the various properties examined.

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 (22405.78kJ/kg) which was significantly different from other selected tinders. *C. sinensis* peels had the lowest calorific value (18155.36kJ/kg). The energy values of *K. grandifoliola* wood sawdust and *P. caribaea* needles (20797.94 kJ/kg and 20772.61 kJ/kg respectively) are not significantly different.

Table 2: Energy Characteristics of the Selected Tinders

Tinder Type	Calorific Value (kJ/kg)			
	Minimum	Maximum	Mean	C.V (%)[*]
Citrus sinensis (Peels)	18149.08	18161.64	18155.36 ±6.28[a]	0.05
Hildegardia barteri (Leaves)	18932.16	18944.72	18938.44±6.28[b]	0.05
Khaya grandifoliola (Wood Sawdust)	20791.46	20804.02	20797.74±6.28[c]	0.04

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Monodora myristica (Seed)	22399.50	22412.06	22405.78±6.28[d]	0.04
Pinus caribaea (Needles)	20762.14	20783.08	20772.61±10.47[c]	0.07
Thaumatococcus daniellii (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) 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 least content of ash which was significantly different from other selected tinders while *H. barteri*(14.25) had the highest content of ash 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 difference 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)

Table 3: Proximate Analysis of Selected Tinder Samples

Tinder Type	Proximate Analysis				
	Moisture Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Ash Content (%)	Lignin Content (%)
Citrus sinensis (Peels)	11.00	71.25±0.75[a]	21.51±1.00[a]	7.25±0.25[a]	18.20±0.05[a]
Hildegardia barteri (Leaves)	12.10	70.05±0.5[a]	15.25±0.75[b]	14.25±0.25[c]	18.40±0.02[a]
Khaya grandifoliola (Wood Sawdust)	12.60	66.13±0.23[b]	23.63±0.48[a]	10.25±0.25[b]	16.20±0.02[b]
Monodora myristica (Seed)	12.40	67.75±0.75[b]	23.25±0.25[a]	9.00±0.25[b]	39.72±0.14[c]
Pinus caribaea (Needles)	12.04	61.00±0.5[c]	28.75±0.75[c]	10.25±0.25[b]	44.16±0.13[d]
Thaumatococcus daniellii (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 using Duncan's Multiple Range Test at 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 (30299.42kJ/kg) while ABCD10%WS had the lowest energy value (25634.42kJ/kg). Energy values of all the material combinations are statistically different.

Table 4: Energy Value of the Compounded Lighter

Material Combination	Calorific Value (kJ/kg)		
	Minimum	Maximum	Mean ± S.E*
AB10%WS	30293.13	30305.70	30299.42±6.28[a]
ABC10%WS	26310.72	26323.28	26317.00±6.28[b]
ABCD10%WS	25623.95	25644.89	25634.42±10.65[c]
ABCDE10%WS	26779.73	26792.29	26786.01±6.28[d]
AB15%WS	29807.37	29819.93	29813.65±6.28[e]
ABC15%WS	29752.93	29765.49	29759.21±6.25[f]
ABCD15%WS	26712.73	26725.29	26719.01±6.28[g]
ABCDE15%WS	25665.83	25678.39	25672.11±6.28[h]

*S.E = Standard Error
Mean values with the same alphabet are not significantly different using Duncan's Multiple Range Test at p<0.05

Proximate analysis of the compounded lighter materials

From Table 5, percentage volatile matter reduces as the material combination increases though values were not significantly different. Unlike the percentage volatile matter, percentage ash content of all the material combinations are significantly different. Table 6shows 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 all had a significant effect on the percentage fixed carbon and percentage ash with p<0.05. Conversely, there was no significant effect of compounding on volatile matter of the compounded lighter with p=0.378.

Table 5: Proximate Analysis of the Compounded Lighter

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]

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ABC15%WS	67.45±0.04[a]	24.07±0.07[e]	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 using Duncan's Multiple Range Test at $p<0.05$

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

		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 (8×10^{-3} gmin^{-1}) while ABC10%WS combusts with high ignition time (35.33s). AB15%WS had the least rate of combustion (7.2×10^{-3} 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 ($p=0.442$) does not have a significant effect on the combustion rate (gmin^{-1}) of the compounded lighter.

Table 7: Combustion properties of the compounded lighter

Material Combination	Density (g/m³)	Ignition Time (s)	Burning Time (s)	Combustion Rate (gmin^{-1})
AB10%WS	39.56±4.21	13.33±0.33	117.33±2.91	8.00×10^{-3}
ABC10%WS	20.52±1.98	35.33±1.20	157.00±3.46	7.96×10^{-3}
ABCD10%WS	22.25±0.77	28.00±2.31	127.00±2.65	7.88×10^{-3}
ABCDE10%WS	19.02±0.51	21.33±0.88	85.67±2.03	7.92×10^{-3}
AB15%WS	20.20±0.48	30.33±2.33	129.33±2.40	7.20×10^{-3}
ABC15%WS	18.76±0.80	21.00±0.58	74.33±1.00	7.63×10^{-3}
ABCD15%WS	19.66±0.54	25.00±2.58	197.50±3.50	7.67×10^{-3}
ABCDE15%WS	22.32±1.33	27.67±6.28	70.67±4.26	7.54×10^{-3}

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

		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			
	Material Combination	0.048	3	0.016	1.076	0.412[ns]

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		Sum of Squares	Df	Mean Square	F	Sig.
Combustion Rate	Compounding	0.628	1	0.628	42.098	0.000*
(gmin⁻¹)	Interaction	0.045	3	0.015	0.998	0.442ns
	Error	0.119	8	0.015		
	Total	0.840	15			

* = significant; ns = not significant

Discussion

The high energy content found in *Monodora myristica* 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 (13785-17428kJ/kg) and black walnut hull (17719-21193kJ/kg) as reported by Jekayinfa and Omisakin, (2005). In accordance to the Austrian standard for fuel pellets and briquettes, all the tinder samples selected are considered adequate since they had gross calorific values between 18000-22400 kJ/kg mostly within the range of the prescribed minimum value (18000 kJ/kg), (Austria ONORM M7135) and 17500-19500 kJ/kg reported by Germany DIN51731/DINplus standard (Stephen *et al.*, 2014).

Khaya grandifoliola (sawdust) had average lignin content out of the range reported by Maha (2015) for hardwood stems (18% -25%); this 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 content of lignin 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 confirms the presence of tannins, terpenoids, alkaloids, flavonoids and cardiac glycosides all making an essential compound which supports biomass combustion.

C. sinensis among other materials studied had the highest content of volatiles and this may imply that it loses most of its gases and essential oils during combustion which could practically 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 had a higher volatile content than coal, while herbaceous biomass also tend to have volatile content slightly higher than that of woody biomass or certain agro-industrial residues. By comparison, percentage ash content, fixed carbon and volatile matter of other lignocellulosic materials such as rice straw, wheat straw and rice hull are reported by Jenkins *et al.,* (1998). 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 a percentage fixed carbon higher than most biomass fuels reported by Miles *et al.,* (1995). 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 increase 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 of refining (Shaw, 2008). All the material combination and compounding ratio could be considered adequate because their respective calorific value was higher than the recommended minimum standard for fuel pellets by Austria ÖNORM M7135.

The compounded lighter had a volatile matter and fixed carbon higher than some other fuels such as rice straw, wheat straw and rice hull. 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 it does not have a 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 content of volatiles. AB10%WS had the highest content of volatiles 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). Conversely, among other material combination, ABCDE15%WS had the least content of volatiles, a high ignition time, lowest burning time, low combustion rate and highest content of ash; this in a way seem less appropriate for the desired end use.
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.

Conclusions

As a result of compounding, there was an increase in the heating value of the lighter which reveals the effect of compounding on the energy value of lignocellulosic biomass. From the results revealing the various properties of the formulated and compounded lighter, it could be concluded that the solid charcoal lighter produced from lignocellulosic tinders could be a better substitute to existing liquid charcoal lighter because it could burn and combust freely with less ignition hazard and less volatile emission. The formulation and compounding ratio, AB10%WS was found to be the most preferred formulation and compounding ratio as it exhibits the least ignition time, better combustion

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rate and low ash. AB10%WS was the combination of *Citrus sinensis* peels with the needles of *Pinus caribaea* and compounded with 10% (by mass) of wood sawdust from *Khaya grandifoliola*.

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