

Energy properties of non-timber forest tree shell residues for fuel

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Abstract: A study was undertaken to determine some energy properties of three non-timber forest tree residues: Bush mango (*Irvingia*), Achi (*Brachystegia eurycoma*) and Para Rubber (*Hevea brasiliensis*) shells for fuel. Some ultimate properties (Carbon, Hydrogen, Oxygen, and Nitrogen contents) of the ground shells were determined. The proximate properties determined were volatile matter, ash and fixed carbon contents, and calorific values. The shells for the three samples were reduced with a hammer mill to 2.00 mm particle sizes. Mean of the energy properties of samples were compared using New Duncan's Multiple Range Test to determine if there were significant differences ($P \leq 0.05$). Results obtained showed that *Irvingia* shells had the highest volatile matter of 75.03% and HHV of 19.53 MJ kg⁻¹. The volatile matter of the three shells was of the order: *Irvingia* (75.03%) > Rubber (62.33%) > *B. eurycoma* (58.77%). Higher heat value for Rubber, *B. eurycoma* and *Irvingia* shells were 15.87, 15.20 and 19.53 MJ kg⁻¹, respectively. Ash content obtained from the shell samples were of the order: *Irvingia* (5.10%) < Rubber (21.57%) < *B. eurycoma* (23.20%), fixed carbon were of the order: Rubber (2.50%) < *Irvingia* (7.17%) < *B. eurycoma* (10.70%). The *Irvingia* shell had the most favourable energy properties for fuel due to its high calorific values, volatile matter and the least ash content, which makes it a good feedstock for bioenergy. The moisture contents (%wb) of the three samples: *Irvingia*, *B. eurycoma* and rubber shells increased from; 5.51%-16.35%, 4.94%-16.39% and 2.85%-15.15%, respectively as it was observed that the absorption of moisture starts earlier in rubber, *B. eurycoma* and *Irvingia* respectively.

Keywords: biomass, biomass fuel, calorific value, residues, energy properties

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1 Introduction

Renewable resources contributed to about 19.3% of the global energy consumption in 2015 with about 50% of the renewable resources from biomass (REN21, 2017). The projection is that biomass has the potential to contribute up to 36% of global energy need in the next 15-20 years when produced and used in a sustainable manner (IRENA, 2014). Biomass feedstocks are versatile because it can be used for production of heat, power, transport fuels and bioproducts. Residues from agricultural and forest field and processing operations has and will significantly contribute to the biomass feedstock

resource especially in developing countries. This study focus on the residue obtained from three cash crops in Nigeria - *Hevea brasiliensis* (Para rubber), *Irvingia gabonensis* (Bush mango) and *Brachystegia eurycoma* (Achi). *Hevea brasiliensis* is a perennial plantation crop cultivated as an industrial crop. Kengni et al. (2011) explained that sweet bush mango (*I. gabonensis*), so called because of its sweet fruit pulp, and bitter bush mango (*I. wombolu*) which has bitter-tasting fruit, are found in their natural range in the humid forest zone of West and Central Africa. *Irvingia* tree has a wide range of usage with most important product of both species being processed as seed cake, which is widely used in soups and stews. *Brachystegia eurycoma* is an economically valuable tree crop mostly grown in the tropical rain forest of West Africa that is used for food and medicine applications. The edible seed is used as a thickener in soup preparation, and for body temperature control in the

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rural part of eastern Nigeria (Onimawo and Egbekun, 1998).

Therefore, the specific objectives of this study were to quantify the energy related characteristics of these residues, and their moisture absorption characteristics. These residues are biological in nature and therefore will exchange moisture with the environment.

2 Material and methods

2.1 The samples

The shell residues of three non-timber forest trees (*Brachystegia eurycoma*, *Irvingia gabonensis* and *Hevea brasiliensis*) were sourced locally from Umudike environment: Rubber from Michael Okpara University of Agriculture, Umudike Rubber plantation, and *B. eurycoma* and *Irvingia* from Ahaba Imenyi Isuikwuato, both in Abia State, Nigeria. The moisture content of samples were measured in percentage wet basis at 103°C for 24 hours using ASABE standard S358.2 (ASABE, 2011). The samples were each reduced with hammer mill (TRF 400) with 3 mm screen. The reduced particles were sieved in a set of sieves and 2.00 mm particle sizes were used for the study. After grinding, proximate and ultimate compositional analyses, and moisture absorption tests of the samples were conducted (in triplicates) on the samples as described below.

2.2 Proximate analysis of samples

2.2.1 Ash and volatile matter contents

Based on Swedish Standard CENT/TS 15148 (SIS, 2006) volatile matter content was determined by weighing about 1 g of each ground sample into a crucible and placed in a 900°C volatile matter furnace (model VMF 10/6/3216P, Carbolite, Hope Valley, U.K.) for 7 minutes to determine the volatile matter of samples. For ash content determination, 2 g of a sample was weighted into a crucible and placed in a muffle furnace (model F6020C, ThermoScientific, Dubuque, IA) that was programmed to ramp to 575°C according to the NREL method for ash determination (Sluiter et al., 2008). The percentage ash and volatile matter contents were based on the percent ratio of final mass of material remaining in the crucible to the original sample mass after accounting for the moisture content of samples.

2.2.2 Fixed carbon of samples

The fixed carbon of the three ground residual samples was determined from the reported percentages of moisture content, volatile matter and ash content. This was calculated using the Equation (1):

$$FC = 100 - (MC + VM + AC) \times 100 \quad (1)$$

where, *FC* = Fixed carbon (%); *MC* = Moisture content (%); *VM* = Volatile matter (%). *AC* = Ash content (%).

This was done in three replications.

2.2.3 Calorific value of samples

Heating values of the ground samples were obtained with an IKA C200 calorimeter (IKA Works Inc., Wilmington, NC). Half gram (0.5 g) of the each sample was weighed and pressed into a pellet using IKA C21 pelleting press (IKA Works, Wilmington, NC). The resulting pellet was reweighed and placed in the bomb of the calorimeter. The calorimeter was then operated according to manufacturer's guidelines.

2.3 Ultimate analysis of samples

Carbon, hydrogen and nitrogen contents of samples were determined in triplicate with an elemental analyser (Model 2400 Series 11 Perkin-Elmer, Shelton, CT). The samples were passed through a standard #40 screen before they were analysed. Approximately 300 mg of samples were used. Helium was used as a carrier gas.

2.3.1 Rate of moisture sorption of samples

Agricultural materials are hygroscopic in nature. Therefore, they have the ability to exchange moisture with the atmosphere (Singh, 2004). This experiment was designed to determine the rate at which the ground samples absorb or desorb moisture from an environment. Moisture sorption property of the samples was carried out in a chamber (0.9 m × 1.8 m × 0.9 m) that was supplied with conditioned air from a conditioner (Model #9221-2110, Parameter Generation and Control, Inc., Black Mountain, NC). The samples were exposed to air conditioned at a temperature of 25°C (±1°C) and relative humidity of 65% (±3%). A schematic drawing of the test system is shown in Figure 1.

To determine the rate of moisture sorption of the samples, a thin layer of the samples (100-150 g) was placed in a wire mesh basket hung from a digital weighing balance (Model PM 4600, Mettler-Toledo,

Columbus, OH) (accurate to 0.01 g). Sample masses were monitored and continuously recorded on a personal computer (PC) at 5 mins interval until equilibrium was reached depending on the temperature and relative humidity of the conditioned air entering the chamber. A communication software (Windmill RS232, Windmill Software Ltd., Manchester, UK) was used to interface the weighing balance to the personal computer. An experiment was considered completely when the mass of sample did not change by more than 0.01 g within a span of one hour. The moisture content of a sample after the end of each experiment was verified using a moisture analyser (MB45, Ohaus Corporation, Pine Brook NJ). Experimentation of each temperature and relative humidity combination was performed in replicate.

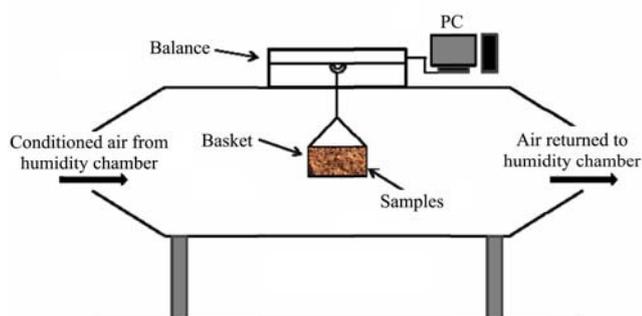


Figure 1 Schematic diagram of rate of set up for moisture sorption study

3 Results and discussion

3.1 Ash content of samples

Ash content of the three biomass samples of *Irvingia*, *B. eurycoma* and rubber shells are: 5.1%, 23.20% and 21.57%, respectively shown in Table 1. The ash content of *Irvingia* shell is lowest of the samples while *B. Eurycoma* shells have the highest percentage ash content. The ash content of *B. eurycoma* and rubber shell samples were higher than published values for some agricultural materials: peanut hulls (5.89%), cocoa hulls (8.25%), almond shells (4.81%) and cotton stalks (17.30%) (Ebeling and Jenkins, 1985). Jenkins et al. (1998) also gave ash contents of almond shells (3.29%), almond hulls (6.13%) and pistachio shells (1.41%). Ash is the non-combustible component of biomass. Therefore, the higher the fuel's ash content was, the lower its calorific value and the lower the volatile matter content was (Van Loo and Koppejan, 2008).

3.2 Volatile matter of samples

The amount of volatile matter in the three samples (*Irvingia*, *B. eurycoma* and rubber shells) are respectively 75.03%, 58.77% and 62.33% (Table 1). All the three samples have high volatile matter like other biomass samples. Ebeling and Jenkins (1985) reported that walnut, pistachio and almond shells have 78.28%, 82.03% and 73.45% volatile matter, respectively. Also, Jenkins et al. (1998) gave volatile matter of almond shells (76%), almond hulls (73.80%) and pistachio shells (81.64%). As volatile matter represent the carbon, hydrogen and oxygen components (usually a mixture of short and long chain hydrocarbon) in the biomass that turn to vapour when heated.

Table 1 Summary of energy properties of samples

Property	<i>Irvingia</i> shell	<i>B. eurycoma</i> shell	Rubber shell	Mean	LSD _{0.05}
Ash content, %	5.10 ^a	23.20 ^b	21.57 ^b	16.62	1.689*
Volatile matter, %	75.03 ^a	58.77 ^b	62.33 ^c	65.38	1.486*
Fixed carbon, %	7.17 ^a	10.70 ^b	2.50 ^c	6.79	2.379*
HHV, MJ kg ⁻¹	19.53 ^a	15.20 ^b	15.87 ^c	16.87	0.188*
LHV, MJ kg ⁻¹	16.73 ^a	13.93 ^b	13.37 ^c	14.68	0.258*

Note: Means that have the same alphabet on a row are statistically same while means with different alphabets are significantly different at 5% level of probability. NS = not significant. '*' = significant at 5%. LSD = least significant differences. LHV = lower heating value.

3.3 Fixed carbon of the samples

Fixed carbon of the samples are *Irvingia* shell, 7.17%; *B. eurycoma* shell, 10.70% and rubber shell, 2.50% shown in Table 1. Rubber shells have the lowest fixed carbon while *B. eurycoma* shells have the highest fixed carbon. The amounts of fixed carbon for the three samples are lower than the values obtained for some biomass samples. Ebelings and Jenkins (1985) reported the fixed carbon content of walnut shells, almond shells, and peanut hulls to be 21.16%, 21.74% and 21.09%, respectively. Jenkins et al. (1998) also obtained fixed carbon for almond shells, almond hulls and pistachio shells to be 20.71%, 20.07% and 16.95%, respectively. Jaafar and Ahmad (2011) published that fixed carbon of raw palm kernel shell (PKS) was 10.85% which was in the same range of 10.70% obtained for *B. eurycoma* shell. The results for this study show that these residues may not be good for charcoal production since the amount of charcoal that can be produced by an energy feedstock is limited by the amount of fixed carbon in the feedstock.

3.4 Higher heating value (HHV) of samples

HHV for the three ground biomass samples are shown in Table 1. The HHV for *Irvingia* shell, 19.53 MJ kg⁻¹; *B. eurycoma* shell, 15.20 MJ kg⁻¹ and rubber shell, 15.87 MJ kg⁻¹, respectively. *Irvingia* shell has the highest HHV followed by rubber shell and then *B. eurycoma* shell. In comparison with other biomass samples, the HHV of *B. eurycoma* and rubber shells are lower than HHV values published by Ebeling and Jenkins (1985) for walnut shell (20.18 MJ kg⁻¹), peanut hull (18.64 MJ kg⁻¹) and rice hull (16.14 MJ kg⁻¹). Jaafar and Ahmad (2011) also published the HHV of raw palm kernel shell as 18.81 MJ kg⁻¹ and Uemura et al. (2010) for raw palm kernel shell as 19.78 MJ kg⁻¹. However, the HHV of *Irvingia* shell is in the same range with the HHV for other biomass samples (Ebeling and Jenkins, 1985). The higher the HHV is, the easier and better the samples will be burned.

3.5 Elemental composition of the shell samples

The summary of elemental composition for the three biomass samples are given in Table 2. The result showed that carbon composition of the three biomass samples studied ranged from 35.03% to 44.50% with *B. eurycoma* having the highest (44.50%) and rubber shell least (35.03%). Carbon is the most important constituent of biomass and represents the major contribution to the overall heating value followed by oxygen and then hydrogen. When carbon is not combusted completely during combustion, it leads to emissions of unburned gases, especially carbon monoxide.

Table 2 Summary of the elemental composition of shells samples

Element	<i>Irvingia</i> shell	<i>B. eurycoma</i> shell	Rubber shell	Mean	LSD _{0.05}	Typical value
Carbon, %	42.63 ^a	44.50 ^b	35.03 ^c	40.72	1.224*	30-60
Hydrogen, %	5.73 ^a	5.67 ^a	4.90 ^b	5.43	0.698*	5-6
Oxygen, %	45.62 ^a	25.60 ^b	37.27 ^c	36.16	1.665*	30-40
Nitrogen, %	0.80 ^a	0.60 ^a	1.00 ^a	0.80	NS	<1

Note: Means that have the same alphabet on a row are statistically the same while means with different alphabets are significantly different at 5% level of probability. NS = not significant. * = significant at 5%.

Table 2 shows that the oxygen in the three samples studied ranged from 25.60%-45.62% with *Irvingia* as highest (45.62%) while *B. eurycoma* least (25.60%). High

oxygen concentrations in non-timber forest biomass are responsible for increased heating values. The average value of nitrogen content is about 0.080% by weight. The ultimate composition of the three biomass samples are close to what was obtained by Quaak et al. (1999) for typical biomass: Carbon (41%-51%), Hydrogen (5.5%-6.7%), Oxygen (41%-50%), and Nitrogen (0.12%-0.60%). However, Jaafar and Ahmad (2011) reported that the ultimate composition of raw palm kernel shell are: Carbon (46.53%), Hydrogen (5.85%), Nitrogen (0.89%) and Oxygen (42.32%). Uemura et al. (2010) also reported that raw palm kernel shell contain: Carbon (46.68%), Hydrogen (5.86%), Nitrogen (1.01%) and Oxygen (42.01%).

Hydrogen is converted to H₂O during combustion significantly contributing to the overall heating value of the biomass. Nitrogen contribution to the overall heating value of the biomass is zero as it does not oxidize in any significant quantities and it is released in the gas phase as N₂. Chlorine is almost completely vapourized forming HCl, Cl₂ and alkali chlorides during combustion. Oxygen in the biomass reduces the amount of air needed for combustion and is found in the combustion products chemically bound in the molecules of CO₂ and H₂O.

3.6 Rate of moisture sorption of ground samples

The rate of moisture absorption of each ground samples of *Irvingia*, *B. eurycoma* and rubber shells during exposure to conditioned air for about 48 hours is shown in Figure 2. It was observed that absorption of moisture starts earlier in rubber, *B. eurycoma* and *Irvingia*, respectively. It can be seen that the initial rate of moisture absorption of *B. eurycoma* and rubber shells are the same until after about 6 hrs when the rate of moisture uptake in *B. eurycoma* becomes higher than that of rubber with both having reduced moisture rate over time. The moisture contents (% wet basis) of the three samples: *Irvingia*, *B. eurycoma* and rubber shells increased for 5.51%-16.35%, 4.94%-16.39% and 2.85%-15.15%, respectively. The implication of the result is that ambient relative humidity and temperature affects the moisture content of the samples during storage and transport and these changes can occur in a period of two days or less. The result obtained from the three biomass samples

studied is similar to the pecan shell which moisture content increased to 16.92% from the initial moisture content of 15.02% (wb) at 80% relative humidity and 25°C temperature (Littlefield, 2010). *Irvingia* shell has the highest absorption rate of moisture throughout. The result also shows that as time goes above 7 hrs, the rate of moisture absorption tends towards constant i.e at percentage moisture content of above 14%, 15% and 16% for rubber, *Irvingia* and *B. eurycoma* shells, respectively implying the samples are saturated with moisture. However, *B. eurycoma* and *Irvingia* shells have higher moisture absorption rate with time than rubber shell. Consequently, the higher the moisture absorption rate is, the more the heat content decreases during combustion after about two days.

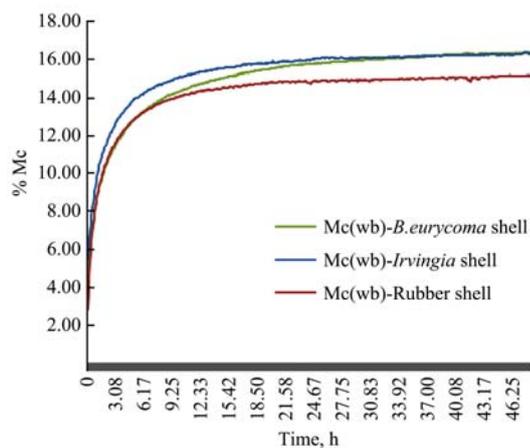


Figure 2 Rate of moisture sorption of ground samples

4 Conclusion and recommendation

The energy properties of three non-timber forest residues samples: rubber, *Brachystegia eurycoma* and *Irvingia* shells were studied. Results obtained showed that *Irvingia* had the highest volatile matter of 75.03% and calorific values.

i. HHV of *Irvingia* is highest at 19.53 MJ kg⁻¹ while that of *B. eurycoma* and rubber shells are: 15.20 MJ kg⁻¹ and 15.87 MJ kg⁻¹, respectively.

ii. LHV of the samples are: *Irvingia* shell of 16.73 MJ kg⁻¹, *B. eurycoma* of 13.93 MJ kg⁻¹ and rubber shell of 13.37 MJ kg⁻¹ as shown in Table 1.

iii. Ash content is lowest in *Irvingia* at 5.10% and highest in *B. eurycoma* at 23.20%.

iv. Fixed carbon is lowest in Rubber at 2.50% and highest in *B. eurycoma* at 10.70%.

v. The rate of moisture absorption starts earlier in rubber, *B. eurycoma* and *Irvingia* and the MC wb ranges are: 2.85%-15.15%, 4.94%-16.39% and 5.51%-16.35%, respectively.

It is recommended that *Irvingia* shell has the most favourable energy properties. However, since biomass samples are hygroscopic, these residues should be used soon after collection to reduce moisture sorption.

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